



SOLUTIONS FOR THE BUILT WORLD

Champlain Towers South

University of
Minnesota

2023 Structural
Engineering Seminar
Series

February 21, 2023

Matthew Fadden, PhD, PE

Gary Klein, PE, SE



www.wje.com

WJE ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

Wiss, Janney, Elstner Associates, Inc.

WJE Collapse Investigation

Presentation Outline

- WJE Project Team
- Investigation Objectives & Approach
- Findings & Observations
 - Document Review
 - Site Observations
 - Laboratory Testing
 - Structural Analysis
 - Theory of Collapse
- Summary

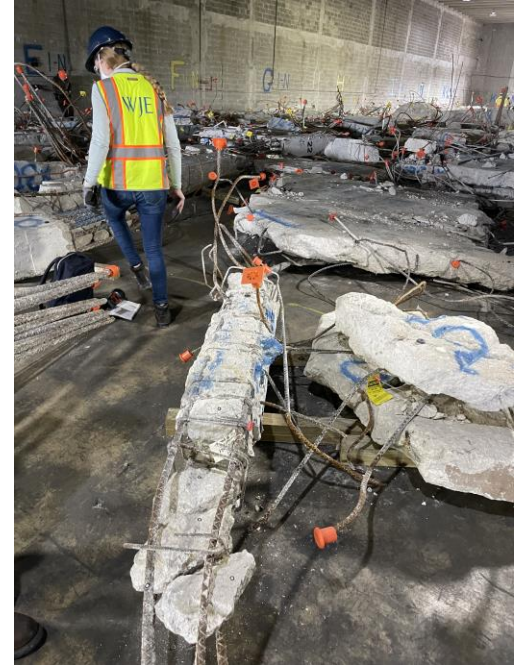


WJE

WJE Project Team



WJE@Work



WJE Project Team

- **Project Managers:** Matthew Fadden and Gary Klein (NB)
- **South Florida:** Alejandra Corona, Crisol Ortiz, Sedona Iodice, Brent Chancellor, Brian Calderone, Zack Sumislaski, Dirk Heidbrink
- **Document Review:** Audrey Ryan (LON), Elie Hantouche (CHI), Robert Kraus (SF)
- **Modeling:** Jeff Rautenberg (MIN), Tanner Swenson (MIN)
- **Geotech:** Swapna Danda (WDC), Rich Finno (Affiliated Consultant)
- **Site Visits/Observations:** Tarka Wilcox (DEN), Prateek Shah (SF), Daria VanAllman (WDC), Anna Quinn (HOU), Emmett Horton (WDC), Heba Elsayed (ATL), Brian Hill (ATL), Ryan Sitar (LA), Doug Stevie (NYC)

WJE

Investigation Objectives & Approach



Investigation Objectives

1. Conduct an investigation that is sufficiently thorough to provide a credible independent opinion as to the cause of the collapse
2. Based on the investigation findings, provide expert services in defense of lawsuits against the condominium association (or pursuit of lawsuits against others)



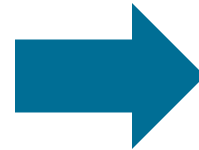
Investigation Approach

Document Review

Site Investigation

Laboratory Studies

Structural Analyses



Root Cause

Findings & Observations

Document Review

What we knew June 24, 2021 – Surfside, FL

75 95 Andytown 638 Bonnet House



Hammocks Kendall Pinecrest

- A building had partially collapsed at ~1:30 am
- 100+ people were feared missing or dead
 - 98 bodies were ultimately recovered
- Cause was unclear
- Investigation via social media/news/photos/videos

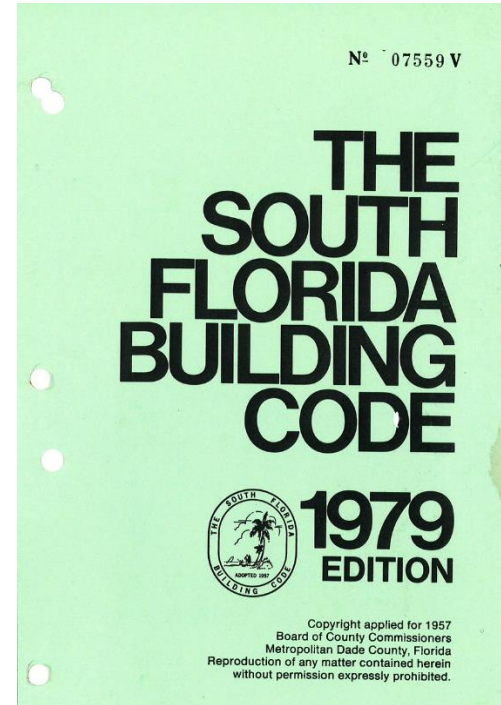
Building Description

- 12 story L-shaped structure with 136 units built in 1981
- Reinforced concrete flat plate construction
- Parking on lobby level and basement garage
- Pool deck terrace on the south side of the buildings



