Update on NIST's Investigation of the Partial Collapse of Champlain Towers South in Surfside, Florida

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01 The Partial Collapse, Genesis of the Investigation

02 Description of Building, Investigative Approach

03 Social Sciences, Collapse Timeline

04 As-built & Precollapse Conditions, Structural Tests, SSI Analyses

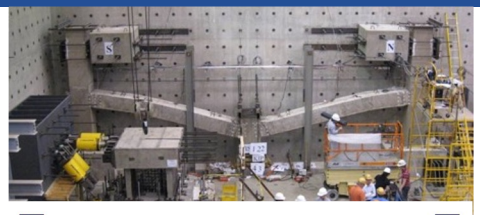
05 Materials Testing, Code Checks, Computer Simulations, Status of Failure Analysis

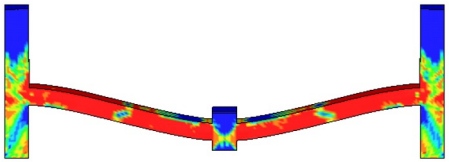
06 Codes and Standards of Practice, Potential Recommendation Topics

07 Closing Comments, Impact of the Investigation

01 The Partial Collapse, Genesis of the Investigation

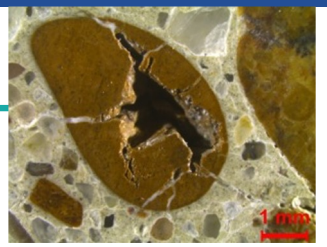
Disaster Resilience Work across NIST (and scales)





Structural Eng. & Earthquake Eng.

Infrastructure Materials Science

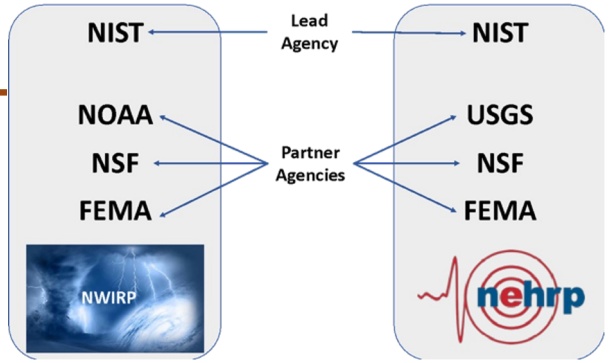


Community Resilience

Field Studies

NCST Investigations

Interagency Leadership



Resilience

Extramural Programs

Long History of Disaster Studies at NIST

Earthquakes	Hurricanes	Construction & Building	Tornadoes	Fires
San Fernando, CA (1971)	Camille, MS/LA (1969)	Skyline Plaza Apartments, Bailey's Crossroads, VA (1973)	Jarrell, TX (1997)	DuPont Plaza Hotel, San Juan, PR (1986)
Mexico City, Mexico (1985)	Alicia, Galveston, TX (1983)	Willow Island Cooling Tower, WV (1978)	Spencer, SD (1998)	First Interstate Bank Building, Los Angeles, CA (1988)
Loma Prieta, CA (1989)	Hugo, SC (1989)	Kansas City Hyatt Regency, Kansas City, MO (1981)	Oklahoma City, OK (1999)	Loma Prieta Earthquake, CA (1989)
Northridge, CA (1994)	Andrew, FL (1992)	Riley Road Interchange, East Chicago, IN (1982)	**Joplin, MO (2011)**	Hillhaven Nursing Home (1989)
Kobe, Japan (1995)	Fran, NC (1996)	Harbor Cay Condominium, Cocoa Beach, FL (1981)	Moore OK (2013)	Pulaski Building, Washington, DC (1990)
Kocaeli, Turkey (1999)	Mitch and Georges, LAC (1998)	L'Ambiance Plaza, Hartford, CT (1987)		Happyland Social Club, Bronx, NY (1990)
Maule, Chile (2010)	Katrina and Rita (2005)	Ashland Oil Tank Collapse, Floreffe, PA (1988)		Oakland Hills, CA (1991)
Christchurch, NZ (2011)	***Matthew & Florence, NC (2016 & 2018)**	U.S. Embassy, Moscow, USSR (1987)		Watts St, New York City (1994)
	Harvey, TX (2017)	Murrah Federal Building, Oklahoma City, OK (1995)		Northridge Earthquake, CA (1994)
	***Maria, PR (2017)**	**World Trade Center Disaster, New York, NY (2001)**		Kobe, Japan (1995)
		Dallas Cowboys Indoor Practice Facility, May 2009		Vandalia St, New York City (1998)
		***Champlain Towers South, Surfside, FL (2021)**		Cherry Road, Washington, DC (1999)
				Keokuk, IA (1999)
				Houston, TX (2000)
				Phoenix, AZ (2001)
				Cook County Administration Building Fire (2003)
				The Station Nightclub, RI (2003)
				Charleston, SC, Sofa Super Store Fire (2007)
				Witch Creek & Guejito, CA, WUI Fire (2007)
				Amarillo, TX, WUI Fire (2011)
				San Francisco, CA (2012)
				Gatlinburg, TN WUI (2016)
				Fuse-47, MD (2017)

***Ongoing Studies**

NCST Investigations

National Construction Safety Team (NCST) Act

NCST Act* (Oct. 1, 2002)

The National Construction Safety Team Act was enacted to provide for the establishment of investigative teams ("Teams") ***to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life.***

José Izquierdo-Encarnación

Kimberly Shoaf

Donald Dusenberry

Unique to NCST

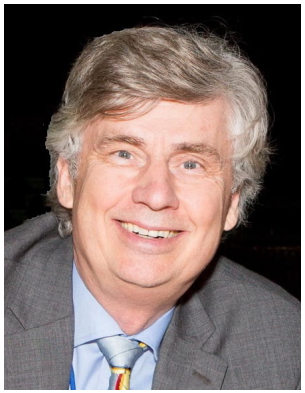
- Subpoena authority
- NIST investigator credentials
- ***Federal advisory committee (up to 12 appointed members)***
- Follow through on recommendations and report(s) to Congress

*National Construction Safety Team (NCST) Act (Public Law 107-231, codified at 15 U.S.C. 7301 et seq.) and the Implementing Regulations (15 C.F.R. Part 270).

Lori Peek

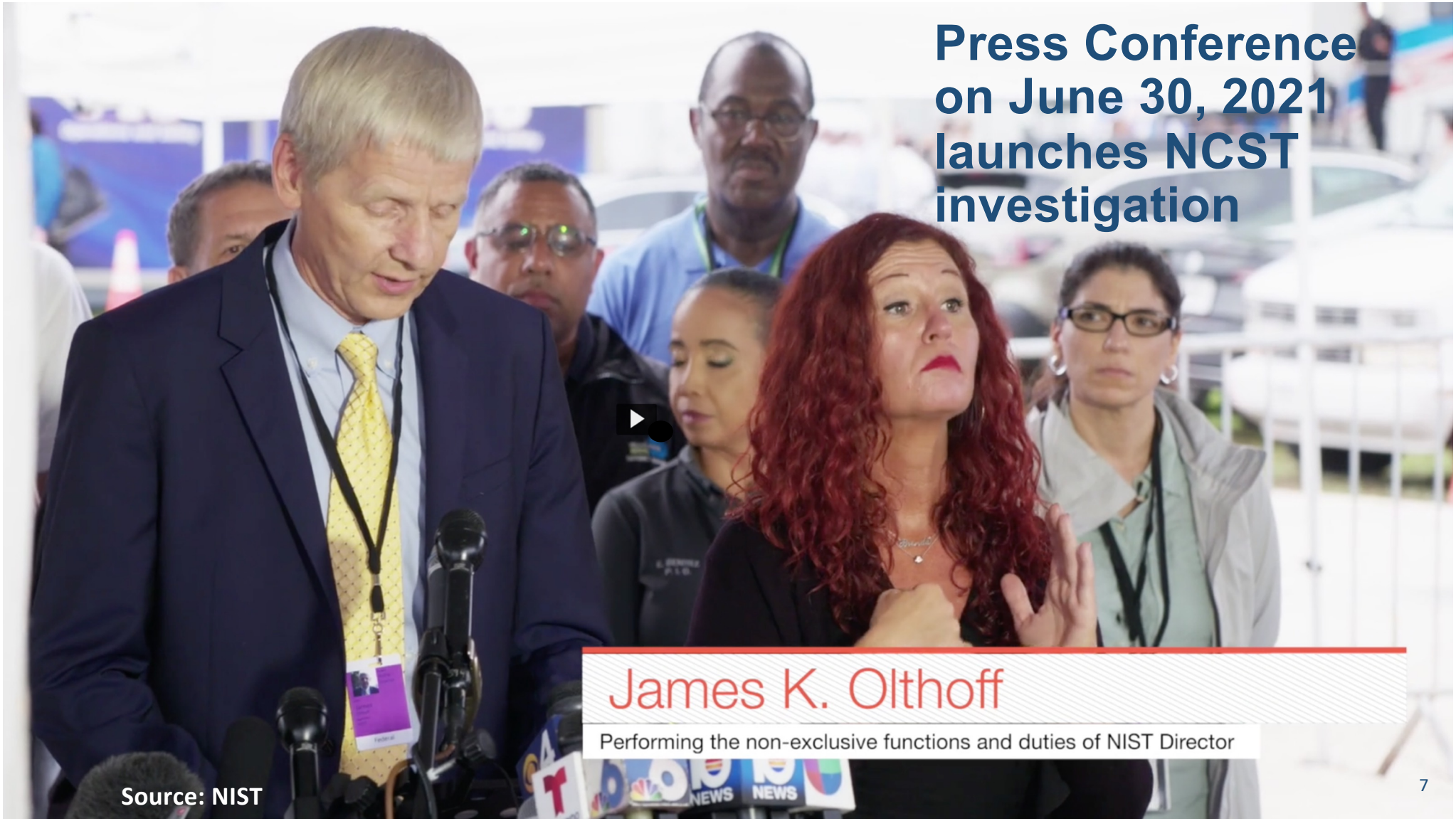
Kurtis Gurley

Aspasia Zerva



John Osteraas

Press Conference on June 30, 2021 launches NCST investigation



Source: NIST

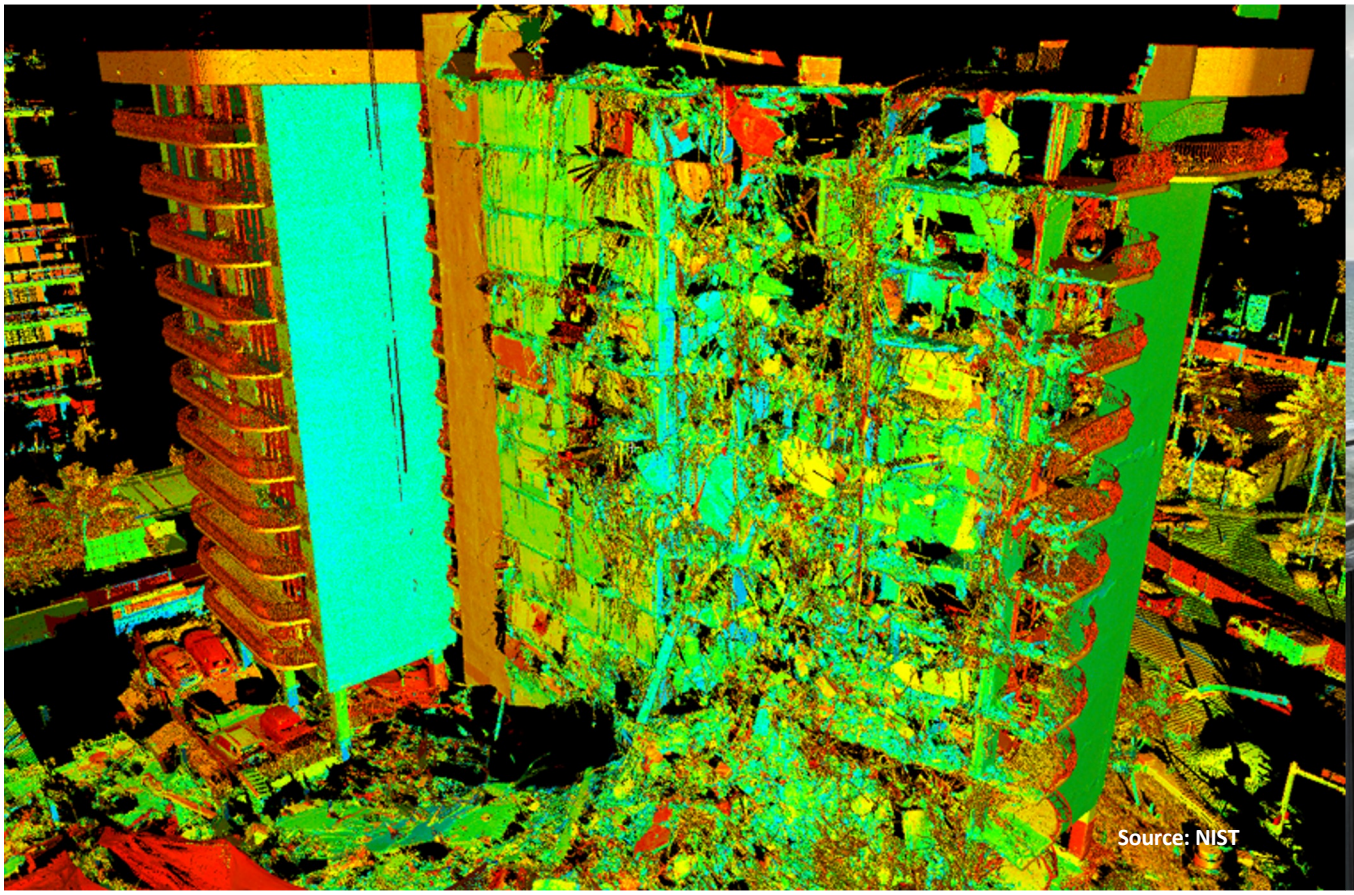
NIST Coordinates Evidence Handling, and Establishes Evidence Tagging Protocols, with First Responders & Incident Command

1. INCIDENT NAME:	2. DATE PREPARED:	3. TIME PREPARED:
Champlain Towers Building Collapse	7/01/2021	2000 hrs

EVIDENTIARY RUBBLE HANDLING PROCEDURE

Source: Miami-Dade County

Experts from FEMA, NSF NHERI RAPID, USGS, and USACE Support On-Site Remote Sensing Activities



Experts from NSF NHERI RAPID, FSU, Miami-Dade Fire Rescue, and VA Beach Fire Dept. Support Remote Sensing Activities

NIST Conducts a Subsurface Investigation with Experts from USACE and Georgia Tech (via NIST Disaster Resilience Research Grant)

Source: NIST

Source: NIST

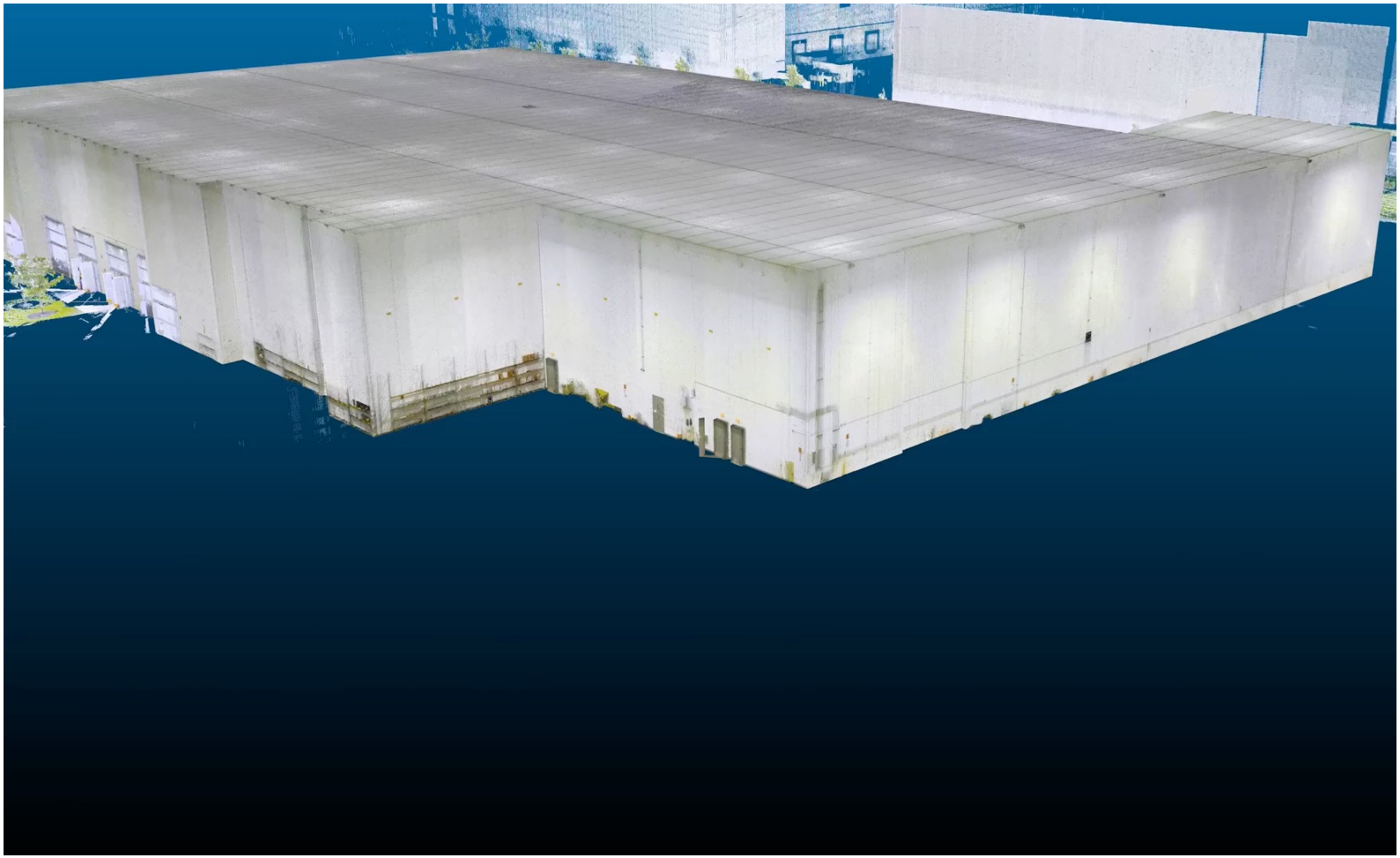
NIST Conducts Wave Attenuation Tests with Experts from NSF NHERI@UTexas, Utah State University, and Georgia Tech (DRRG)

Source: NIST

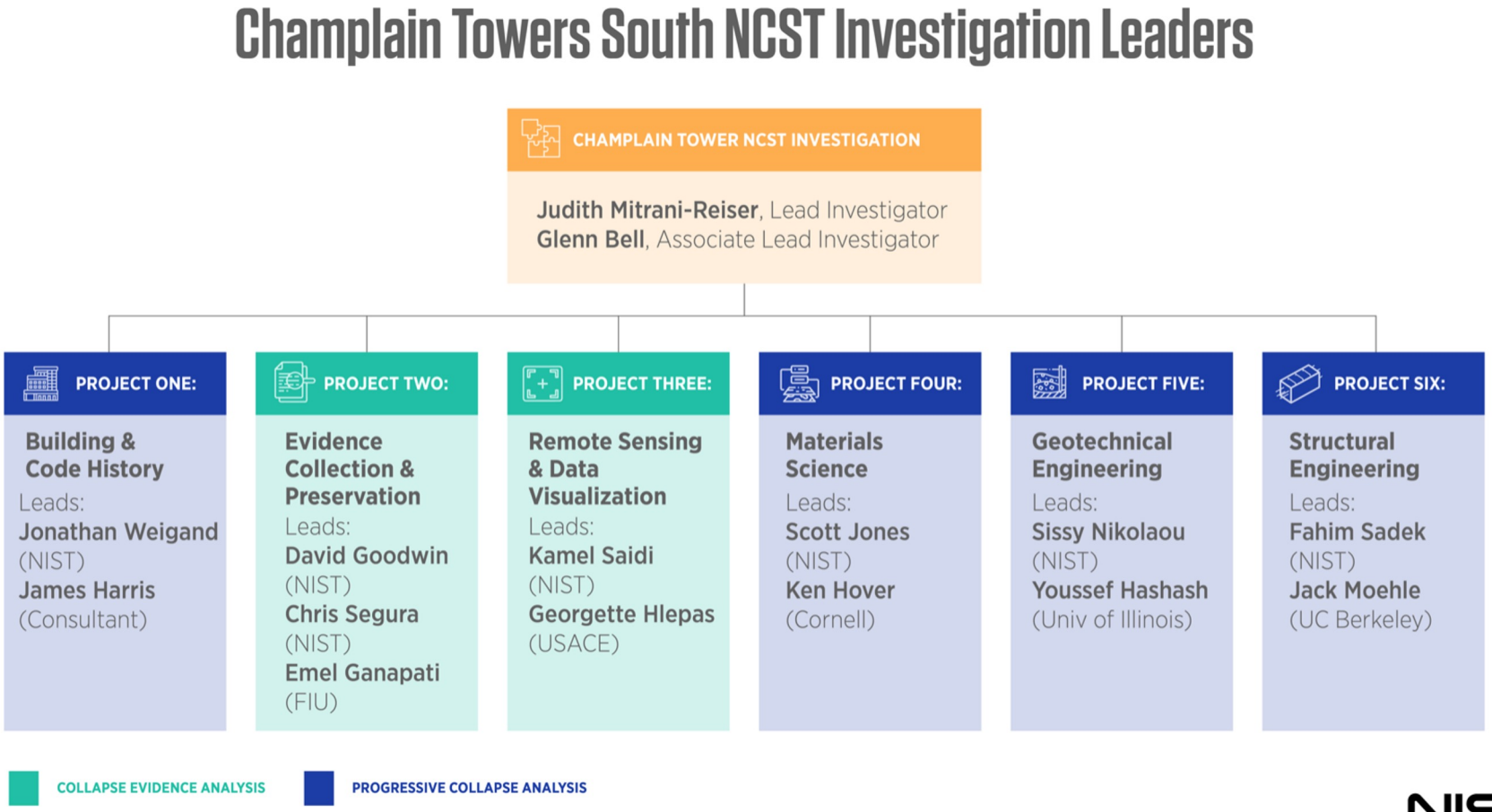
Source: NIST

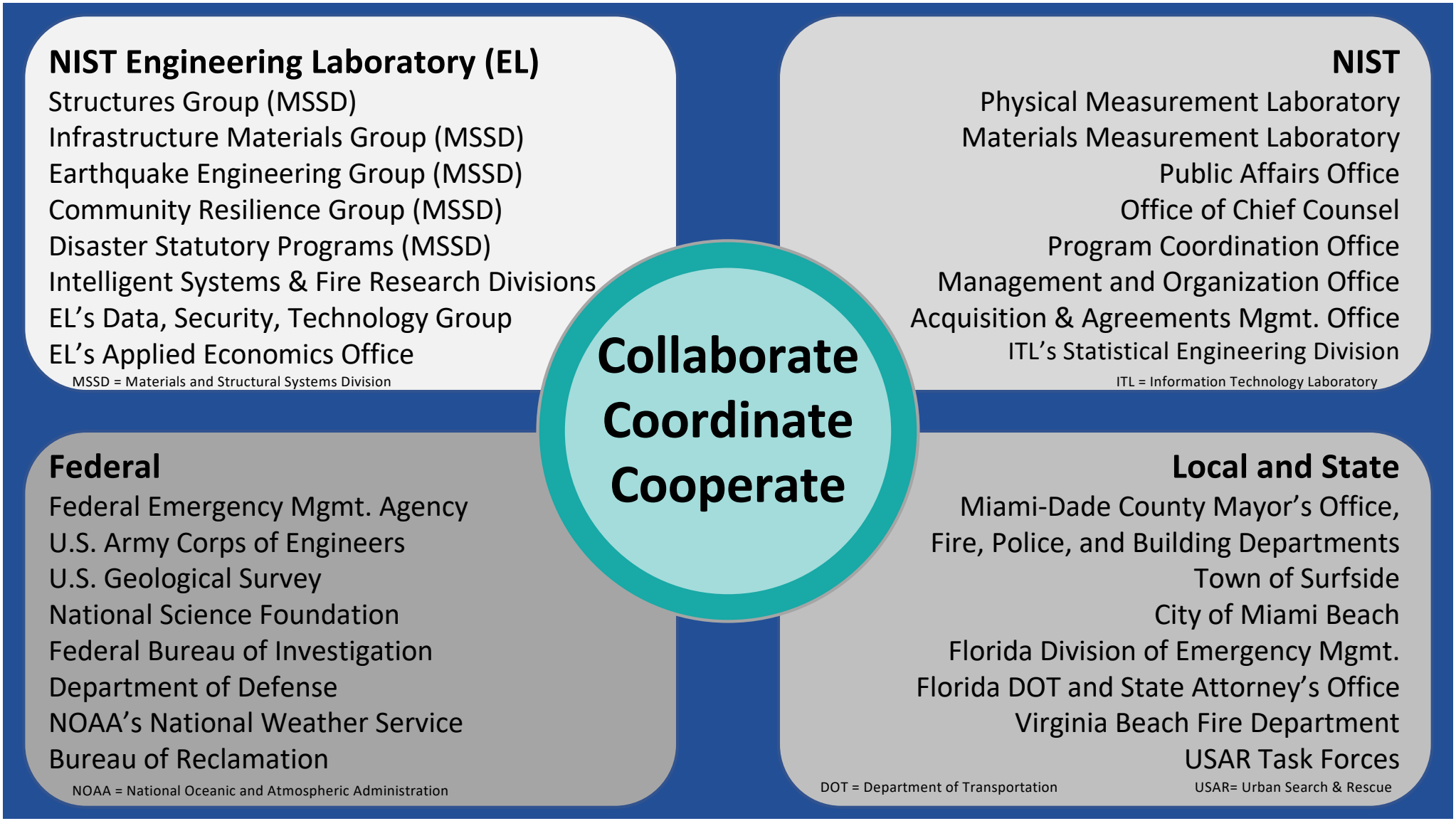
Source: Utah State University

Final Organization and Storage of CTS NCST Evidence



Organization Structure of the Champlain Towers South NCST Investigation




NIST Engineering Laboratory (EL)
Structures Group (MSSD)
Infrastructure Materials Group (MSSD)
Earthquake Engineering Group (MSSD)
Community Resilience Group (MSSD)
Disaster Statutory Programs (MSSD)
Intelligent Systems & Fire Research Divisions
EL's Data, Security, Technology Group
EL's Applied Economics Office
MSSD = Materials and Structural Systems Division
NIST
Physical Measurement Laboratory
Materials Measurement Laboratory
Public Affairs Office
Office of Chief Counsel
Program Coordination Office
Management and Organization Office
Acquisition & Agreements Mgmt. Office
ITL's Statistical Engineering Division
ITL = Information Technology Laboratory
Collaborate
Coordinate
Cooperate
Federal
Federal Emergency Mgmt. Agency
U.S. Army Corps of Engineers
U.S. Geological Survey
National Science Foundation
Federal Bureau of Investigation
Department of Defense
NOAA's National Weather Service
Bureau of Reclamation
NOAA = National Oceanic and Atmospheric Administration
Local and State
Miami-Dade County Mayor's Office,
Fire, Police, and Building Departments
Town of Surfside
City of Miami Beach
Florida Division of Emergency Mgmt.
Florida DOT and State Attorney's Office
Virginia Beach Fire Department
USAR Task Forces
DOT = Department of Transportation
USAR= Urban Search & Rescue

Disclaimers

IMPORTANT: ALL DATA ARE PRELIMINARY

- These presentations describe preliminary data gathered to date as well as preliminary analyses of these data. Data and analyses are subject to change.
- Once all data are finalized and analyzed, they will inform a broader understanding of the likely technical cause or causes of the collapse – and NIST's findings and recommendations.
- These presentations do not constitute NIST findings or recommendations.
- All survey and interview data collection included a consent process that specifies the allowable uses of data and protections of respondents.
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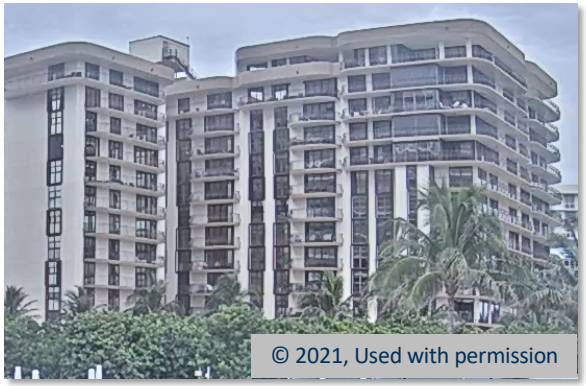
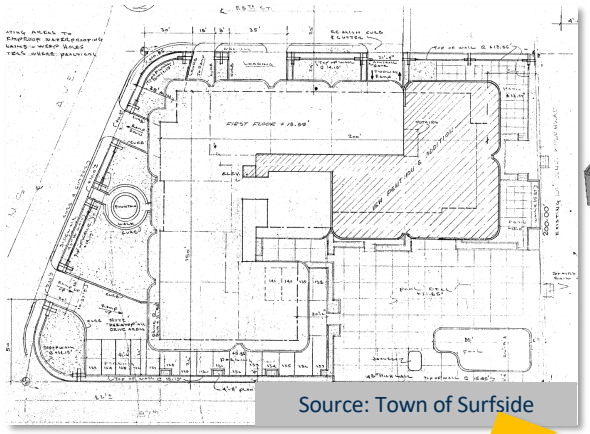
02

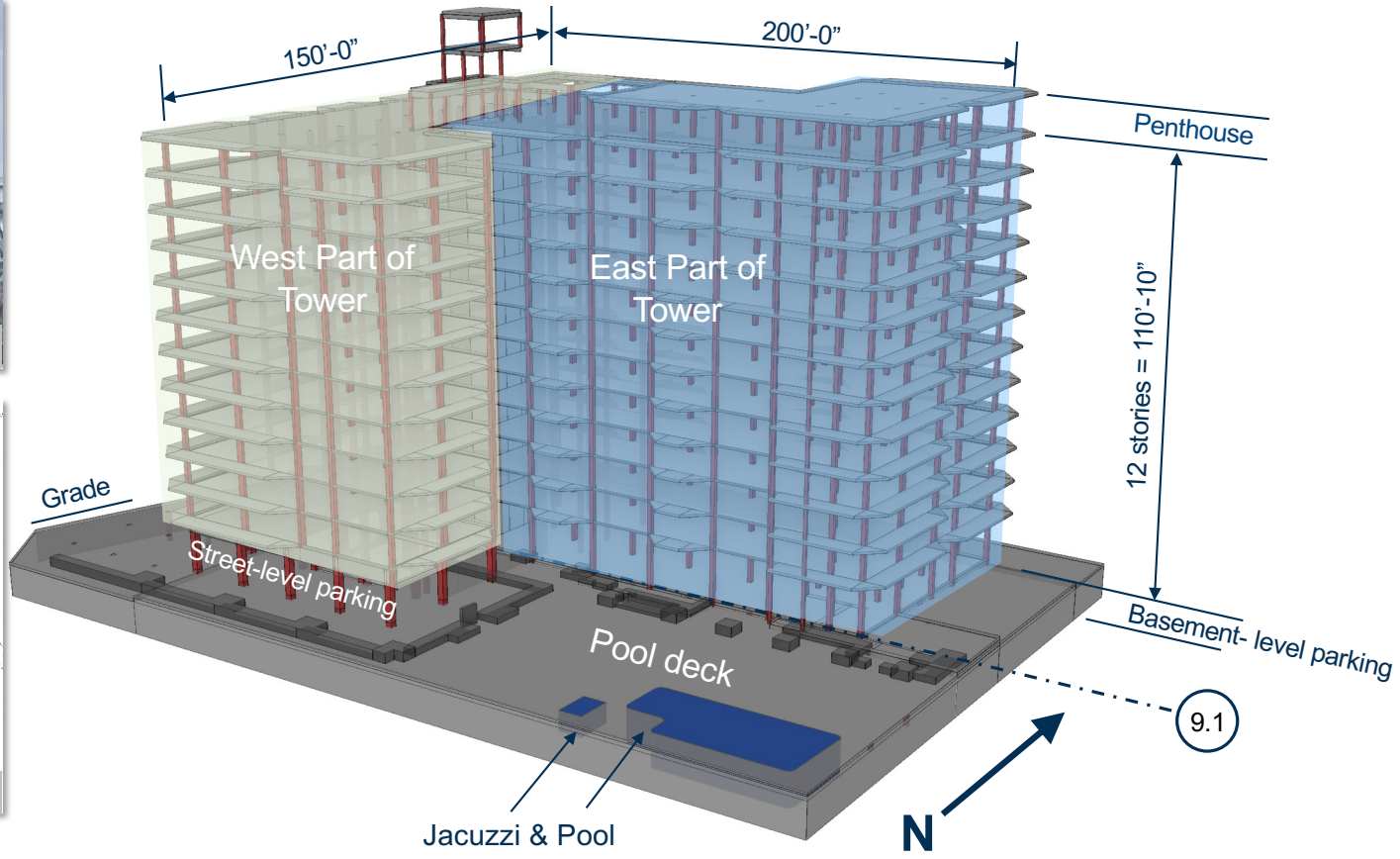
Description of Building, Investigative Approach