Codes and Design Standards (1981)

- South Florida Building Code 1979
- ACI 318-77: Building Code Requirements for Reinforced Concrete

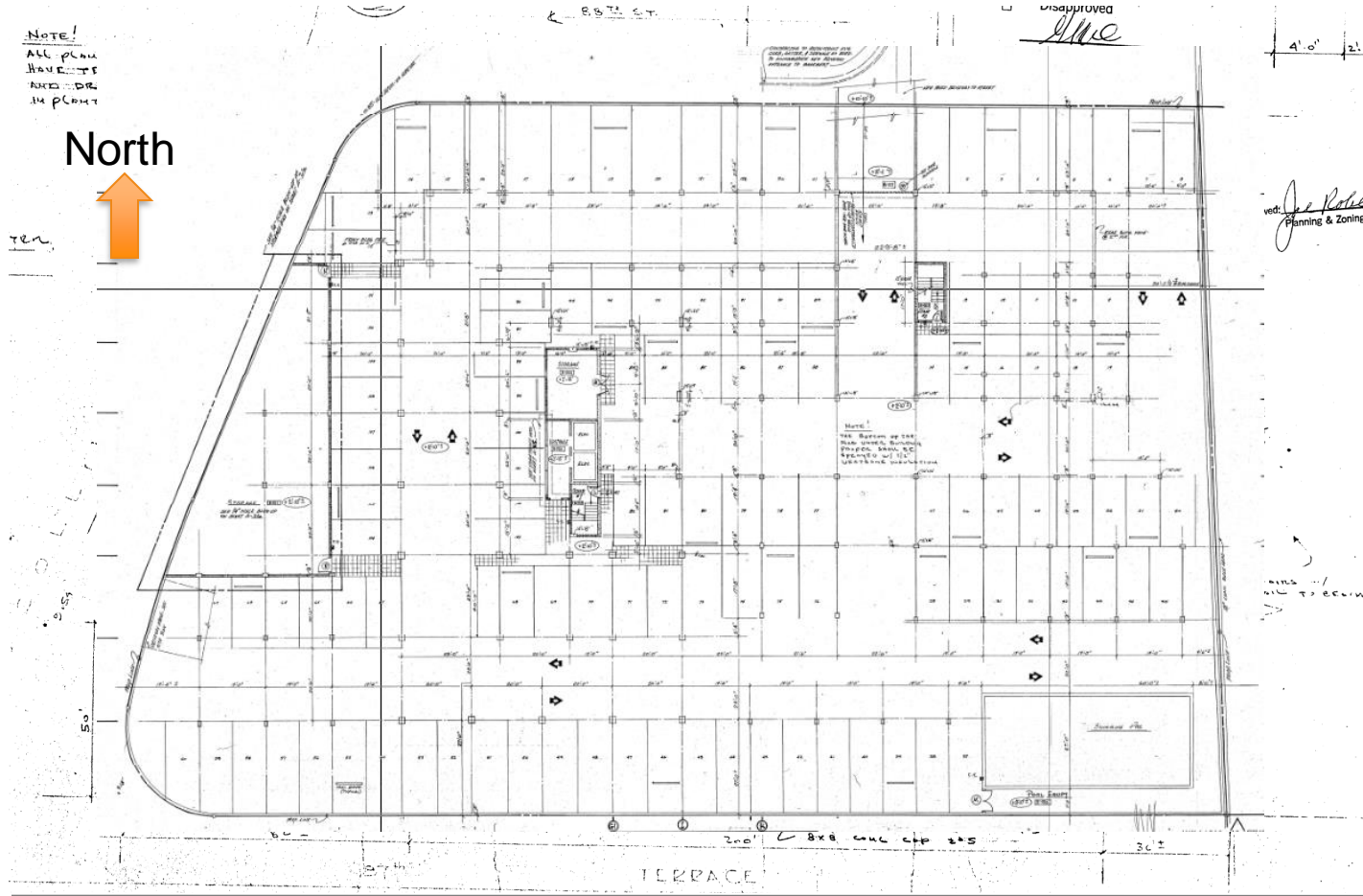


NOTE!
ALL PLANS
HAVE BEEN
REVISED
IN PLAN

North



ten.