Description of the Building

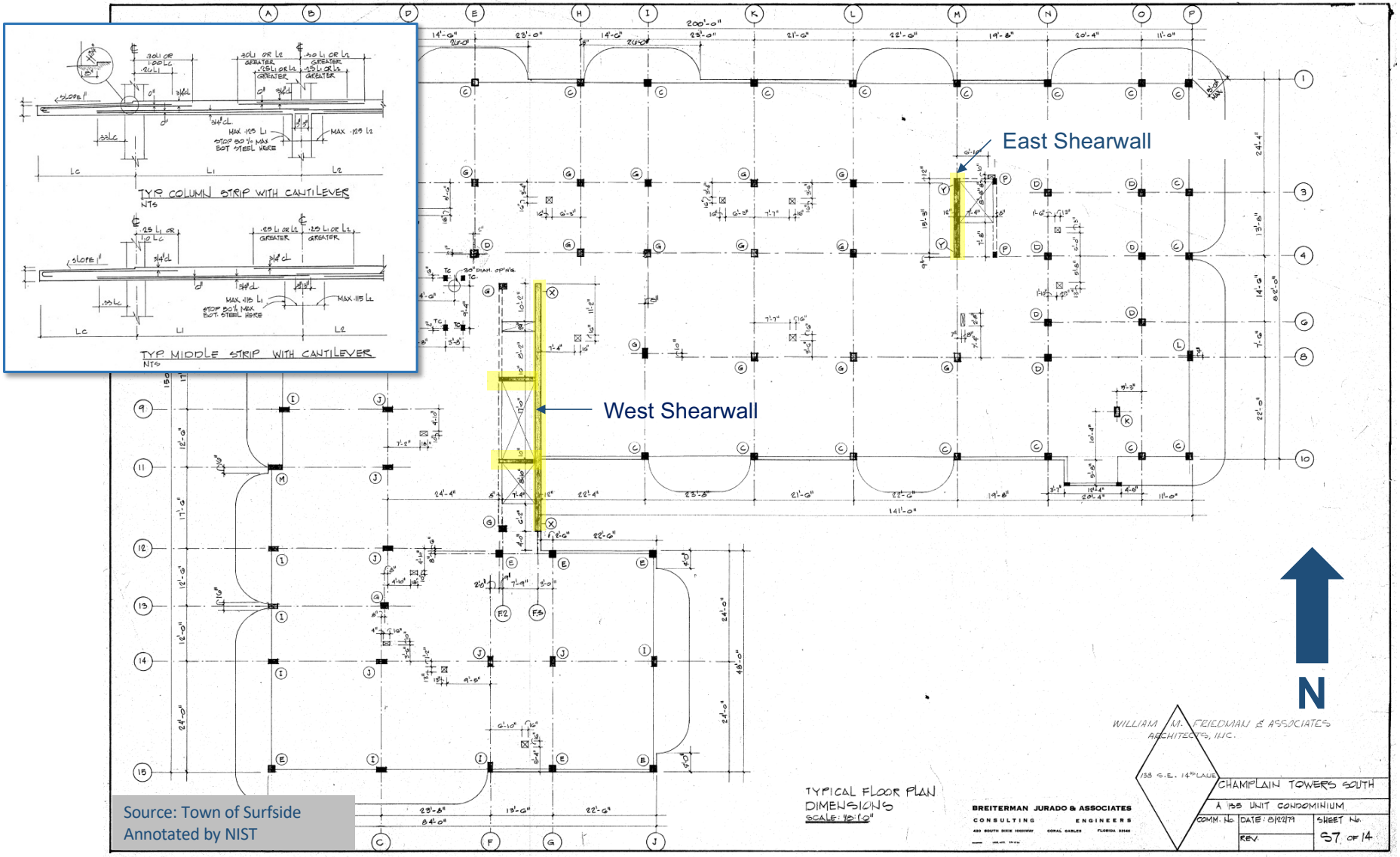




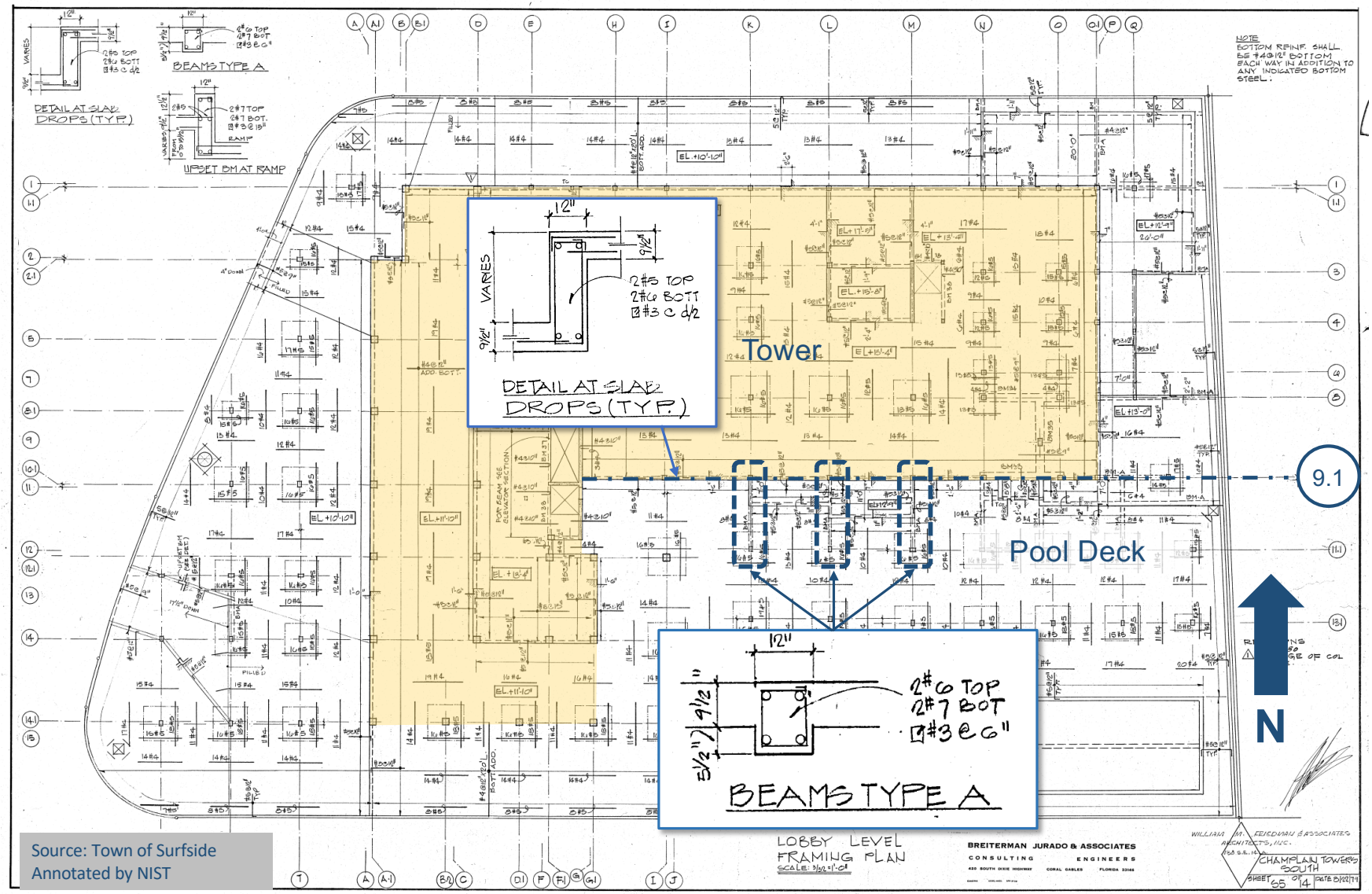
direction of view



Source: NIST

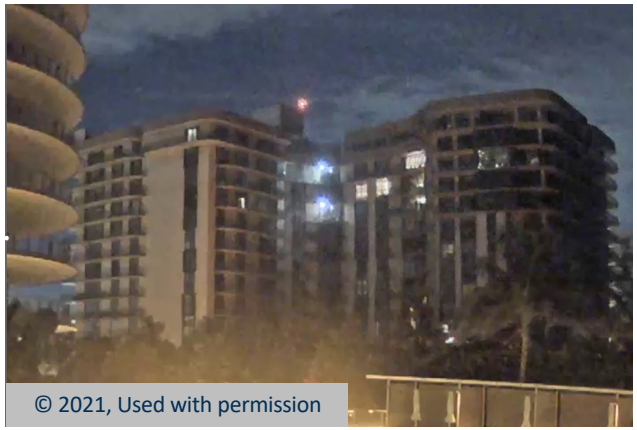


Source: Town of Surfside
Annotated by NIST

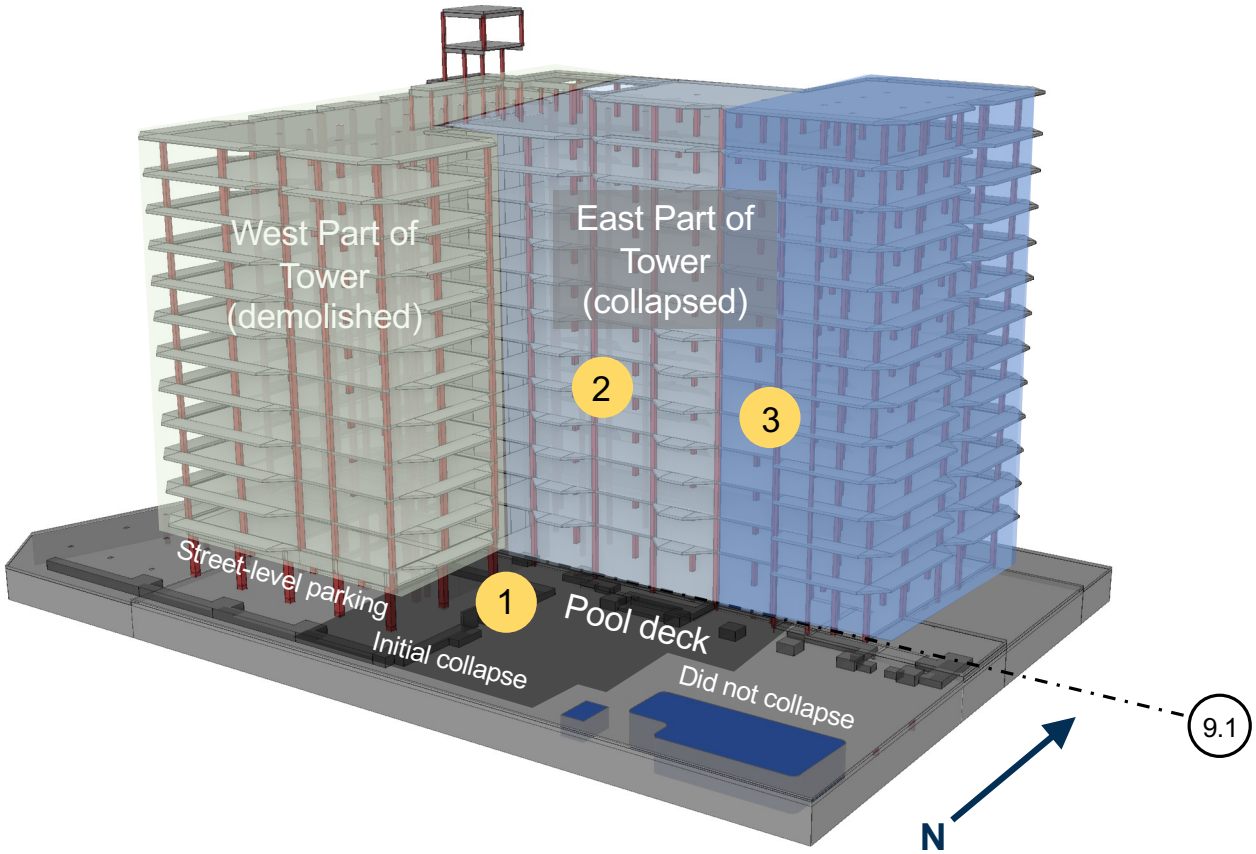


Source: Town of Surfside
Annotated by NIST

The Partial Collapse

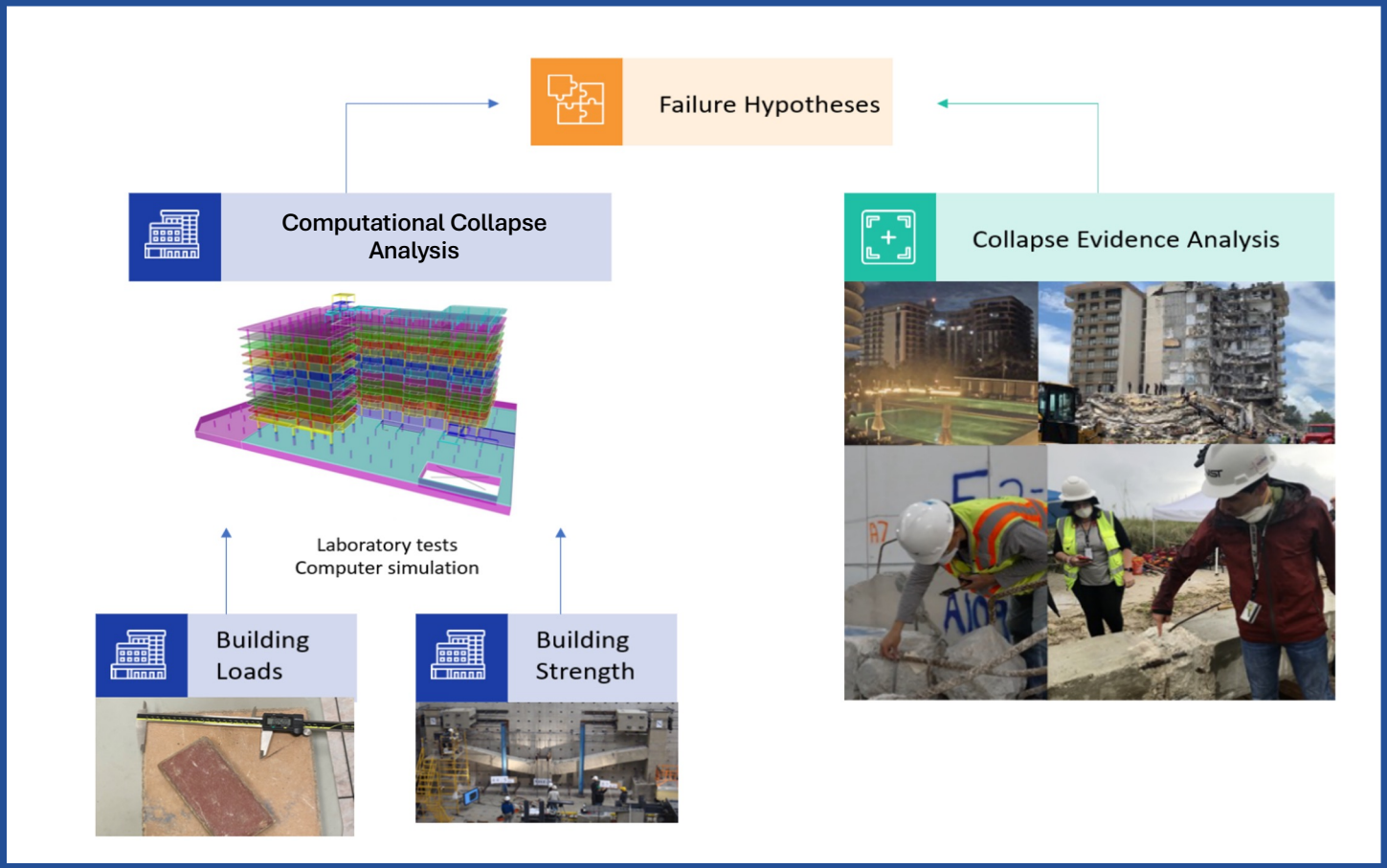


South Face Video Footage

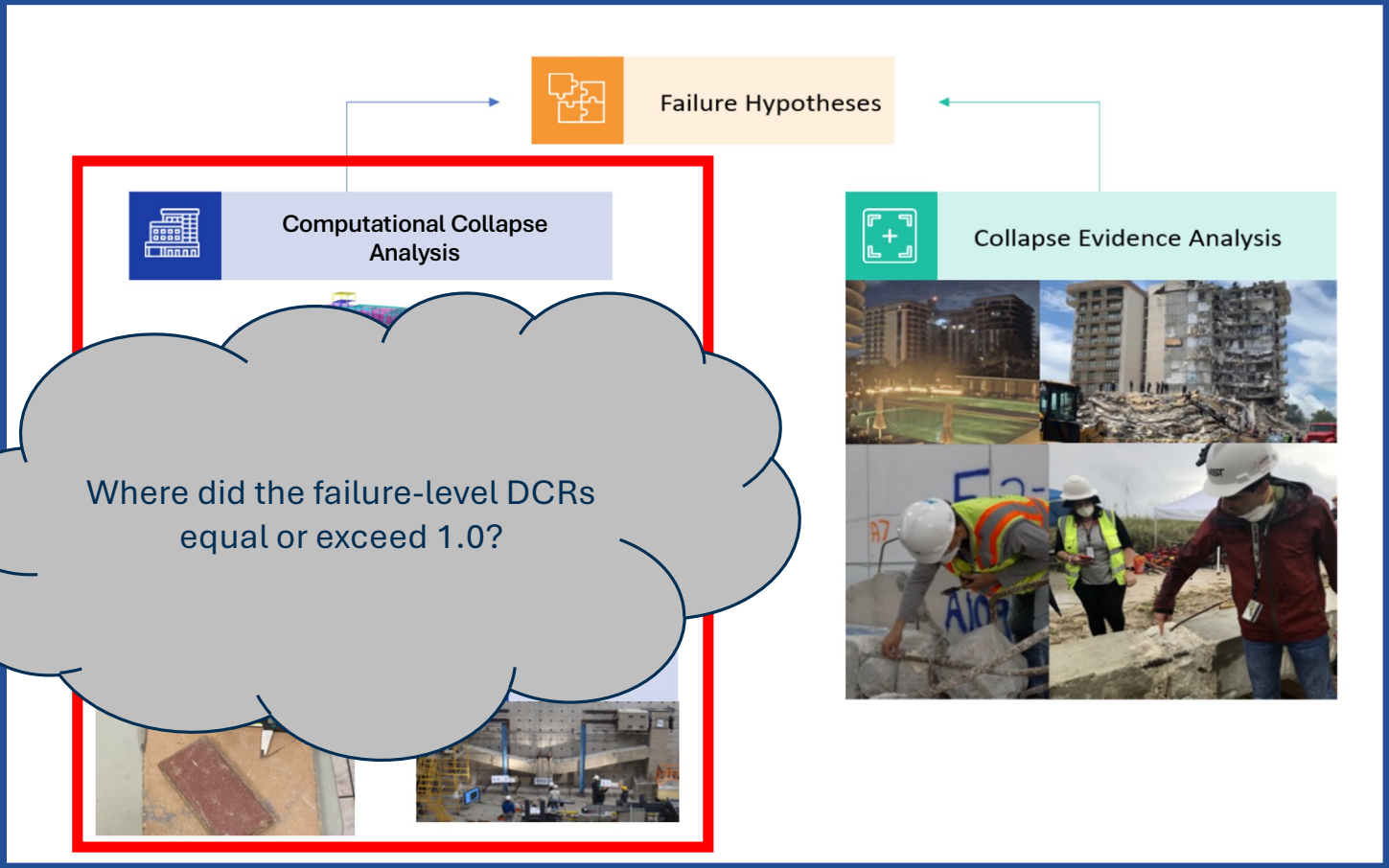


Source: NIST

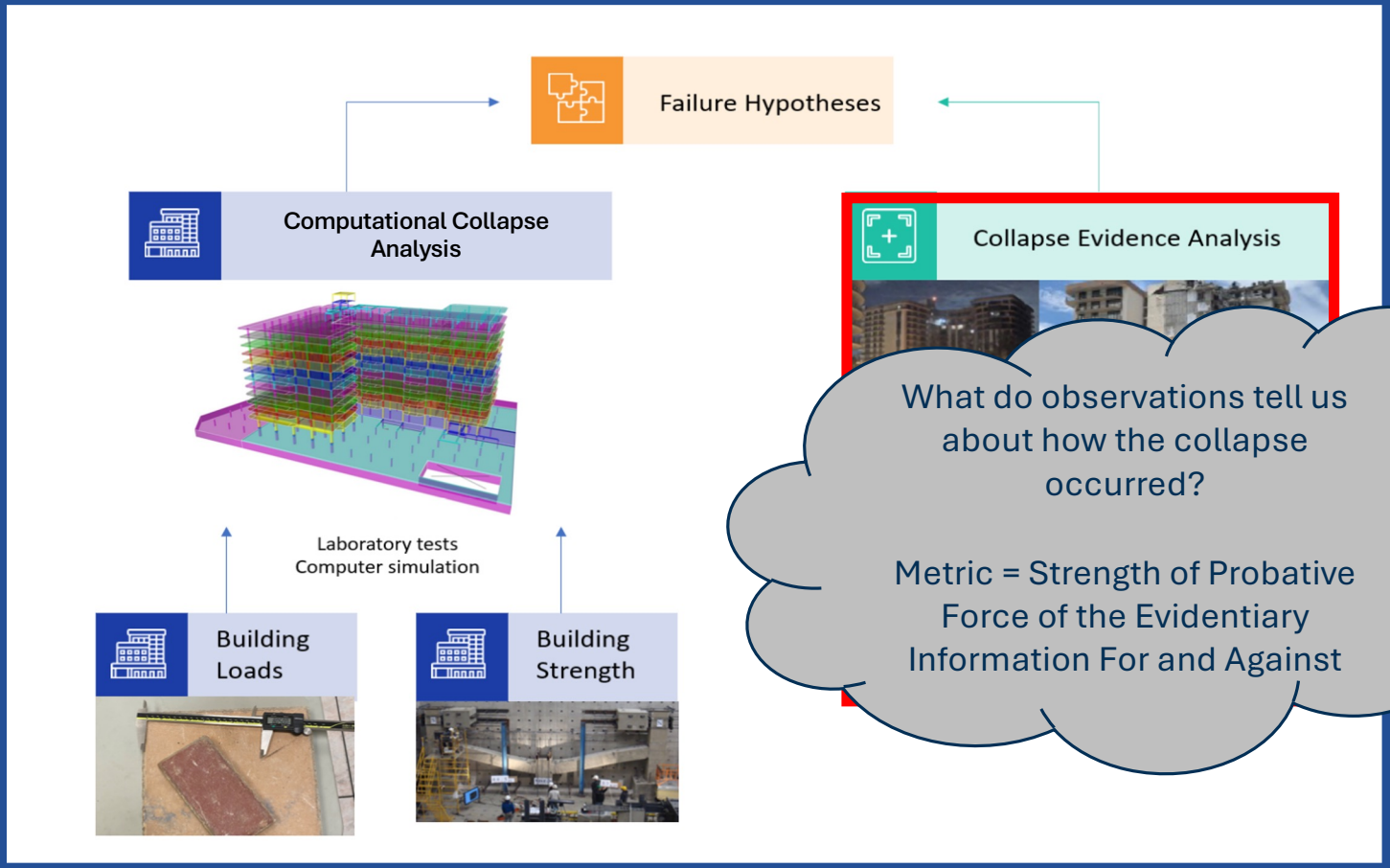
Investigative Approach



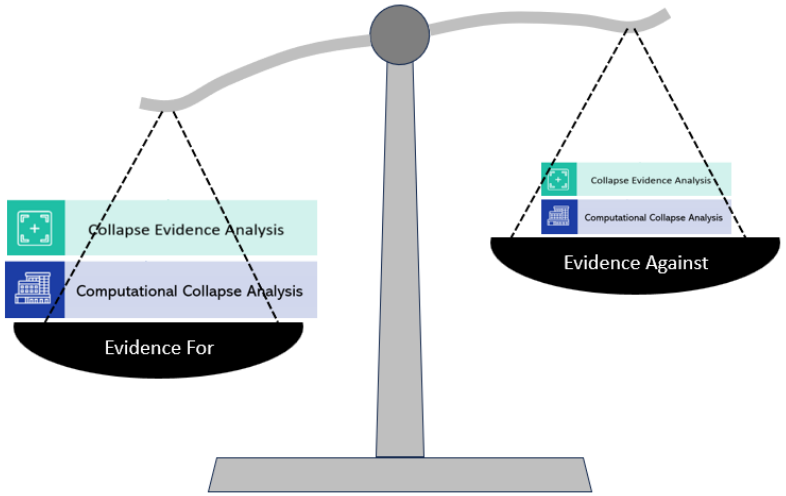
Investigative Approach



Investigative Approach



Weighing Evidence > Relative Likelihoods of Failure Hypotheses



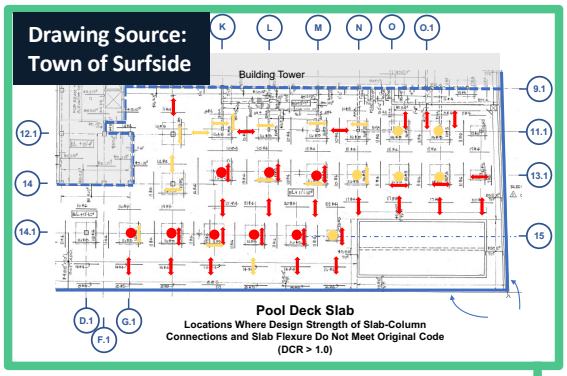
Most Likely Scenario or Scenarios

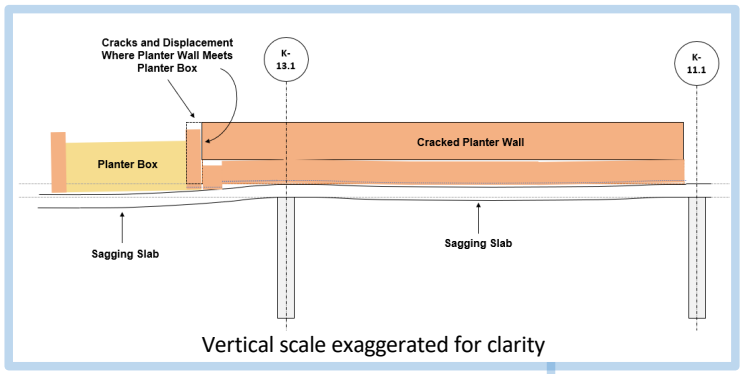
Everything Else
(so unlikely that it's not mentioned above)

03

Social Sciences, Collapse Timeline

Timeline of the Site/Building History and Collapse





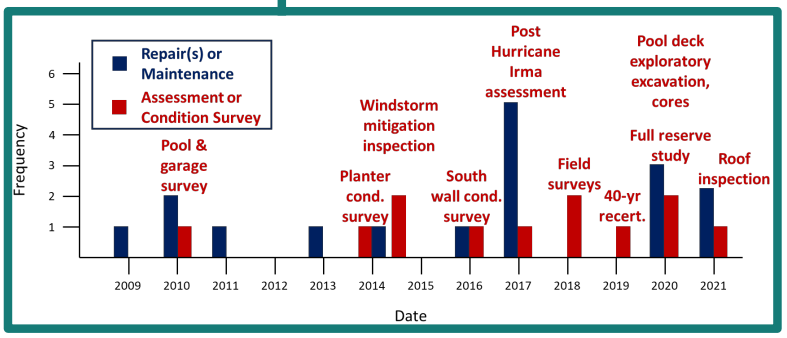
Site History — 1900-1979

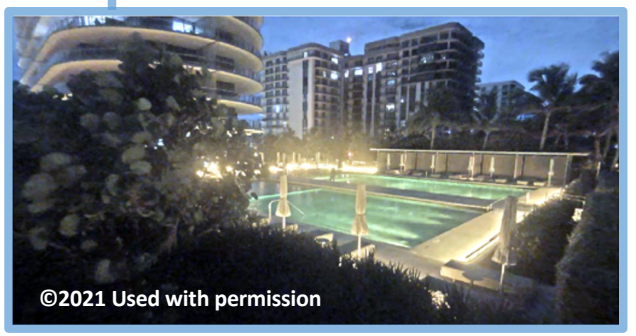
CTS Design & Construction — 1979-1981

CTS Building History — 1981-2021

Champlain Towers South Collapse

- Weeks/Days Prior to Collapse
- Hours/Minutes Prior to Collapse
- Initiation & Progression





Timeline of the Site/Building History and Collapse

Site History 1900-1979

CTS Design & Construction 1979-1981

CTS Building History 1981-2021

Champlain Towers South Collapse

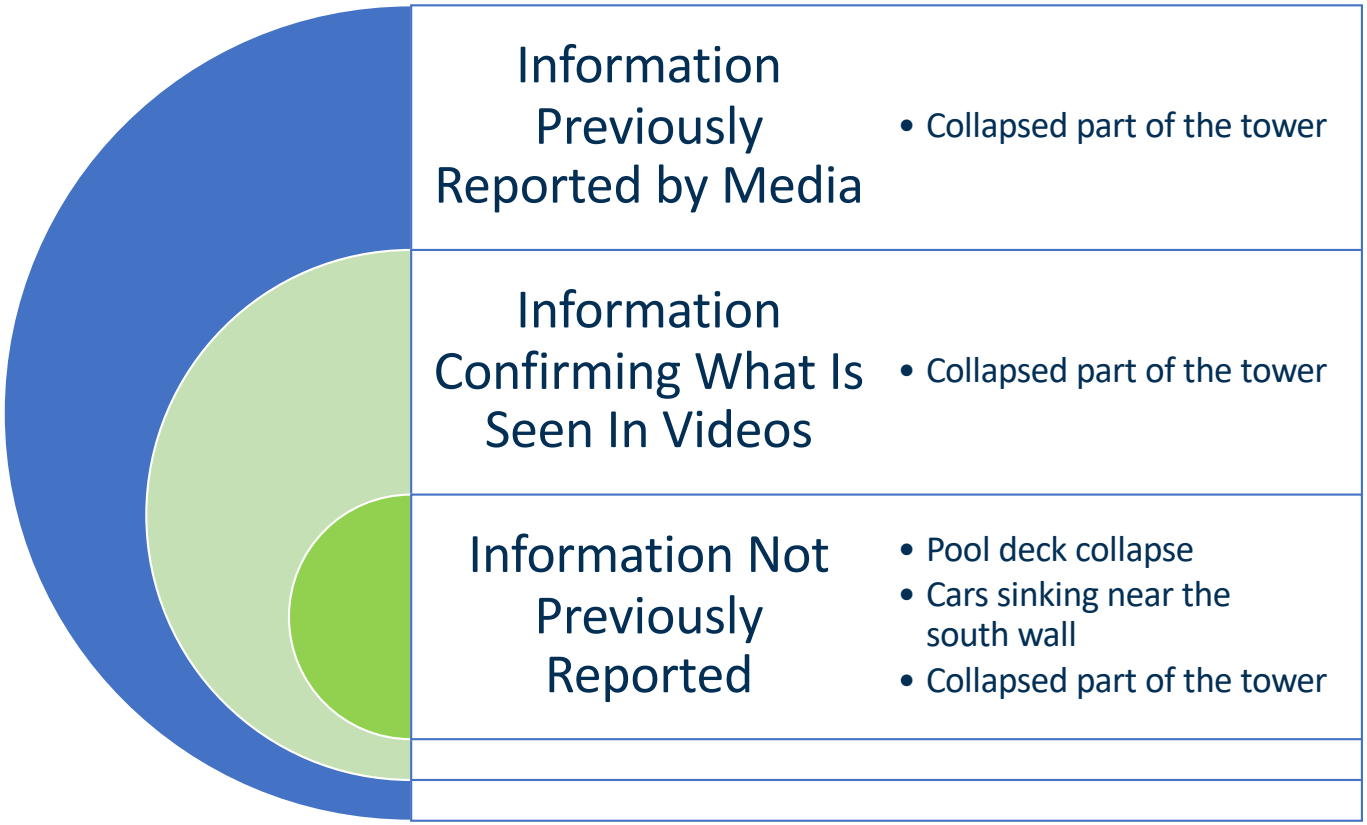
Visual Evidence Presented in Slides Spans 4 min 14 s

Weeks/Days Prior to Collapse

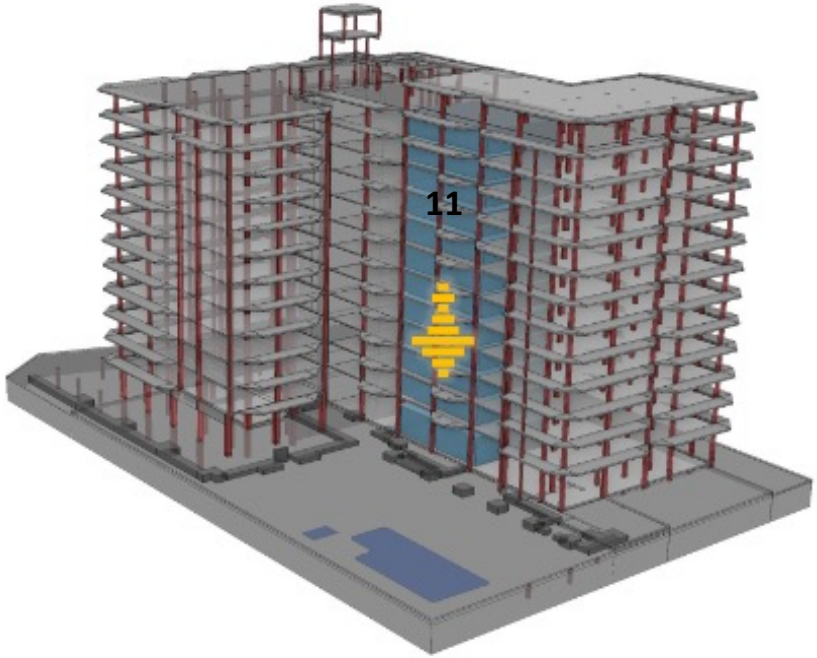
Hours/Minutes Prior to Collapse

Initiation & Progression

Timeline of Collapse Initiation and Progression is Informed by Interviews



Timeline of Collapse Initiation and Progression is Informed by Interviews



- Noises in the 11 stack units from above the 1st floor before 1 am
- Like “knocking” or a “hammer” or “table” & “chairs” being moved above
- Noises getting “louder and louder” and “more intense” closer to the time of the pool deck collapse

Source: NIST

Timeline of Collapse Initiation and Progression is Informed by Interviews

Source: NIST

Direction of cars sinking

- Car alarms "going off"
- Cars sinking into the ground near the south wall from the East towards the West
- Sinking does not "go all the way" to Collins Avenue

Timeline of Collapse Initiation and Progression

01:18:18

01:21:50

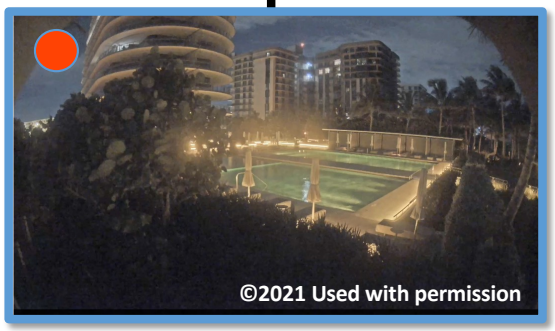
~01:22

Visual Evidence Presented in Slides Spans 4 min 14 s

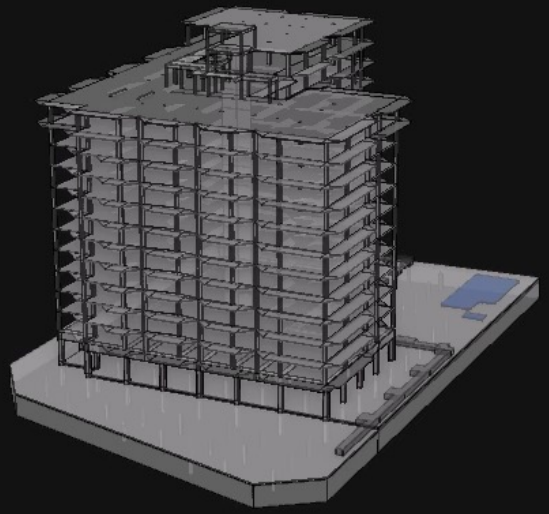
01:21:39

01:22:14

01:22:17



Footage of Collapse Initiation and Progression



Source: NIST

Footage of Collapse Initiation and Progression

CONTENT WARNING:

The following slides contain images, video footage, and other content that some may find disturbing.

Participants desiring to leave the meeting may do so now.

Timeline of Collapse Initiation and Progression: Ramp Video

01:18:18

01:21:50

~01:22

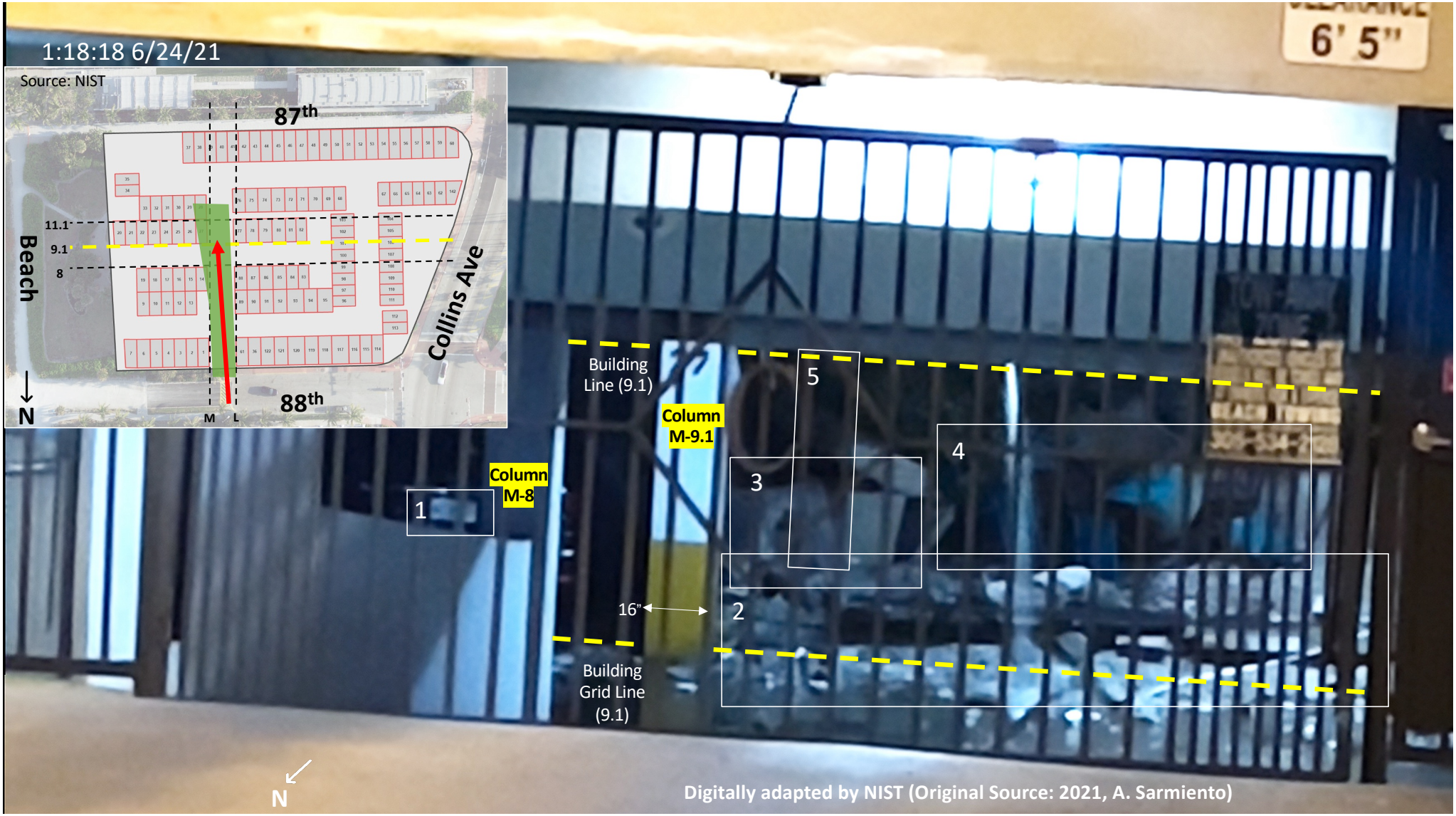
Visual Evidence Presented in Slides Spans 4 min 14 s

01:21:39

01:22:14

01:22:17


1:18:18 AM 6/24/2021
6' 5"
N
Digitally adapted by NIST (Original Source: 2021, A. Sarmiento)


1:18:18 6/24/21
Source: NIST
87th
88th
Collins Ave
Beach
11.1
9.1
8
M
L
N
6' 5"
Building Line (9.1)
Column M-9.1
Column M-8
1
2
3
4
5
16"
Building Grid Line (9.1)
N
Digitally adapted by NIST (Original Source: 2021, A. Sarmiento)

Timeline of Collapse Initiation and Progression: Beach Walkway Video

01:18:18

01:21:50

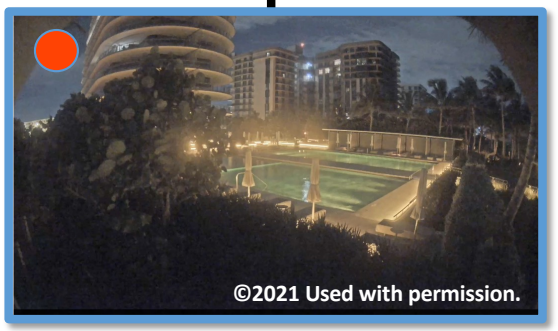
~01:22

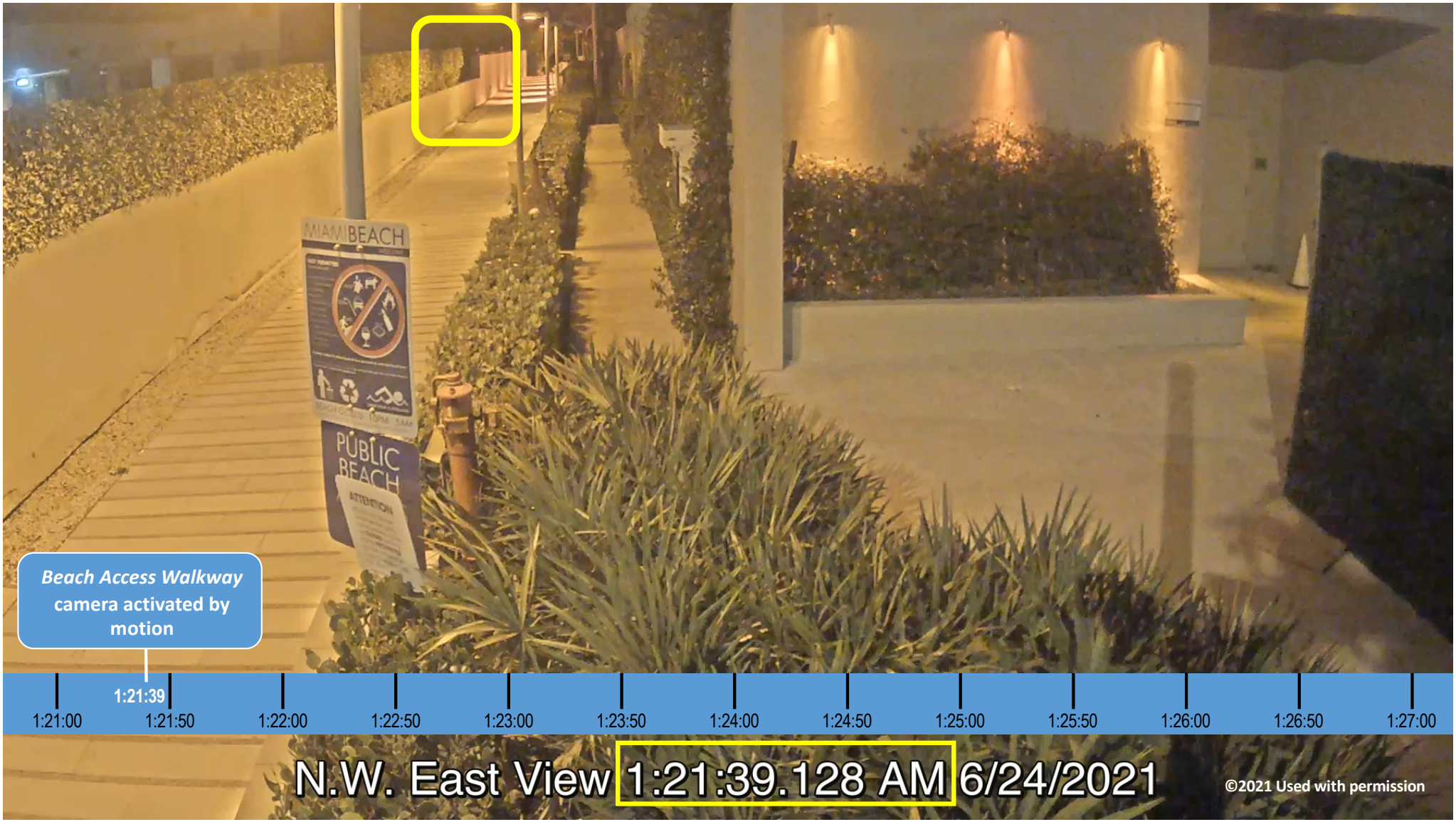
Visual Evidence Presented in Slides Spans 4 min 14 s

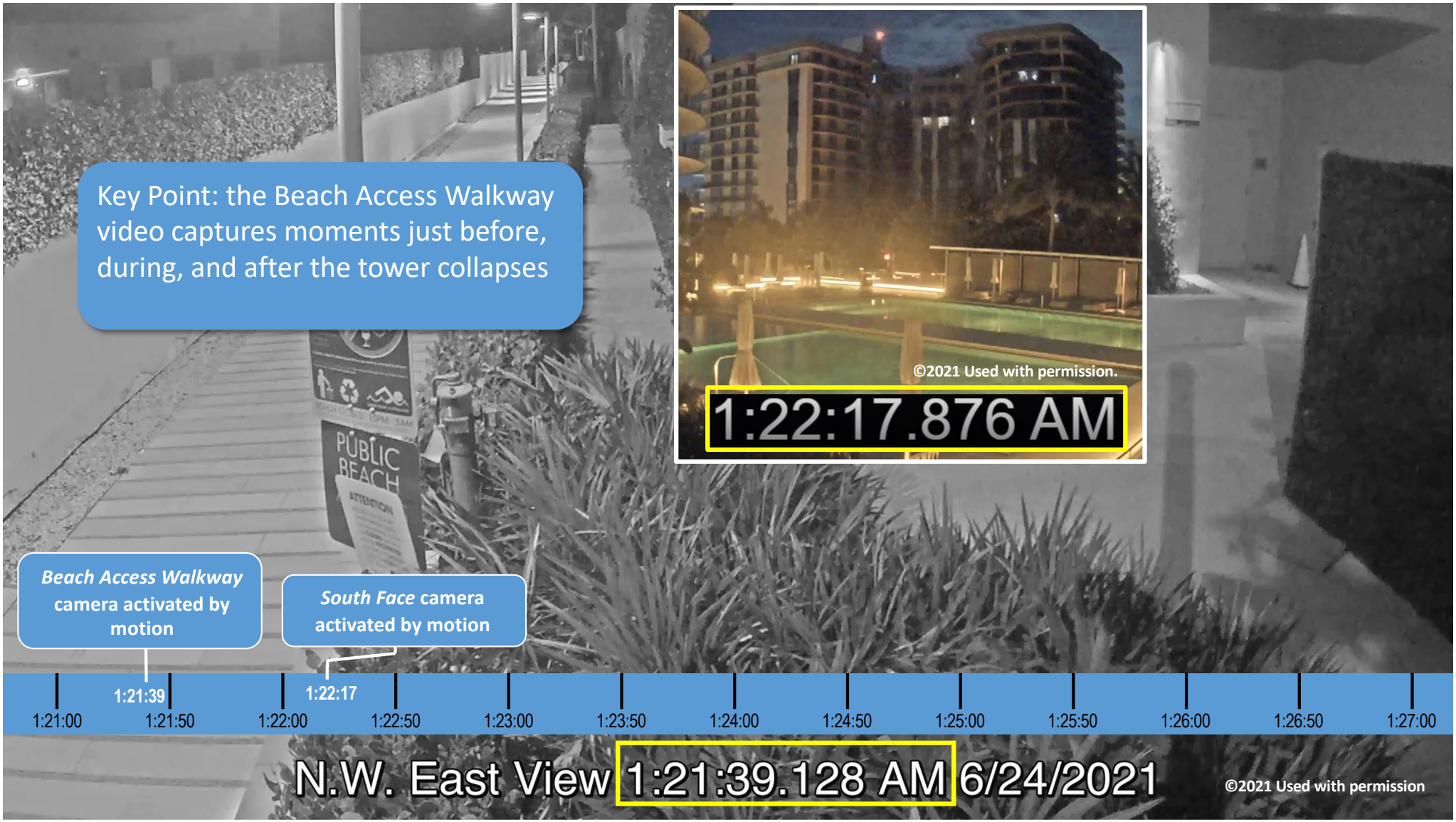
01:21:39

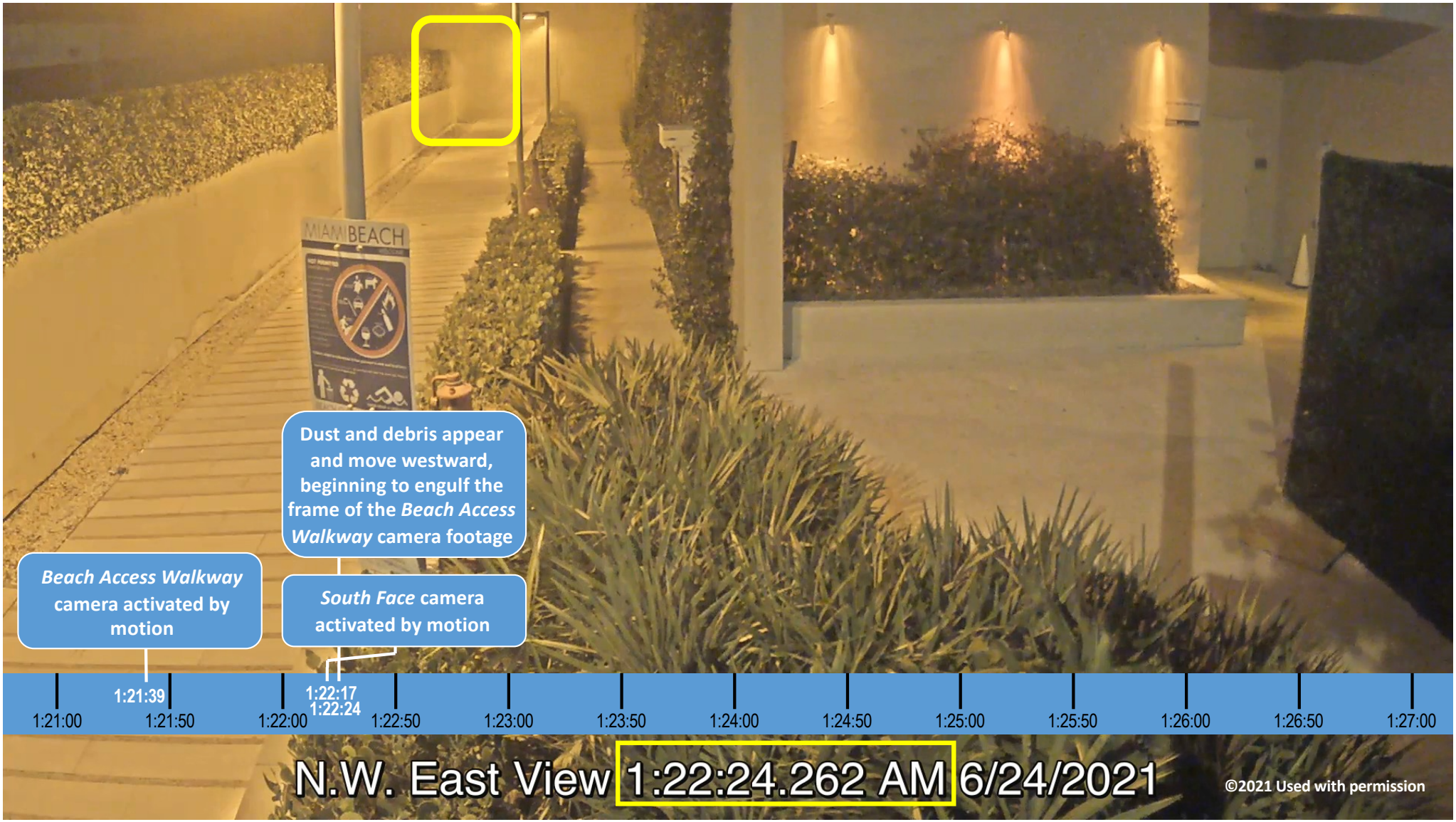
01:22:14

01:22:17




MIAMIBEACH
PUBLIC BEACH
ATTENTION
Beach Access Walkway camera activated by motion
1:21:39
1:21:00
1:21:50
1:22:00
1:22:50
1:23:00
1:23:50
1:24:00
1:24:50
1:25:00
1:25:50
1:26:00
1:26:50
1:27:00
N.W. East View 1:21:39.128 AM 6/24/2021
©2021 Used with permission


Key Point: the Beach Access Walkway video captures moments just before, during, and after the tower collapses
©2021 Used with permission.
1:22:17.876 AM
PUBLIC BEACH
Beach Access Walkway camera activated by motion
South Face camera activated by motion
1:21:39
1:22:17
1:21:00
1:21:50
1:22:00
1:22:50
1:23:00
1:23:50
1:24:00
1:24:50
1:25:00
1:25:50
1:26:00
1:26:50
1:27:00
N.W. East View 1:21:39.128 AM 6/24/2021
©2021 Used with permission