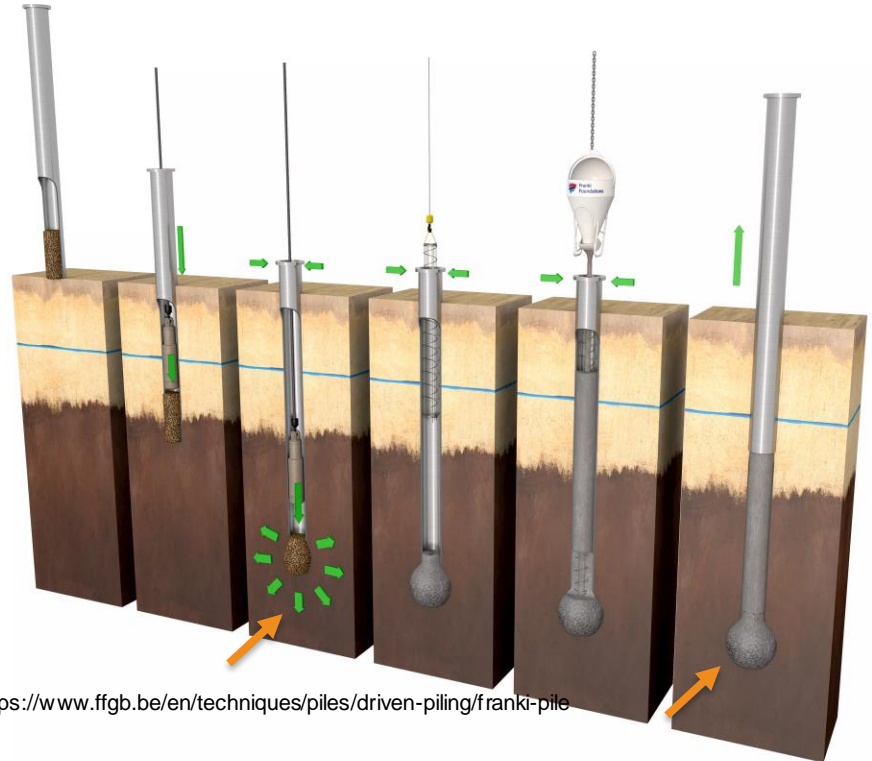
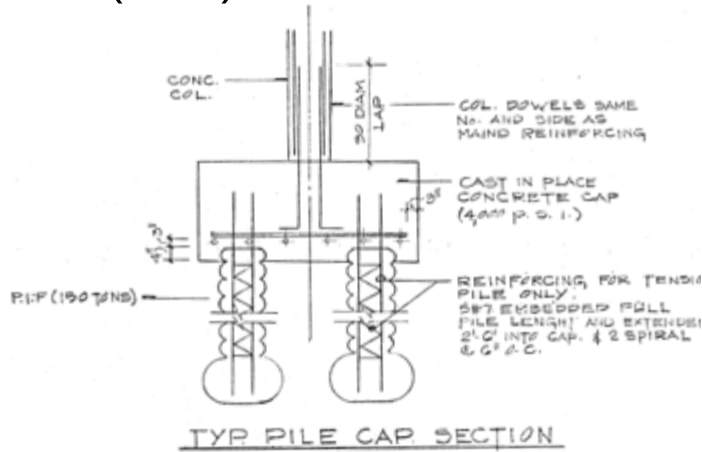
ved. Joe Rohr
Planning & Zoning

Architect
William M. Friedman
& Associates
Architects Inc.

**Structural
Engineer**
Breiterman Jurado &
Associates

Foundations

- 150-ton Franki piles, a.k.a. pressure-injected footings (PIFS)



<https://www.ffgb.be/en/techniques/piles/driven-piling/franki-pile>

1996 Retrofit Pool Deck & Garage

Western Waterproofing performed:

- Planter waterproofing
- Paver installation
- Concrete structural repairs

WESTERN
WATERPROOFING COMPANY OF AMERICA
CONTRACTORS • A MISSOURI CORPORATION

1941 WEST COPANS ROAD • POMPANO BEACH, FLORIDA 33064
BROWARD: (305) 974-4677 DADE: (305) 944-8291 FAX: (305) 974-5126

March 22, 1996

Thomas Conway
Building Manager
Town of Surfside
9293 Harding Avenue
Surfside, FL 33154


Dear Mr. Conway,

Western Waterproofing Co. will be starting a project at Champlain Towers South located at 8777 Collins Avenue, Surfside FL. Included in the scope of work will be concrete structural repair in the parking garage. This type of repair entails removing loose concrete overhead, treating steel rebar with rust inhibitive coating and patching back with repair mortar. Also included in the garage will be urethane foam injection in ceiling cracks (approximately 500 lineal ft.).

The condo has retained the services of Tong Le Engineering Inc. Consulting Engineers. 5100 West Copans Road, Margate, FL 33063 to do the inspections and supervise the project.

Please feel free to contact me with any questions.

Sincerely,


Rob Sommer
Sales Manager



A MEMBER OF THE WESTERN GROUP • 1637 N. WARSON RD. • P.O. BOX 32407 • ST. LOUIS, MO 63132 • (314) 427-8733

Continued Repairs 2001-2017

- 2010-2011: Carousel Development and Restoration (CDR) – Concrete repairs
- 2012: Property Manager – Ongoing leakage through the pool deck
- 2013-2014: Scott Vaughn PE/Infinite Aqua – Repairs to the pool, garage ceiling, and planters
- 2017: G. Batista – Specifications and details for planter waterproofing repair

2018 Morabito Report Summary

- Abundant cracking and spalling in garage with calcium carbonate leaching
- Timely repair recommended following ICRI recommendations
- Previous repairs failing due to poor workmanship
- Recommend entrance/pool decks slabs showing distress be removed in their entirety and replaced



Figure J1: Typical cracking and spalling at parking garage columns



Figure J2: Spalling with exposed steel reinforcement at topside of garage deck.