MIAMIBEACH
Dust and debris appear and move westward, beginning to engulf the frame of the *Beach Access Walkway* camera footage
Beach Access Walkway camera activated by motion
South Face camera activated by motion
1:21:39
1:22:17
1:22:24
1:21:00
1:21:50
1:22:00
1:22:50
1:23:00
1:23:50
1:24:00
1:24:50
1:25:00
1:25:50
1:26:00
1:26:50
1:27:00
N.W. East View 1:22:24.262 AM 6/24/2021
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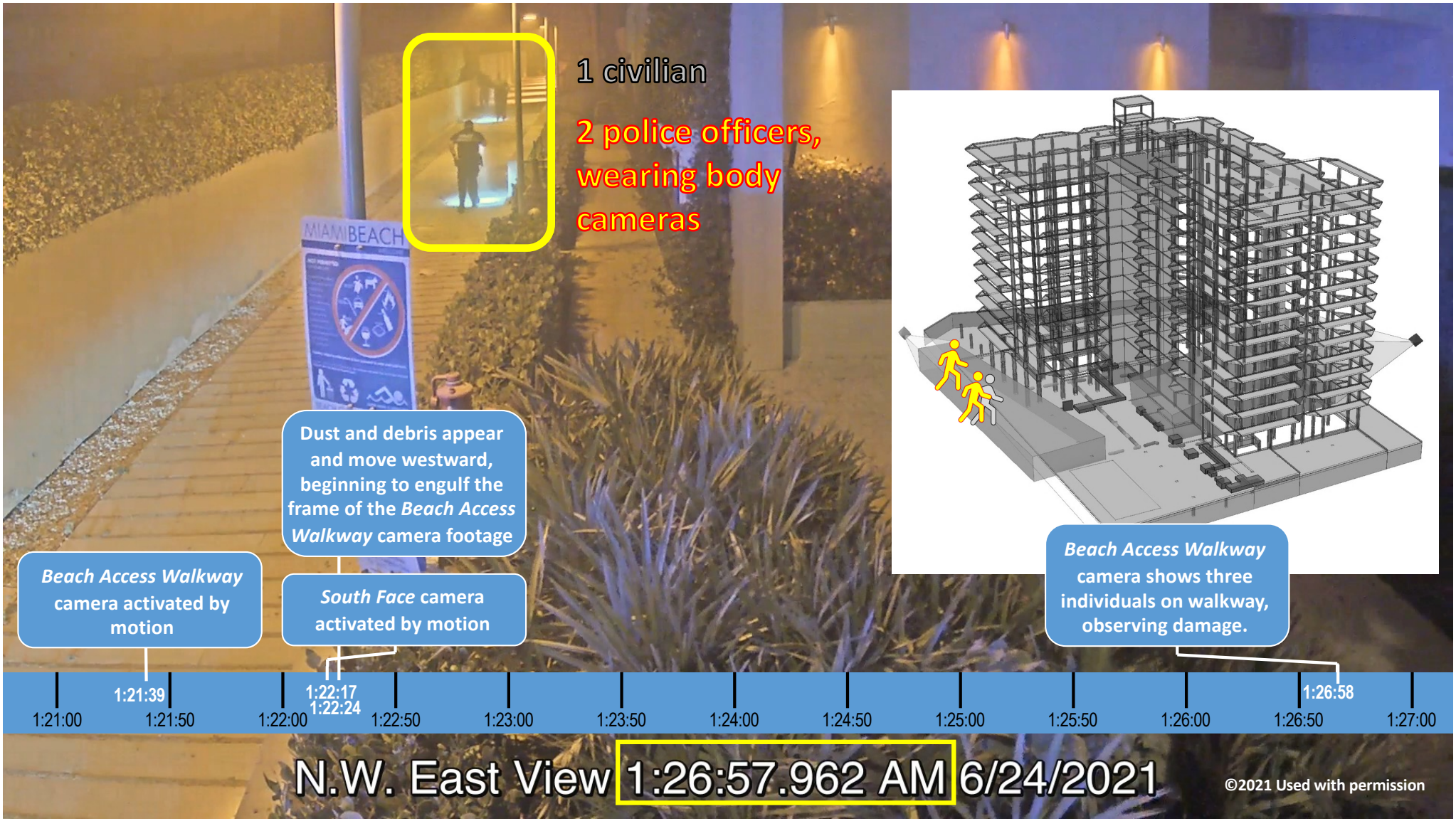
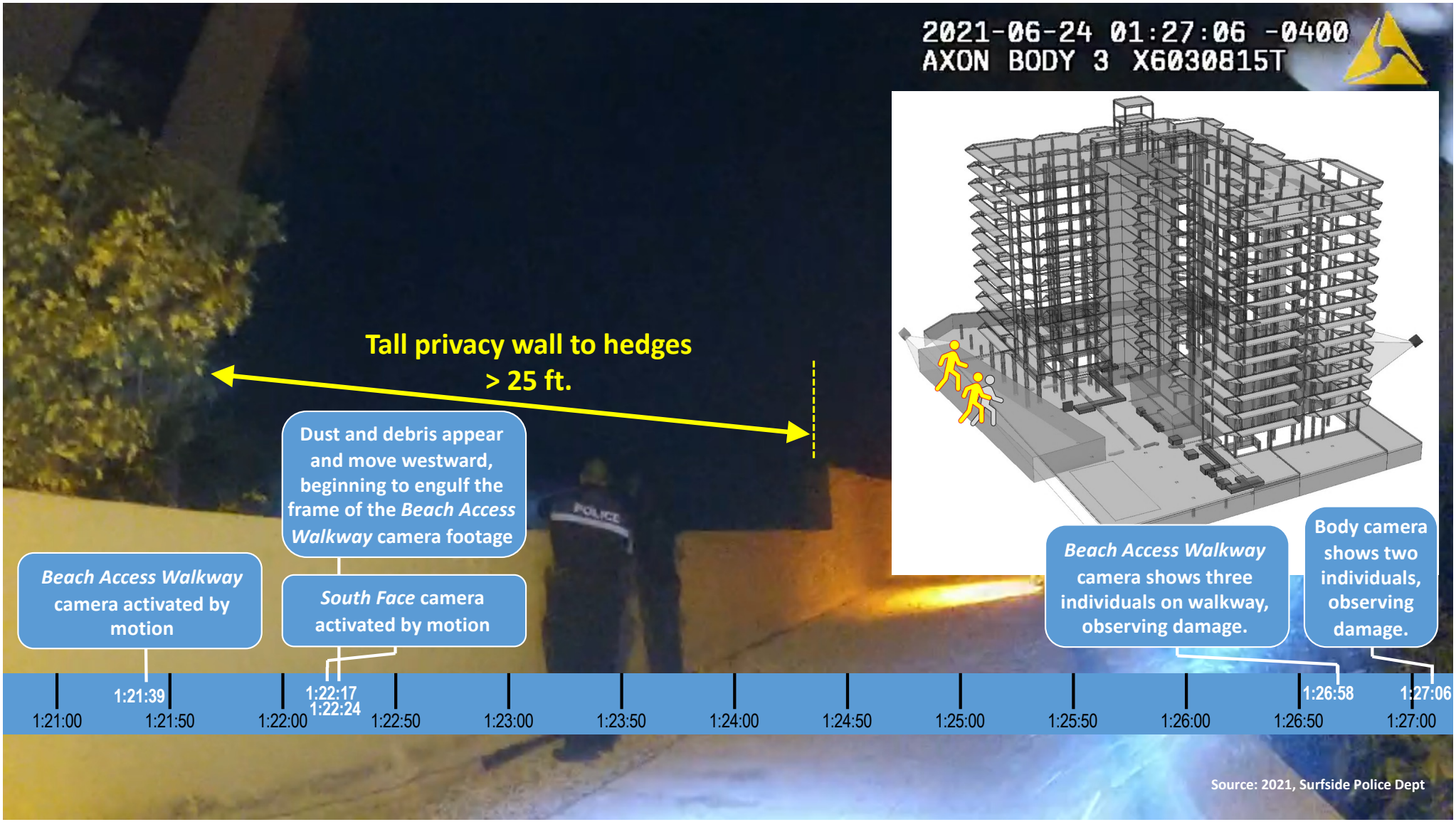
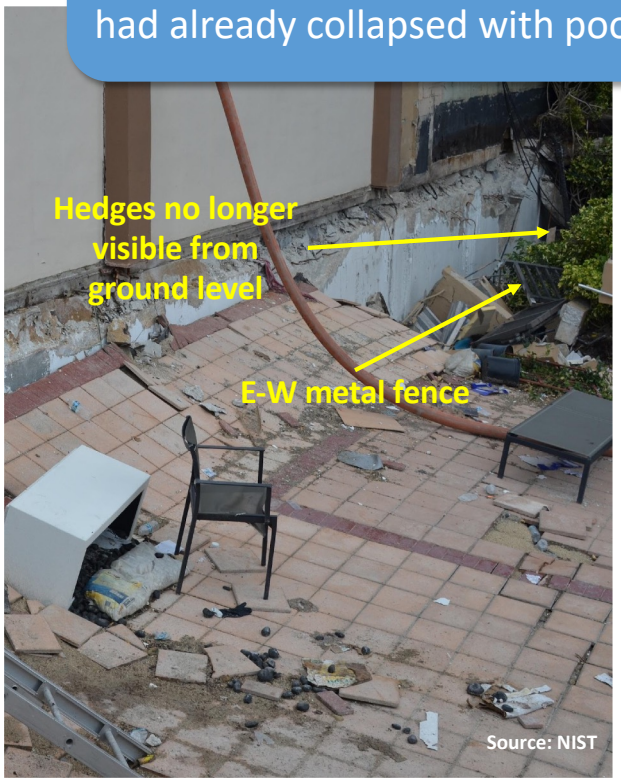

1 civilian
2 police officers, wearing body cameras
MIAMIBEACH
Dust and debris appear and move westward, beginning to engulf the frame of the *Beach Access Walkway* camera footage
Beach Access Walkway camera activated by motion
South Face camera activated by motion
Beach Access Walkway camera shows three individuals on walkway, observing damage.
1:21:00
1:21:39
1:21:50
1:22:00
1:22:17
1:22:24
1:22:50
1:23:00
1:23:50
1:24:00
1:24:50
1:25:00
1:25:50
1:26:00
1:26:58
1:26:50
1:27:00
N.W. East View 1:26:57.962 AM 6/24/2021
©2021 Used with permission


2021-06-24 01:27:06 -0400
AXON BODY 3 X6030815T
Tall privacy wall to hedges
> 25 ft.
Dust and debris appear and move westward, beginning to engulf the frame of the *Beach Access Walkway* camera footage
Beach Access Walkway camera activated by motion
South Face camera activated by motion
Beach Access Walkway camera shows three individuals on walkway, observing damage.
Body camera shows two individuals, observing damage.
1:21:00
1:21:39
1:21:50
1:22:00
1:22:17
1:22:24
1:22:50
1:23:00
1:23:50
1:24:00
1:24:50
1:25:00
1:25:50
1:26:00
1:26:58
1:26:50
1:27:06
1:27:00
Source: 2021, Surfside Police Dept

Comparison to Beach Access Walkway Footage

Key Point: Portion of hedges and the metal fence are not visible in Beach Access Walkway footage because they had already collapsed with pool deck



Timeline of Collapse Initiation and Progression: Upper Story Corridor Video

01:18:18

01:21:50

~01:22

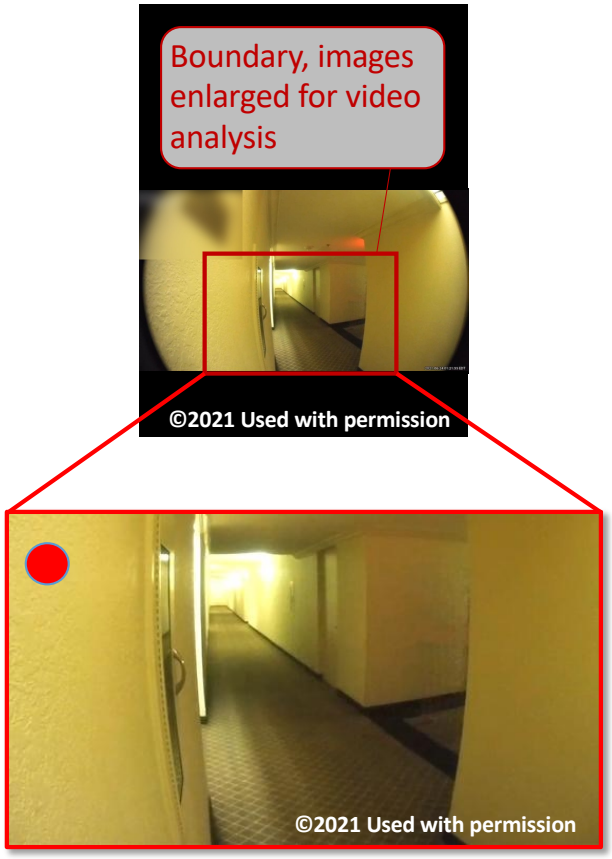
Visual Evidence Presented in Slides Spans 4 min 14 s

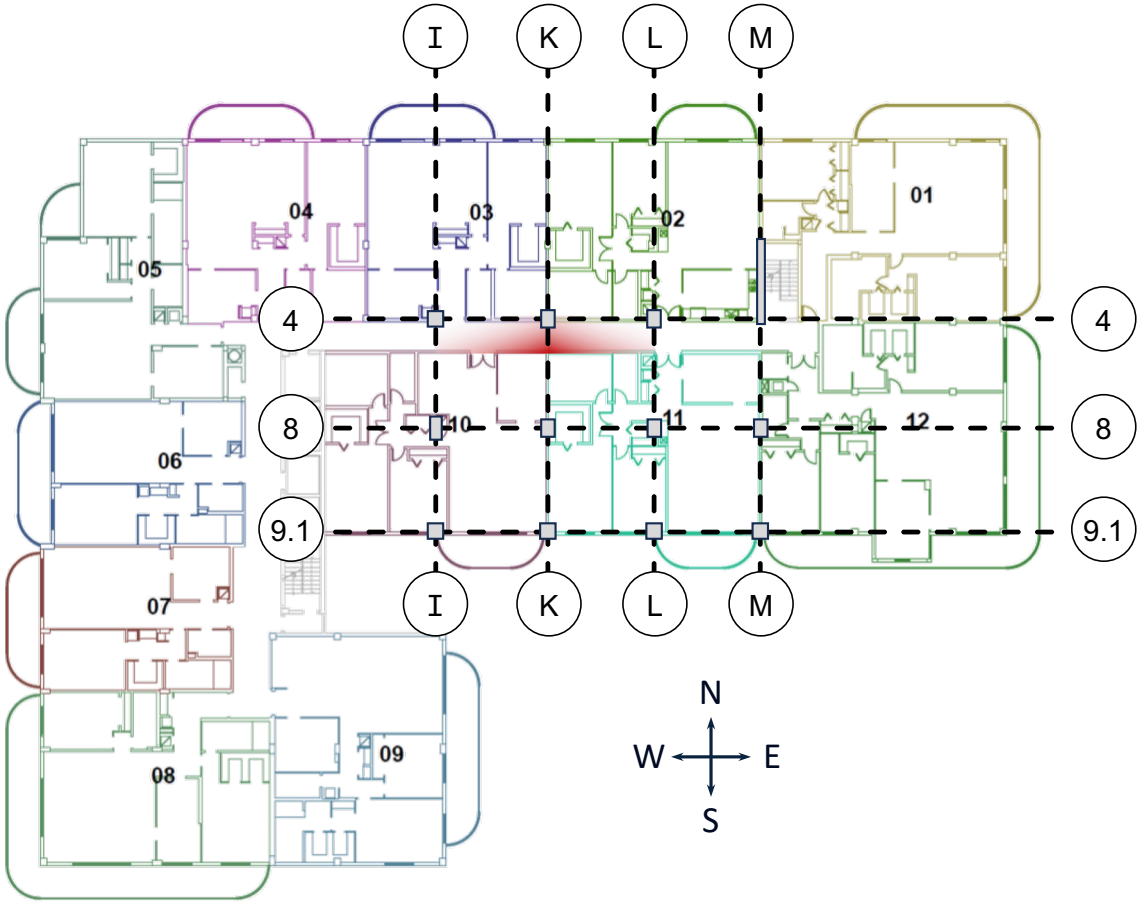
01:21:39

01:22:14

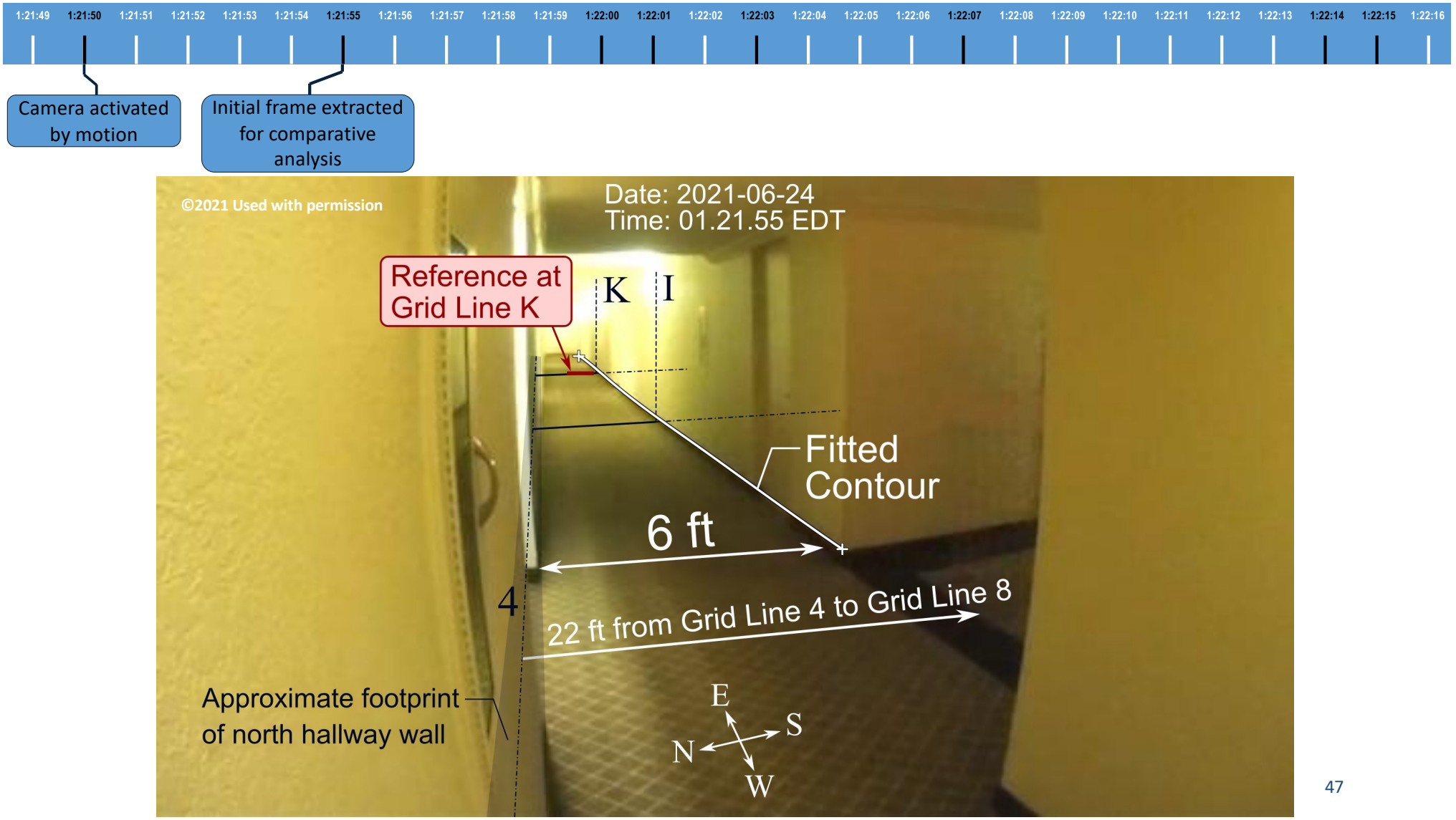
01:22:17

Camera activated by motion





Source: NIST


1:21:49
1:21:50
1:21:51
1:21:52
1:21:53
1:21:54
1:21:55
1:21:56
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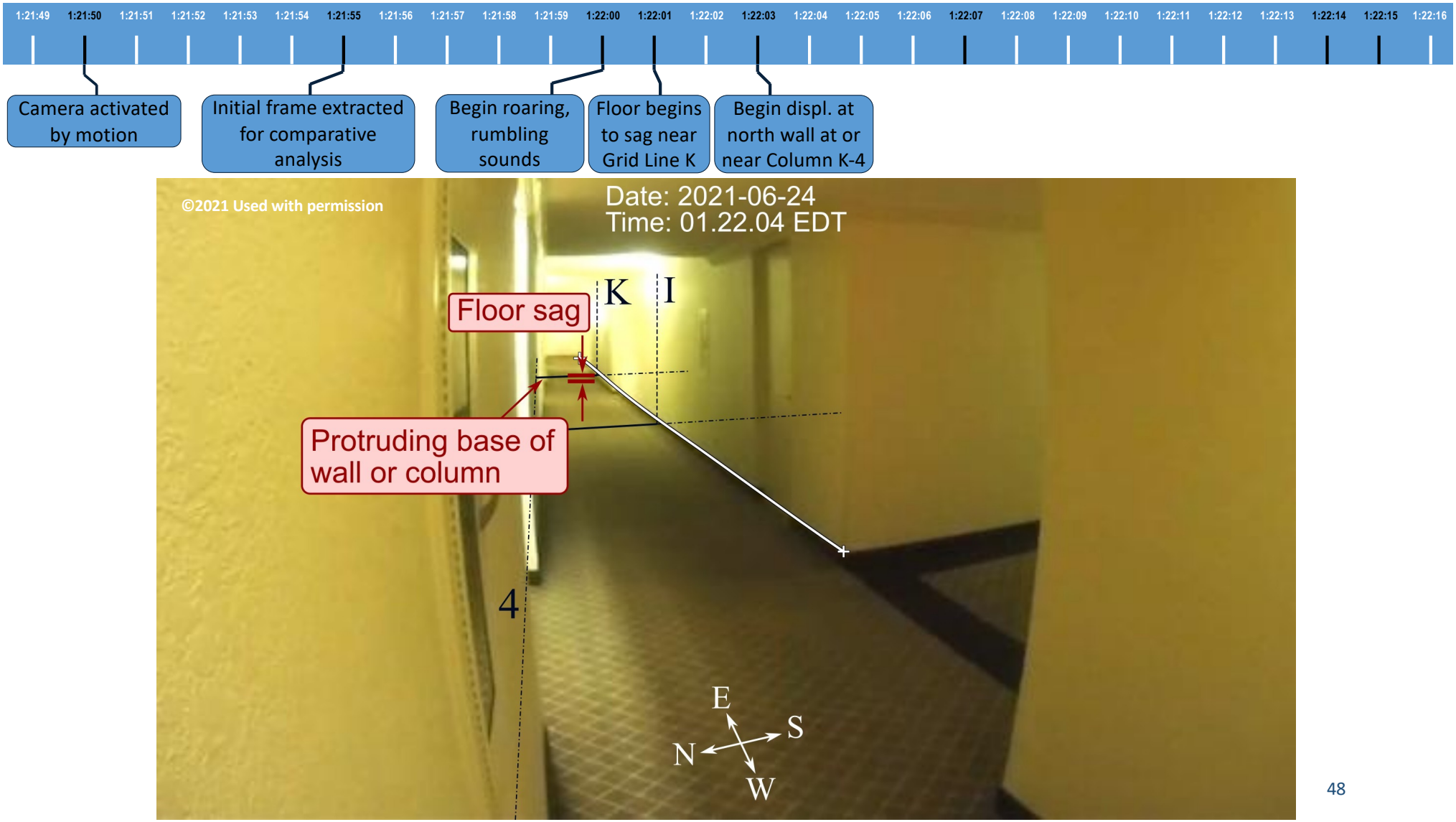
1:21:58
1:21:59
1:22:00
1:22:01
1:22:02
1:22:03
1:22:04
1:22:05
1:22:06
1:22:07
1:22:08
1:22:09
1:22:10
1:22:11
1:22:12
1:22:13
1:22:14
1:22:15
1:22:16
Camera activated by motion
Initial frame extracted for comparative analysis
©2021 Used with permission
Date: 2021-06-24
Time: 01.21.55 EDT
Reference at Grid Line K
K
I
Fitted Contour
6 ft
4
22 ft from Grid Line 4 to Grid Line 8
Approximate footprint of north hallway wall
E
S
N
W


1:21:49
1:21:50
1:21:51
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1:21:55
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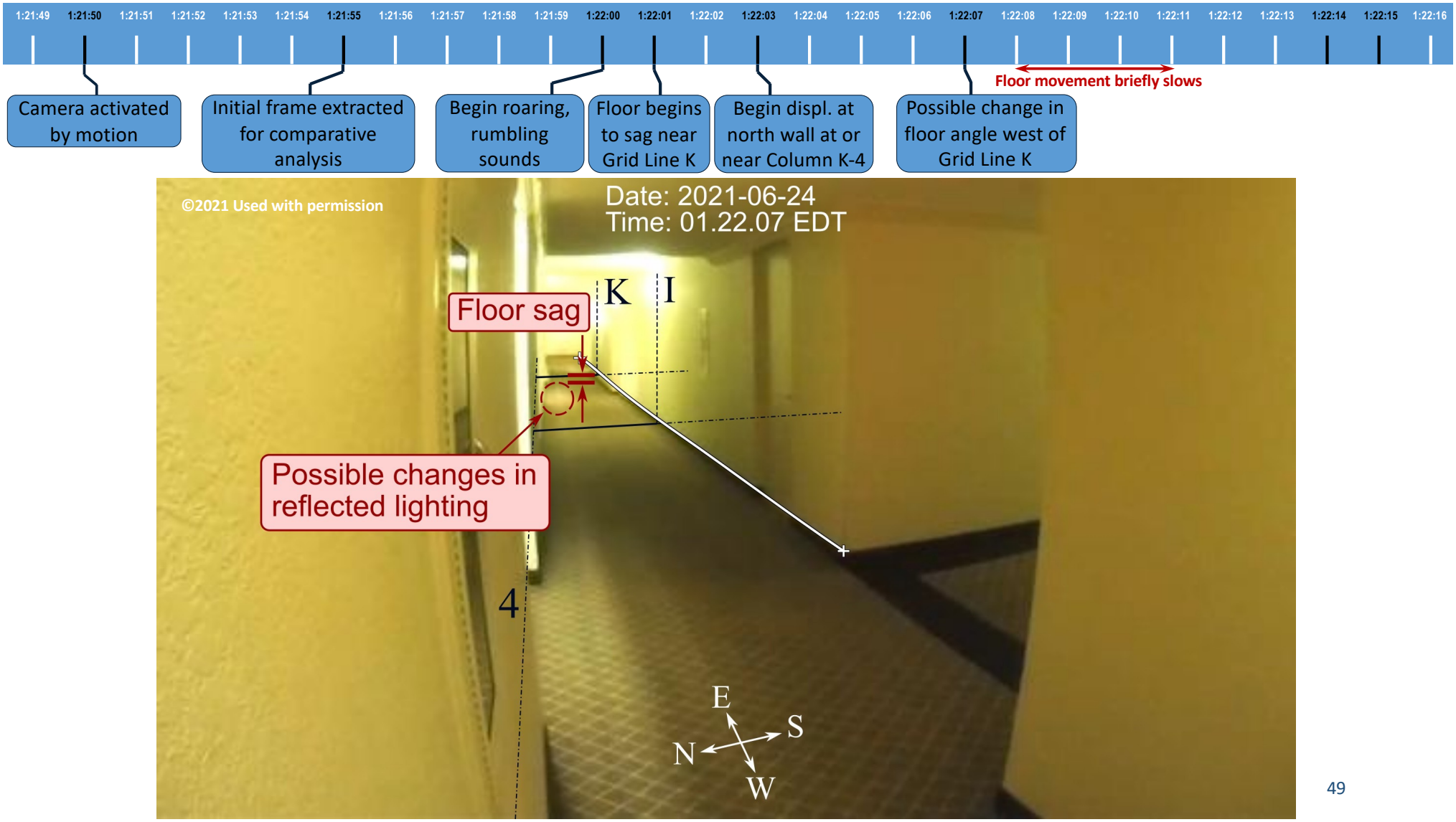
1:21:58
1:21:59
1:22:00
1:22:01
1:22:02
1:22:03
1:22:04
1:22:05
1:22:06
1:22:07
1:22:08
1:22:09
1:22:10
1:22:11
1:22:12
1:22:13
1:22:14
1:22:15
1:22:16
Camera activated by motion
Initial frame extracted for comparative analysis
Begin roaring, rumbling sounds
Floor begins to sag near Grid Line K
Begin displ. at north wall at or near Column K-4
©2021 Used with permission
Date: 2021-06-24
Time: 01.22.04 EDT
K
I
Floor sag
Protruding base of wall or column
4
E
S
N
W


1:21:49
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1:21:58
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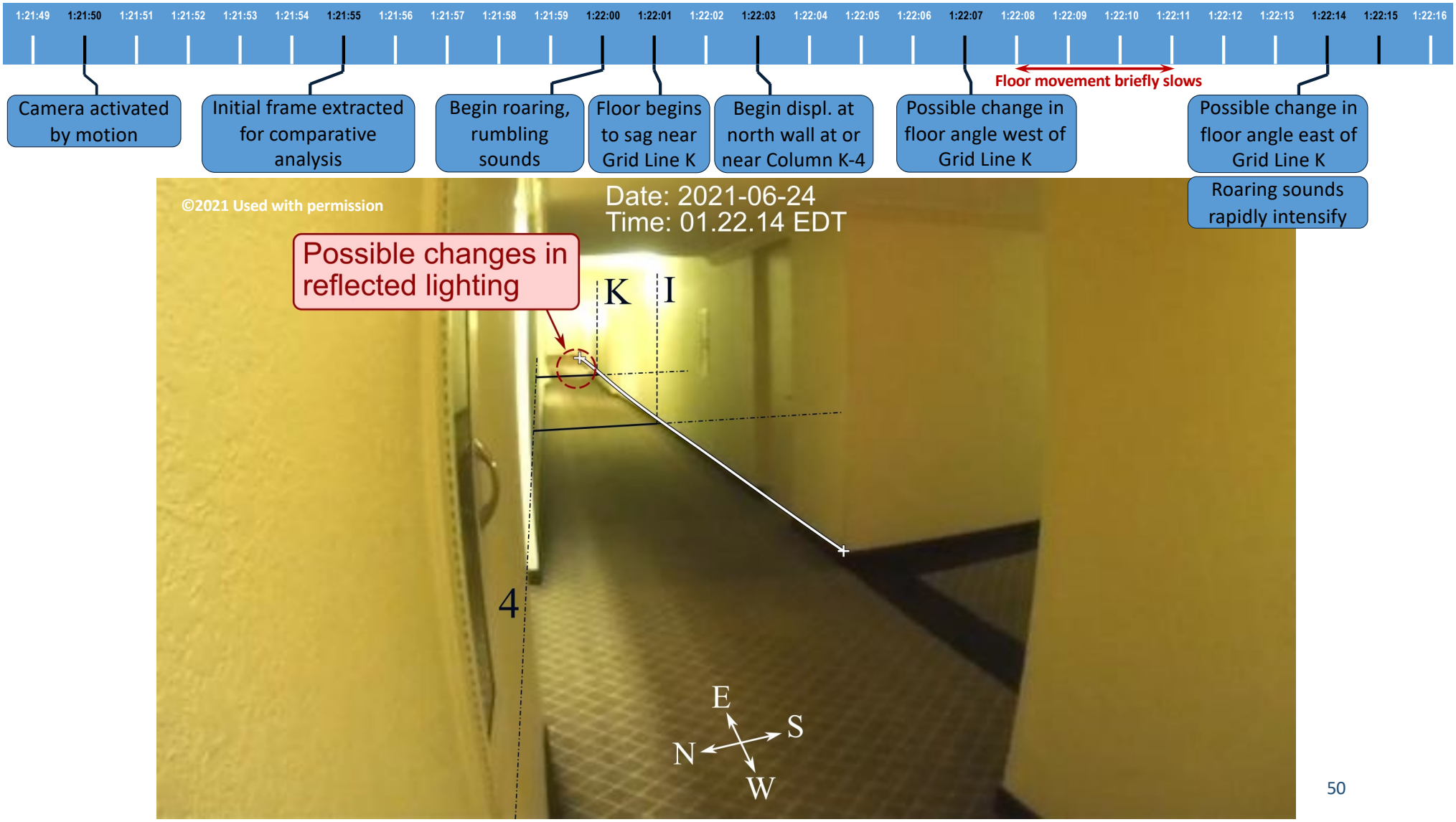
1:22:00
1:22:01
1:22:02
1:22:03
1:22:04
1:22:05
1:22:06
1:22:07
1:22:08
1:22:09
1:22:10
1:22:11
1:22:12
1:22:13
1:22:14
1:22:15
1:22:16
Floor movement briefly slows
Camera activated by motion
Initial frame extracted for comparative analysis
Begin roaring, rumbling sounds
Floor begins to sag near Grid Line K
Begin displ. at north wall at or near Column K-4
Possible change in floor angle west of Grid Line K
©2021 Used with permission
Date: 2021-06-24
Time: 01.22.07 EDT
K
I
Floor sag
Possible changes in reflected lighting
4
E
S
N
W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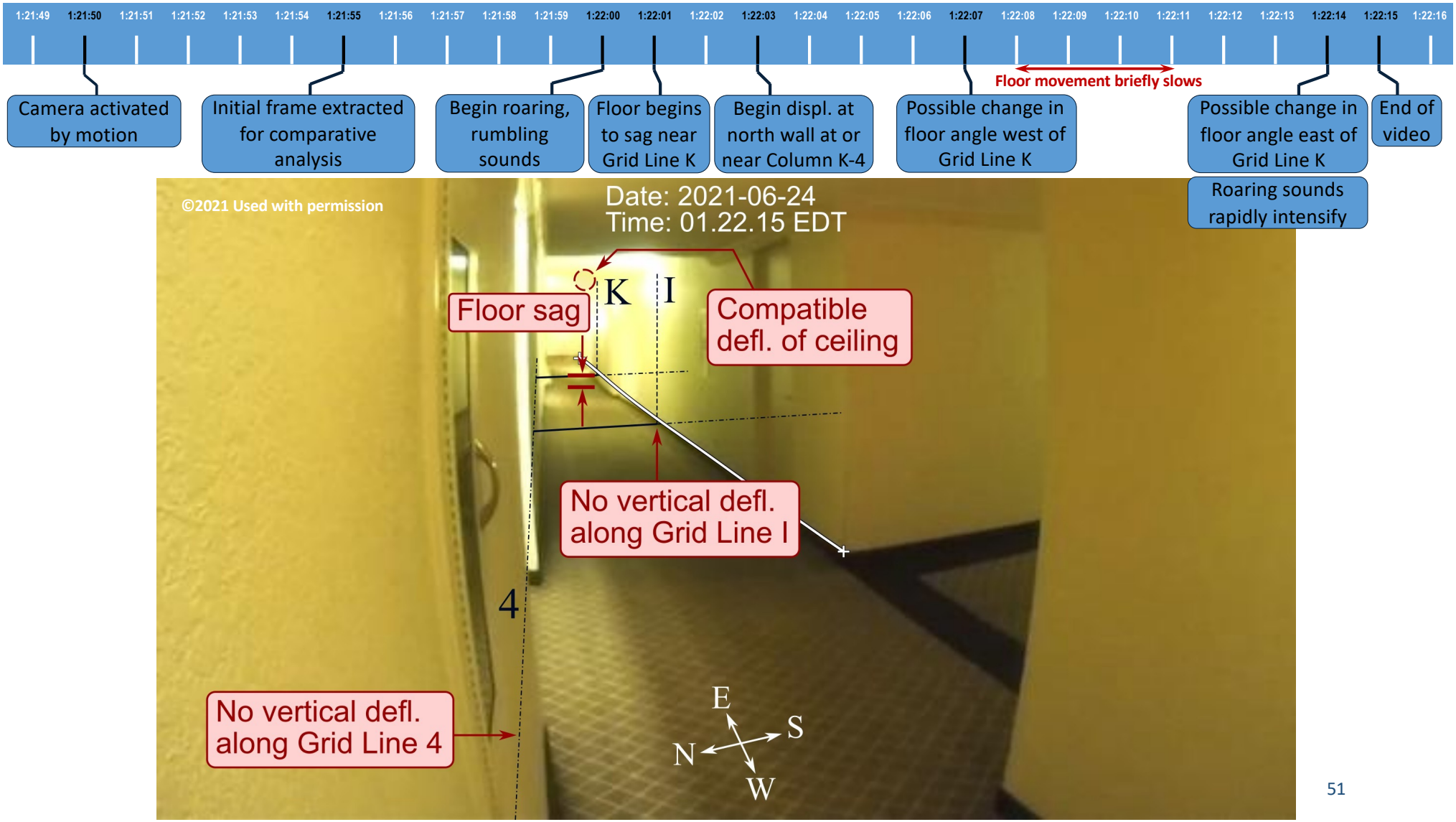
1:22:00
1:22:01
1:22:02
1:22:03
1:22:04
1:22:05
1:22:06
1:22:07
1:22:08
1:22:09
1:22:10
1:22:11
1:22:12
1:22:13
1:22:14
1:22:15
1:22:16
Floor movement briefly slows
Camera activated by motion
Initial frame extracted for comparative analysis
Begin roaring, rumbling sounds
Floor begins to sag near Grid Line K
Begin displ. at north wall at or near Column K-4
Possible change in floor angle west of Grid Line K
Possible change in floor angle east of Grid Line K
Roaring sounds rapidly intensify
©2021 Used with permission
Date: 2021-06-24
Time: 01.22.14 EDT
Possible changes in reflected lighting
K
I
4
E
S
N
W


1:21:49
1:21:50
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1:21:58
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1:22:01
1:22:02
1:22:03
1:22:04
1:22:05
1:22:06
1:22:07
1:22:08
1:22:09
1:22:10
1:22:11
1:22:12
1:22:13
1:22:14
1:22:15
1:22:16
Floor movement briefly slows
Camera activated by motion
Initial frame extracted for comparative analysis
Begin roaring, rumbling sounds
Floor begins to sag near Grid Line K
Begin displ. at north wall at or near Column K-4
Possible change in floor angle west of Grid Line K
Possible change in floor angle east of Grid Line K
End of video
Roaring sounds rapidly intensify
©2021 Used with permission
Date: 2021-06-24
Time: 01.22.15 EDT
K
I
Floor sag
Compatible defl. of ceiling
No vertical defl. along Grid Line I
4
No vertical defl. along Grid Line 4
E
S
N
W

Timeline of Collapse Initiation and Progression: Stack 11 Unit Video

01:18:18

01:21:50

~01:22

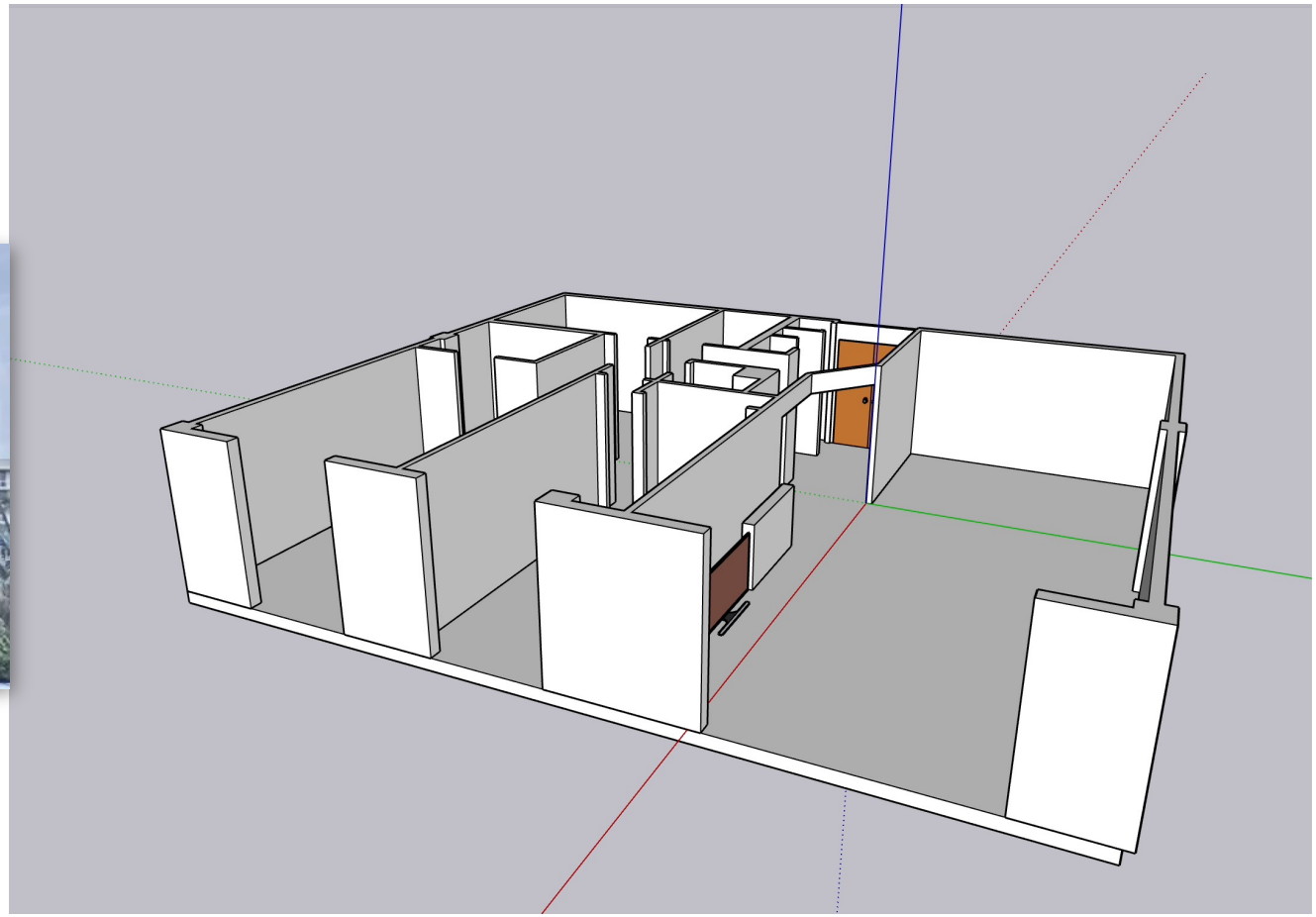
Visual Evidence Presented in Slides Spans 4 min 14 s

01:21:39

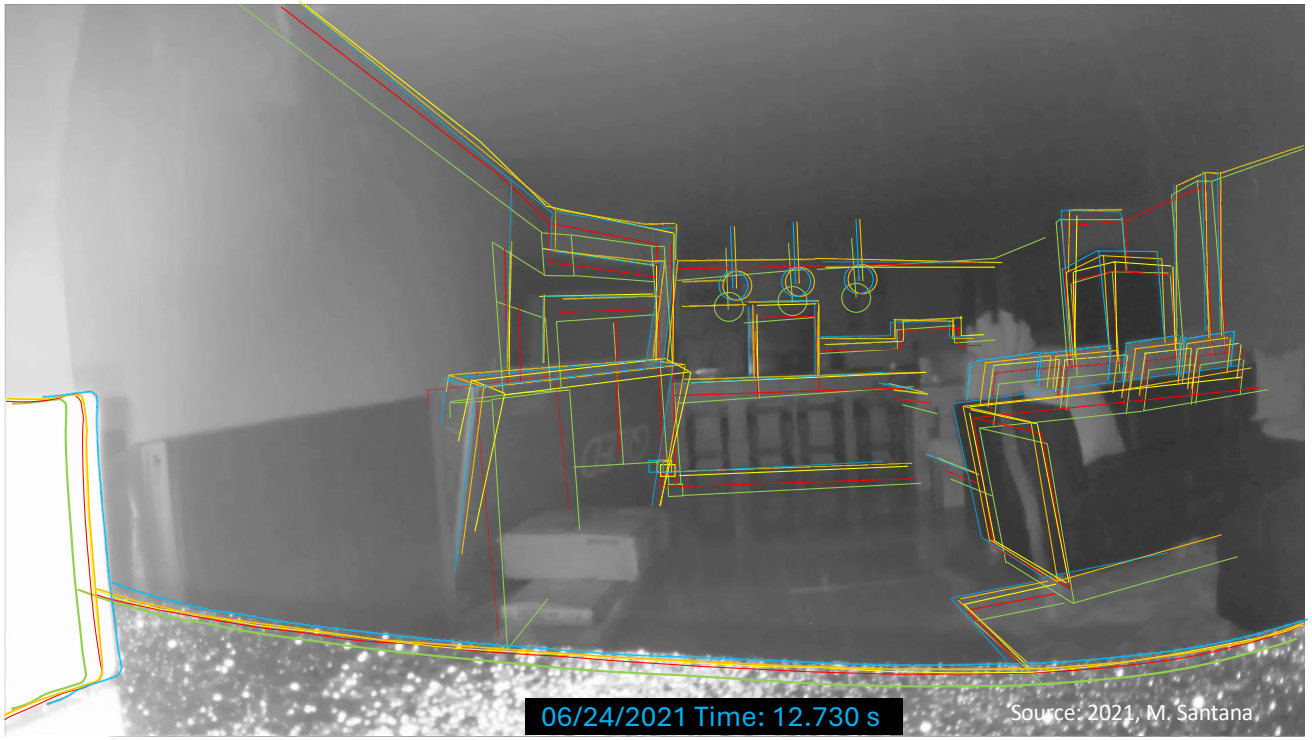
01:22:14

01:22:17

Position and Orientation of 11 Stack Unit Camera



Tracking movement of objects in the 11 Stack Unit Video



Timeline of Collapse Initiation and Progression: South Face Camera Video

01:18:18

01:21:50

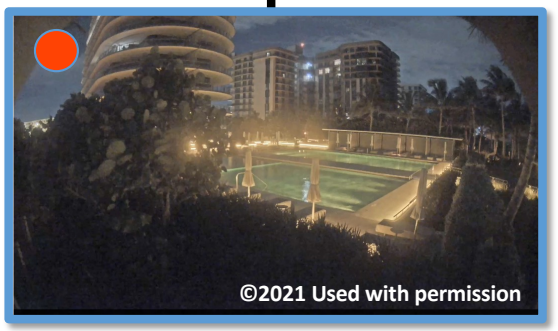
~01:22

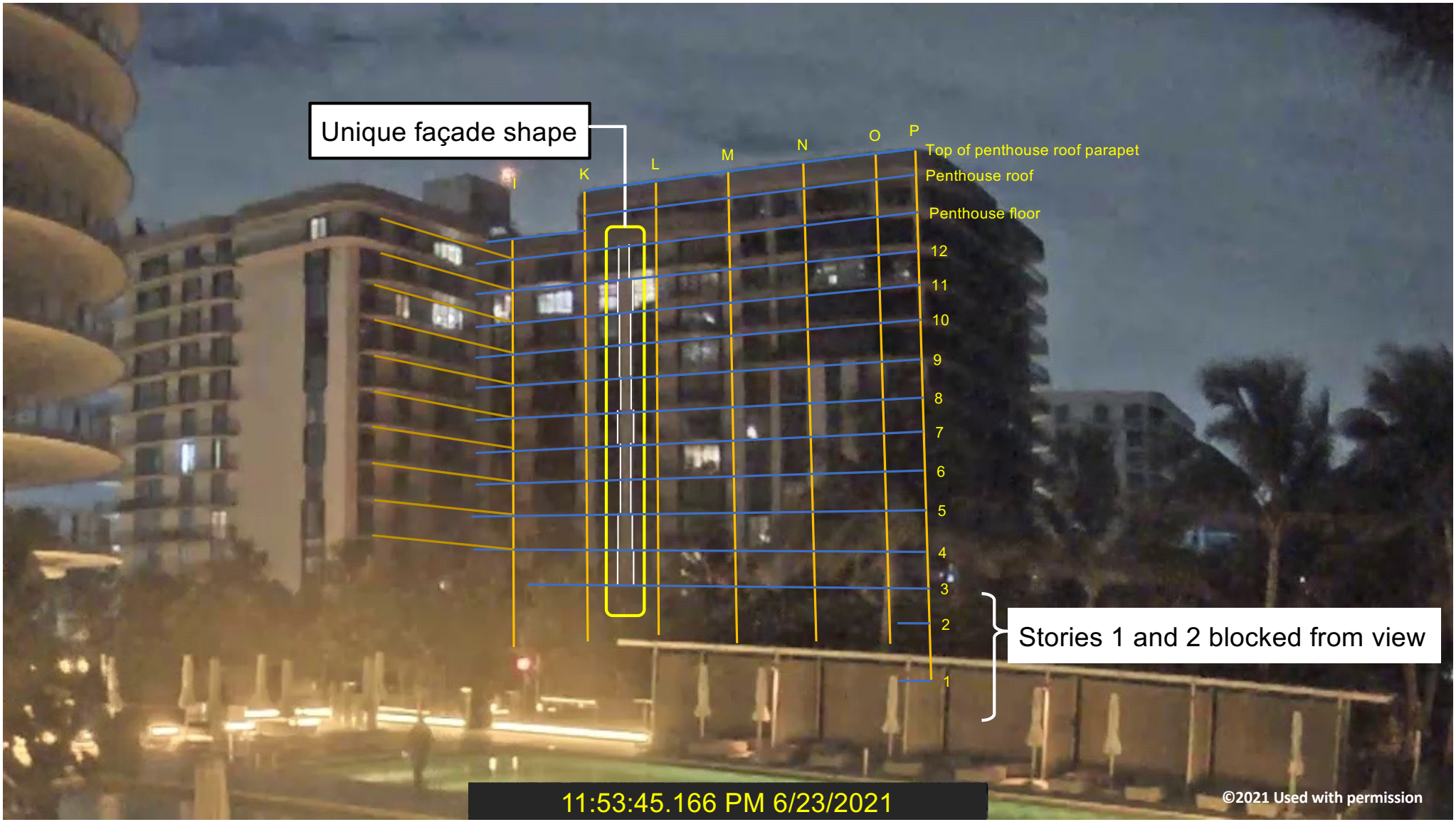
Visual Evidence Presented in Slides Spans 4 min 14 s

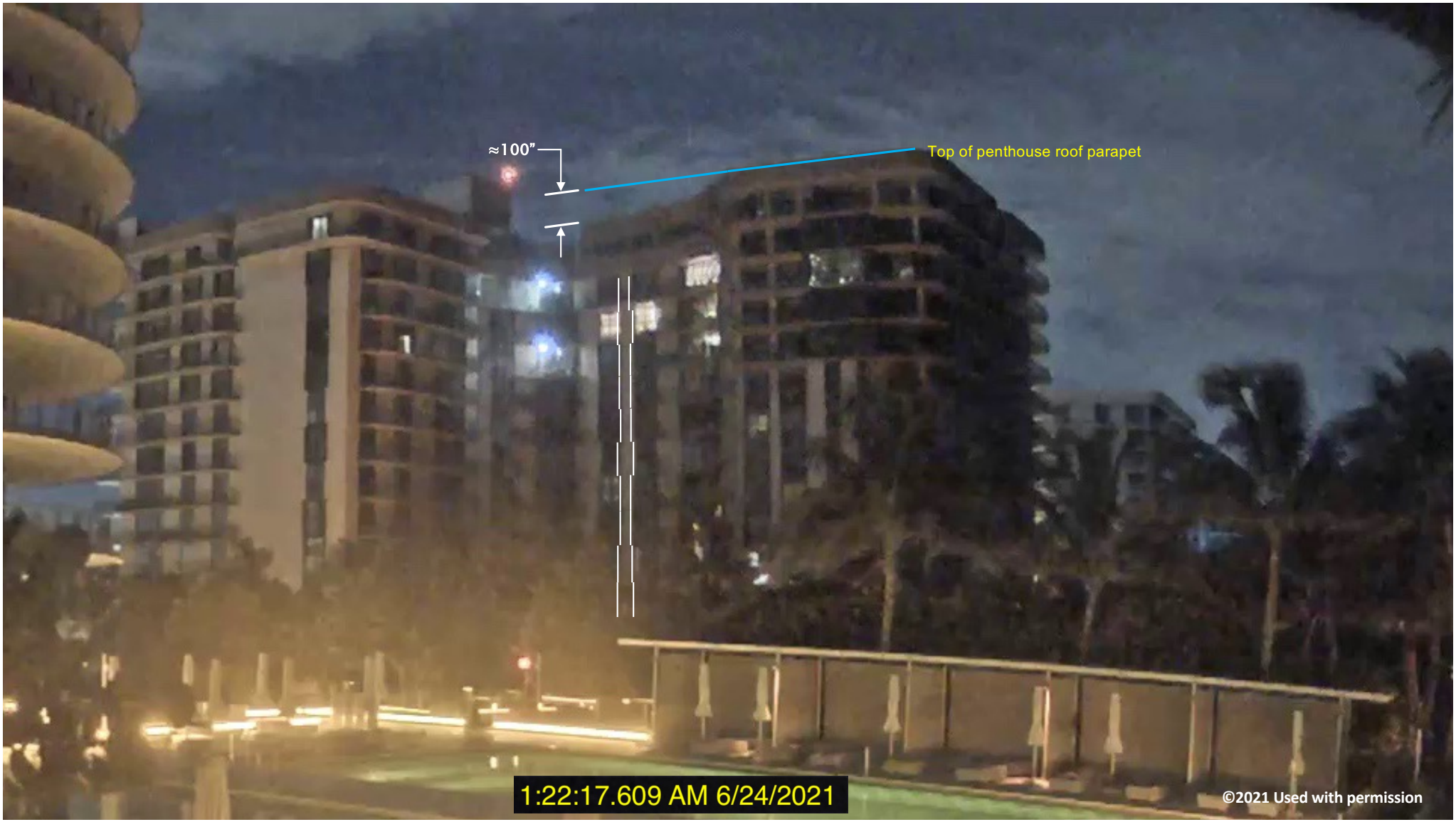
01:21:39

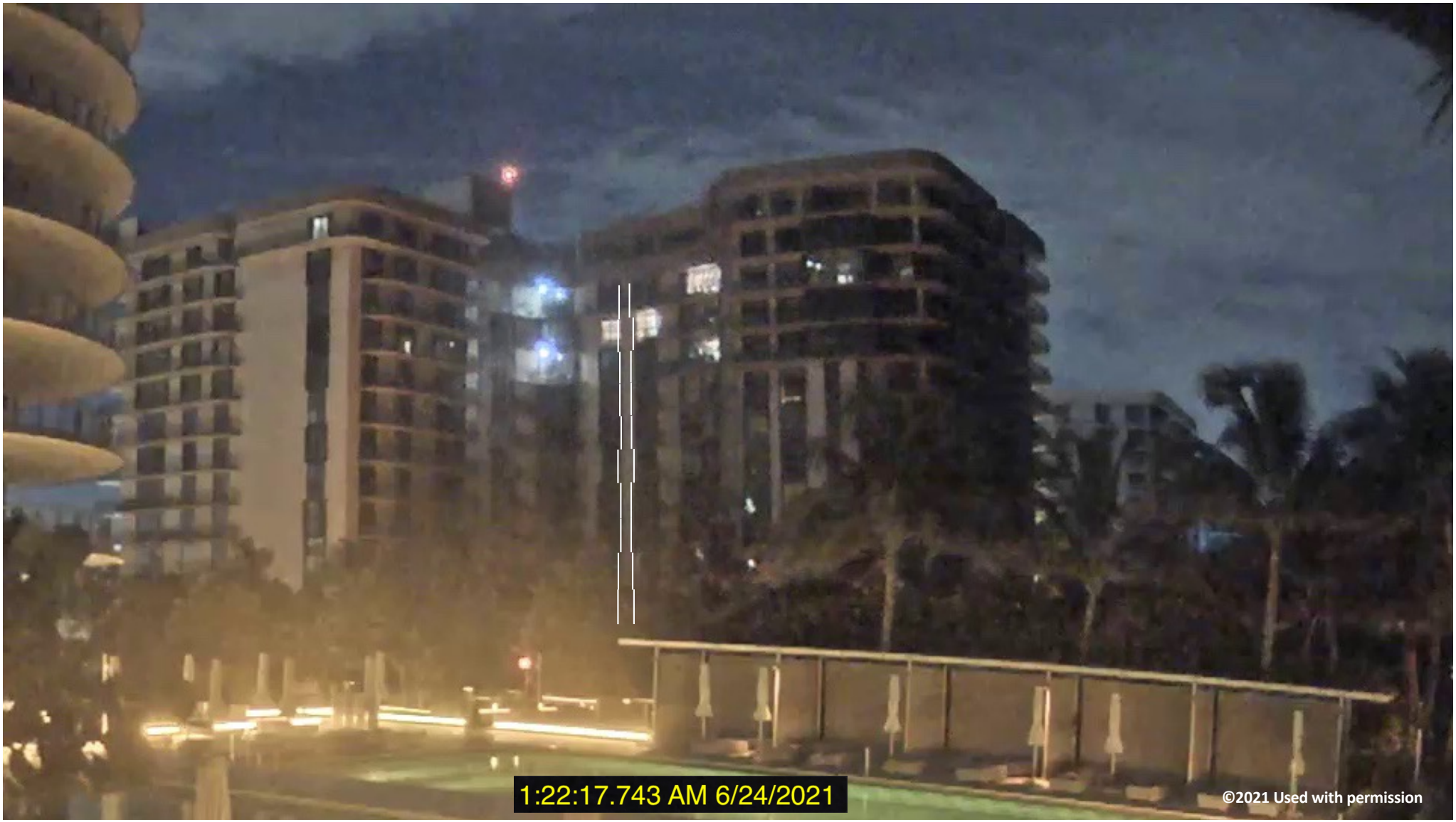
01:22:14

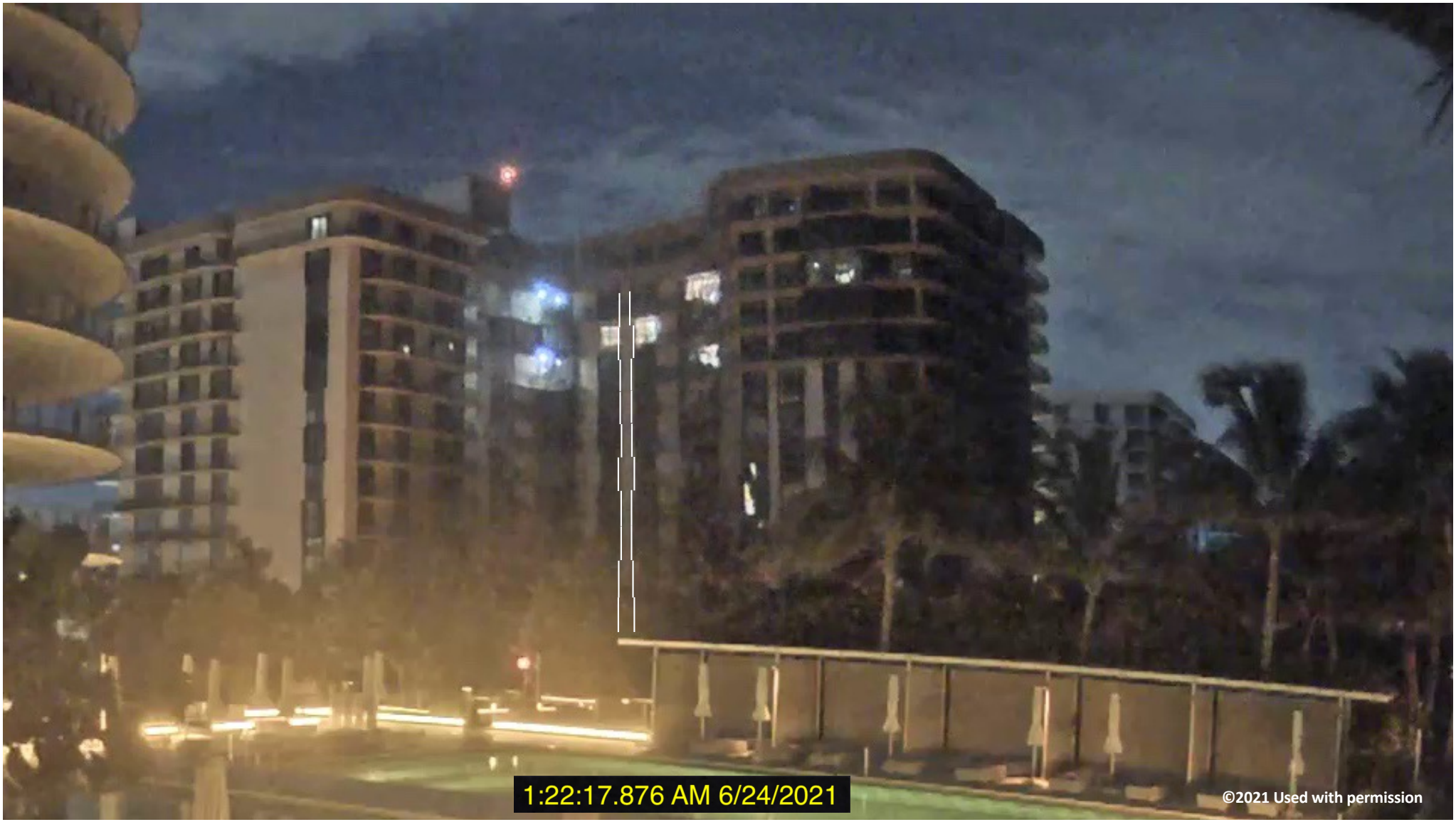
01:22:17

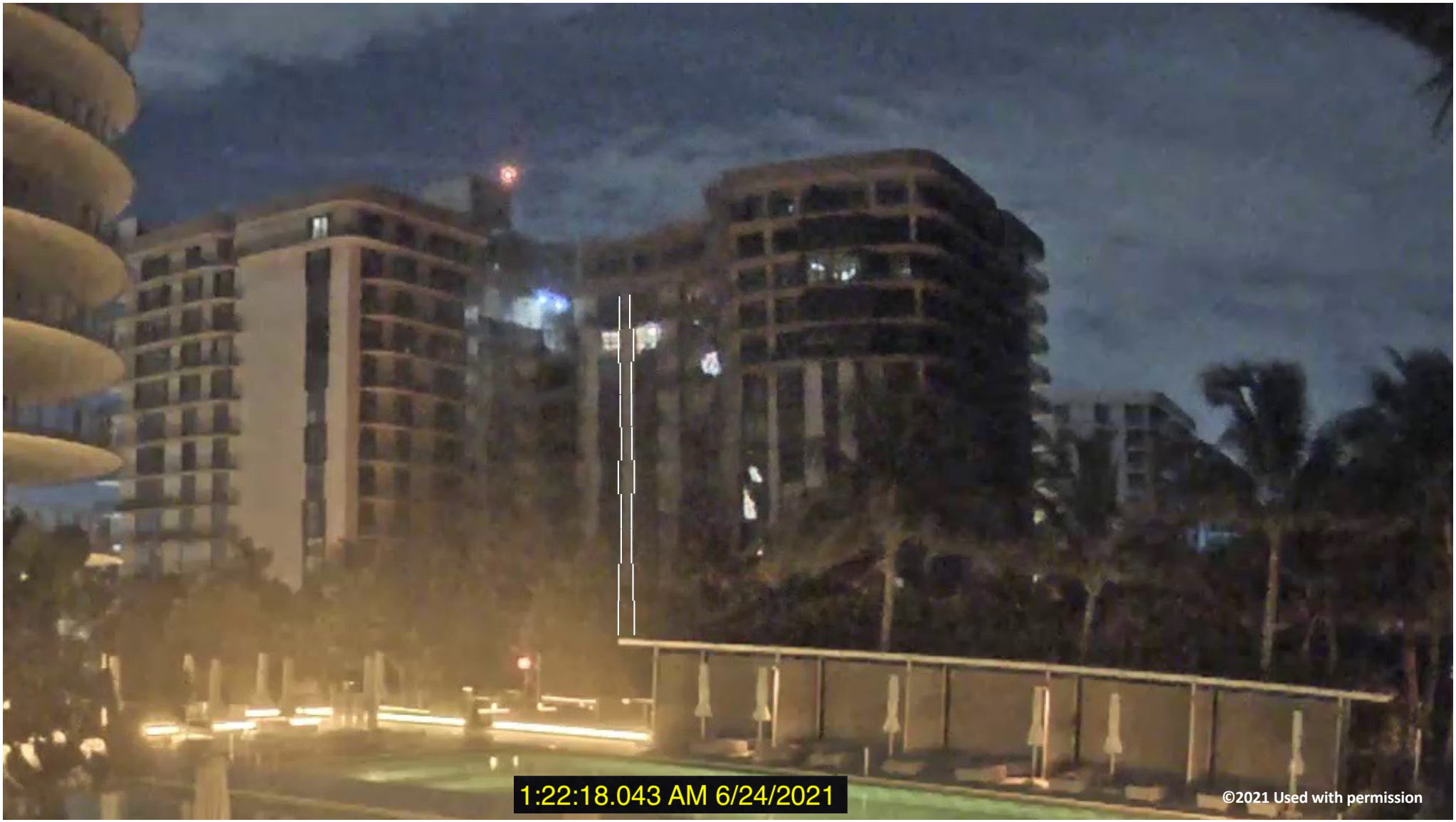



Unique façade shape
J
K
L
M
N
O
P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
10
9
8
7
6
5
4
3
2
1
Stories 1 and 2 blocked from view
11:53:45.166 PM 6/23/2021
©2021 Used with permission

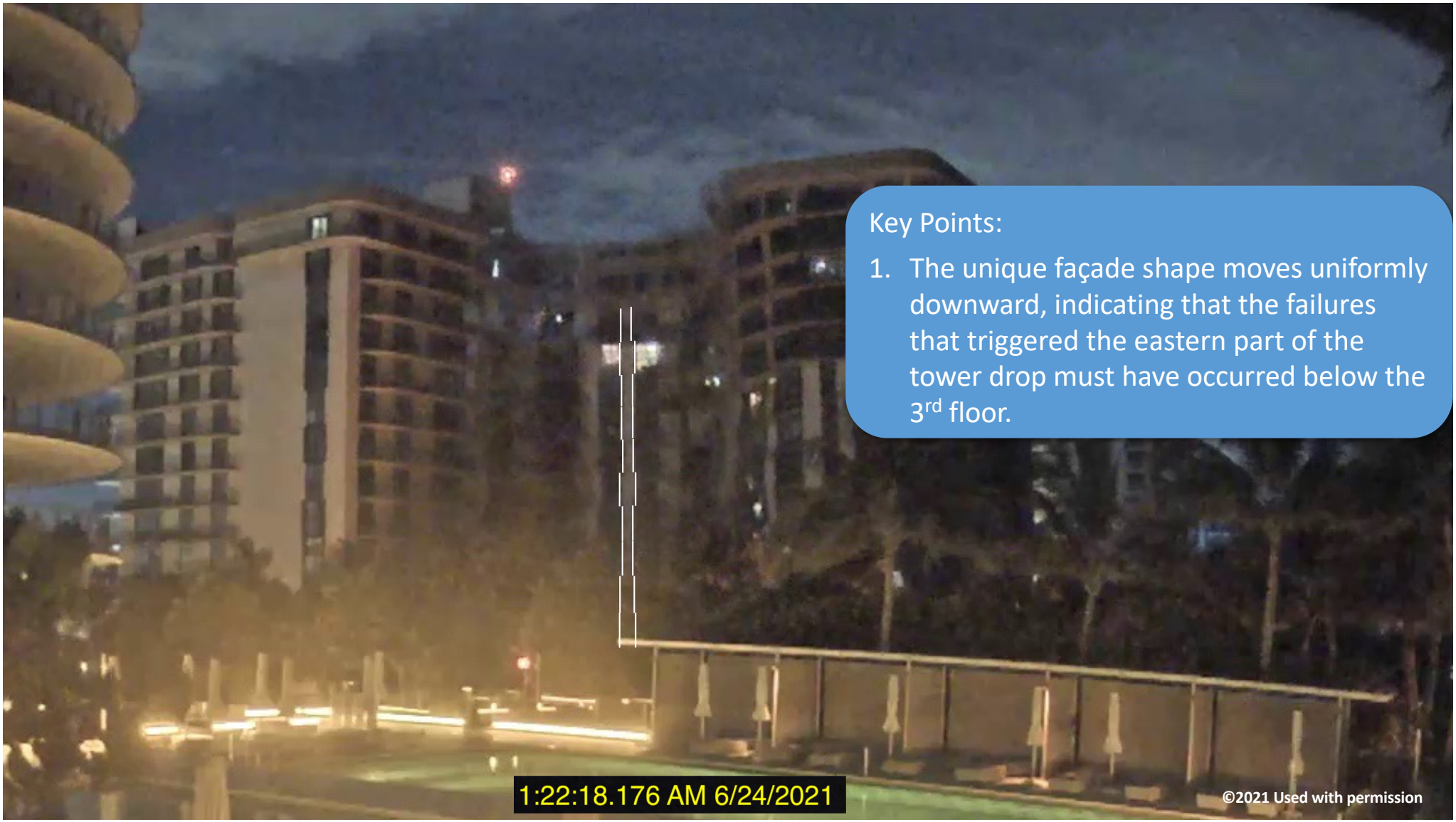

≈100”
Top of penthouse roof parapet
1:22:17.609 AM 6/24/2021
©2021 Used with permission


1:22:17.743 AM 6/24/2021
©2021 Used with permission


1:22:17.876 AM 6/24/2021
©2021 Used with permission


1:22:18.043 AM 6/24/2021
©2021 Used with permission


1:22:18.043+ AM 6/24/2021
©2021 Used with permission


Key Points:
1. The unique façade shape moves uniformly downward, indicating that the failures that triggered the eastern part of the tower drop must have occurred below the 3rd floor.
1:22:18.176 AM 6/24/2021
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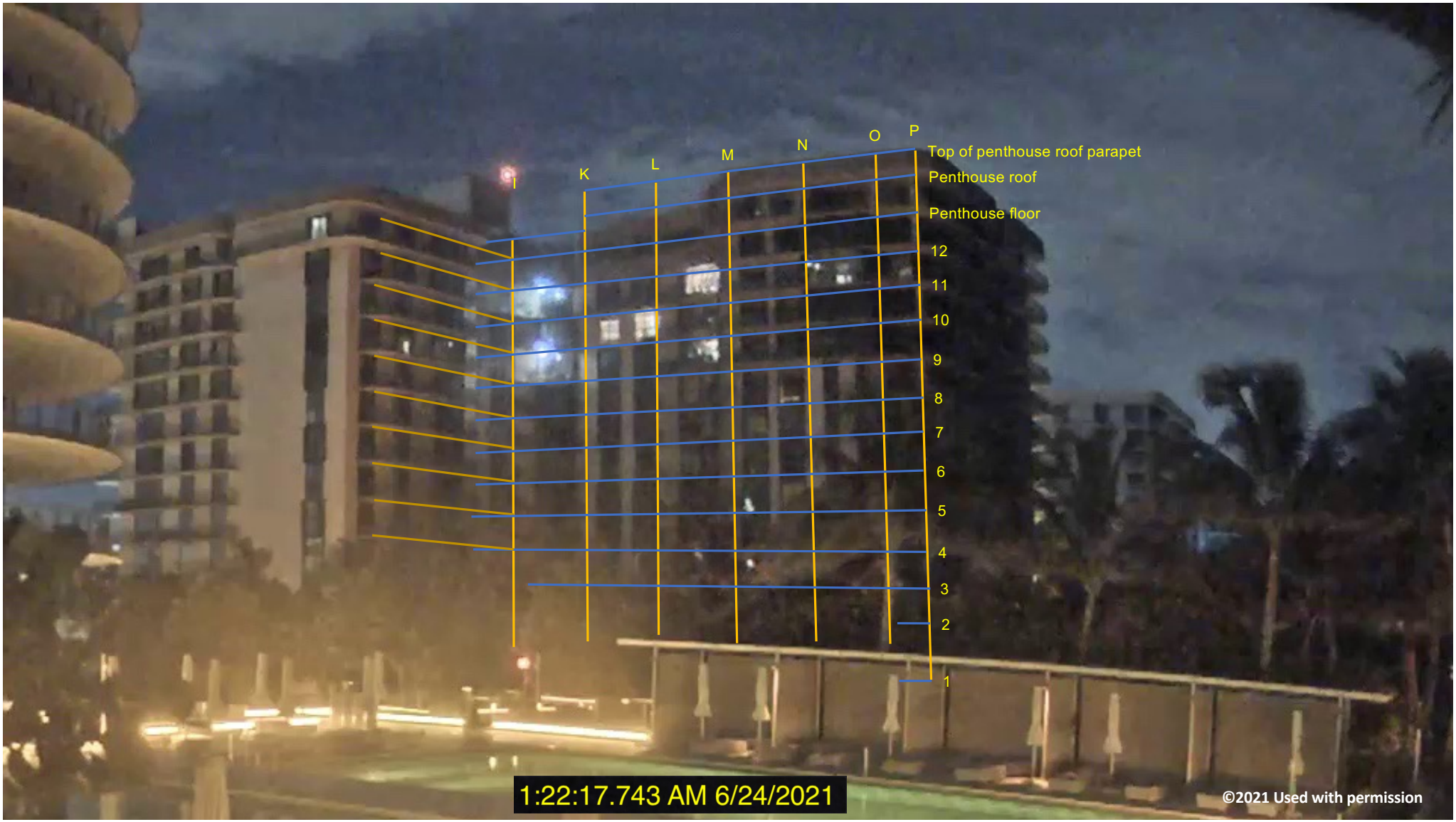
J
K
L
M
N
O
P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
10
9
8
7
6
5
4
3
2
1
1:22:17.609 AM 6/24/2021
©2021 Used with permission


J
K
L
M
N
O
P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
10
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8
7
6
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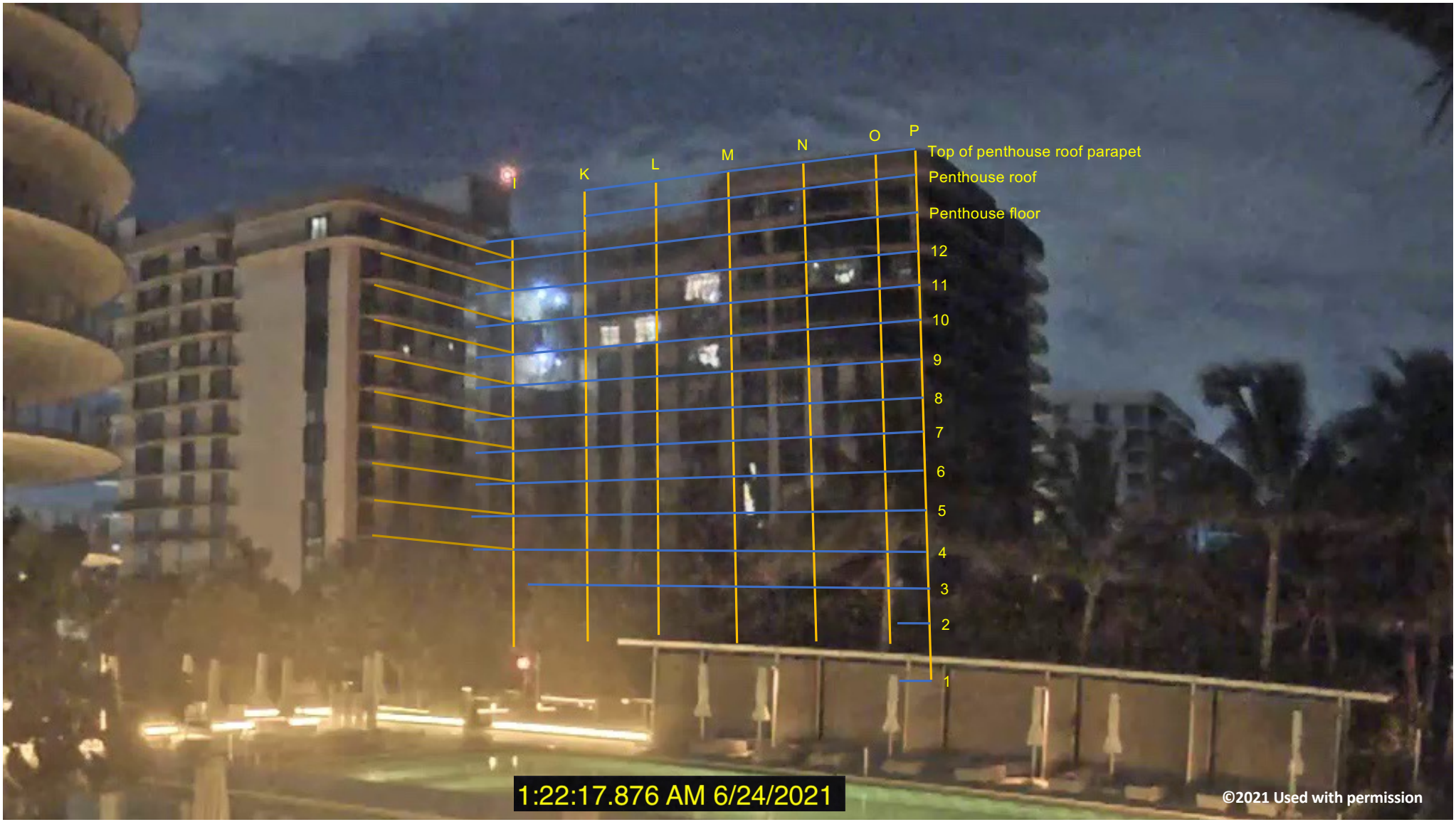
4
3
2
1
1:22:17.743 AM 6/24/2021
©2021 Used with permission


J
K
L
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P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
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4
3
2
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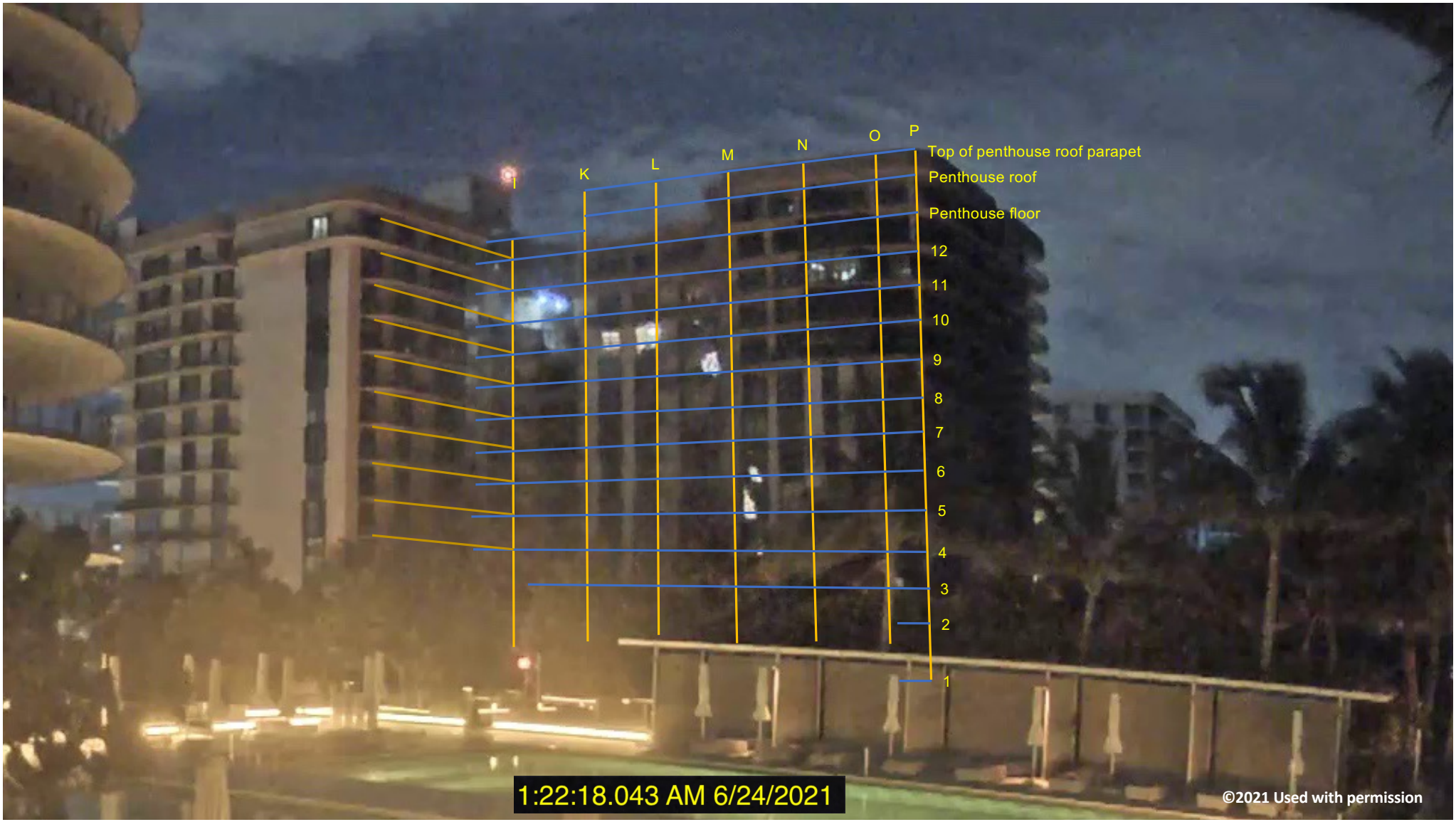
1:22:17.876 AM 6/24/2021
©2021 Used with permission


K
L
M
N
O
P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
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7
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3
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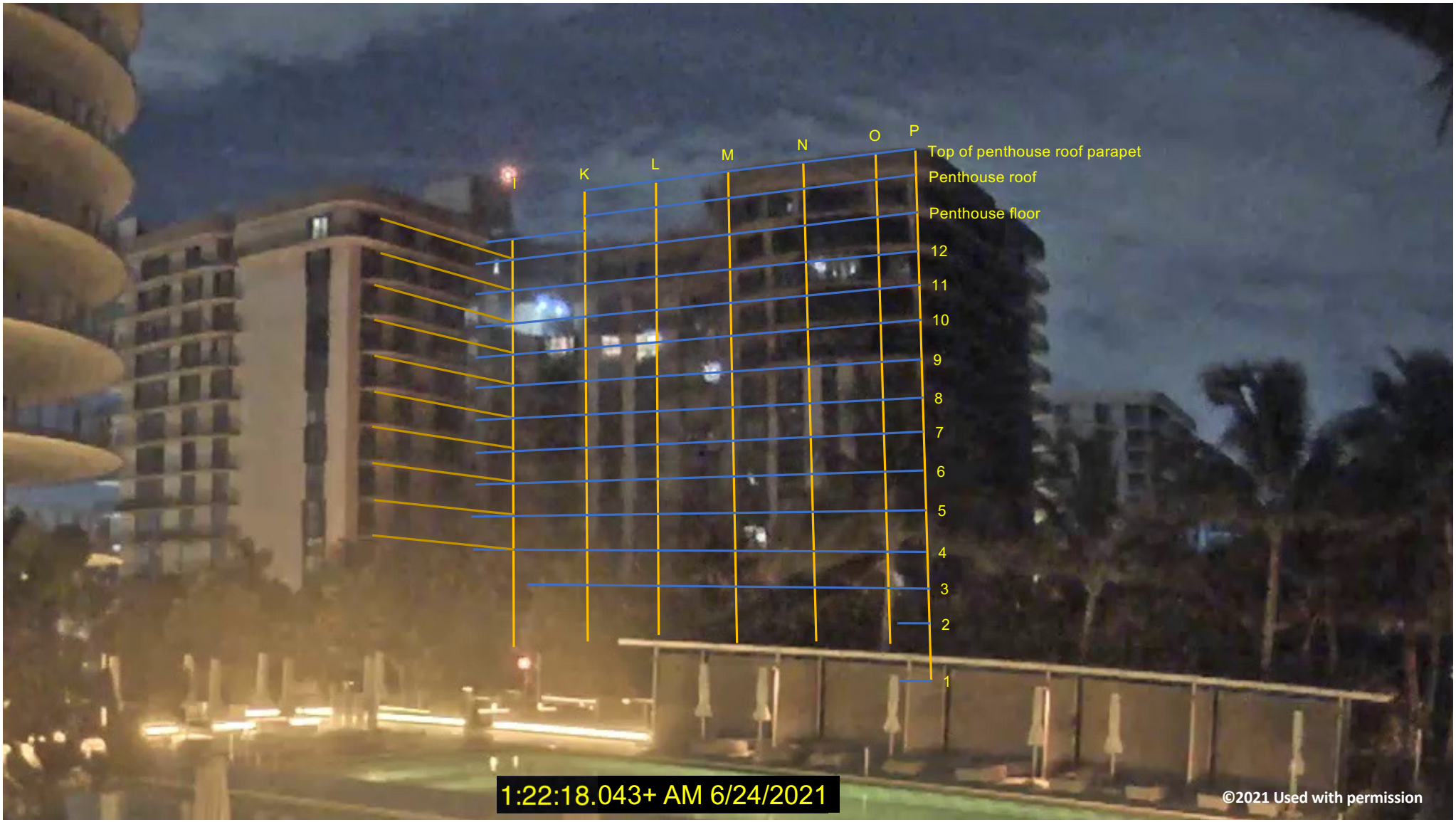
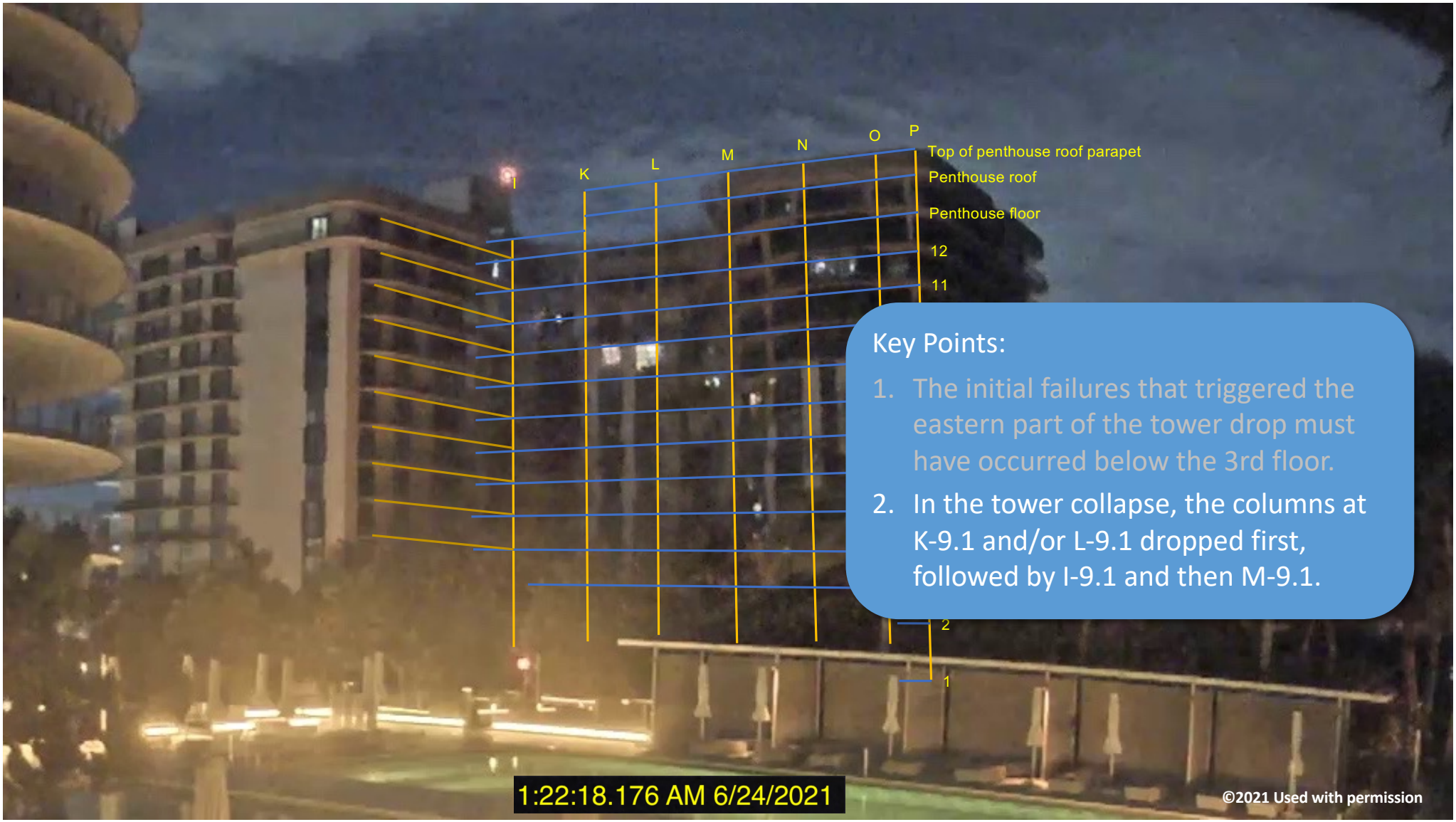
1
1:22:18.043 AM 6/24/2021
©2021 Used with permission


J
K
L
M
N
O
P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
10
9
8
7
6
5
4
3
2
1
1:22:18.043+ AM 6/24/2021
©2021 Used with permission