Morabito Investigation – Deck Finish



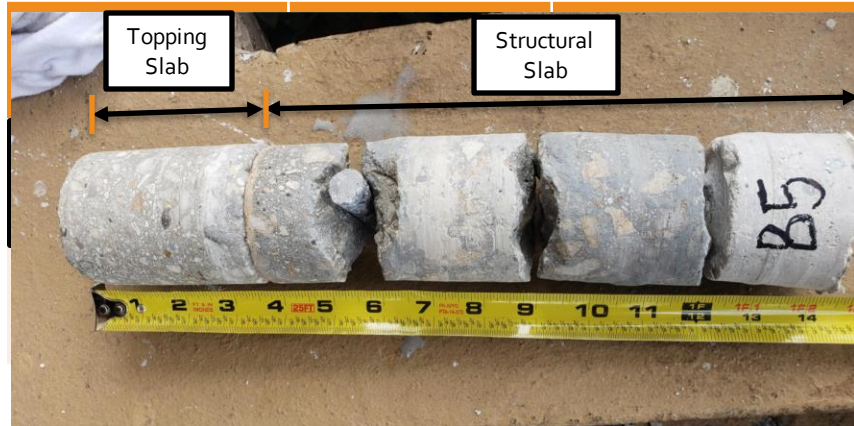
is

(TYP.)

Deck finish
designed

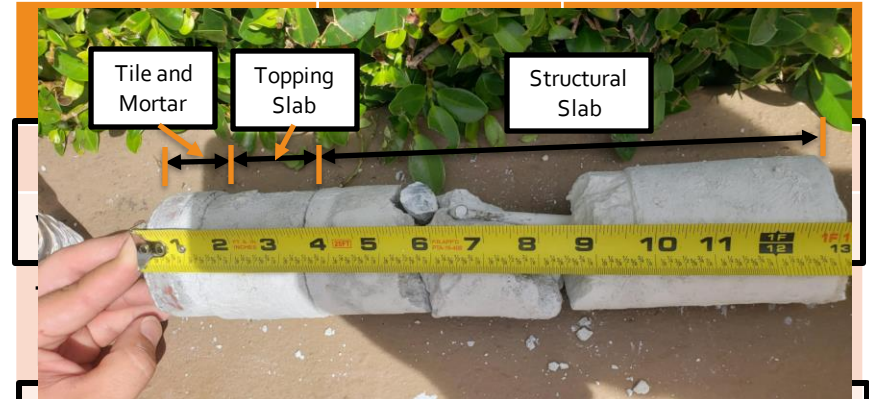
Morabito Investigation – Concrete Core Samples