I
K
L
M
N
O
P
Top of penthouse roof parapet
Penthouse roof
Penthouse floor
12
11
2
1
Key Points:
1. The initial failures that triggered the eastern part of the tower drop must have occurred below the 3rd floor.
2. In the tower collapse, the columns at K-9.1 and/or L-9.1 dropped first, followed by I-9.1 and then M-9.1.
1:22:18.176 AM 6/24/2021
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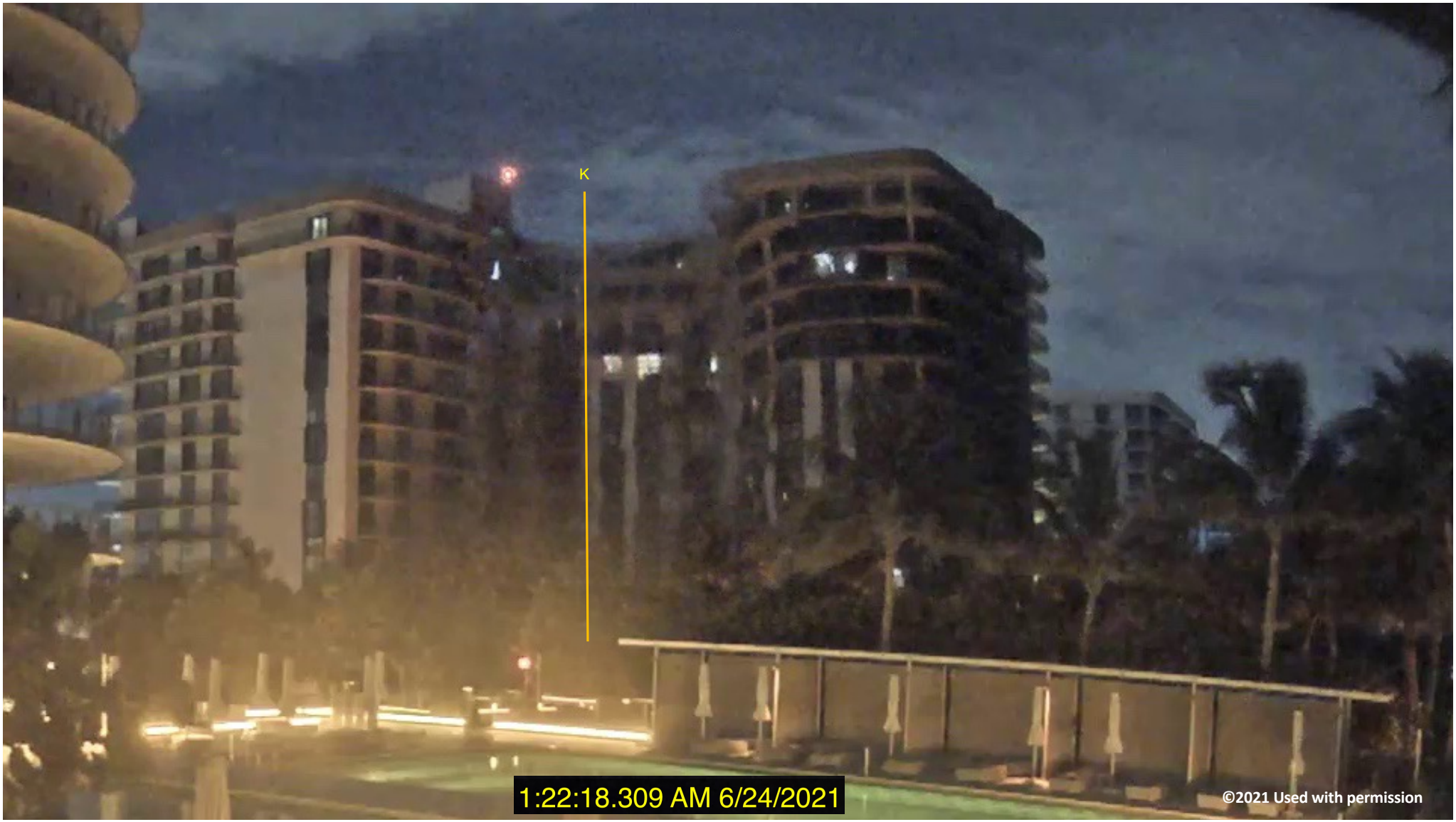
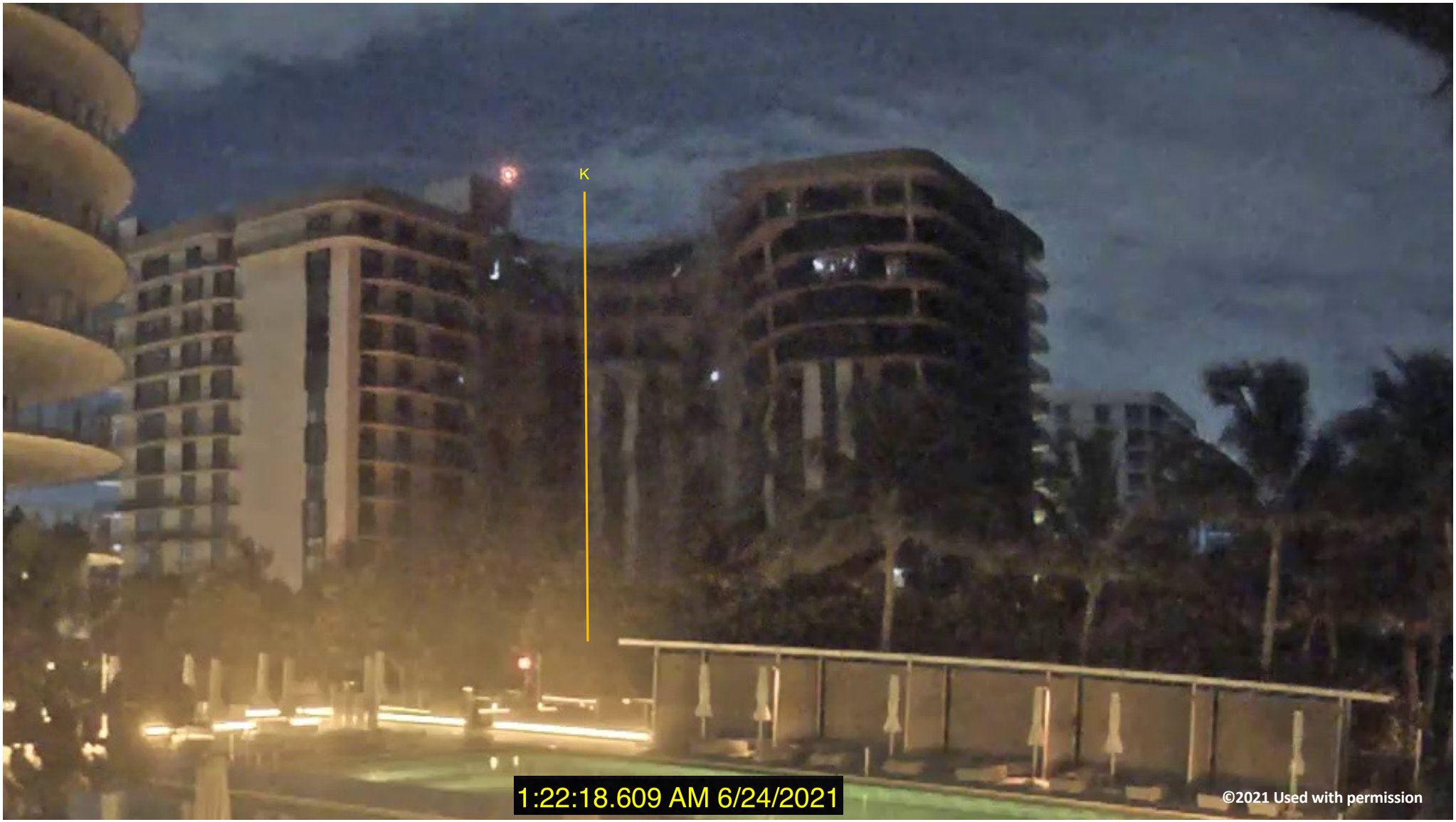
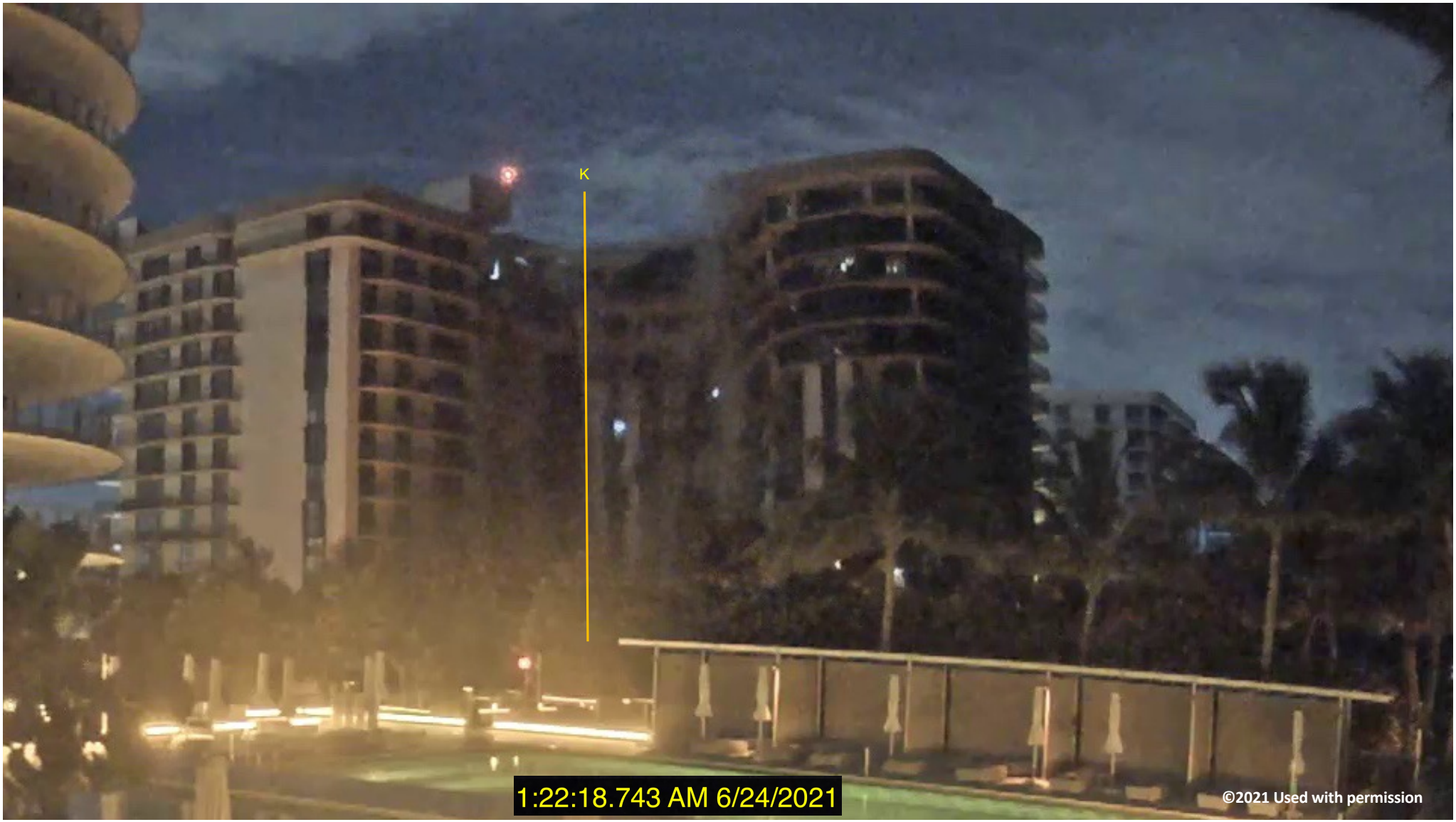
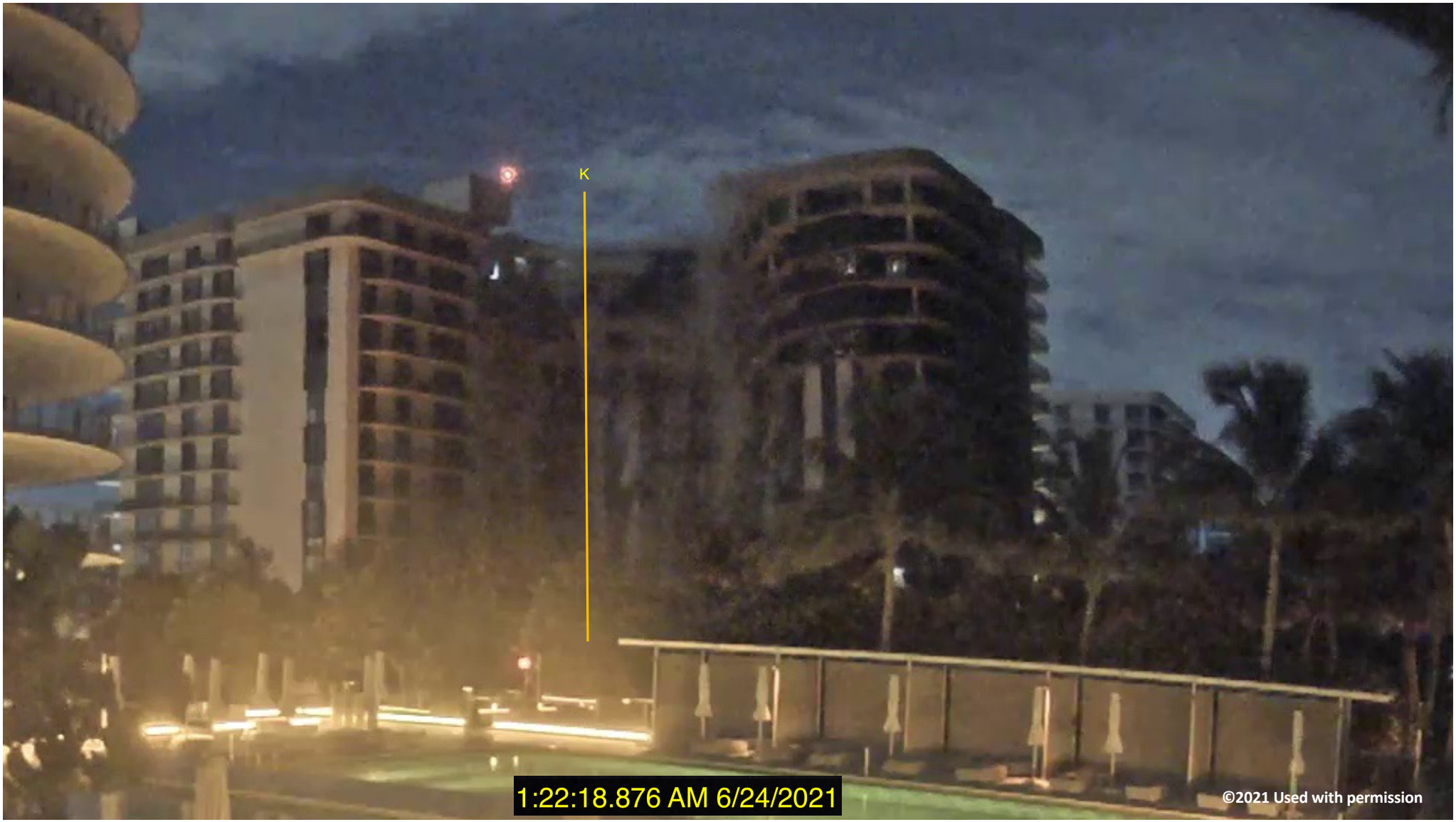
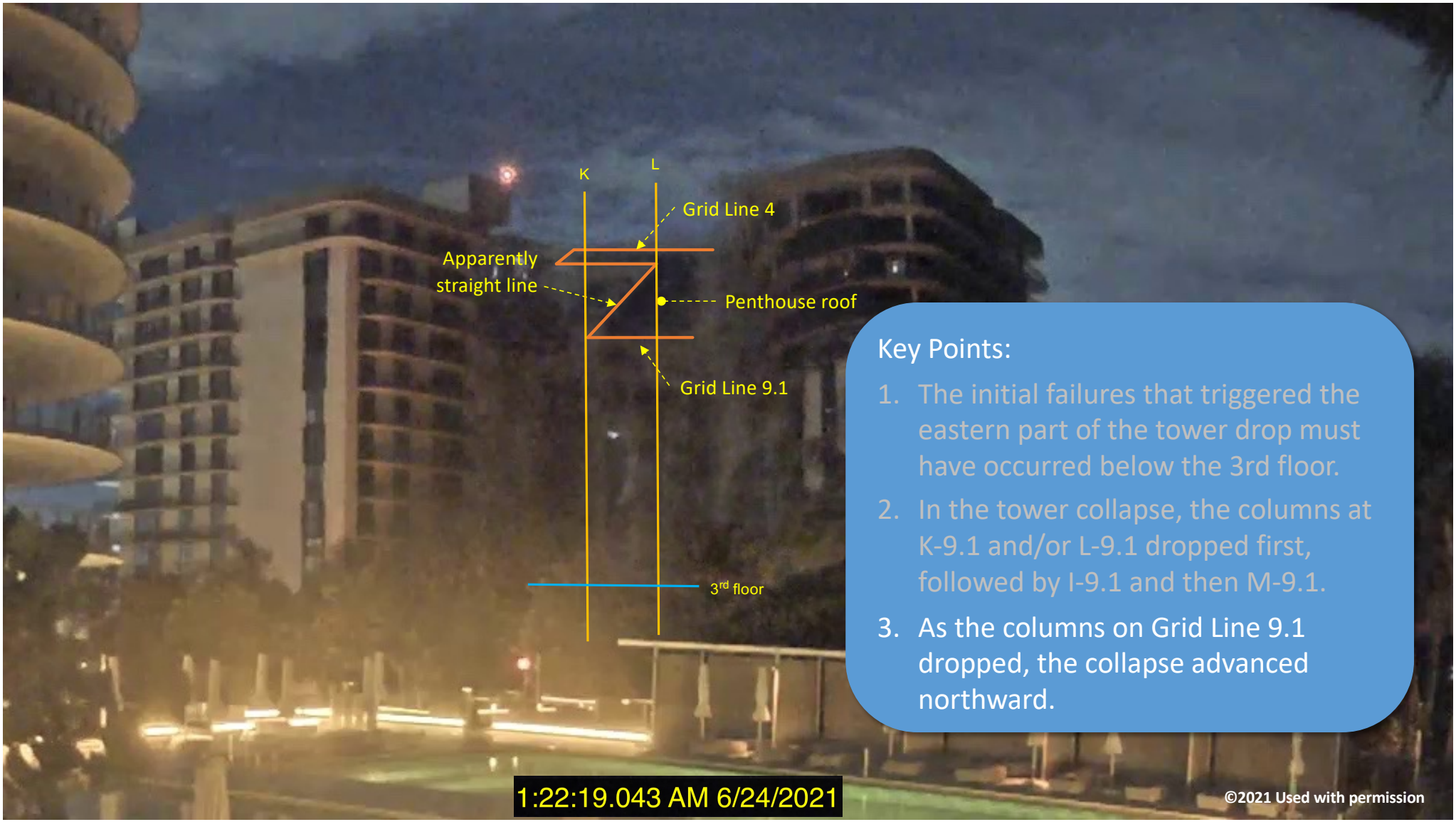

K
1:22:18.309 AM 6/24/2021
©2021 Used with permission


K
1:22:18.609 AM 6/24/2021
©2021 Used with permission


K
1:22:18.743 AM 6/24/2021
©2021 Used with permission


K
1:22:18.876 AM 6/24/2021
©2021 Used with permission



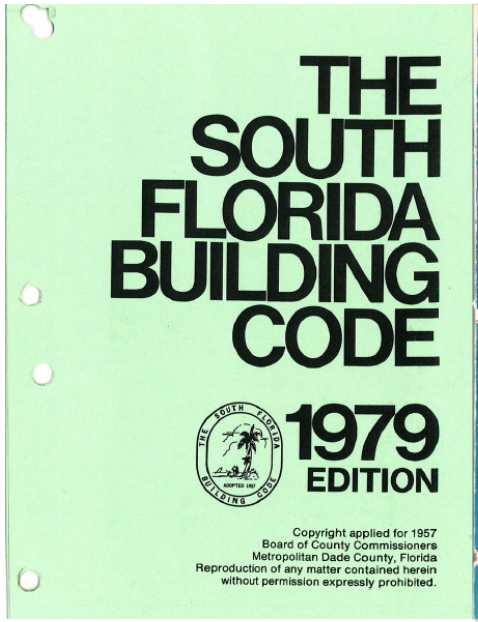
Key Points:

1. The initial failures that triggered the eastern part of the tower drop must have occurred below the 3rd floor.
2. In the tower collapse, the columns at K-9.1 and/or L-9.1 dropped first, followed by I-9.1 and then M-9.1.
3. As the columns on Grid Line 9.1 dropped, the collapse advanced northward.

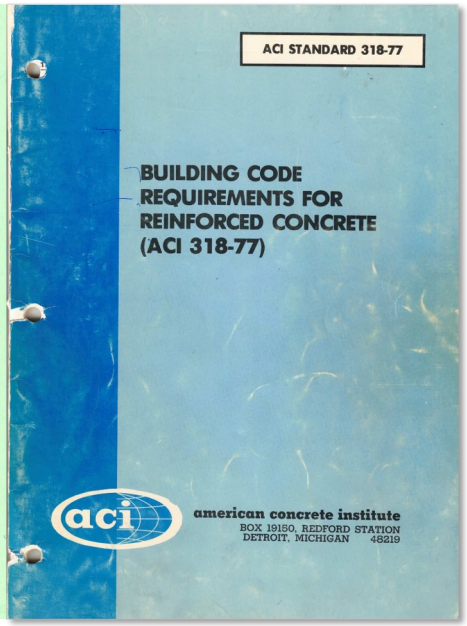
04

As-built & Precollapse Conditions, Structural Tests, SSI Analyses

Design Basis



Source: MDC



Source: ACI

Town of Surfside had hundreds of drawings from the permit application

SFBC: live and wind loads; testing of pile foundations

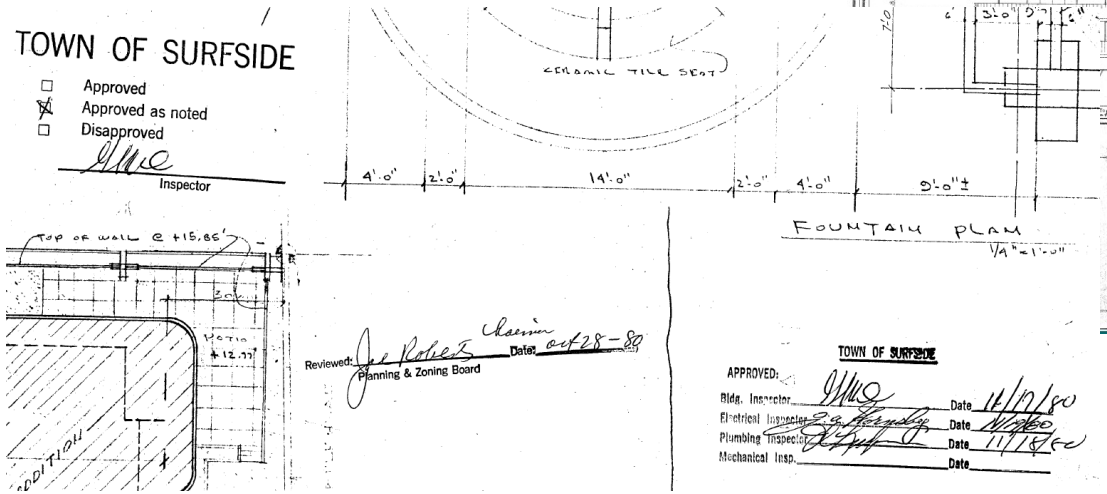
1977 ACI 318: Equivalent Frame Method for two-way slabs

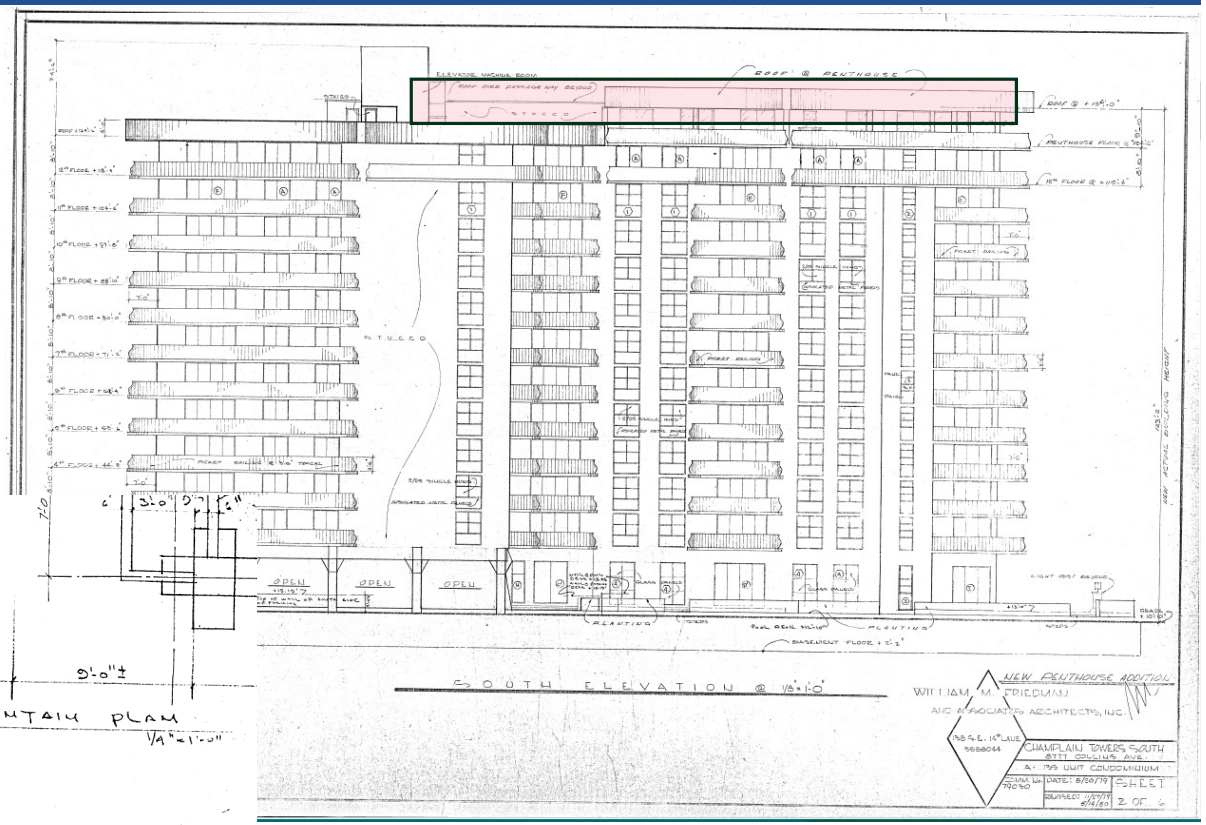
ASCE 7-22 specifies higher wind speeds and pressures

ACI 318-19 has many more requirements for exposure to chlorides, structural integrity, and minimum reinforcement over columns in two-way slabs

Permitting

- Permits were issued
- Partial 13th story added after initial submissions

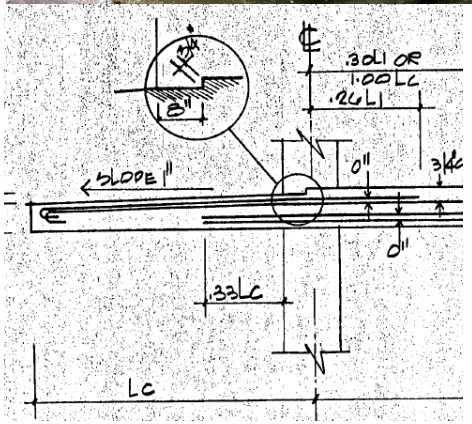




Source: Town of Surfside

Design Detail Issues

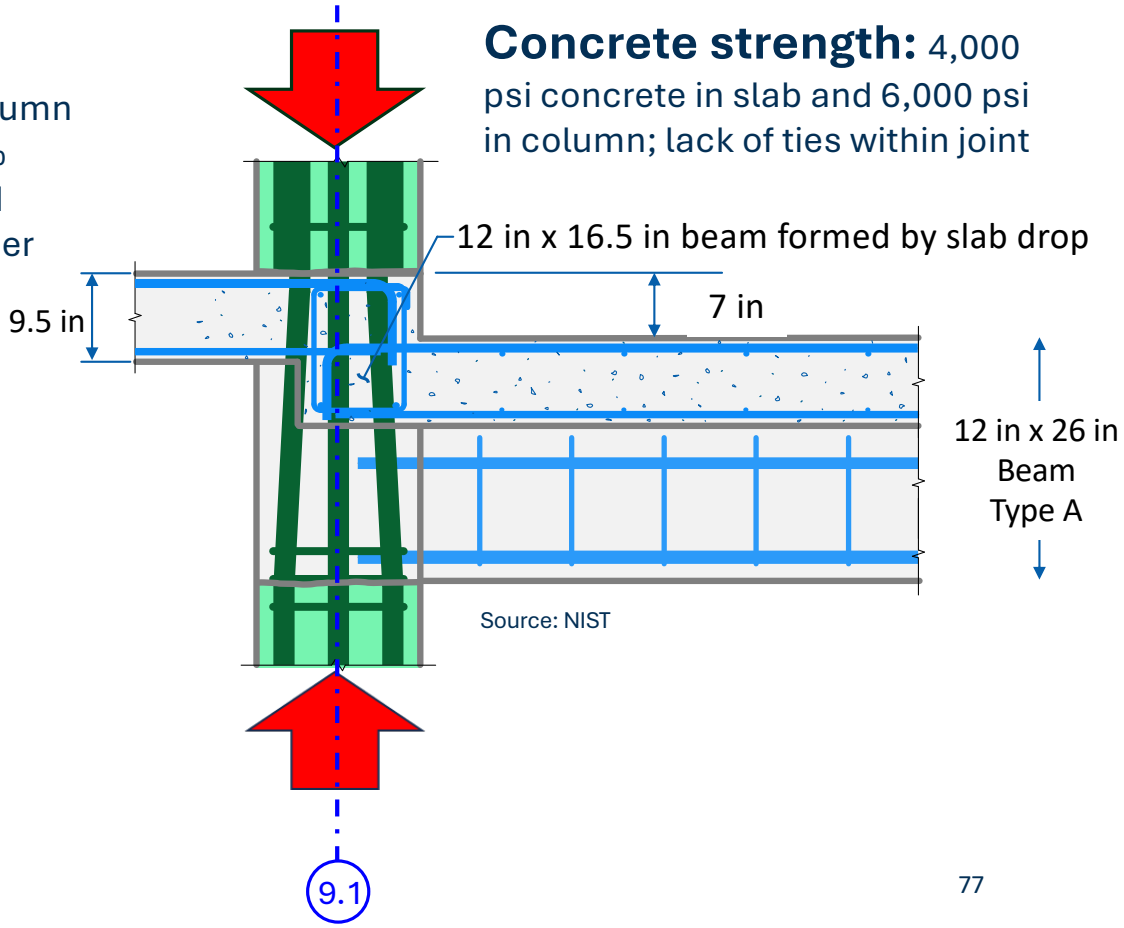
Congestion:
9.75 % vertical reinforcement in column at this splice, vs. 8 % maximum permitted (worst case at another column is 12.2 %)



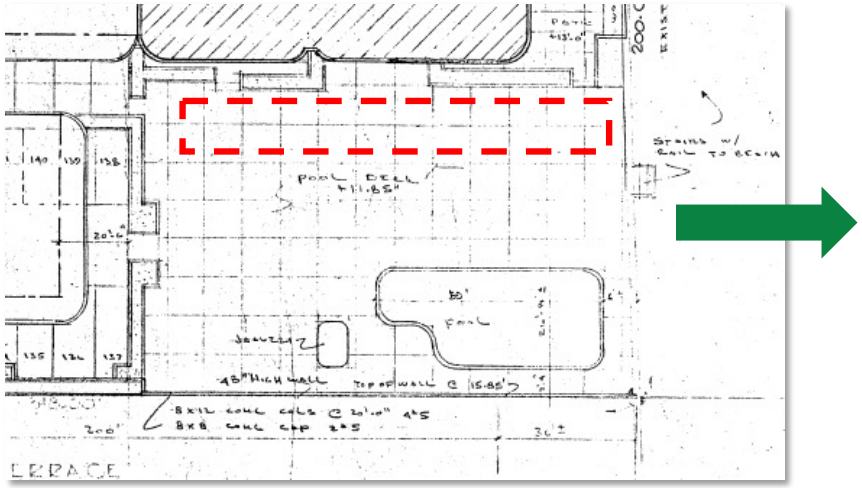
Inadequate cover:
over reinforcement in balcony slabs exposed to weather

Source: Town of Surfside

Concrete strength: 4,000 psi concrete in slab and 6,000 psi in column; lack of ties within joint

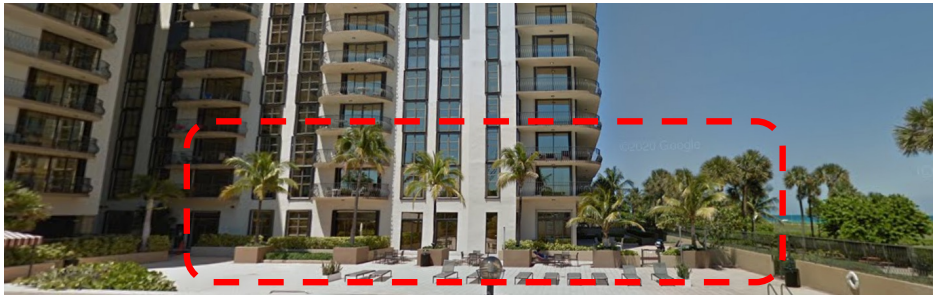


Changes From Design Drawings



Original Architectural Drawing (from Town of Surfside

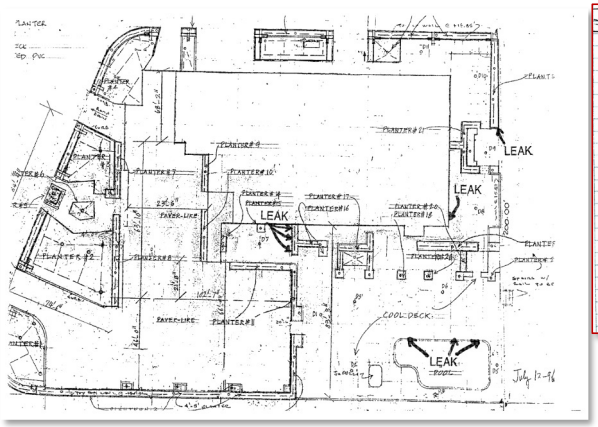
Source: Google Earth image captured November 2019, downloaded May 22, 2023

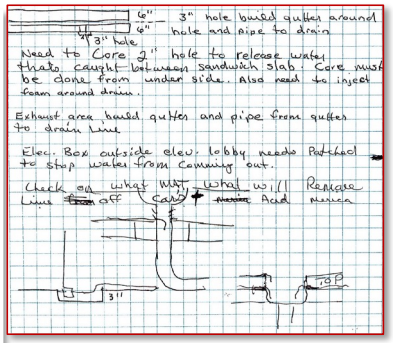


Source: Google Street View image captured March 2015, downloaded May 22, 2023

Palm trees were later removed

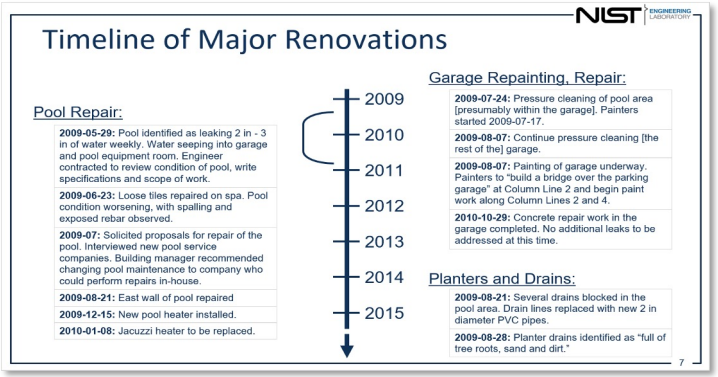
As-Built Conditions





Source: CTS Receiver

Tens of thousands of additional civil litigation files transferred to NIST since March 2024. Records (such as sample above) used by NIST to populate a timeline of pool deck renovations (sample portion below).

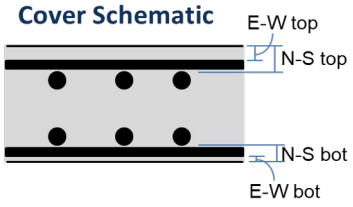


Adapted by NIST (Original Source: CTS Receiver)

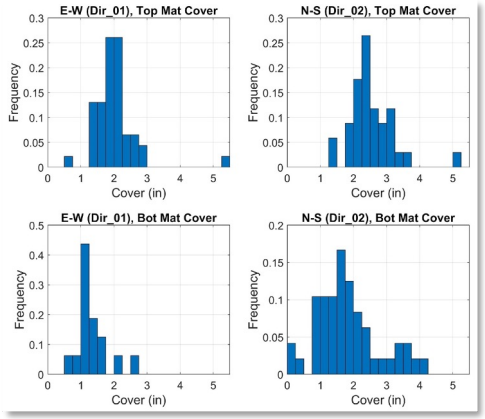
Source: NIST

New digital evidence contributed to mapping of construction joints in pool deck.

Detailed measurements of specimens used to analyze compliance.

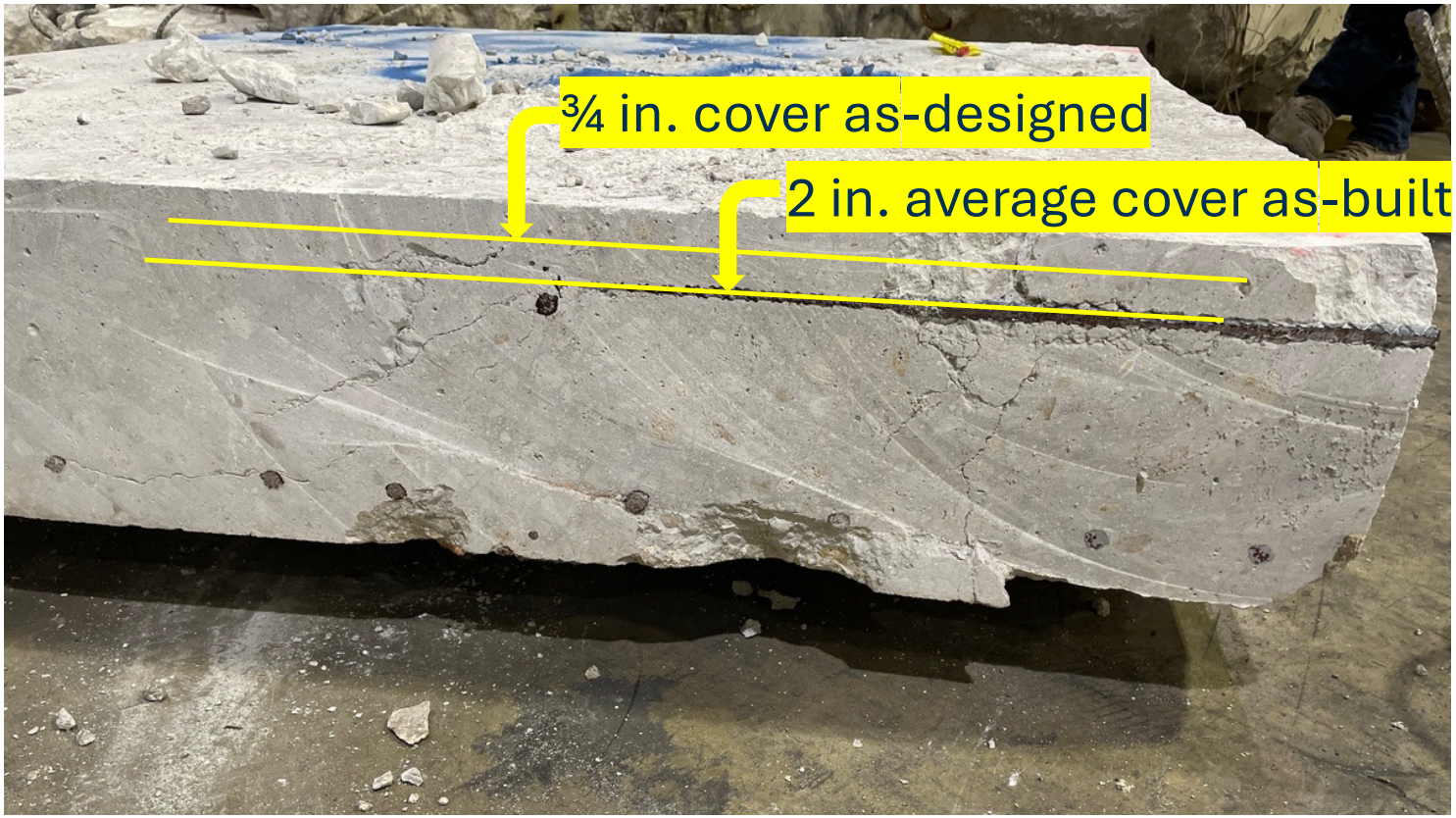


Source: NIST



Preliminary Analysis Results

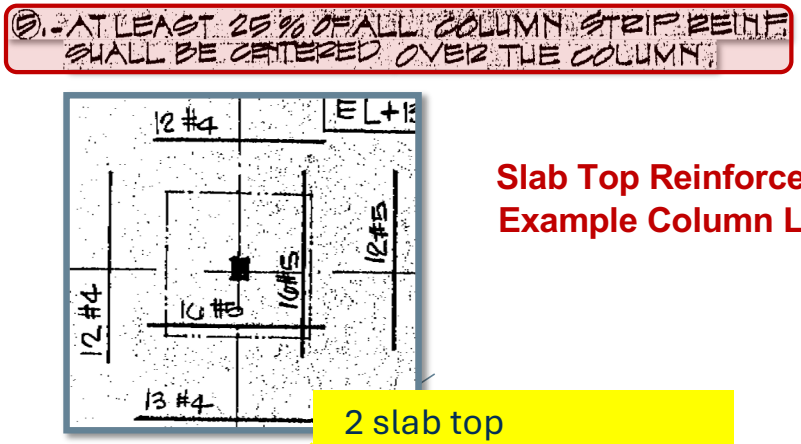
Closer View of Misplaced Top Reinforcement



Source: NIST

As-Built Conditions

Typically, fewer than the specified number of column strip top reinforcing bars are centered over the column in the pool deck slab.



Slab Top Reinforcement at Example Column Location

Example Column Specimen

At this location, only 2 rather than 4 top bars were centered over the column in each direction.

The measured spacing of the top reinforcing bars in the column strips of the pool deck slab specimens commonly ranges from about 20 % to 40 % wider than required by the structural design drawings, resulting in less reinforcing in the column strips than required by the design.

Sources: Photographs – NIST; Drawing Excerpts from Original Structural Design Drawings

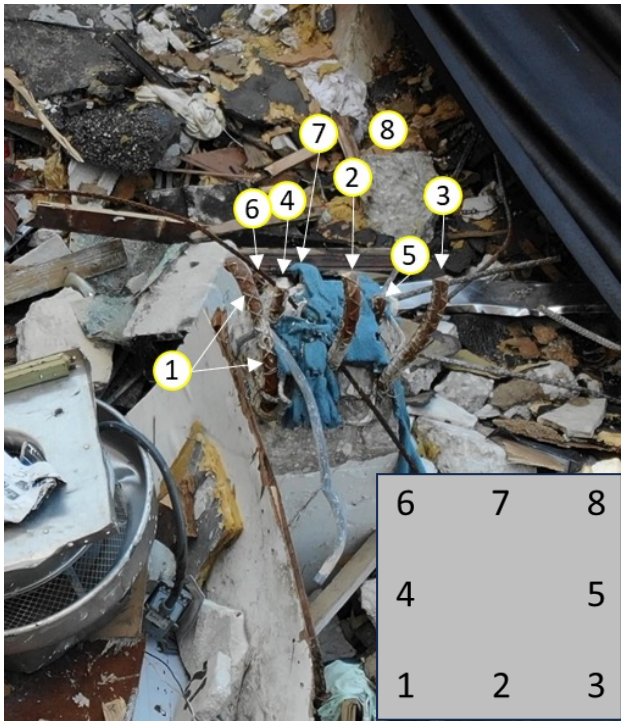
As-Built Conditions

Source: NIST

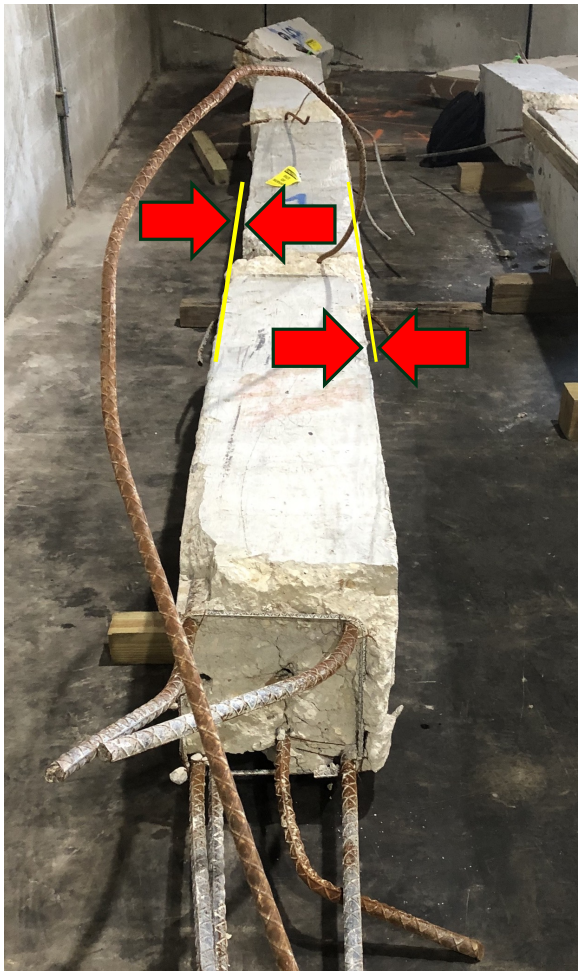
Position of reinforcing cage within columns:

Photos of top of basement column at Grid Line K on south face of tower: bars shifted to the north (excessive cover on near face, but ties against form on far side of column)

Source: NIST



As-Built Conditions

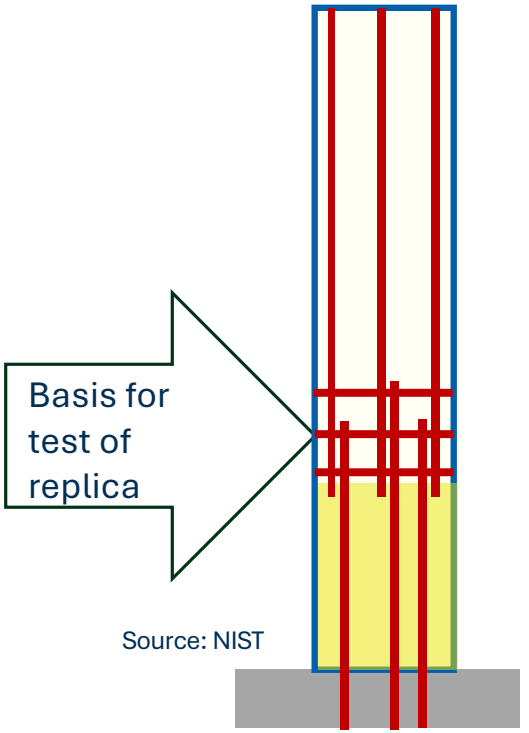


Alignment of concrete: Offset in column from story to story exceeds standard tolerances.

Source: NIST

Source: NIST

Misplaced/short splice: Several columns found with longitudinal bars where the lap splice is shorter than specified.



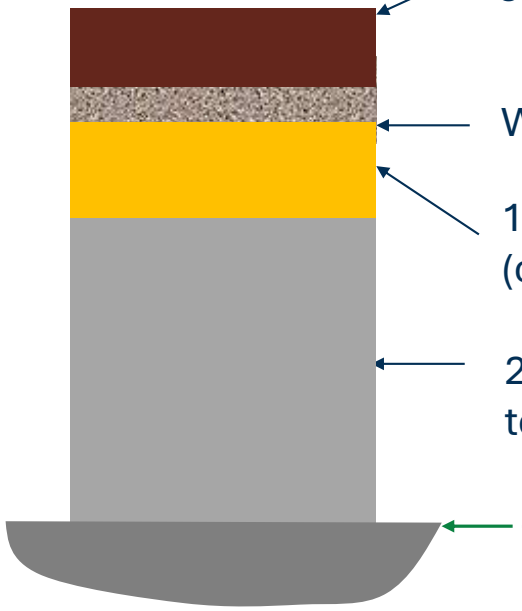
Source: NIST

1995 Pool Deck Rehabilitation

Examples of Additional Fill and Paving

9 in. added sand setting bed

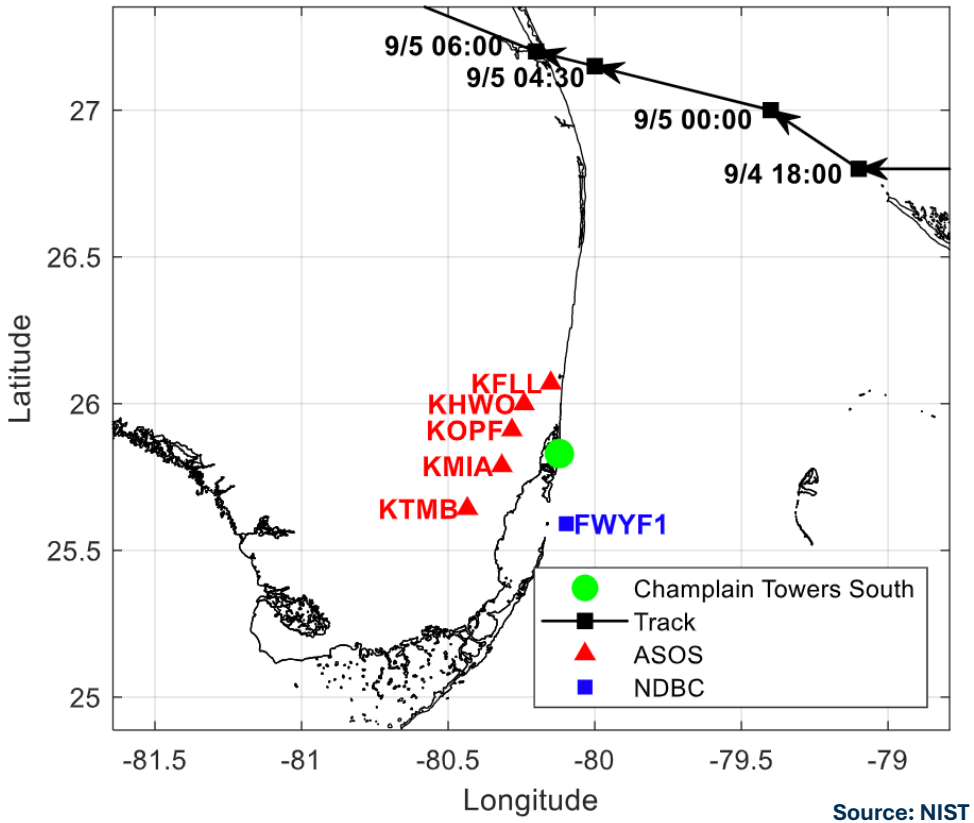
Source: Structures Specialist from US&R Ohio Task Force 1



Schematic based on *observations reported by Morabito Consultants*

Wind Exposure at the Site

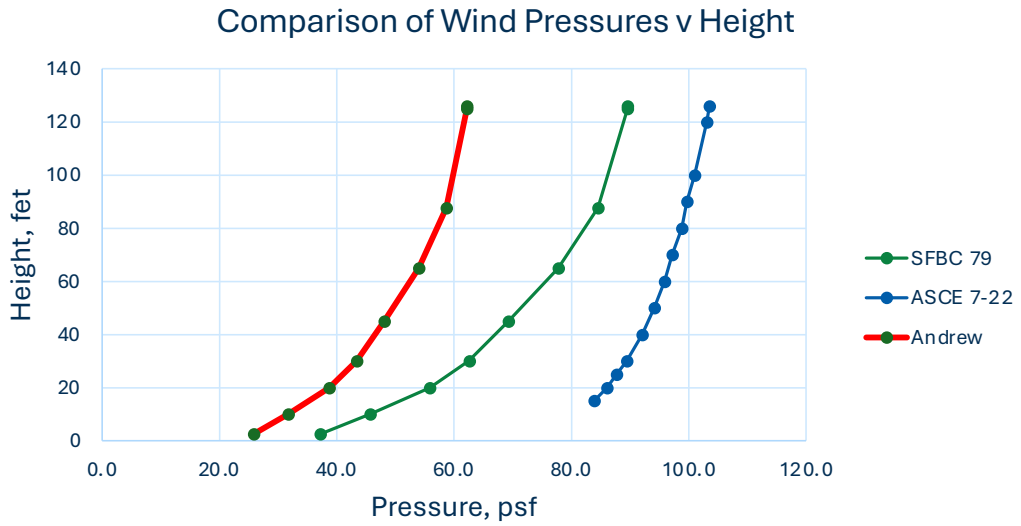
Source: NIST



Source: NIST

Historical Winds

- NIST's wind contractor identified ten highest speed hurricanes over life of CTS
- NIST selected five for detailed analysis
- Contractor:
  - Developed wind field models for the five
  - Computed wind speed and direction at CTS for each



Source: NIST

Historical wind study found highest velocity winds at the building were from Hurricane Andrew, 1992. The pressures were less than required by the 1979 SFBC or by ASCE 7-22.

PRELIMINARY ANALYSIS RESULTS

Evidence of Corrosion

Corrosion of Pool Deck Hooked Column Reinforcement Bars that Were Embedded into Pool Deck Slab

Enlargement of Column Top Showing Hooked Reinforcement Bars with Corrosion

Pool Deck Column Post-Collapse

Source: NIST

Same Column in Primary Evidence Facility

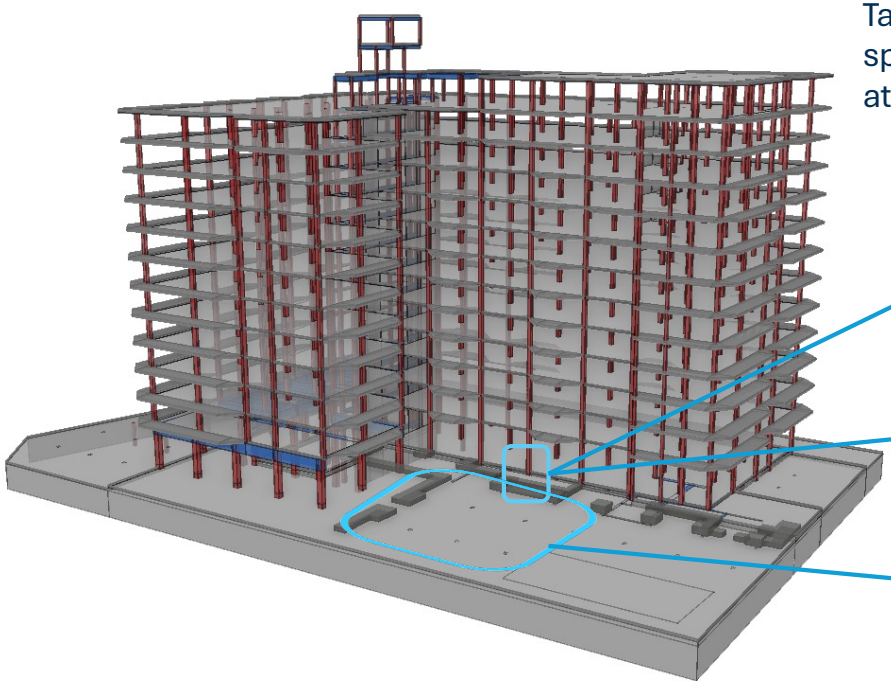
Aged Material Properties

Left: some of the specimens in the warehouse

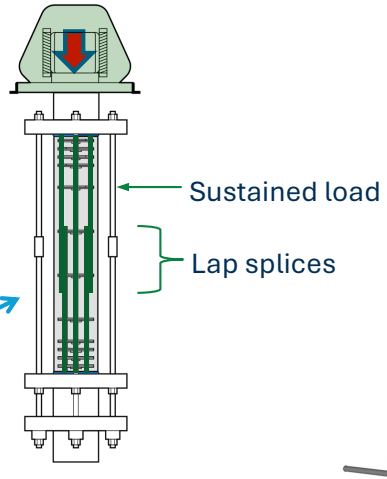
Right: removing samples of concrete for laboratory testing

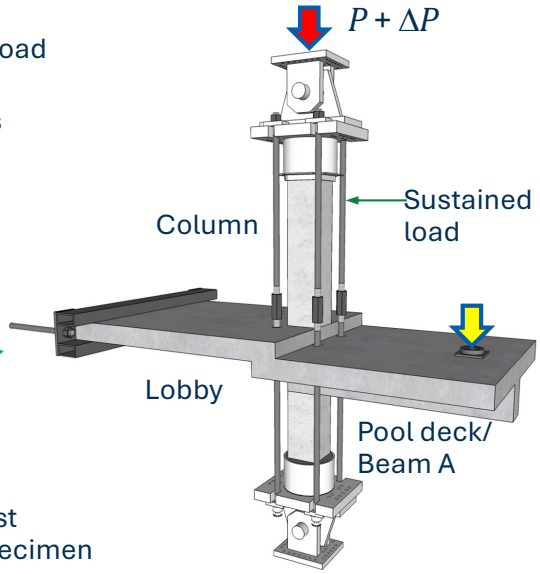
Source: NIST

Structural Laboratory Tests

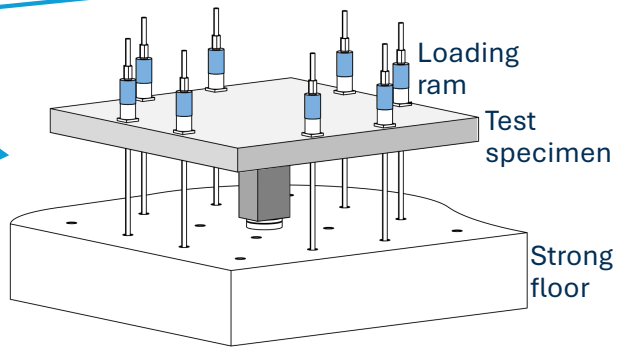


Task 3 – Lap splices in column at L-9.1





Task 2 – Connection at L-9.1



Task 1 – Slab-column connection in pool deck

Test replicas represent conditions in CTS structure as faithfully as possible.

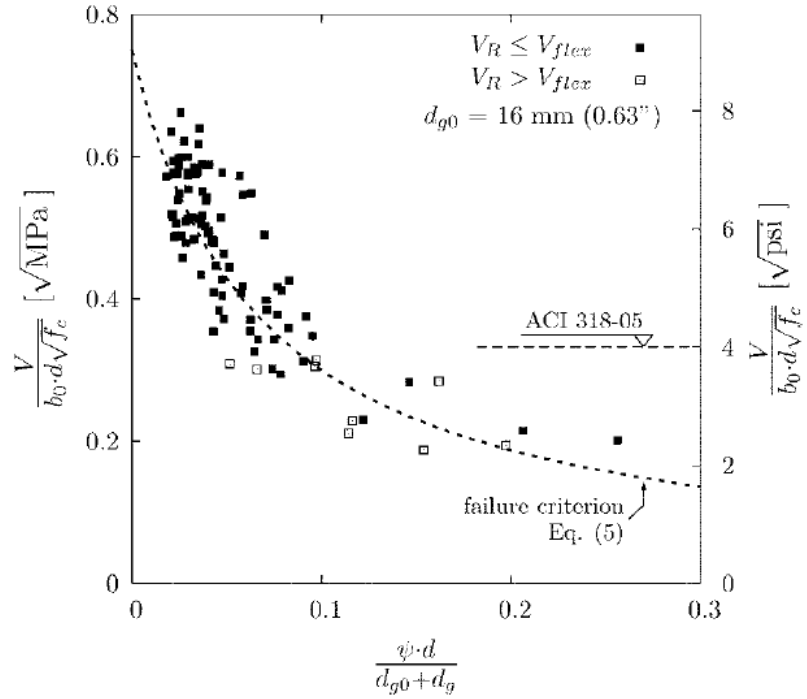
Source all images: NIST

Slab-Column Connection Tests

Test in progress

Source: NIST

Critical shear crack theory



Source: ACI

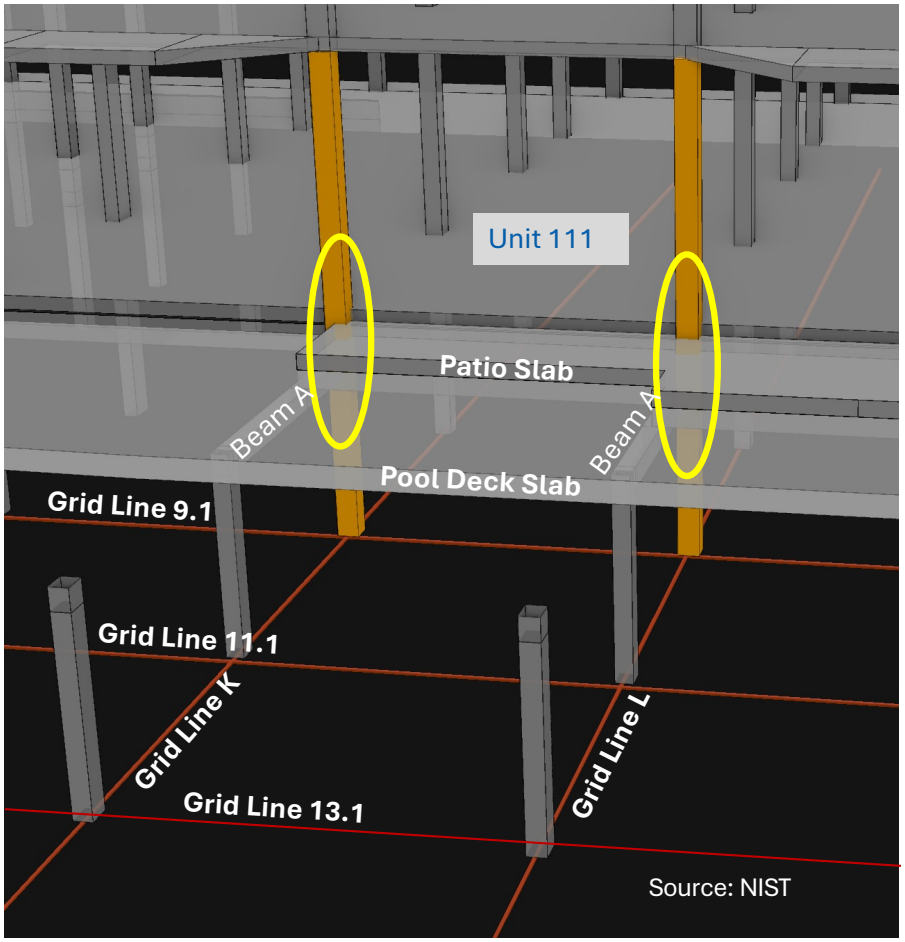
Slab-Column Connection Tests

Post-test, uncorroded

Post-Test, corroded

Source all images: NIST

Columns Along South Edge of Tower

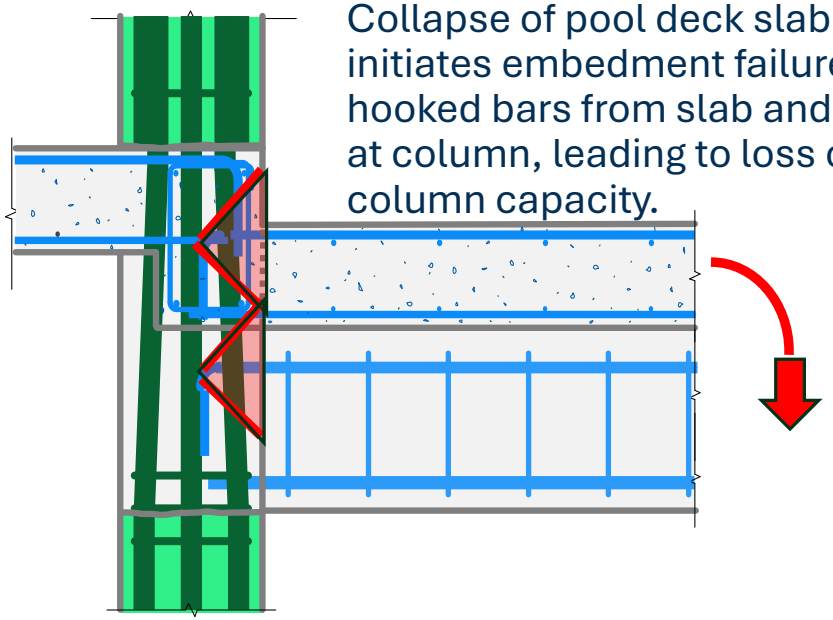


Description of Structure

Structural Columns at Grid Lines K and L along the South Edge of the Tower

- Unit 111's patio is 7 in down from interior floor.
- The pool deck is another 11 in down from the patio. (Shown terminating at Grid 11.1 for clarity of structure below)
- The slab drop beams run along each step.
- Additional beams (Type A) extend from south face of tower to the next row of columns under the pool deck.

Columns Along South Edge of Tower

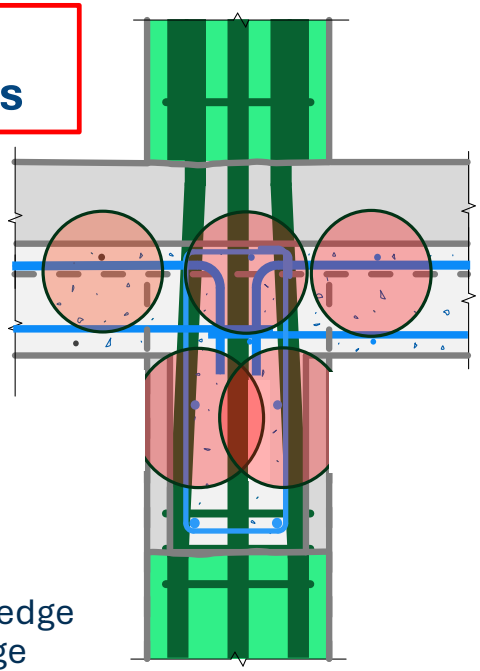


Collapse of pool deck slab initiates embedment failure of hooked bars from slab and beam at column, leading to loss of column capacity.

Description of Failure Progression Hypothesis

Important Issues

- Position of ends of hooked bars
- Strength of concrete
- Position of column reinforcement (vertical and ties)
- Lack of column ties in joint
- Corrosion of reinforcement



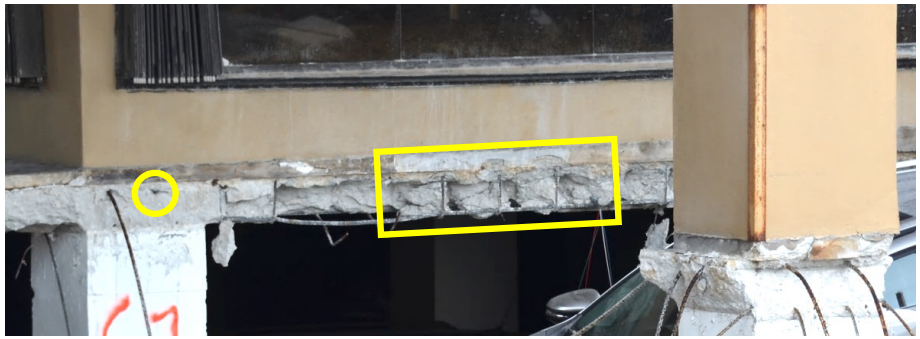
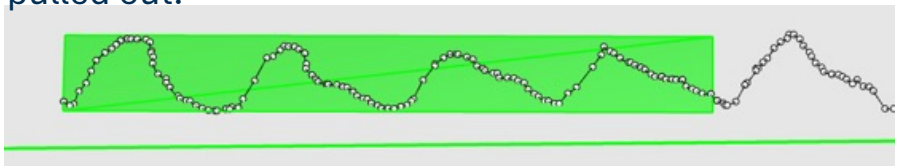
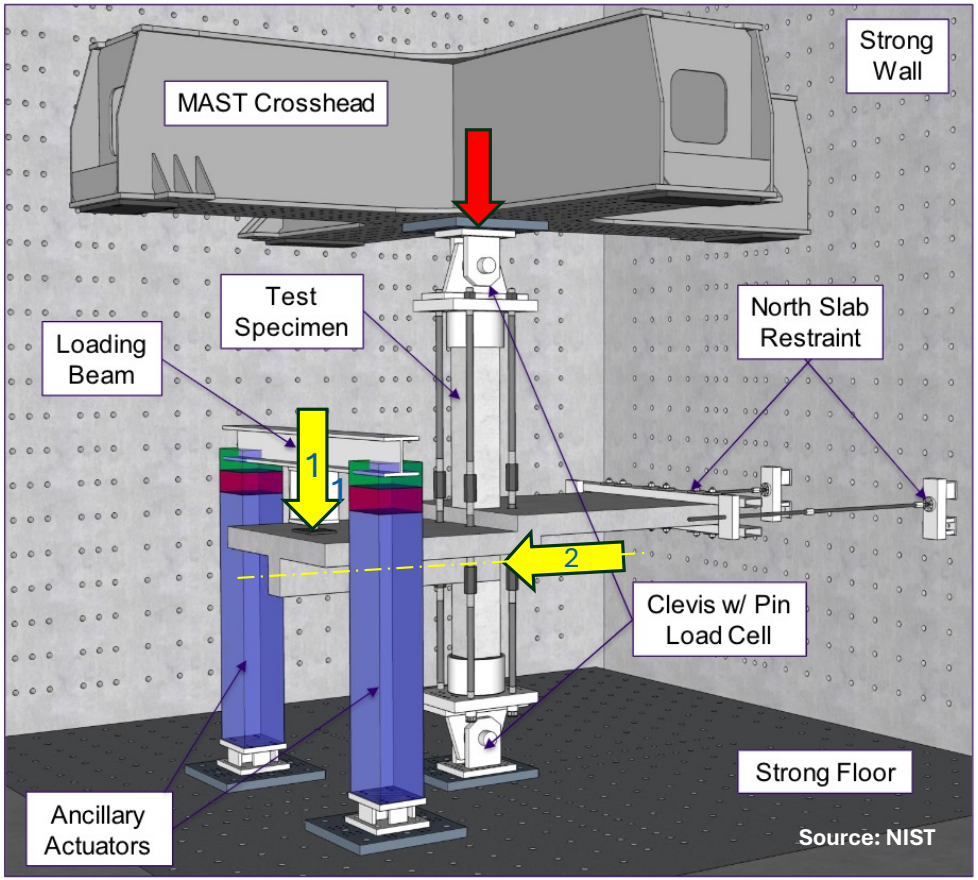


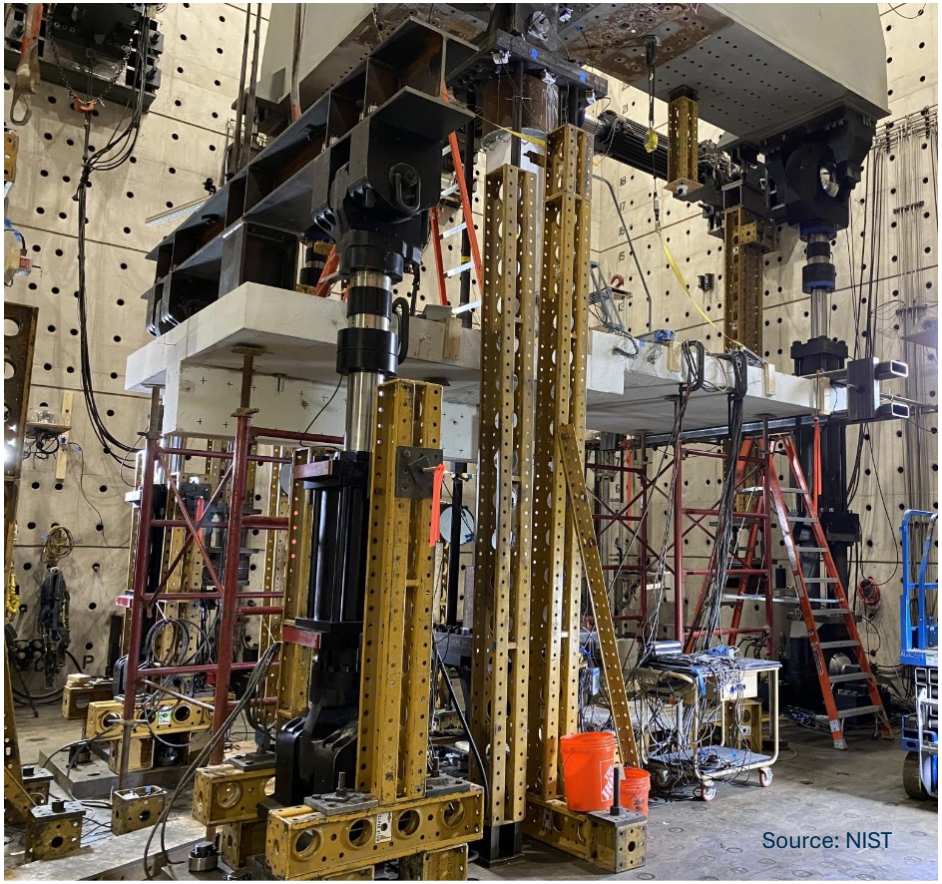
Image (at left) of similar condition at edge of portion that did not collapse. Image analysis of area in yellow box led to the profile (below) of concrete left after bars pulled out.



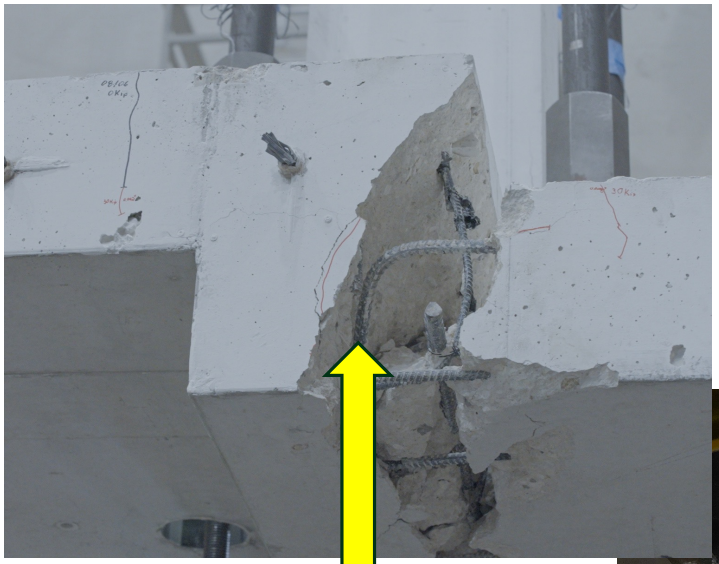
Source all images: NIST

Structural Laboratory Tests – Task 2



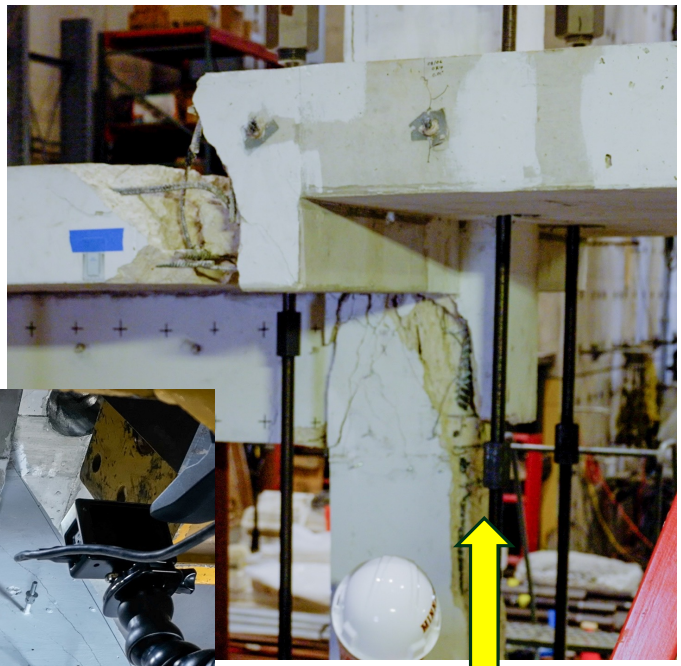


Joint Damage in Tests



Hooked #5 top bars in lower slab broke out of drop beam

Test #2: column bars at south face lose cover and buckle

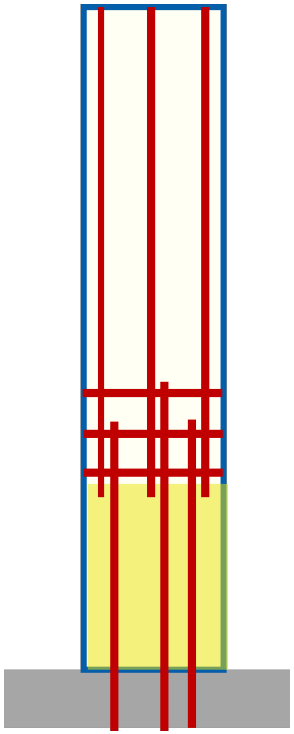


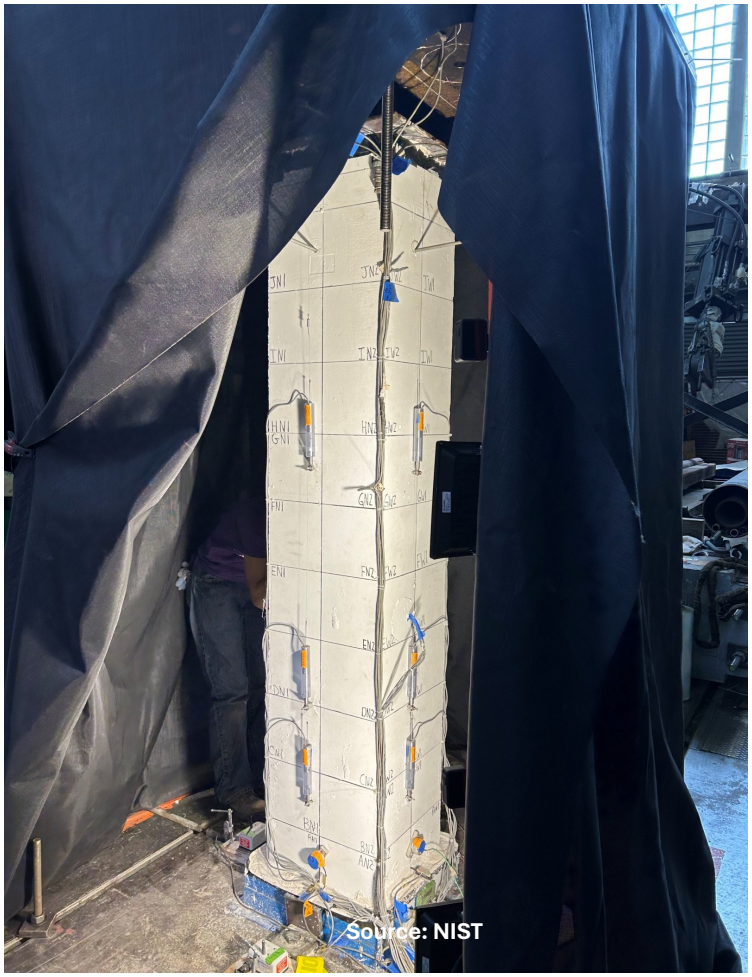
Test #1, column bars at north face lose cover and buckle

Source all images: NIST

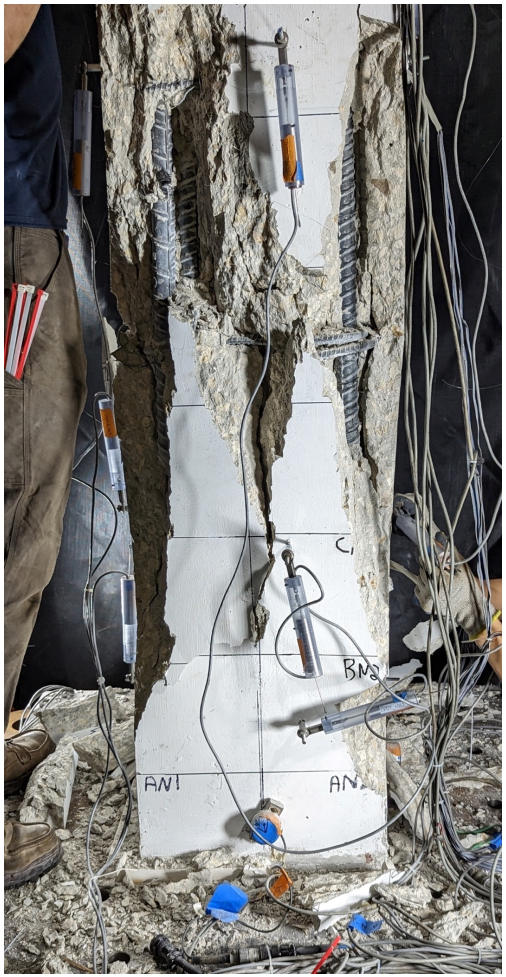
August 2024: Structural Tests at UW

Tests to evaluate effect of short lap splices found on column bars





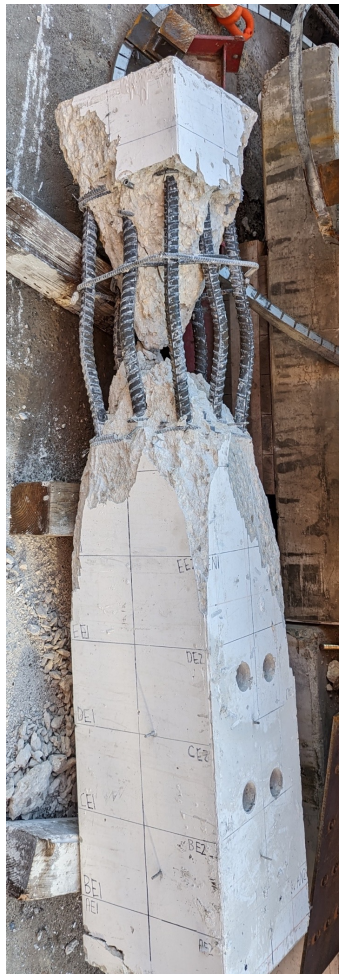
Short Lap Splice Test of Replica Column



Left: specimen with short lap splice and sustained load

Below: close up of same specimen

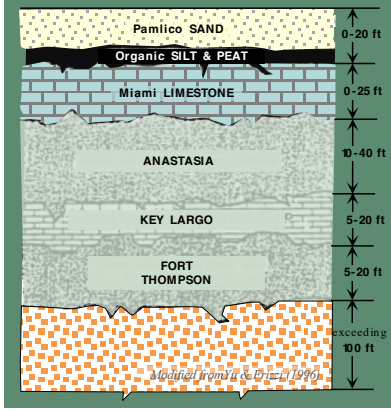
Right: specimen with no lap splices

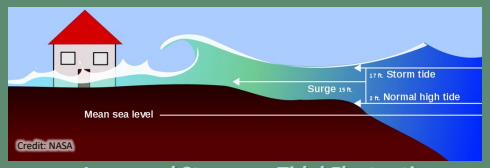


Source all images: NIST

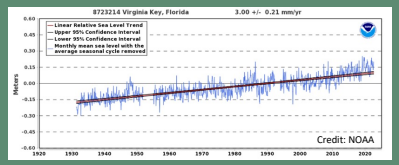
Geotechnical and Historical Data

Regional Geologic Setting and Hazards 1



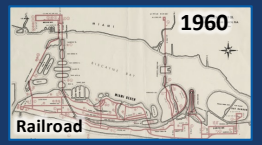


Increased Storms - Tidal Fluctuations

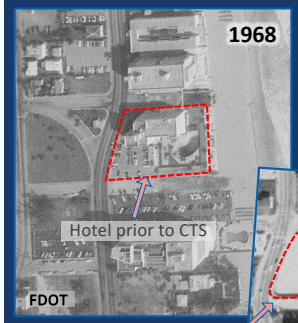


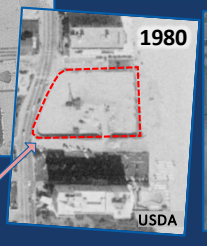
Sea Level Rise - Saltwater Intrusion - Dissolution

Beachfront Development History 2

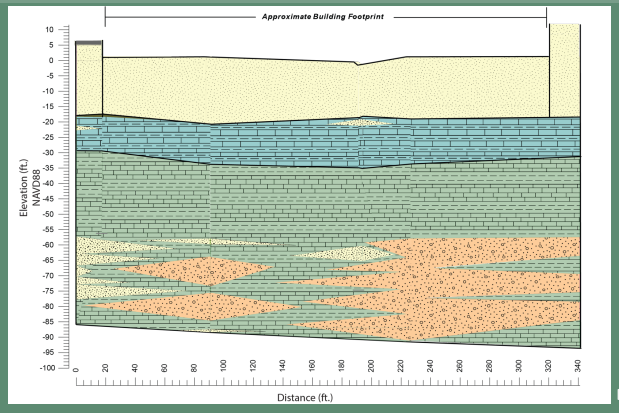


CTS Site History 3



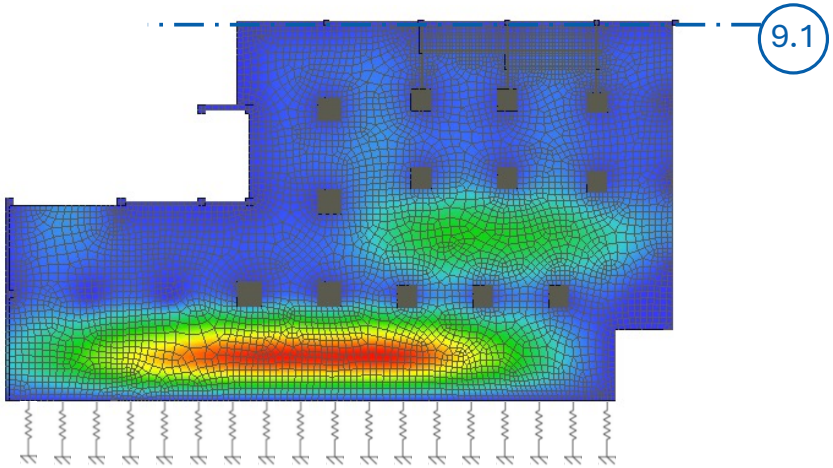


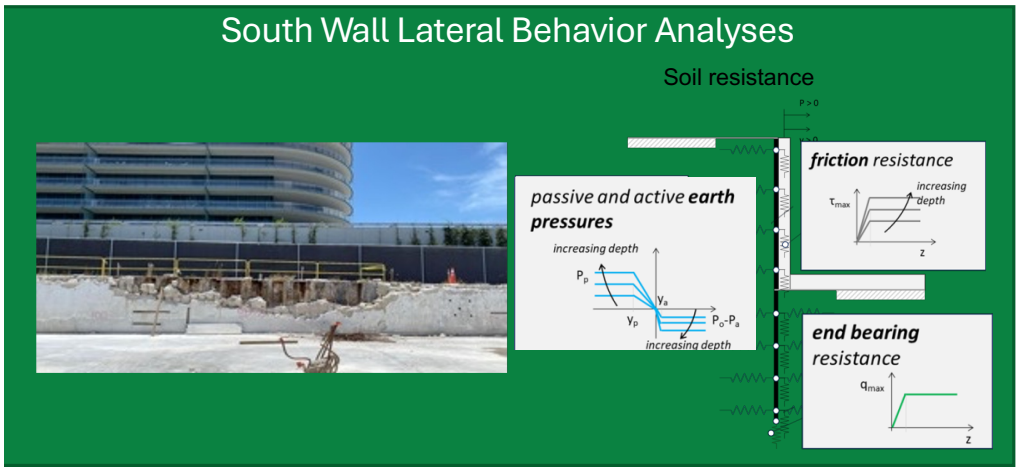
Site-Specific Subsurface Investigations and Evaluations 4



NIST Draft in Progress

Soil-Structure Interaction Analysis





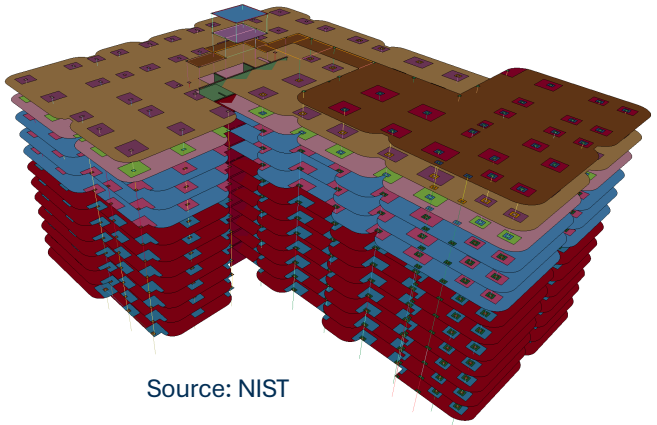
- As two-way slab cracks and the bars yield, the slab extends in-plane.
- Restraint offered by south basement wall and the soil outside the wall can influence the failure load in the slab.
- Careful modeling of the wall, the original sheet piling, and the soil outside the wall provides data to add nonlinear springs to the analytical model of the slab.

Source all images: NIST

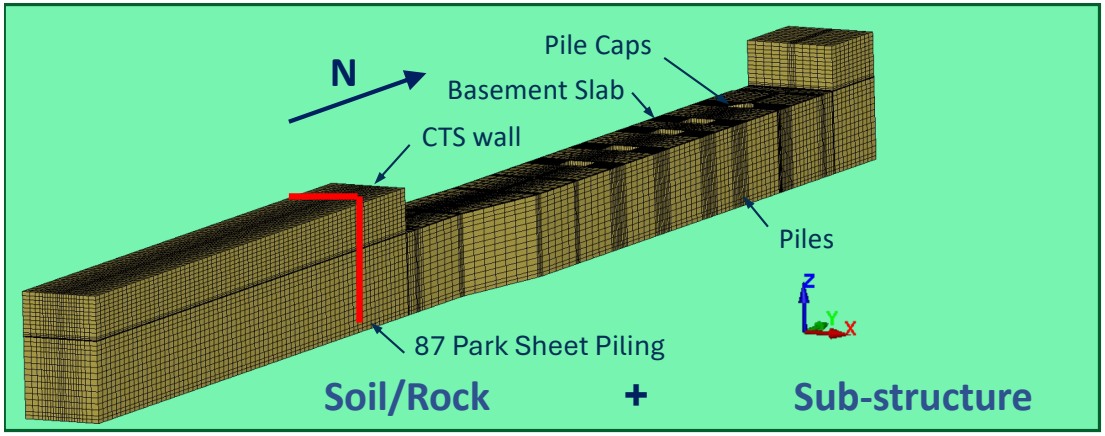
Soil-Structure Interaction Analysis

Effects of the construction of 87 Park:

- Vibrations from driving of sheet piling
- Subsequent excavation



Source: NIST



3D “Slice” model created to study vibrations from sheet pile installation and excavation at 87 Park site. Motions from that model used as base motion input for analysis of building response.