Parking Deck



NOT included in the original structural drawings

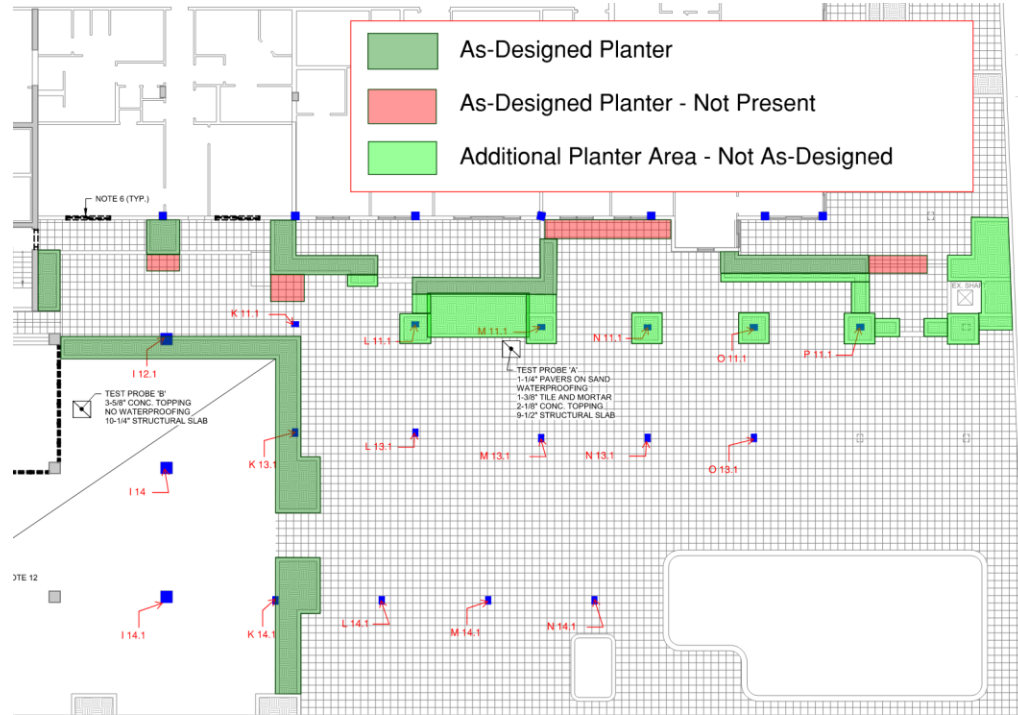
Pool Deck



Concrete	2.1	<i>Varies, not shown in plan</i>
Topping		
Structural Slab	9.5	9.5

*submittal not available, assumed to be as specified

Morabito Investigation - Planters



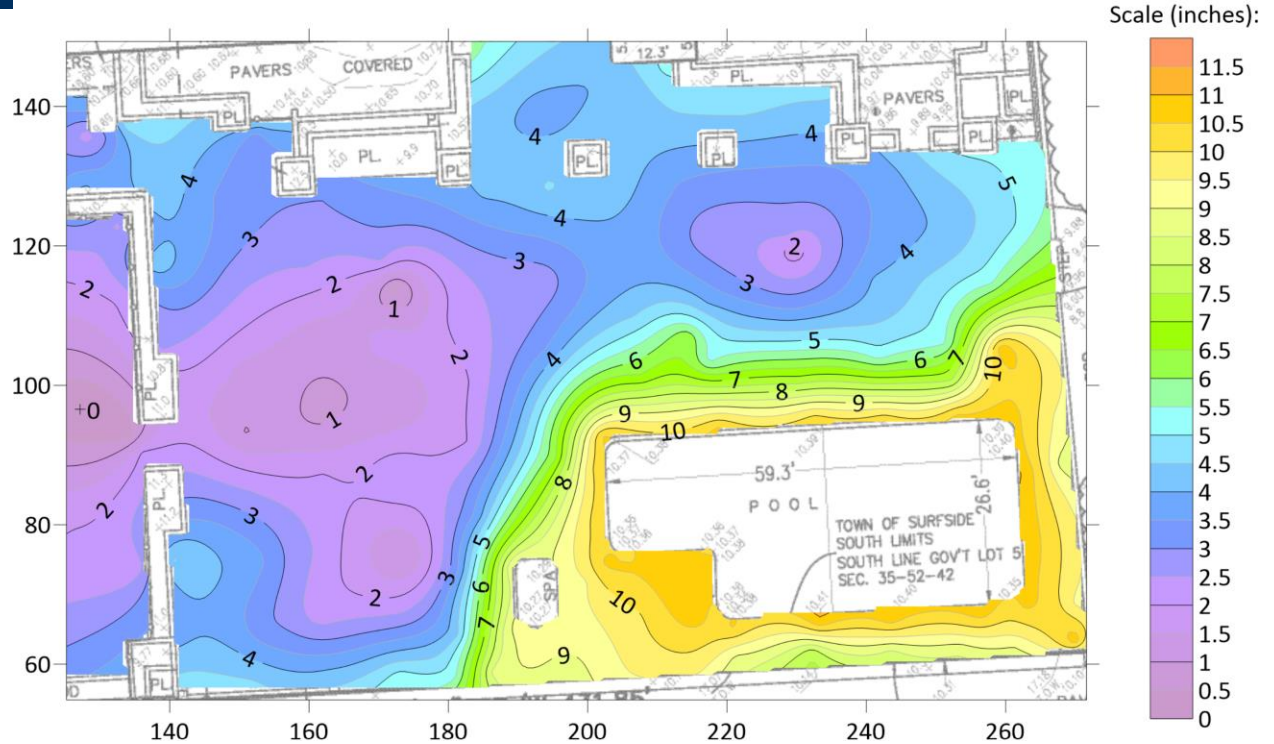
Morabito Calculations

- Morabito analyzed the slab along column line T and the punching shear results were exceeded in every calculation iteration.

2.11.2. Punching Shear Results

Support	V_u kip	v_u psi	M_{unb} k-ft	Comb	Patt	γ_v	v_u psi	ΦV_c psi	
1	80.05	31.9	195.51	U1	All	0.117	343.7	101.5	*EXCEEDED
2	202.56	236.6	10.47	U1	All	0.415	244.8	189.7	*EXCEEDED
3	133.15	183.2	-39.19	U1	All	0.422	217.6	189.7	*EXCEEDED
4	164.83	192.5	12.83	U1	All	0.375	200.5	189.7	*EXCEEDED
5	176.45	206.1	-18.39	U1	All	0.415	217.8	189.7	*EXCEEDED
6	133.61	183.9	6.98	U1	All	0.422	190.0	189.7	*EXCEEDED
7	156.94	216.0	6.70	U1	All	0.422	221.8	189.7	*EXCEEDED
8	146.79	171.5	-25.71	U1	All	0.375	191.2	189.7	*EXCEEDED
9	178.11	180.7	16.77	U1	All	0.380	190.3	189.7	*EXCEEDED
10	77.04	30.7	-172.04	U1	All	0.117	299.8	101.5	*EXCEEDED

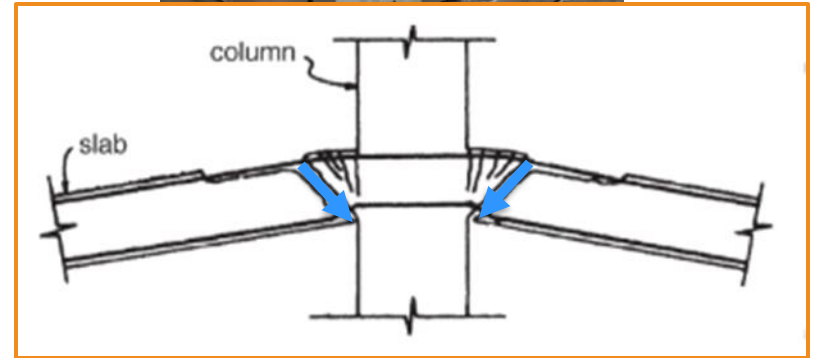
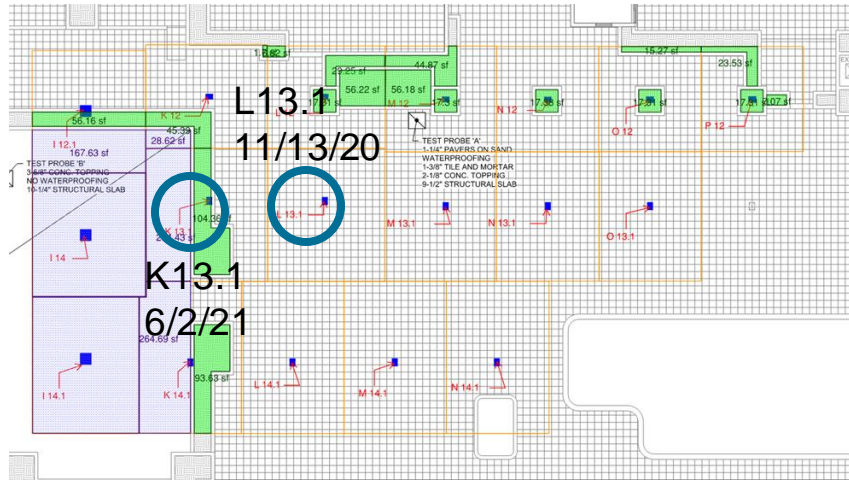
2020 Boundary Survey - Pool Deck