Source: NIST using LS-DYNA software

05 Materials Testing, Code Checks, Computer Simulations, Status of Failure Analysis

Materials Testing and Evaluation

Materials Testing and Evaluation

Goals

- Characterize the mechanical and other physical properties of the of concrete
  - Concrete mixes, concrete elements, casting times and placements, and exposure conditions
- Establish existing concrete mixtures through petrography and chemistry
  - Analyze maturity and degradation / Create surrogate concrete
- Characterize the mechanical properties of the reinforcing steel
  - Identify the extent, severity, effect, and causes of corrosion

Materials Sampling

- Organize parts of structure into **representative groups**
- Extract sufficient samples in each representative group to recognize the variability of material properties in that group and tolerance for error

$$n = (1.96\sigma/\mathrm{E})^2$$

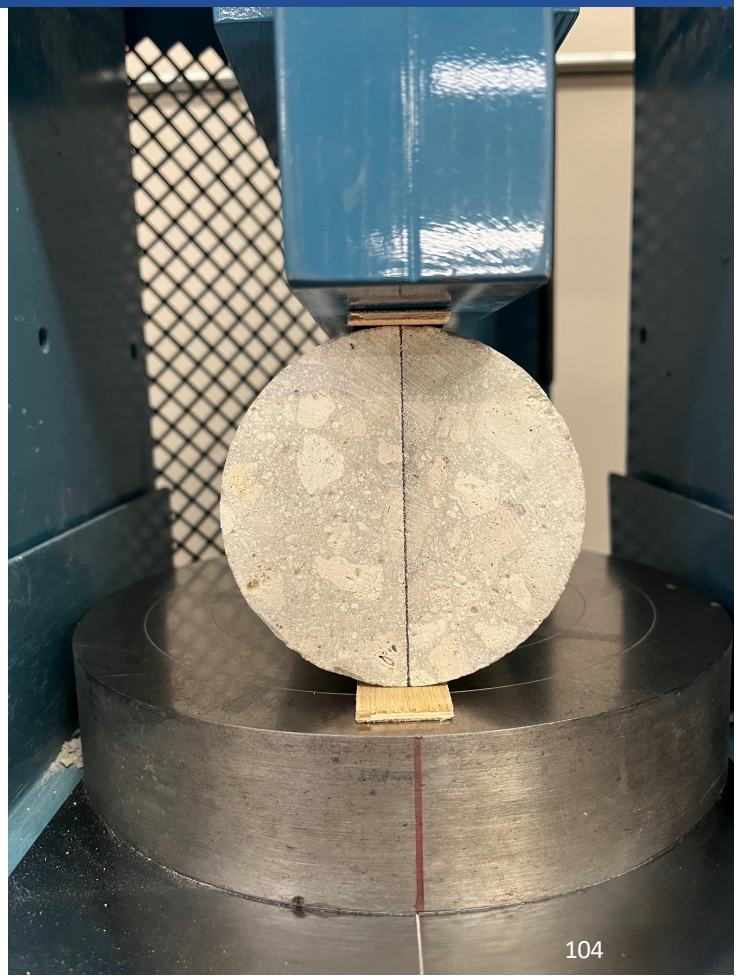
Source for all images: NIST

Materials Testing and Evaluation

594 Tests Completed for Mechanical Properties of Concrete

Compression and modulus of elasticity tests

Splitting tensile tests



Source for all images: NIST

Materials Testing and Evaluation

183 Tests Completed for Mechanical Properties of Reinforcing Steel

Measurement of degree of corrosion of steel reinforcing bars
(assisted by NIST Statistical Engineering Division)

Source for all images: NIST

Materials Testing and Evaluation

Concrete Mixture Design

Determine aggregate proportions and size:

- Air voids, mortar, and aggregate fractions determined by "point count" method and petrography
- Aggregate size determined by statistics-based visual comparison

Determine mixture proportions for surrogate concrete:

- Coarse aggregate and water fraction held constant for workability
- Water-to-cement ratio (w/c) varied to control strength
- Results show that ~ 4000 psi can be achieved at high w/c
- Implications for structure service life and durability

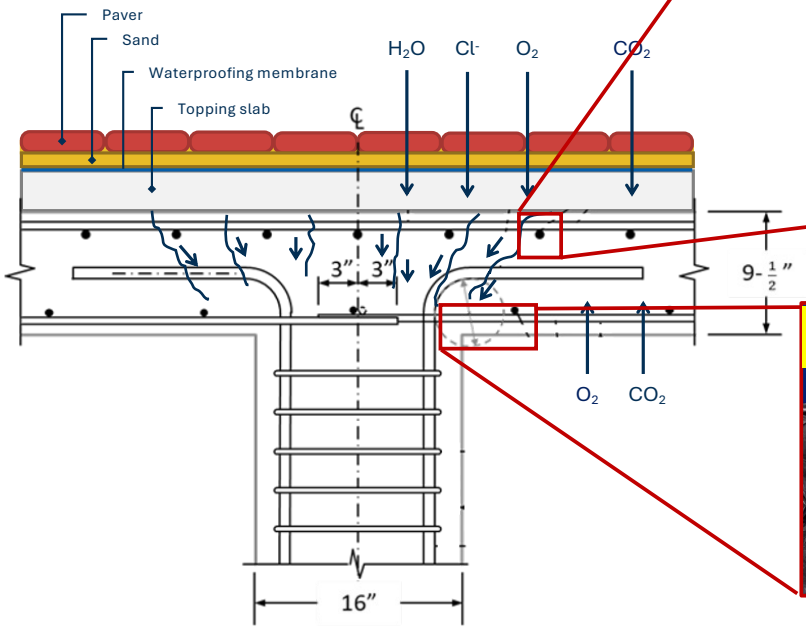
PRELIMINARY ANALYSIS RESULTS

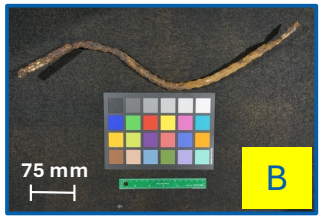
Source for all images: NIST

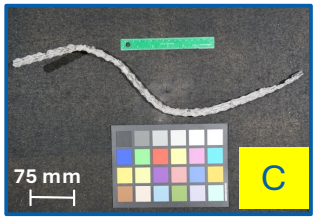
Materials Testing and Evaluation

Degradation Mechanisms

1. Cracking creates a "highway" for Cl^-, H_2O, and CO_2 to reach reinforcing bar causing corrosion
2. Concrete microstructure altered by the environment, changing mechanical properties

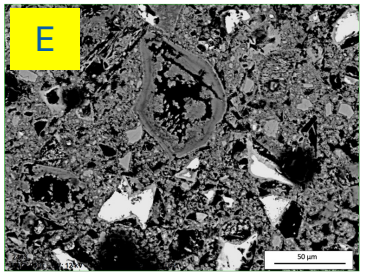






1. Reinforcing bar corrosion

- Corroded reinforcement in slab (A)
- Reinforcement before (B) and after (C) cleaning



2. Concrete degradation

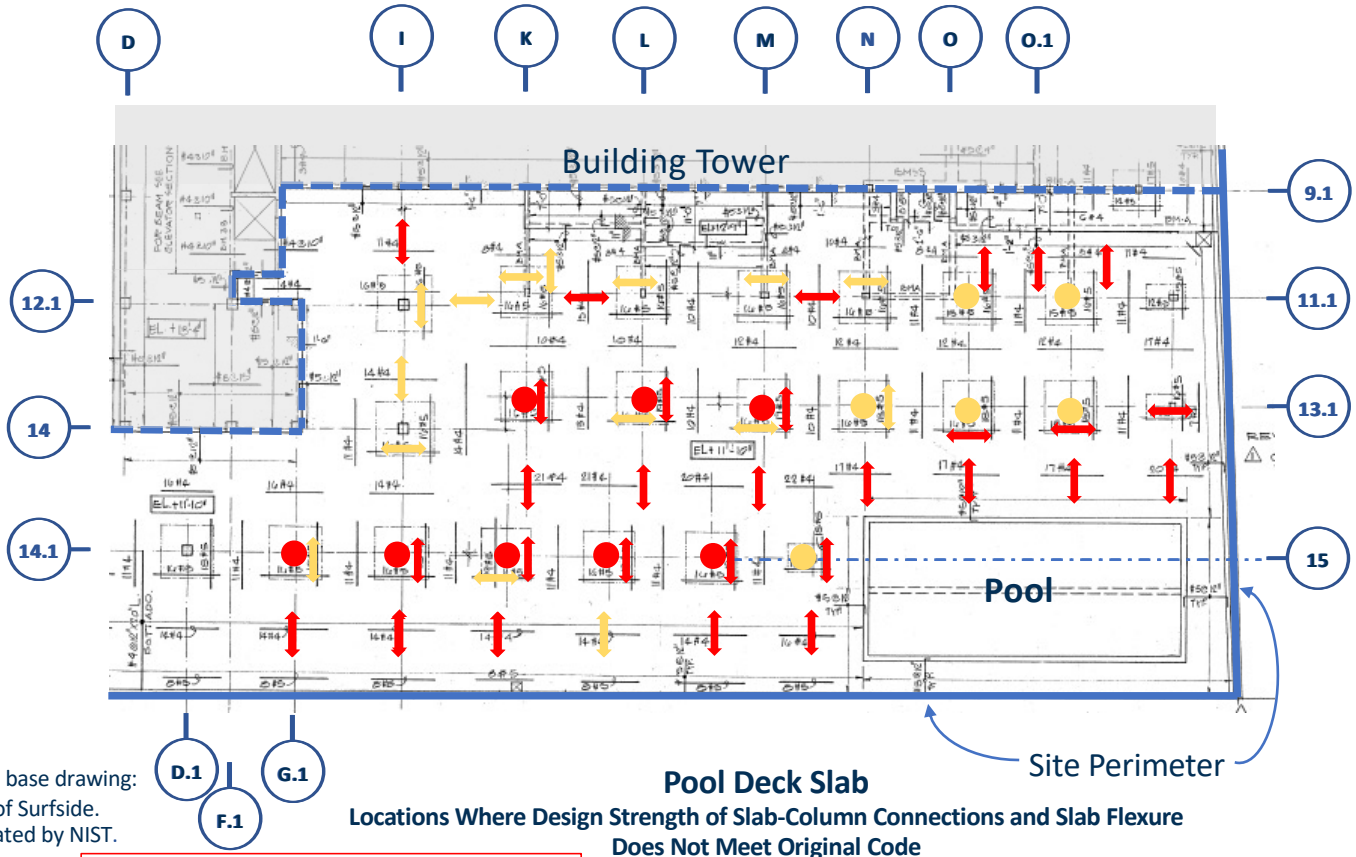
- Specimen extracted from slab near column (D)
- Microstructure characterized by high porosity (black regions at E)

Source for all images: NIST

PRELIMINARY ANALYSIS RESULTS

Structural Code Checks

Structural Code Checks



Source base drawing:
Town of Surfside.
Annotated by NIST.

Pool Deck Slab

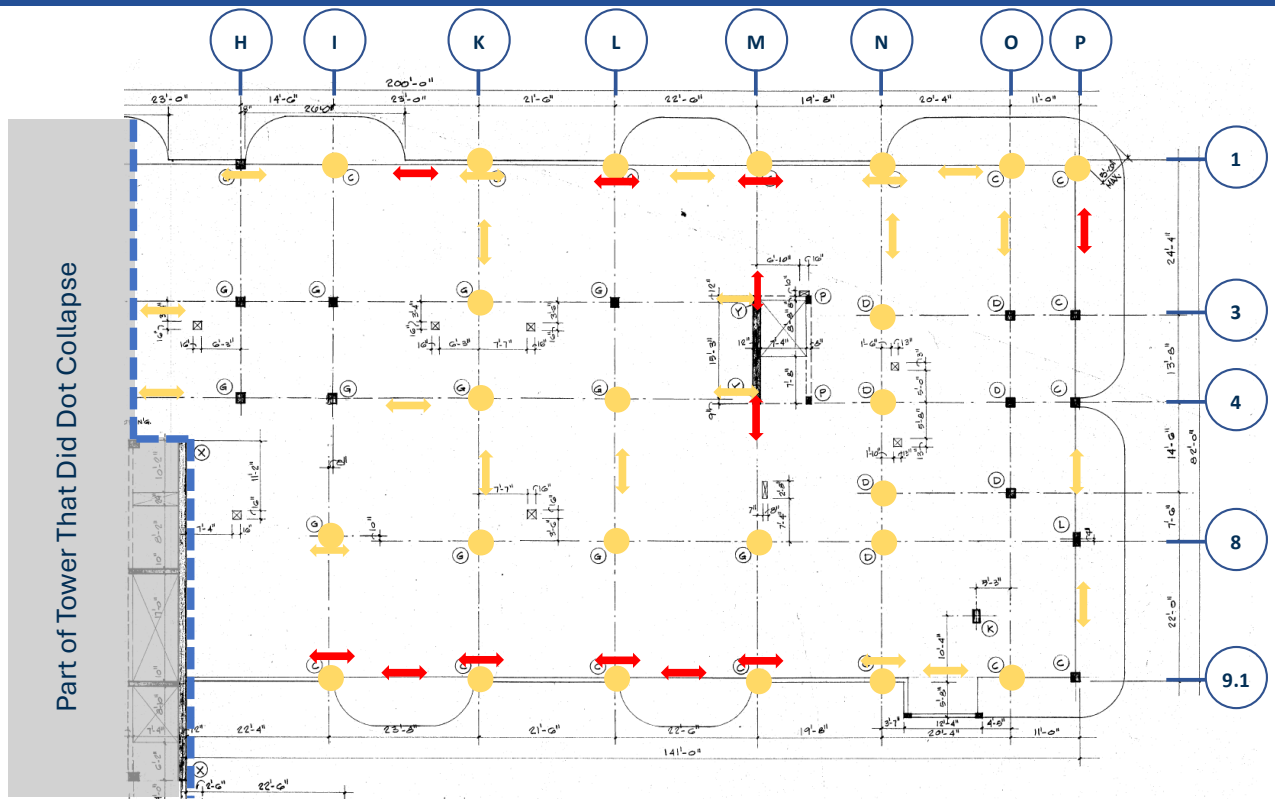
Locations Where Design Strength of Slab-Column Connections and Slab Flexure Does Not Meet Original Code (DCR > 1.0)

PRELIMINARY ANALYSIS RESULTS

Legend

Degree of Understrength	Location of Understrength: slab-column connections	Location of Understrength: slab flexure
severe	●	⟷
moderate	●	⟷

Structural Code Checks



Source base drawing:
Town of Surfside.
Annotated by NIST.

Third Floor Slab

Locations Where Design Strength of Slab-Column Connections and Slab Flexure Does Not Meet Original Code (DCR > 1.0)

PRELIMINARY ANALYSIS RESULTS

Legend

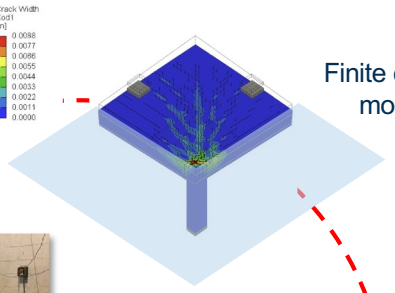
Degree of Understrength	Location of Understrength: slab-column connections	Location of Understrength: slab flexure
severe	●	⟷
moderate	●	⟷

Structural Failure Modeling

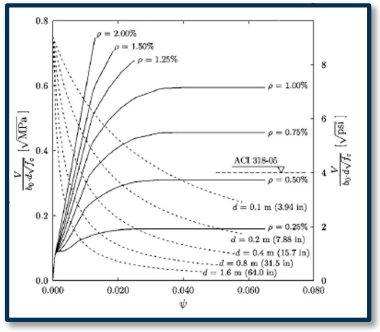
Structural Failure Modeling

Slab-Column Connection Failures in the Pool Deck

Laboratory slab-column connection test.

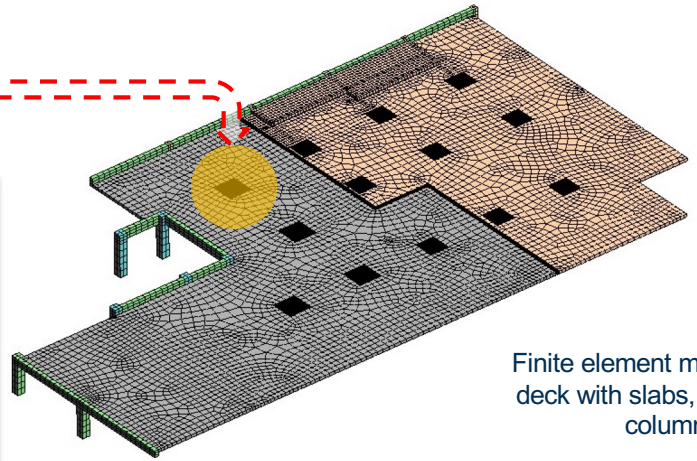


Finite element models.



Critical Shear Crack Theory

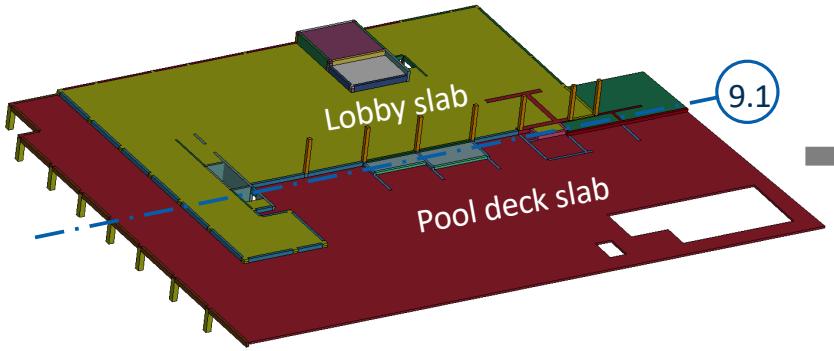
Source: ACI



Finite element model of pool-deck with slabs, beams, and columns.

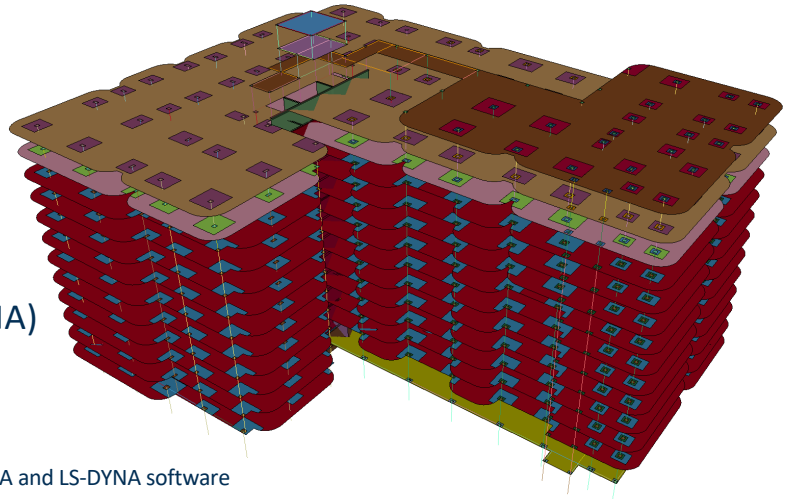
Source all images unless otherwise noted: NIST

Structural Failure Modeling



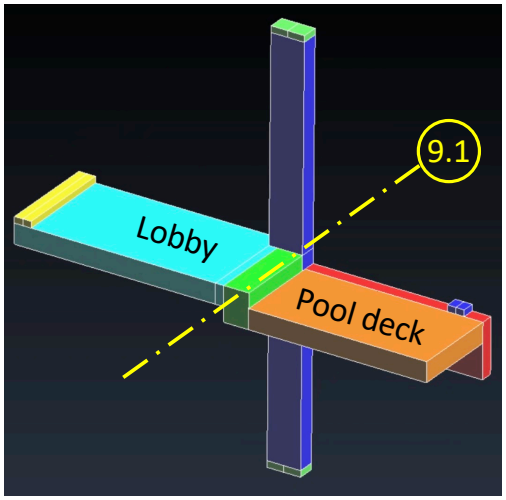
Global and Progression Models

1 **Pool Deck and First Floor Slab Models** (ATENA & LS-DYNA)



Global Tower Model (LS-DYNA)

3



2

Slab-Beam-Column Connection Model (ATENA)

Source: NIST using ATENA and LS-DYNA software

Preliminary Pool Deck Evaluation

Preliminary Pool Deck Evaluation

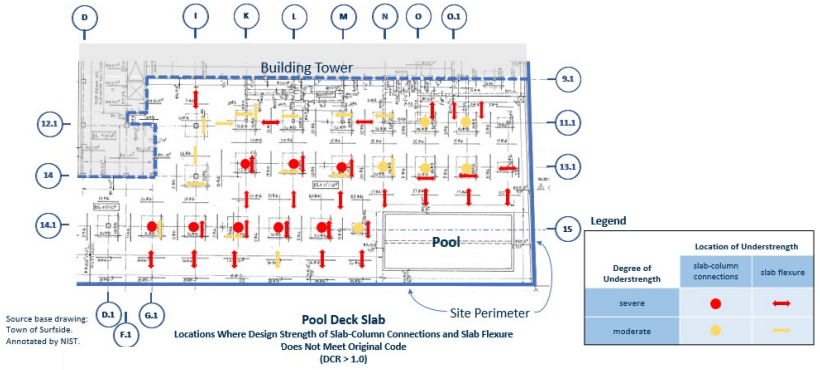
Factors that Led to Critically Low Margins of Safety in the Pool Deck

PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

Factors that Led to Critically Low Margins of Safety in the Pool Deck

Design Understrength
(largest, pervasive)



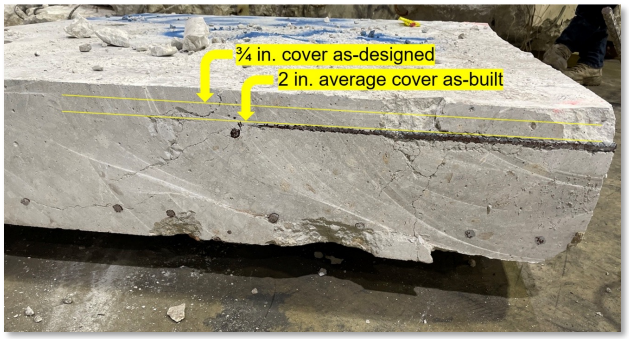
PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

Factors that Led to Critically Low Margins of Safety in the Pool Deck

Design Understrength
(largest, pervasive)

Misplaced Slab Reinforcement
(pervasive)



Top Reinforcement in Pool Deck Lower than Design Requirements

Placement of Top Bars in Column Strips

Source for all images: NIST

PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

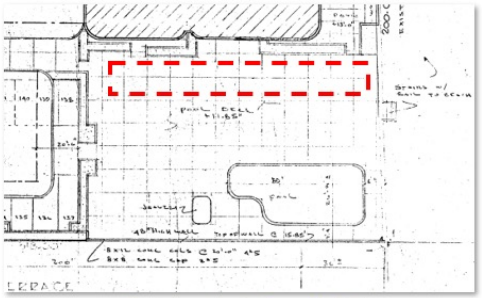
Factors that Led to Critically Low Margins of Safety in the Pool Deck

Design Understrength
(largest, pervasive)

Misplaced Slab Reinforcement
(pervasive)

Heavier, More Extensive Planters
(near north side of pool deck)

Source: Google Earth image captured November 2019, downloaded May 22, 2023



Source base drawing: Town of Surfside
Annotated by NIST

Source for all images: NIST

PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

Factors that Led to Critically Low Margins of Safety in the Pool Deck

Design Understrength (largest, pervasive)	Misplaced Slab Reinforcement (pervasive)	Heavier, More Extensive Planters (near north side of pool deck)	**Added Fill and Paving (variable)**

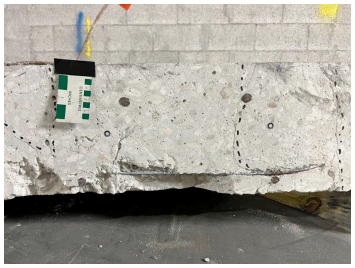
Source for all images: NIST.

PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

Factors that Led to Critically Low Margins of Safety in the Pool Deck

Design Understrength (largest, pervasive)	Misplaced Slab Reinforcement (pervasive)	Heavier, More Extensive Planters (near north side of pool deck)	Added Fill and Paving (variable)	**Corrosion of Slab Reinforcement (variable)**



Source for all images: NIST

PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

Factors that Led to Critically Low Margins of Safety in the Pool Deck

Design Understrength (largest, pervasive)	Misplaced Slab Reinforcement (pervasive)	Heavier, More Extensive Planters (near north side of pool deck)	Added Fill and Paving (variable)	Corrosion of Slab Reinforcement (variable)

- Together, caused the bulk of the critically low margins of safety
- Existed from the time construction was complete – 40 years before the partial collapse

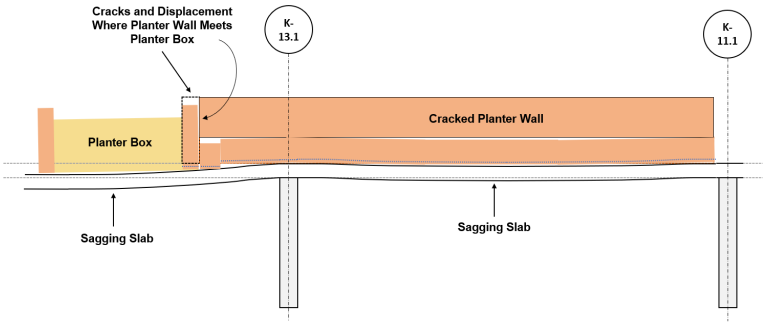
Source for all images: NIST

PRELIMINARY ANALYSIS RESULTS

Preliminary Pool Deck Evaluation

There were indications of severe distress in the pool deck at least three weeks before the collapse

Source: 2021, CTS Receiver.
Annotated by NIST.



(vertical scale exaggerated for clarity)

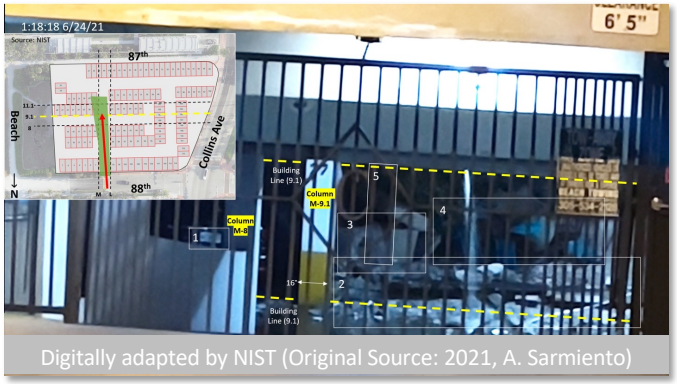
Source: NIST

PRELIMINARY ANALYSIS RESULTS

Collapse Sequence

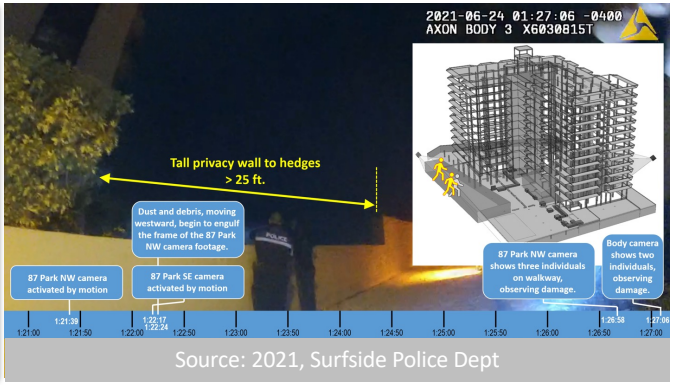
Collapse Sequence

1. The pool deck collapsed between its southern extremity and its connection to the tower more than four minutes before the general collapse of the tower.



Digitally adapted by NIST (Original Source: 2021, A. Sarmiento)

NIST's Analysis of CTS Parking Garage Ramp Video Footage



Source: 2021, Surfside Police Dept

NIST's Analysis of Beach Access Walkway Video Footage

Source: NIST

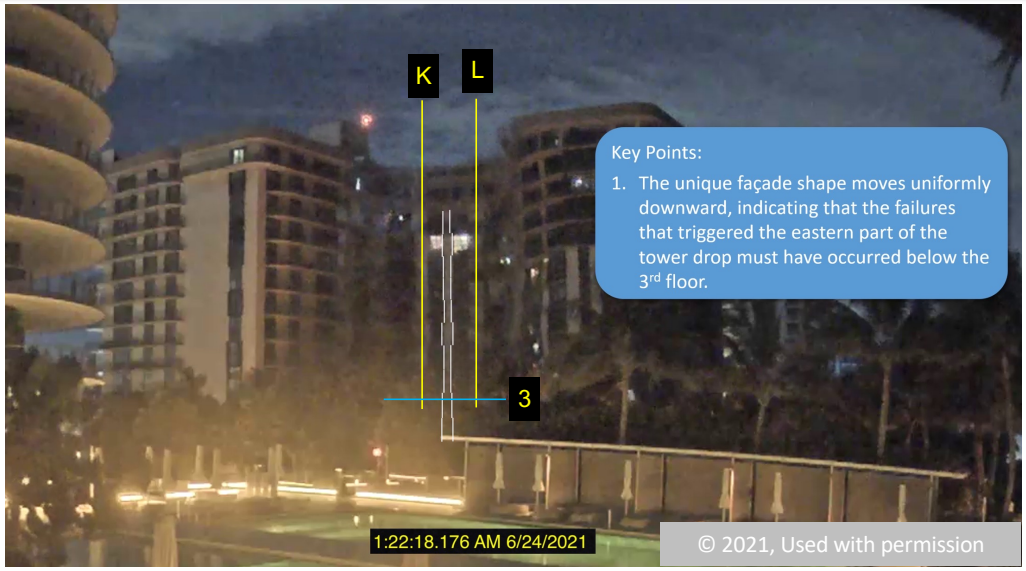
Eyewitness Accounts of Pool Deck Collapse

PRELIMINARY ANALYSIS RESULTS

Collapse Sequence

2. In the tower collapse, Grid Line 9.1 started to drop a second, or a bit more, before 1:22:17 am, the time of the first frame of the South Face Video.

- The columns on Grid Line K and/or L dropped first.
- The initial column failures were low in the building below the 3rd floor.

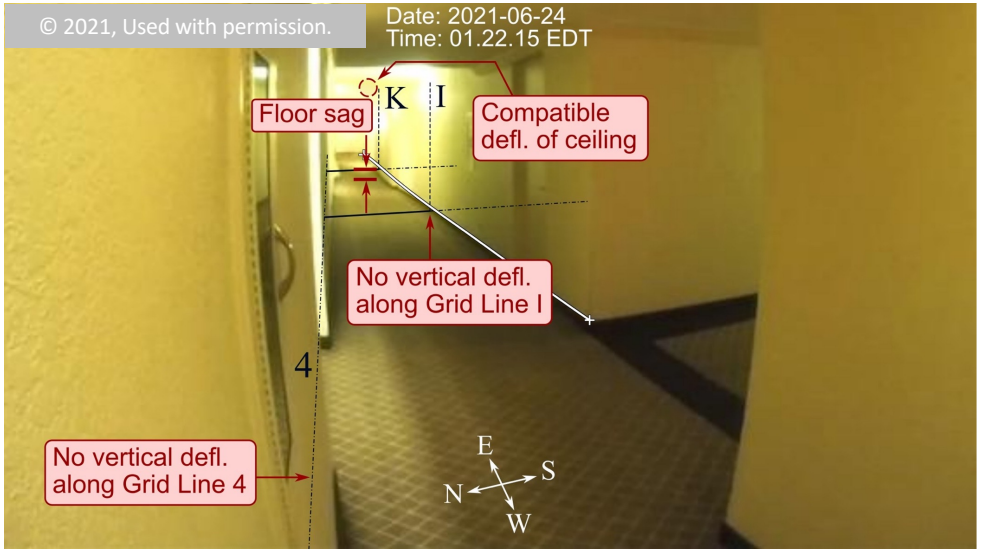


NIST's Analysis of South Face Video Footage

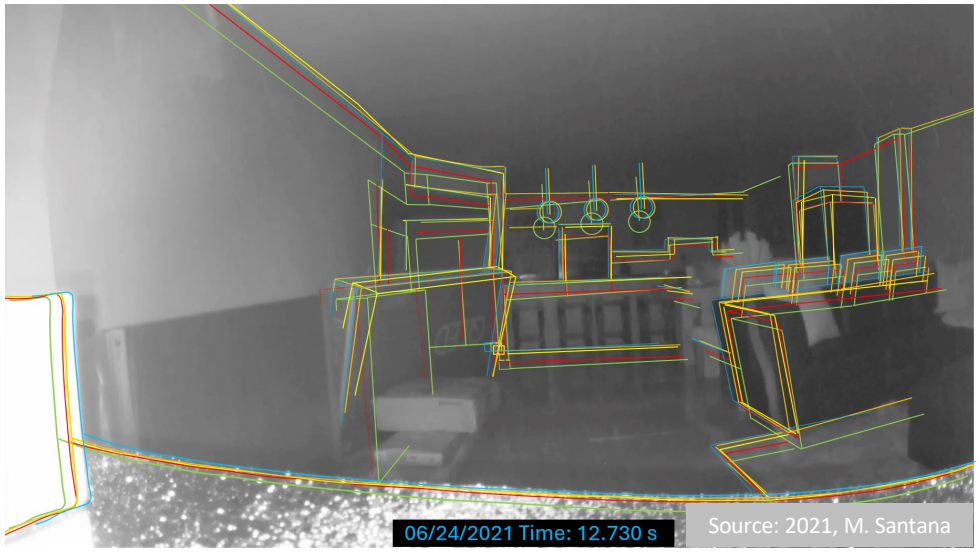
PRELIMINARY ANALYSIS RESULTS

Collapse Sequence

3. Videos show severe structural movements in the tower between Grid Lines K and M and Grid Lines 4 and 9.1 prior to the precipitous drop of the tower along Grid Line 9.1.



NIST's Analysis of Upper Story Corridor Video Footage

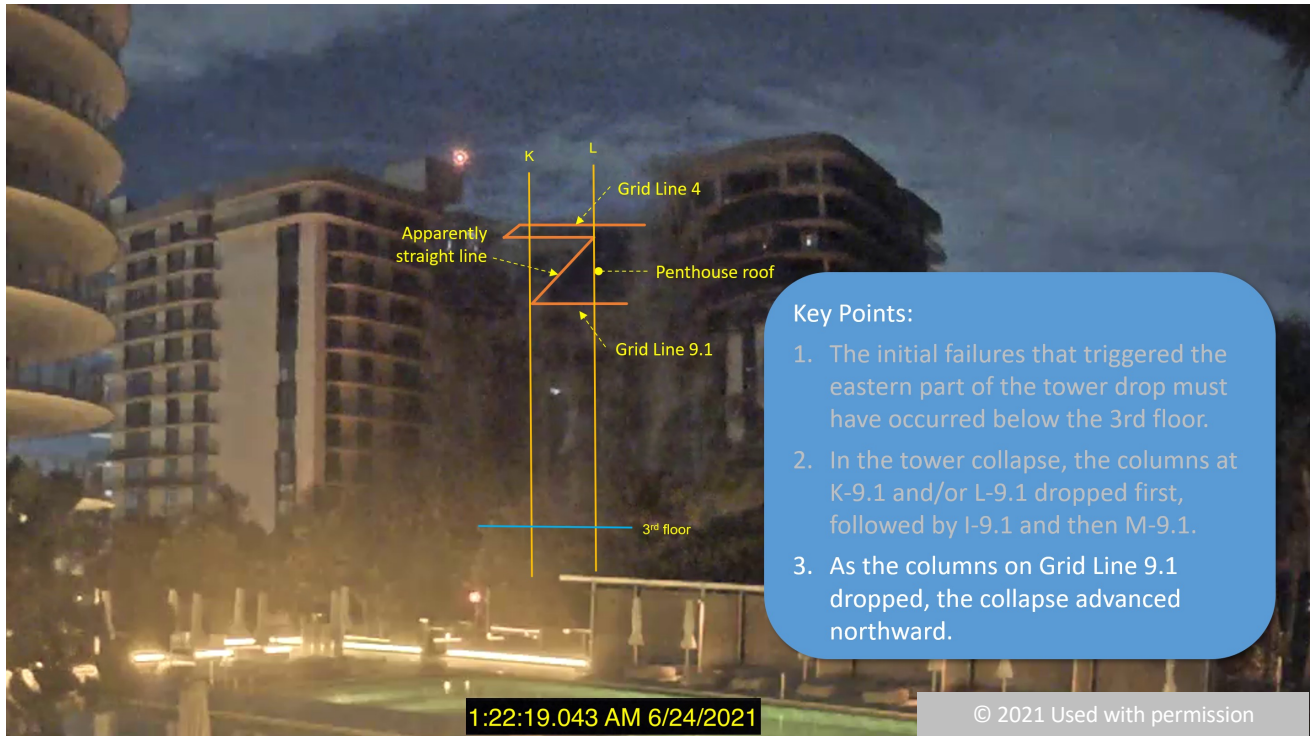


NIST's Analysis of 11 Stack Unit Video Footage

PRELIMINARY ANALYSIS RESULTS

Collapse Sequence

4. As the columns on Grid Line 9.1 dropped, the collapse advanced northward.



PRELIMINARY ANALYSIS RESULTS

NIST's Analysis of South Face Video Footage

Collapse Sequence

5. While there is strong evidence that the collapse initiated in the pool deck, we have not yet ruled out a failure initiation in some part of the tower that precipitated a collapse in the pool deck.

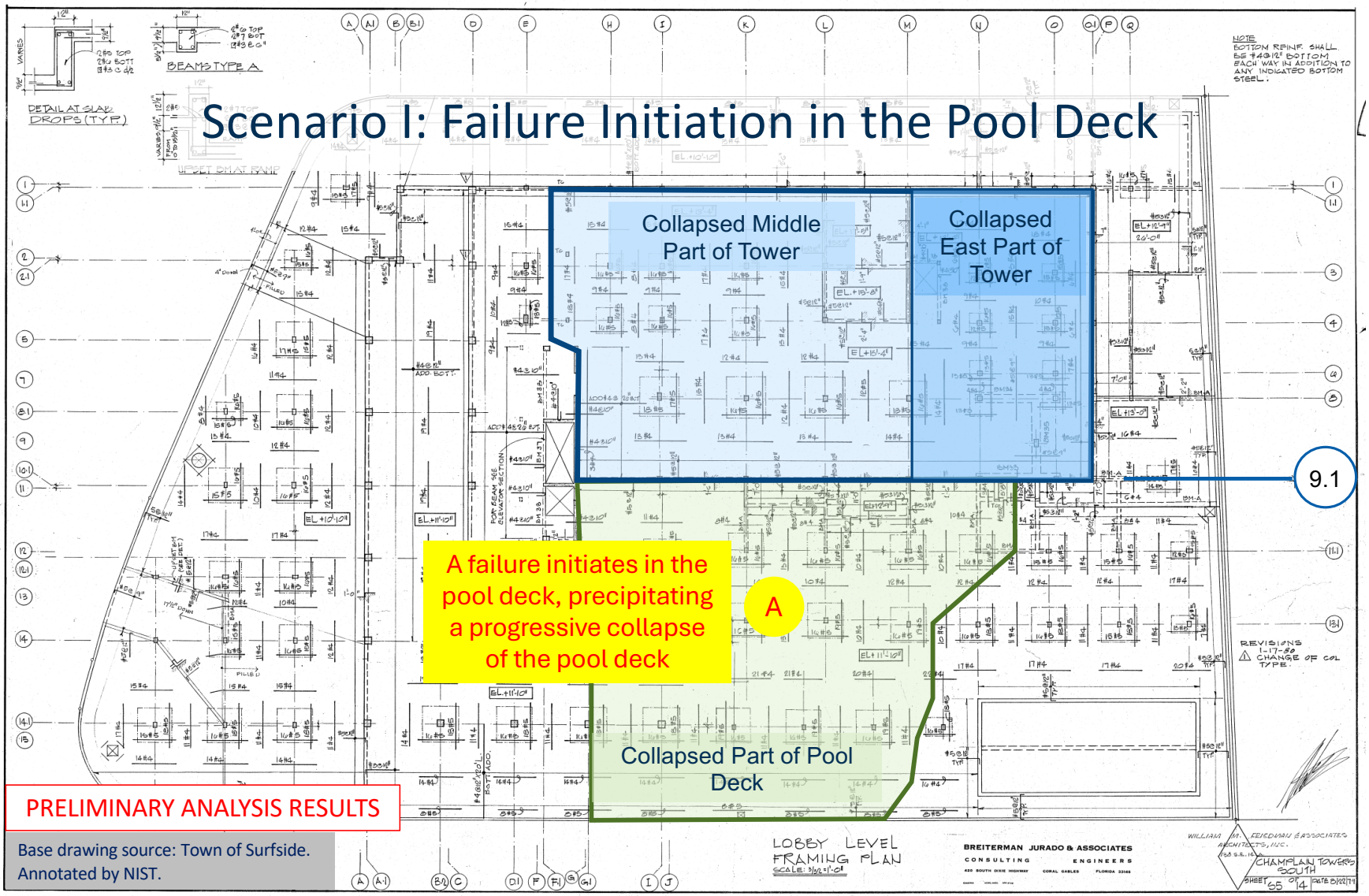
- There were indications of severe distress in the pool deck at least three weeks before the collapse.
- There are also potential initiation points in the tower.

Damage to Pool Deck Planters Three Weeks Before the Collapse Indicated Severe Structural Distress

PRELIMINARY ANALYSIS RESULTS

Failure Initiation and Progression Scenarios

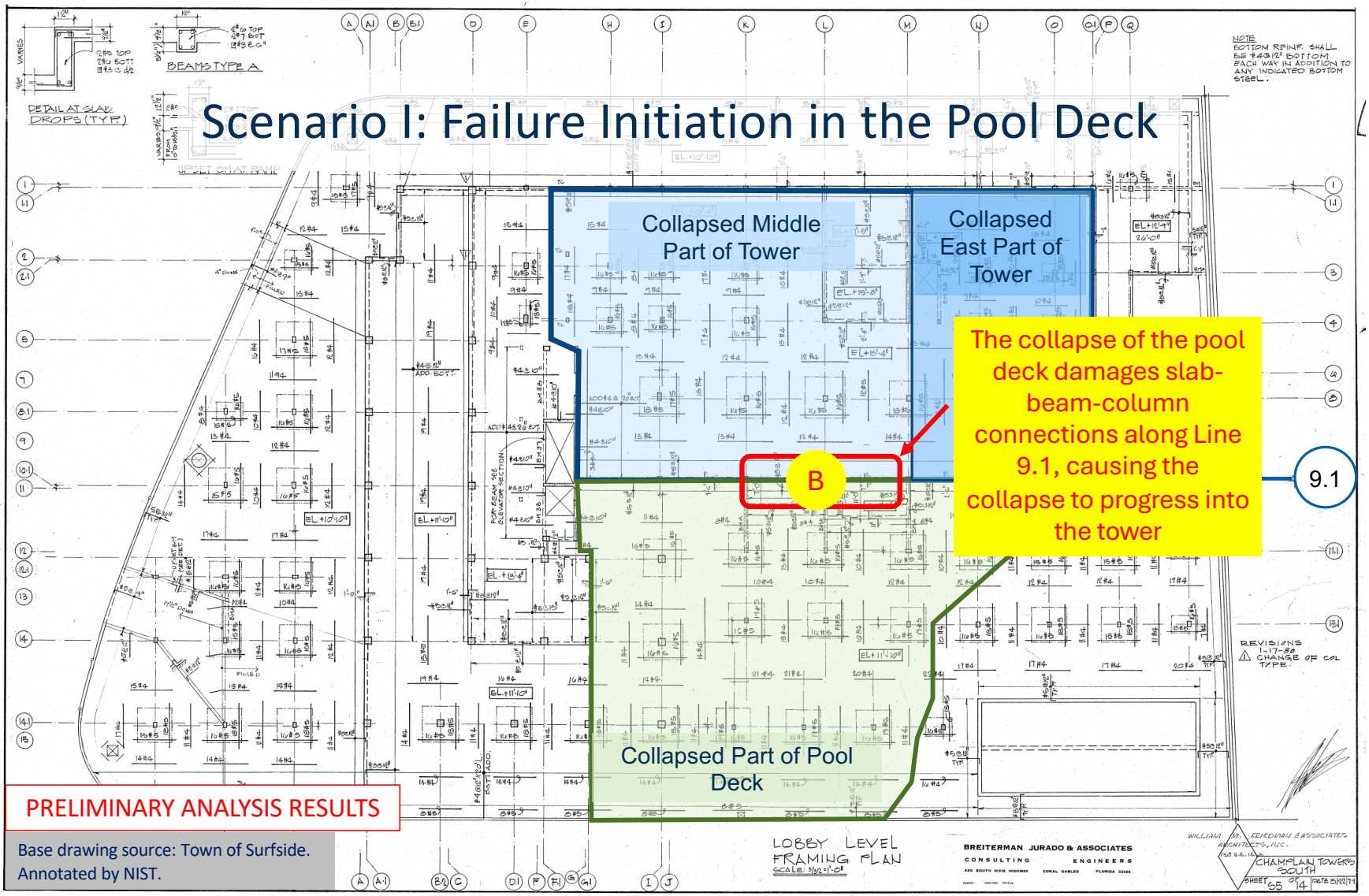
Scenario I: Failure Initiation in the Pool Deck



PRELIMINARY ANALYSIS RESULTS

Base drawing source: Town of Surfside.
Annotated by NIST.

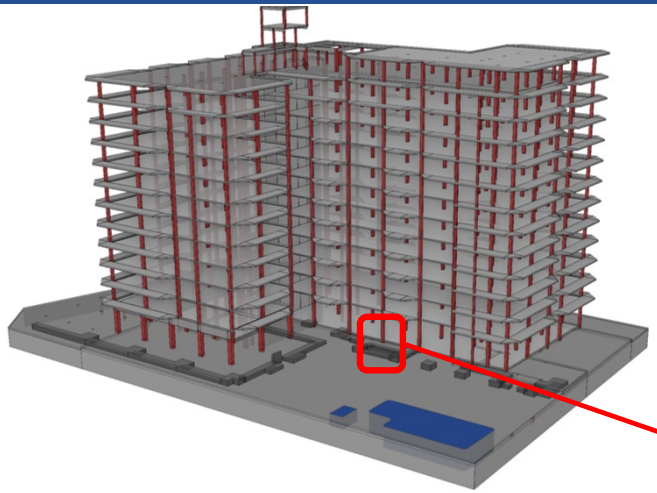
Scenario I: Failure Initiation in the Pool Deck

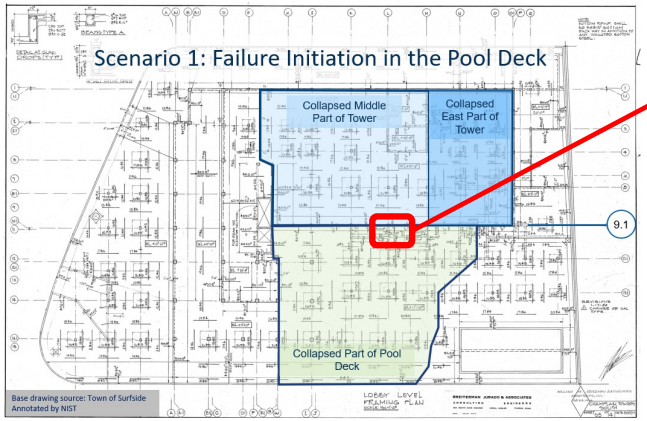


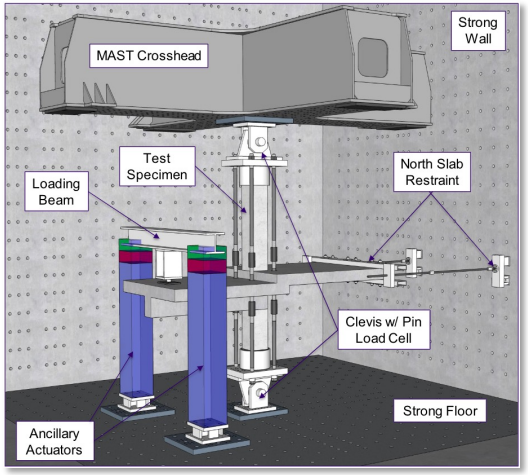
PRELIMINARY ANALYSIS RESULTS

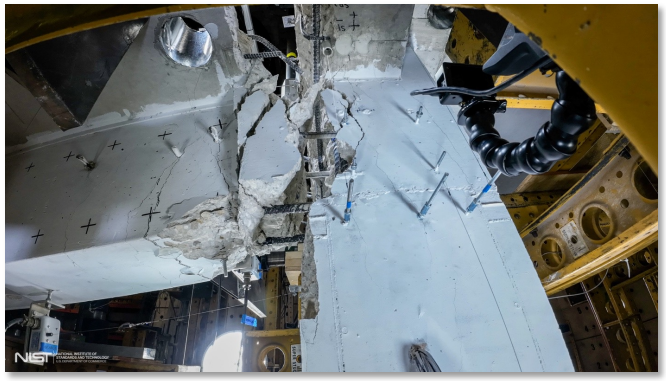
Base drawing source: Town of Surfside.
Annotated by NIST.