Garage Walkthrough Video



L13.1 Slab/Column Distress – Nov. 13, 2020



K13.1 Slab/Planter Distress - June 2, 2021





Apt 711
Rosie / Ring Video

Apt 611
Ileana Montegudo

Bedroom locations overlooking pool deck

Apt 111
Gabe Nir

Apt 412
Cassie

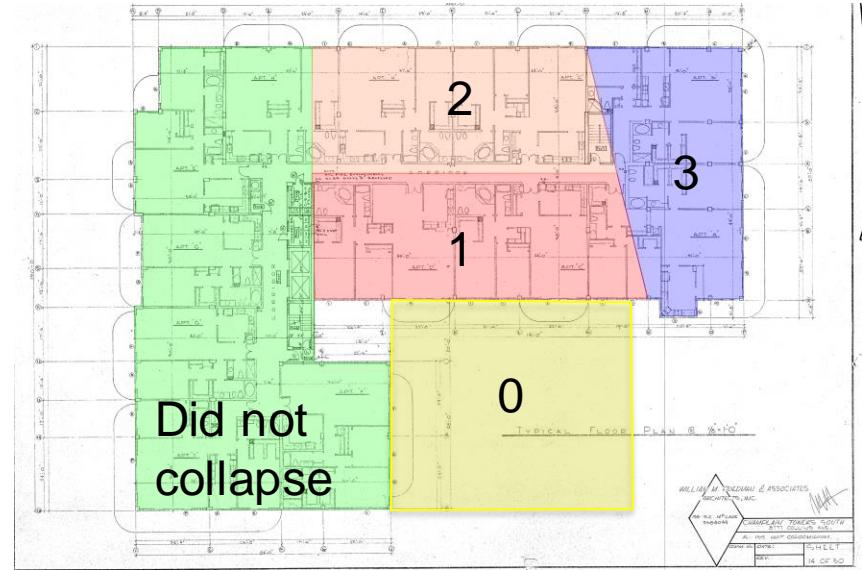
Event Timeline - June 24, 2021

Time	Description	
~12:30 AM	Resident (Unit 111) hearing "construction" noise from garage	
1:10 AM	Security Guard and Resident (Unit 111) heard loud crash, felt rumbling, saw white dust in the air	Pool Deck Collapse
1:15 AM	Security Guard and Resident (Unit 111) heard very loud collapse, felt rumbling and the building sway, saw parking deck had collapsed and more dust	
	Guests at Bluegreen Resort (north of CTS) heard loud crash, felt rush of air from garage	
1:18 AM	TikTok video shows large chunks of concrete debris on the floor of the garage. Debris is located approximately where terrace is attached to south side of the building (approx. Unit 111)	
	Unit 611 notices cracks in her wall and cannot open door. Escapes via west stairs.	
1:20 AM	Unit 412 felt the building shaking, saw the pool deck had collapsed	
~1:22 AM	Three columns on the south face of the building appear to fail near their bases. Area 1 immediately collapses	Building Collapse
	Area 2 collapses immediately after Area 1 spreading some debris to the north	
	Area 3 to the east stands briefly and collapses rotating at the base	