Failure Initiation and Progression Scenarios





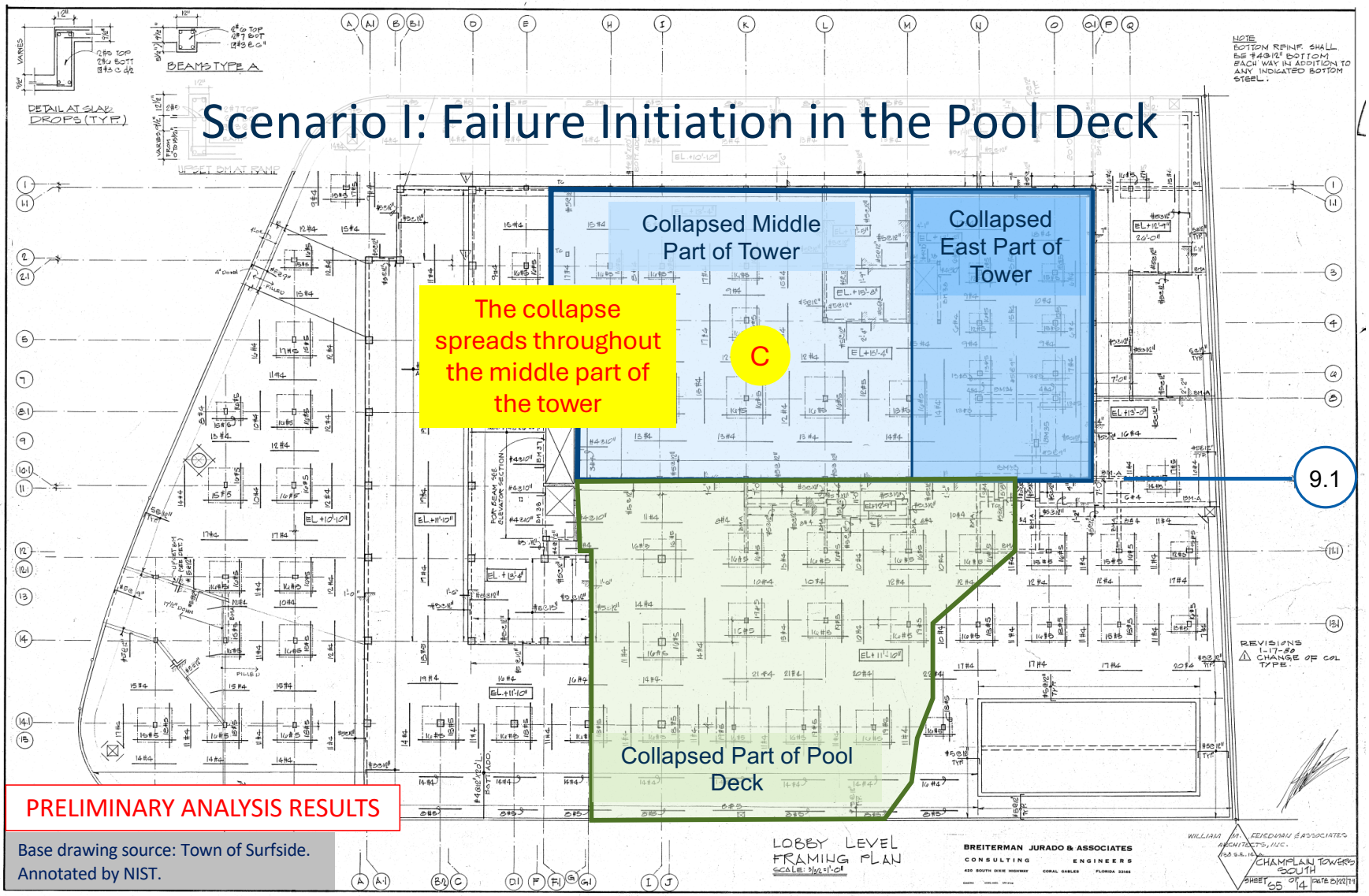




Source: NIST except where noted

PRELIMINARY ANALYSIS RESULTS

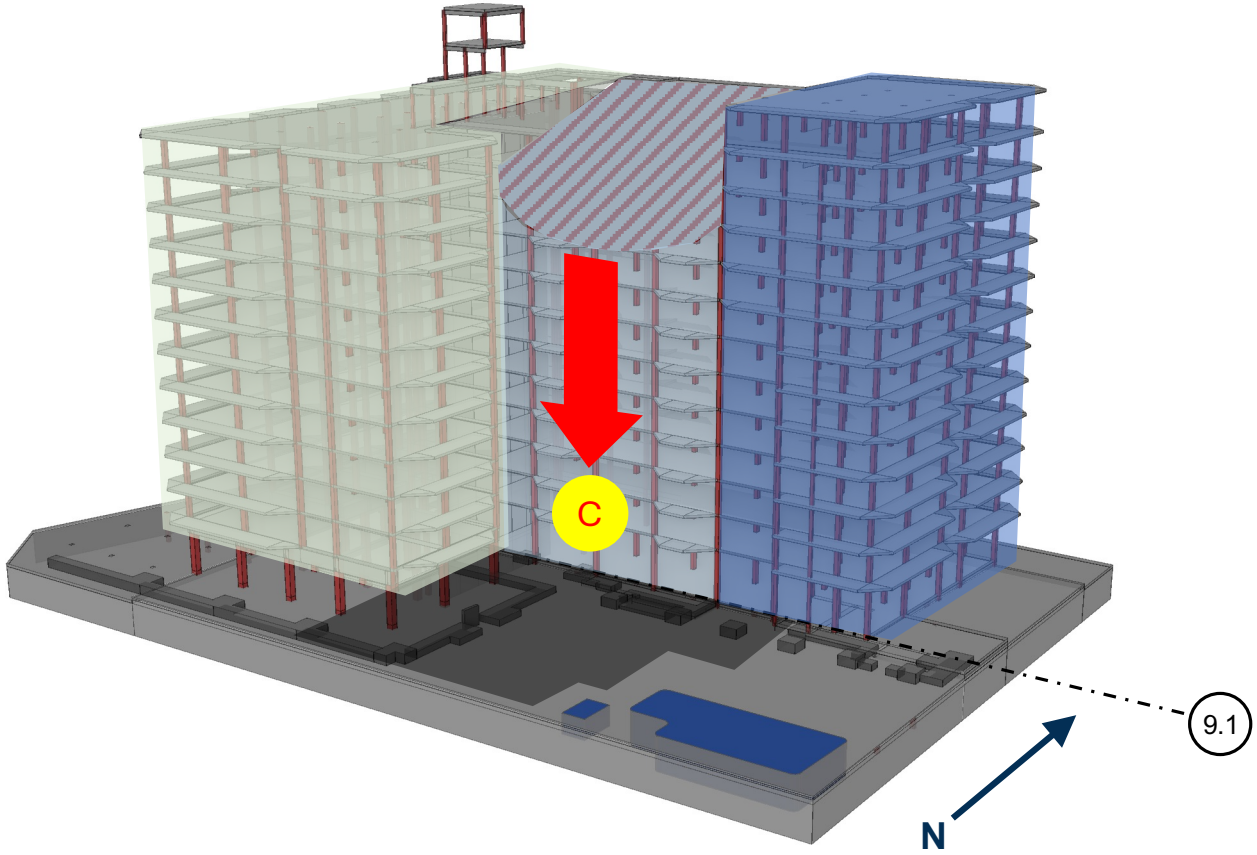
Scenario I: Failure Initiation in the Pool Deck



PRELIMINARY ANALYSIS RESULTS

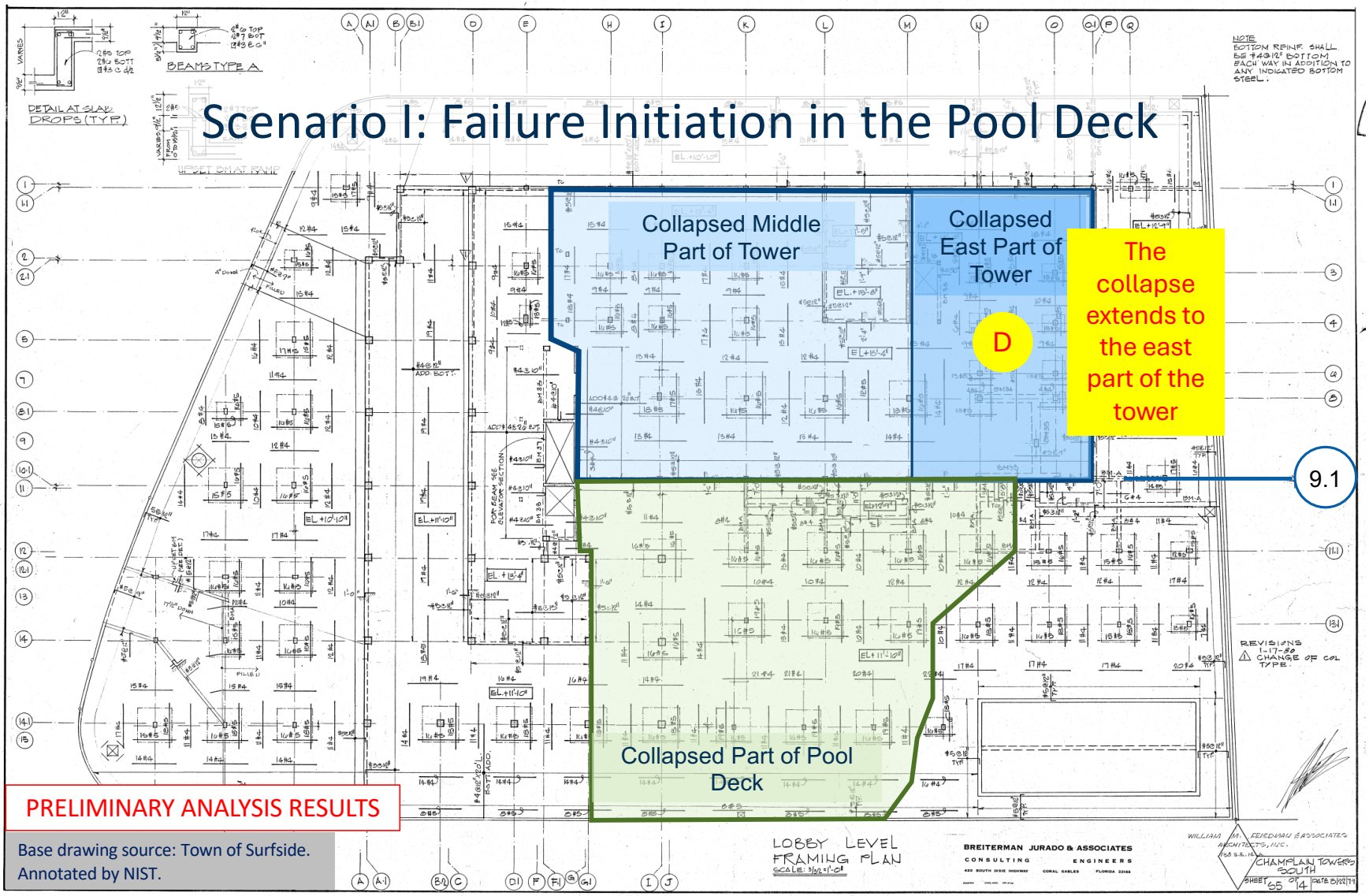
Base drawing source: Town of Surfside.
Annotated by NIST.

Failure Initiation and Progression Scenarios



Source: NIST

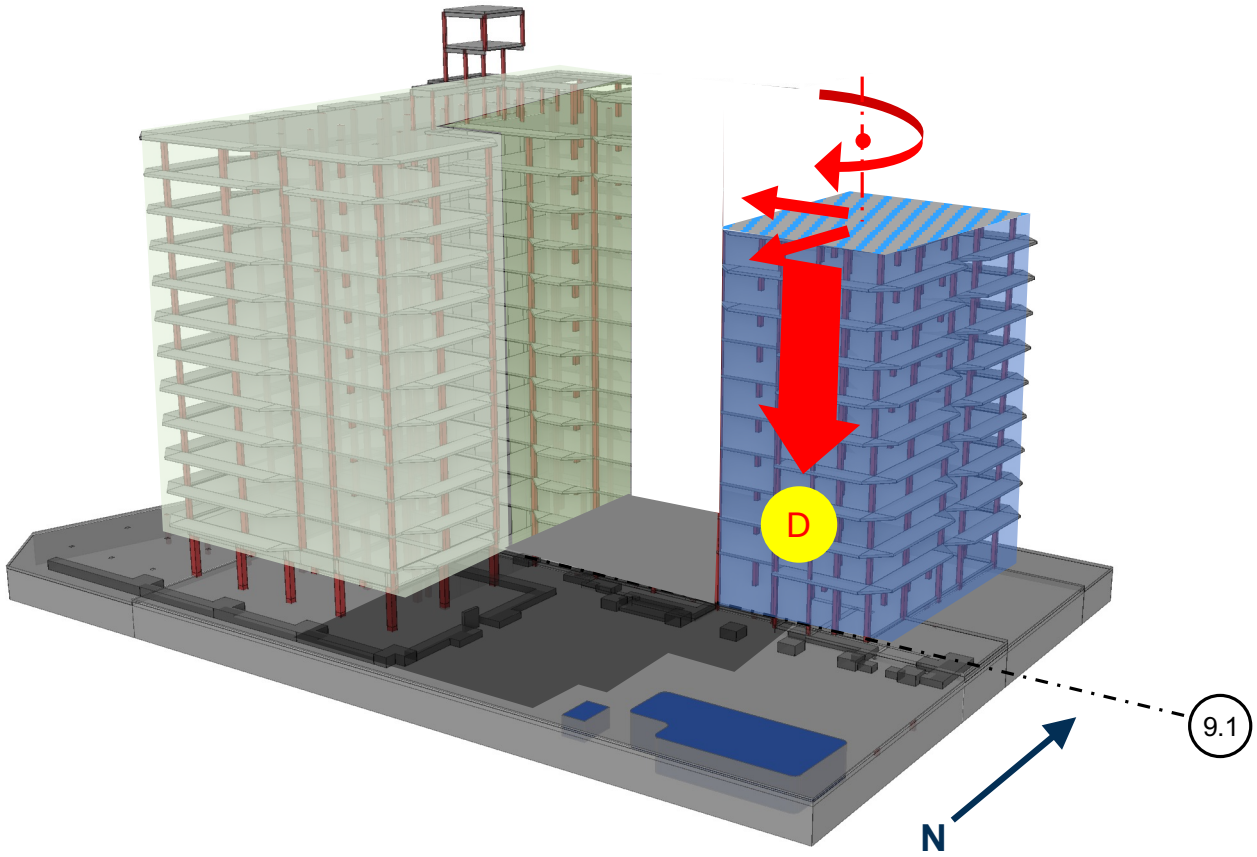
Scenario I: Failure Initiation in the Pool Deck



PRELIMINARY ANALYSIS RESULTS

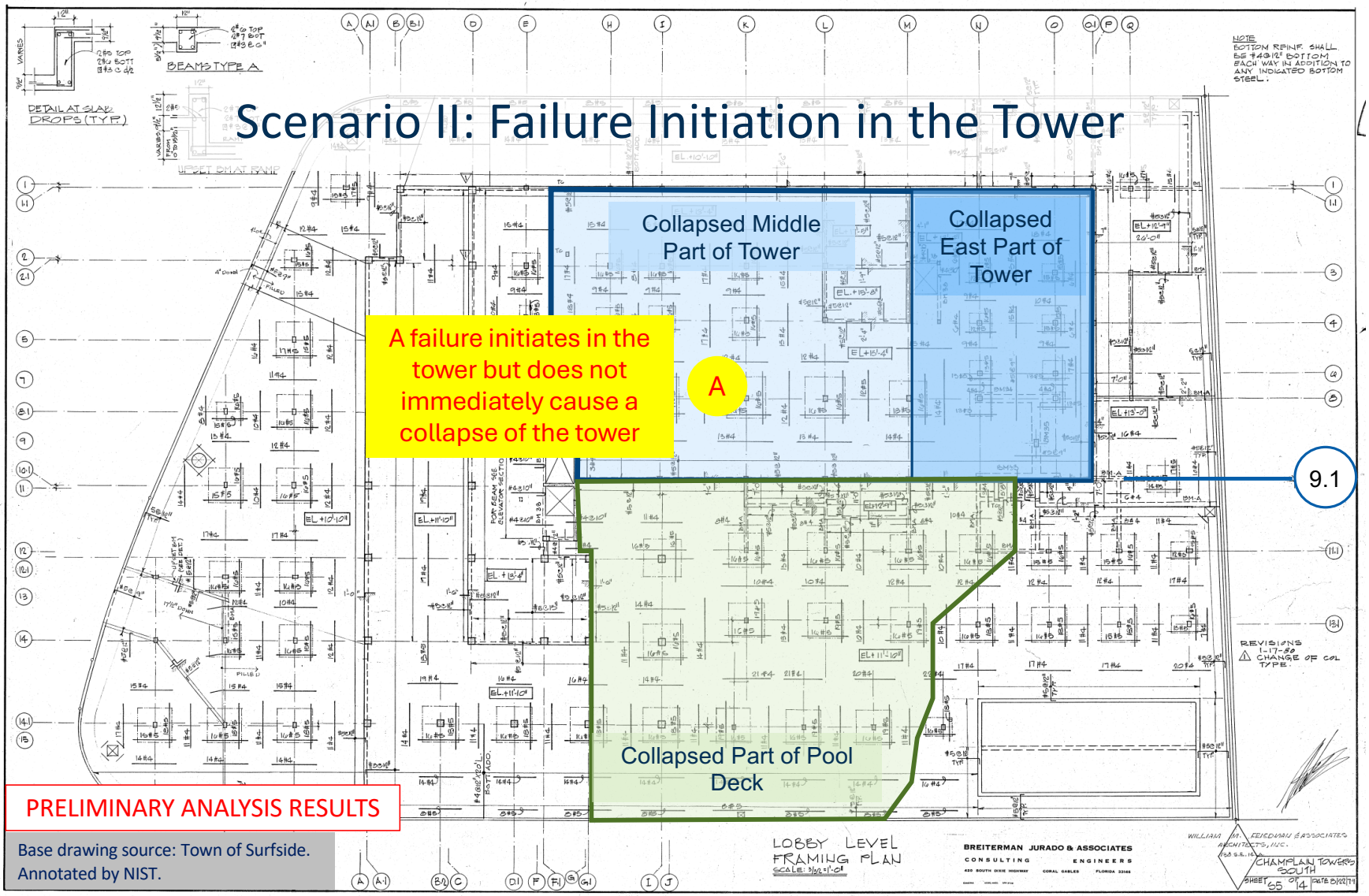
Base drawing source: Town of Surfside.
Annotated by NIST.

Failure Initiation and Progression Scenarios



Source: NIST

Scenario II: Failure Initiation in the Tower

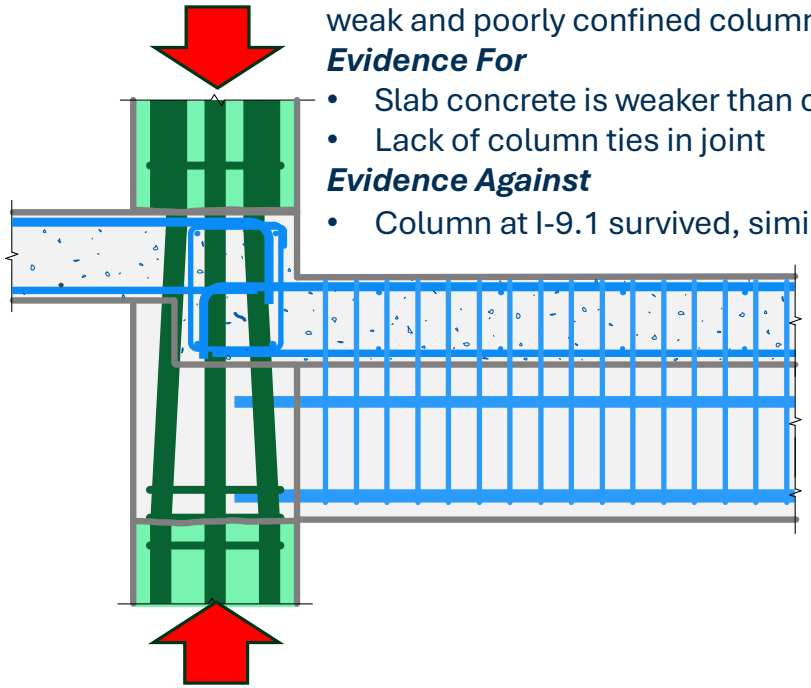


PRELIMINARY ANALYSIS RESULTS

Base drawing source: Town of Surfside.
Annotated by NIST.

Description of Three Scenario II Failure Initiation Possibilities

All three possibilities lead to shortening of column and redistribution of load elsewhere.



Failure Initiation Possibility #1: crushing in weak and poorly confined column/slab/beam joint:

Evidence For

- Slab concrete is weaker than column concrete
- Lack of column ties in joint

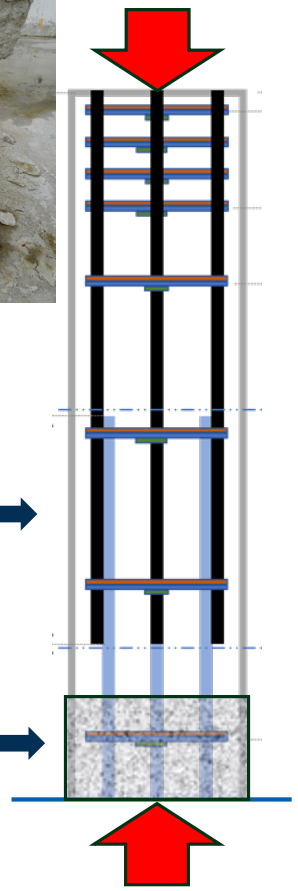
Evidence Against

- Column at I-9.1 survived, similar load

Failure Initiation Possibility #2: partial failure at improper lap splice:

Evidence For: measurements

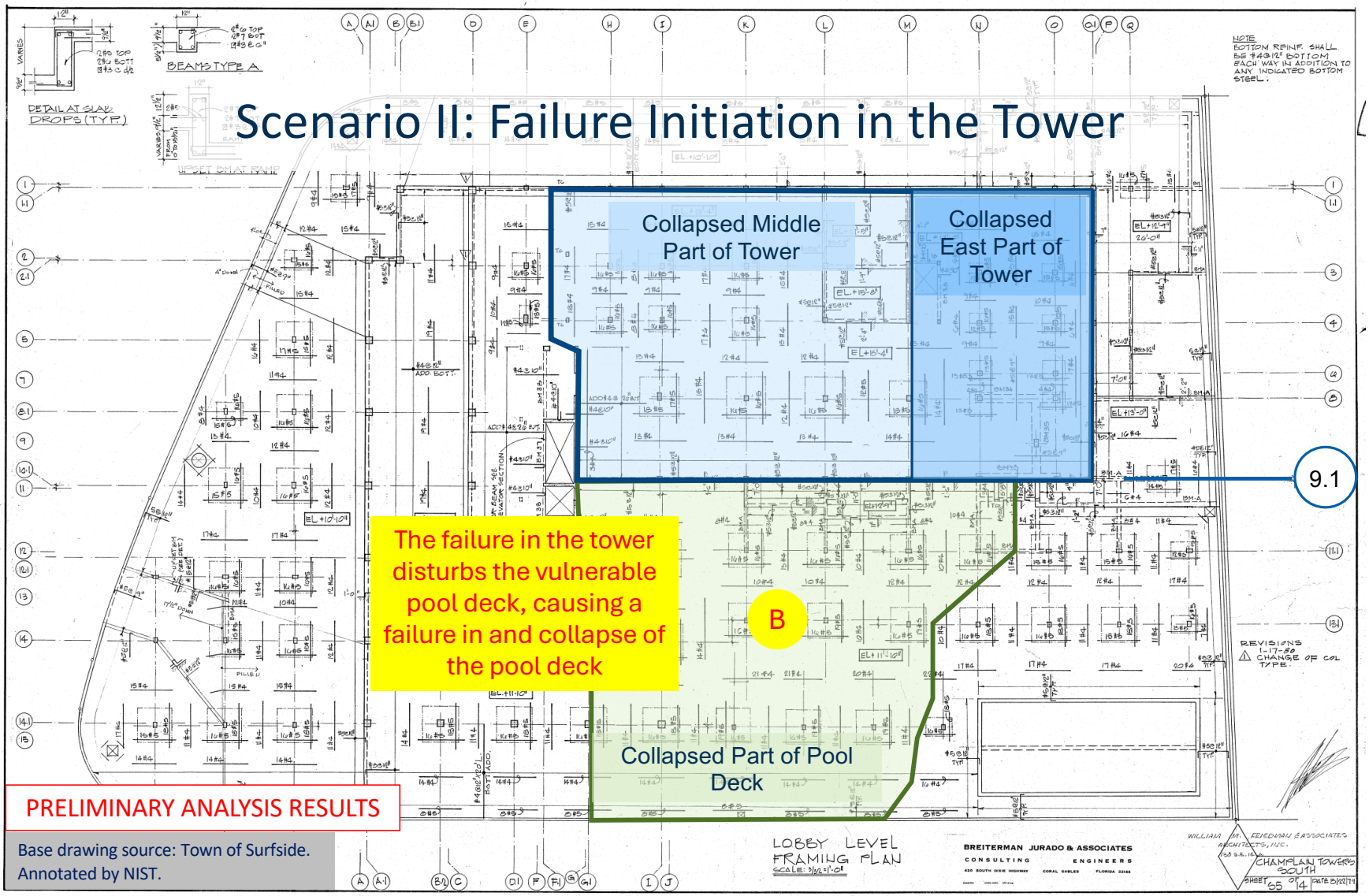
Evidence Against: survival of columns with short splices that permitted such measurements



Failure Initiation Possibility #3: crushing in deteriorated concrete at bottom of column in basement

Source for all images: NIST

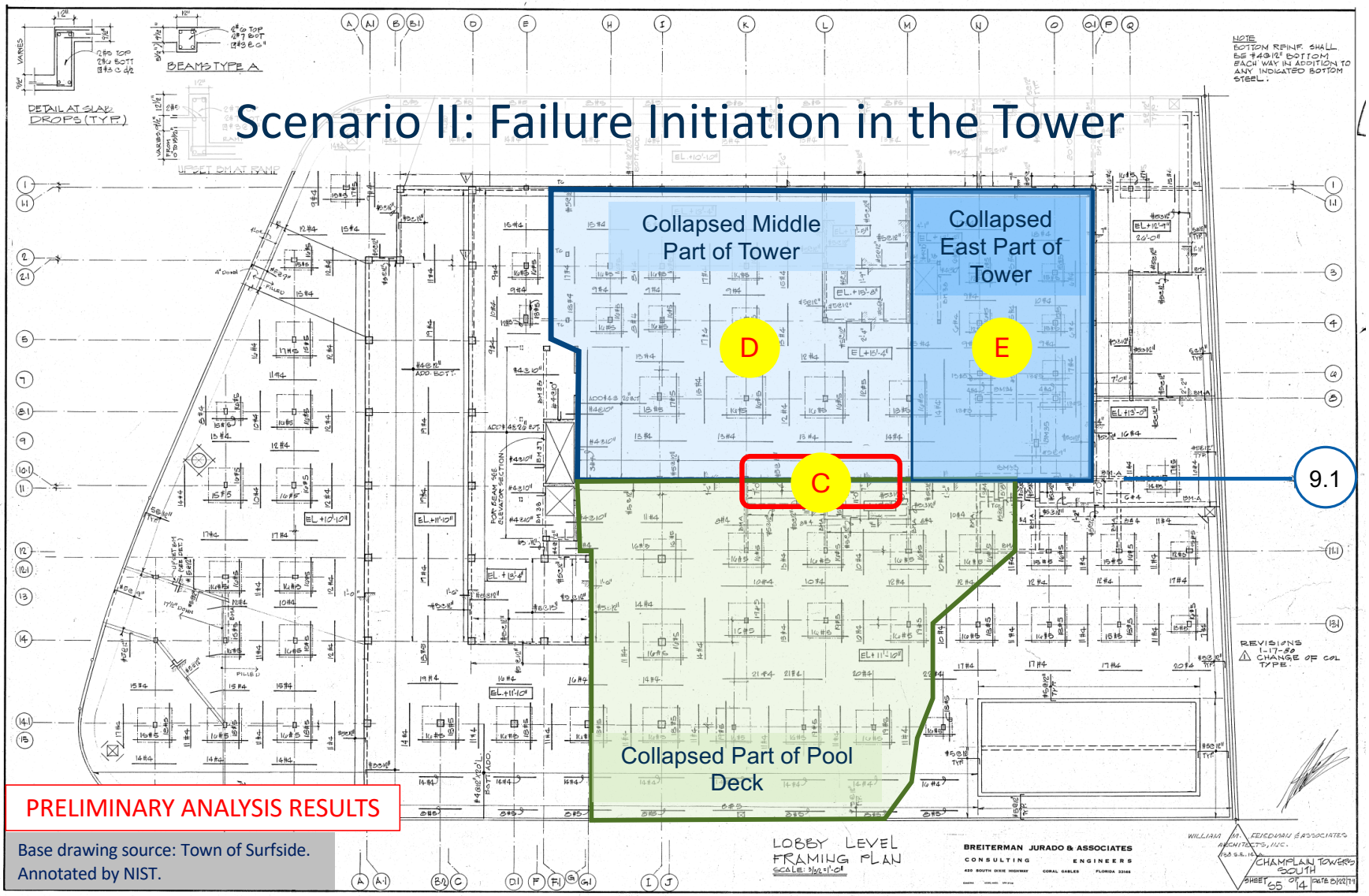
Scenario II: Failure Initiation in the Tower



PRELIMINARY ANALYSIS RESULTS

Base drawing source: Town of Surfside.
Annotated by NIST.

Scenario II: Failure Initiation in the Tower



PRELIMINARY ANALYSIS RESULTS

Base drawing source: Town of Surfside.
Annotated by NIST.

06 Codes and Standards of Practice, Potential Recommendation Topics

Potential Topics for Recommendations

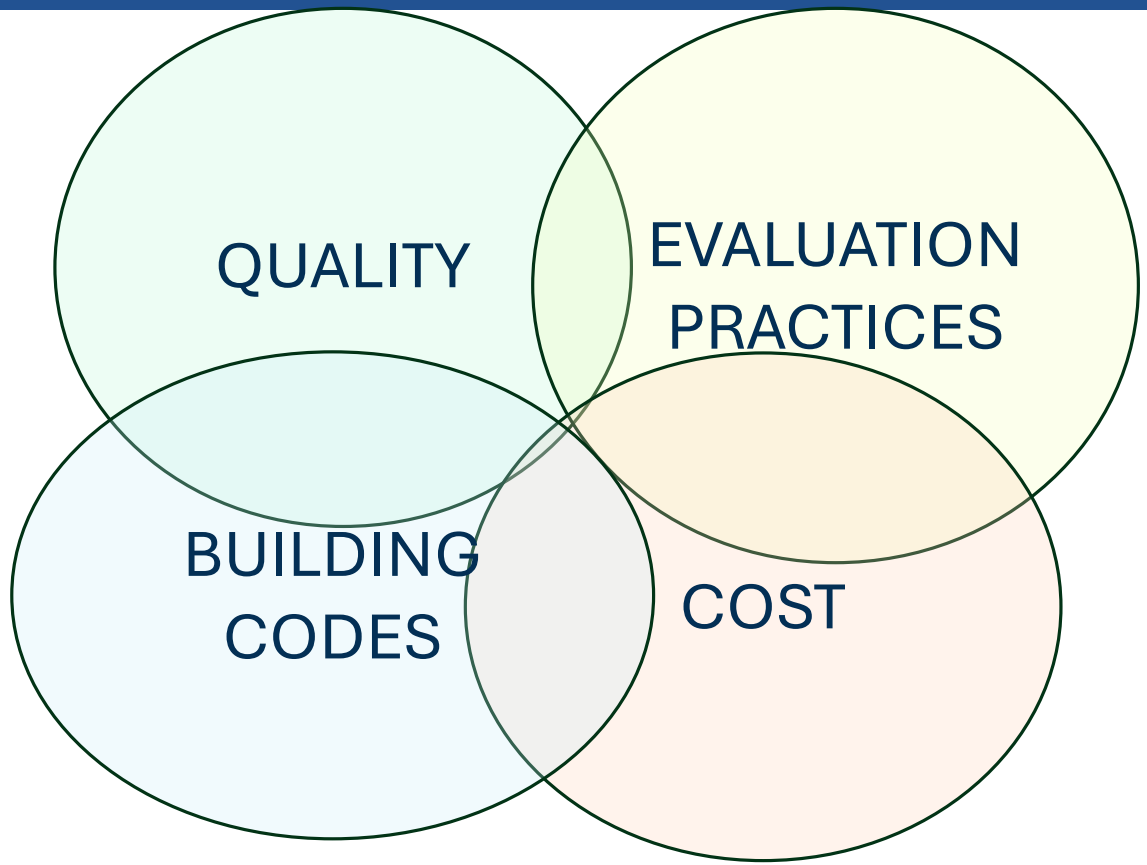
Design

Code Enforcement

Construction

Special Inspection

Records Retention Policies



Maintenance

Joint Ownership Properties

Recertification for Occupancy

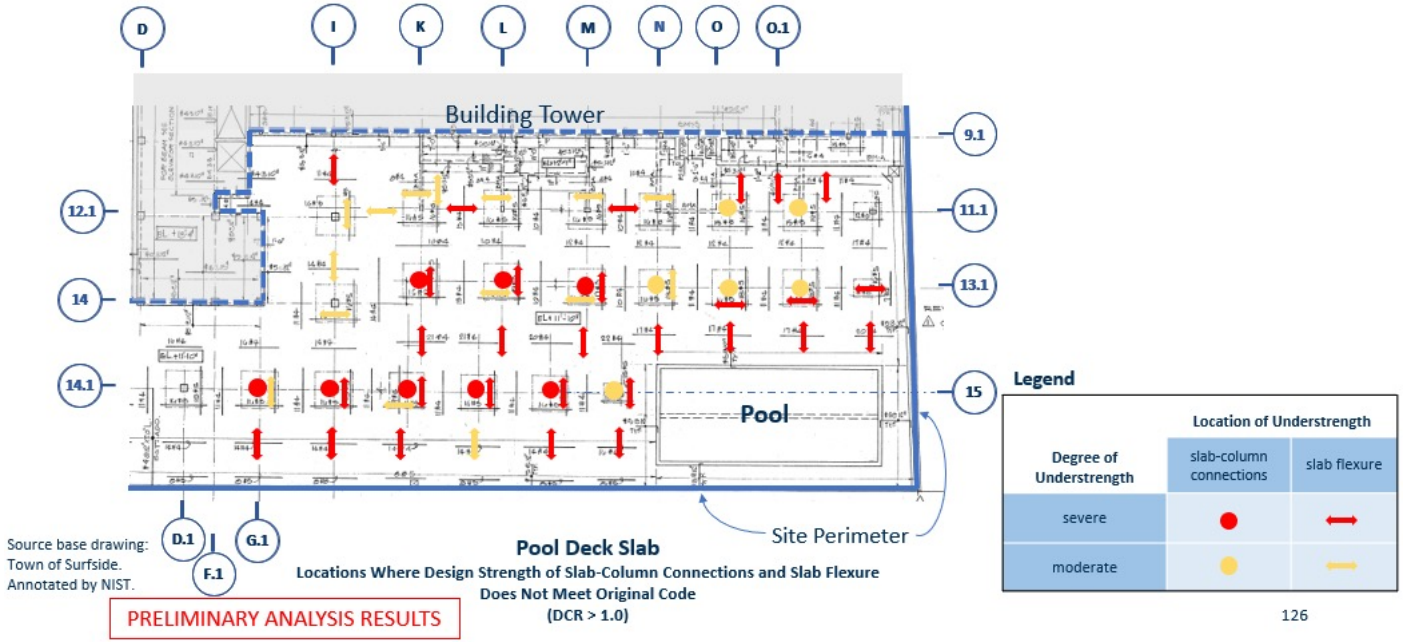
Structural Health Monitoring

Evacuation

Emergency Response

THERE WILL BE A LOT TO TALK ABOUT!

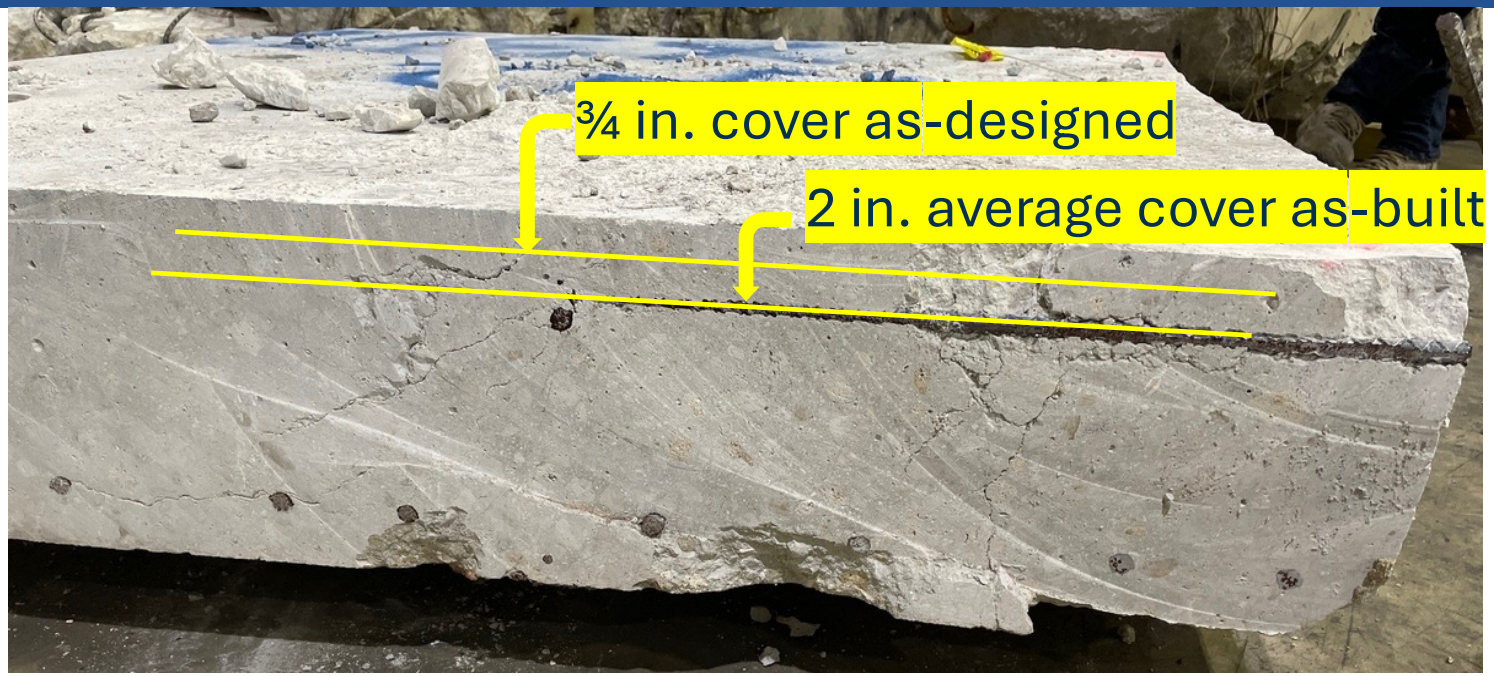
Quality Control/Assurance in Design



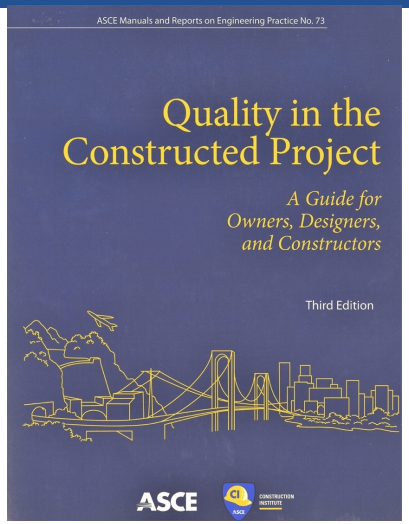
Building codes change over time, but our review showed significant deficiencies under both the codes in effect at original design and those of today.

- Quality control starts with the design engineer and the engineer of record.
- Quality assurance is external, and can be provided by peer reviews, governmental agencies, or other.

Quality Control/Assurance in Construction



Source: NIST

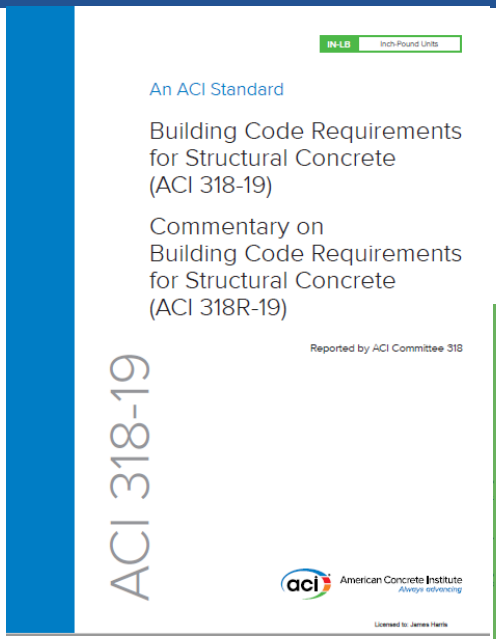


Source: ASCE

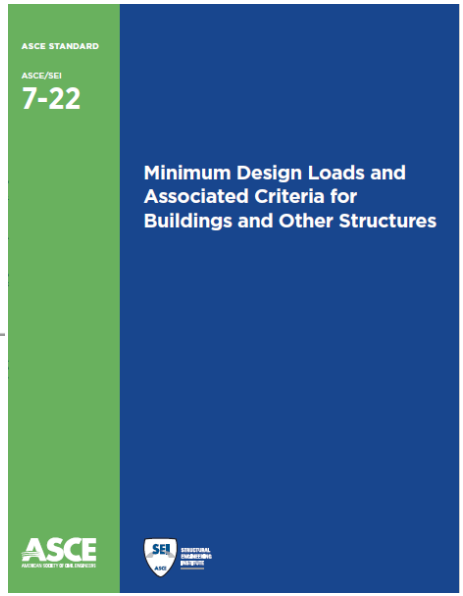
Quality control starts with the installer and proceeds through foreman and superintendent. Quality assurance is external, and it is often provided by code-mandated special inspectors.

Design Codes

- There have been many changes in structural design codes over the years since CTS was built.
  - Minimum flexural reinforcement over columns in flat slabs
  - Reinforcement for structural integrity
  - Concrete properties and cover for high chloride exposure
  - Detailing of beam-column joints
  - Higher design wind speeds for hurricanes
- The effect of those changes is being considered, and will deserve more discussion, as well as the need for additional changes



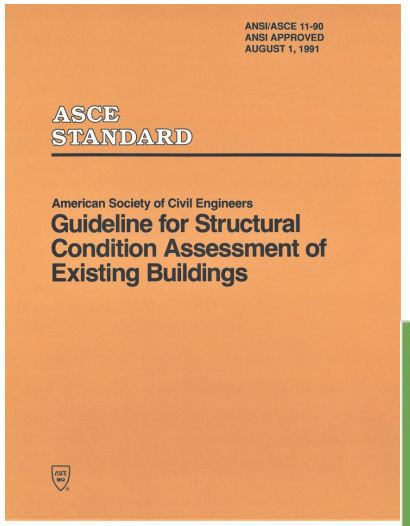
Source: ACI

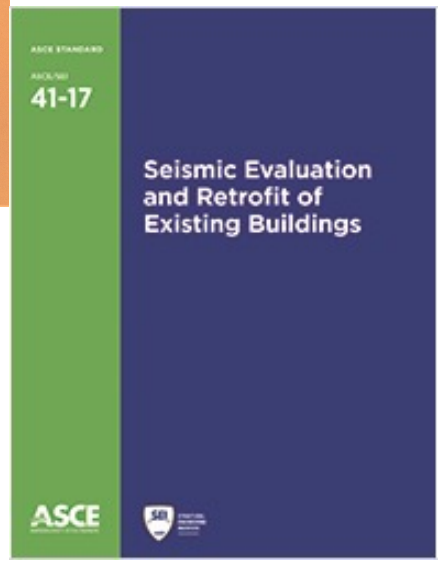


Source: ASCE

Evaluation Requirements and Guides

- Miami-Dade's ordinance requiring recertification once a building reached 40 years of age began in 1975
- State of Florida implement a new law following the collapse of CTS beginning the recertification at age 30 years
- Both are focused on degradation
- *Is this enough?*



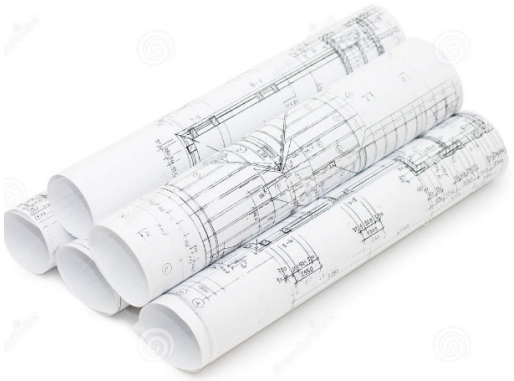


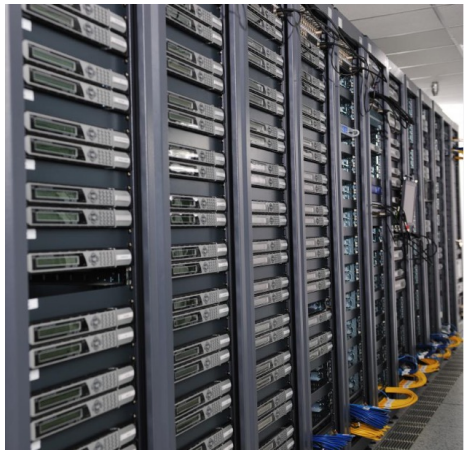
Source: ASCE

Manual for Bridge Evaluation (AASHTO)

Records Retention

- One key aspect of controlling the cost of evaluation is the retention of records from the original design and construction, any peer review, and prior evaluations.
- As we transition from paper to digital records, this process needs to be carefully vetted.





07

Closing Comments, Impact of the Investigation

NIST's Investigation of the Champlain Towers South Partial Collapse

NIST CTS Information

https://www.nist.gov/champlain

Public Meeting Videos

https://www.nist.gov/disaster-failure-studies/champlain-towers-south-collapse-ncst-investigation/public-meeting-videos

NIST DFS Portal

https://www.nist.gov/disaster-failure-studies/data-submission-portal