1:22 AM - 8701 Collins Ave Video



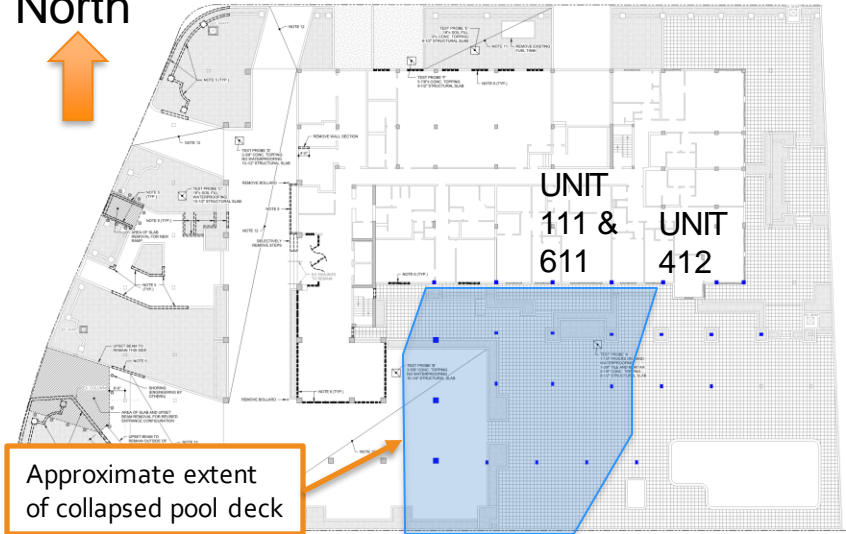
~1:22 am



Pool Deck Collapse

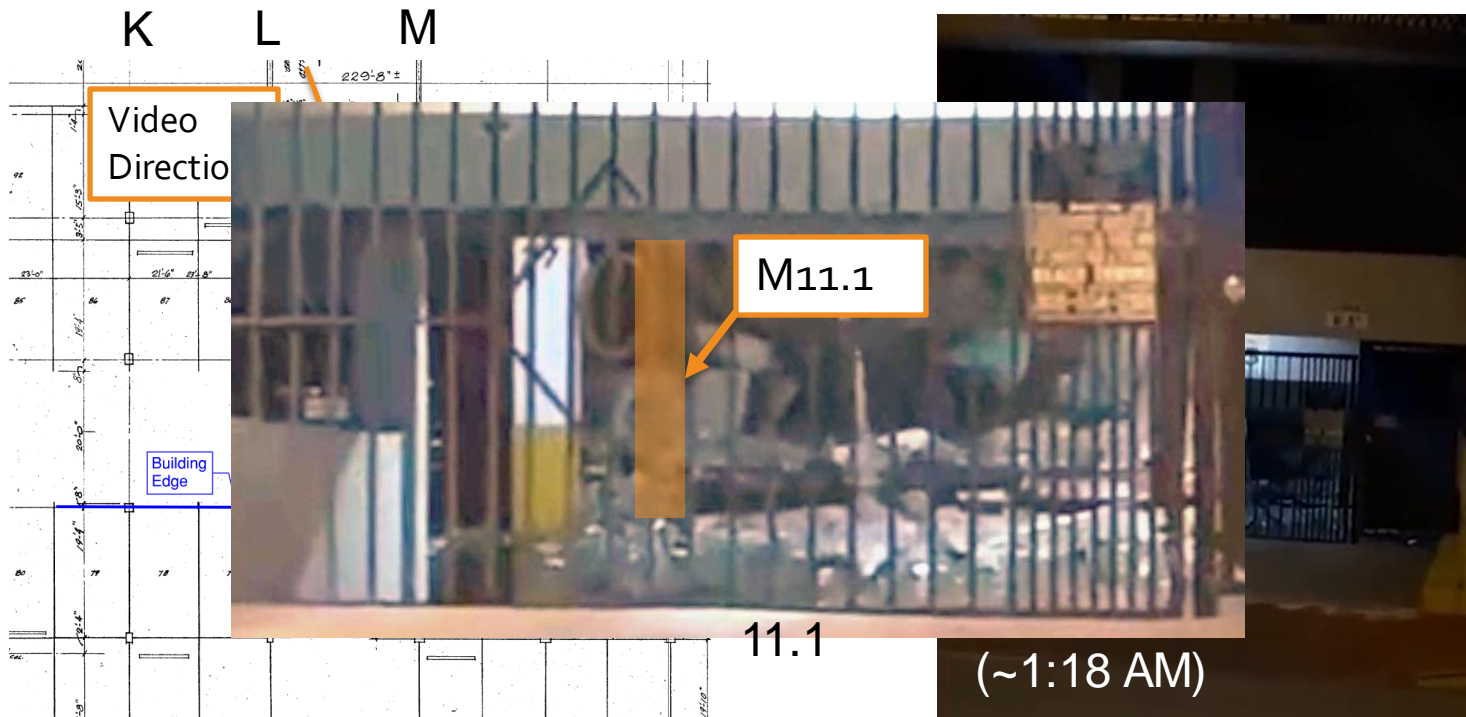


North



Approximate extent of collapsed pool deck

1:18 AM - TikTok Video



~1:15-1:22 AM - Unit 711 Ring Video



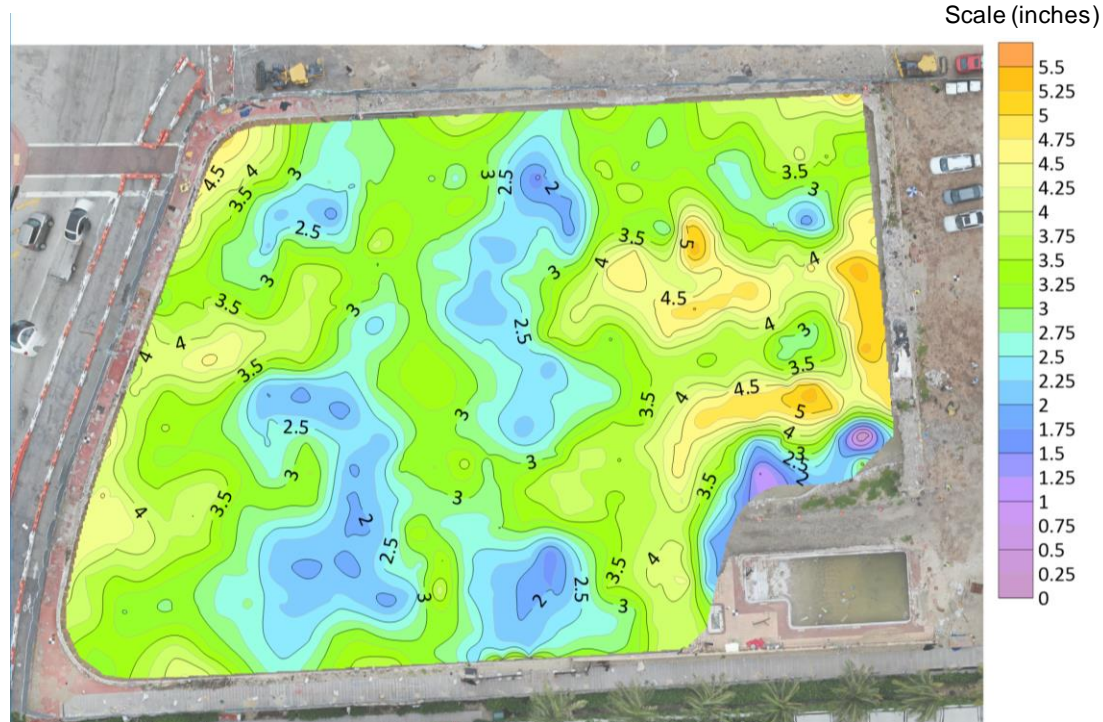
Findings & Observations

Site Investigation

Collapse Site – October 2021



Basement Slab Survey - Topography



Joint Testing Protocol

CHAMPLAIN TOWERS SOUTH COLLAPSE INVESTIGATION:

Joint Protocol for Testing and Material Sampling – Collapse Site

In accordance with the Court Order dated September 1, 2021, this document presents the protocol for testing and material sampling at the collapse site (the “Protocol”) and has been developed considering input from involved Participants.

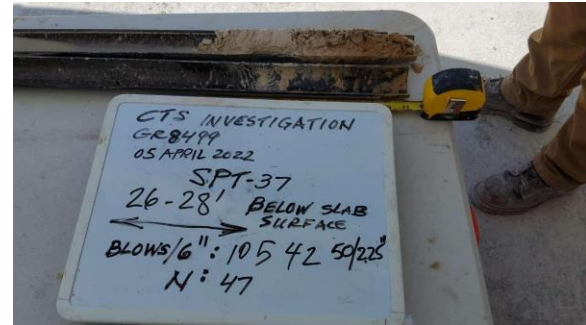
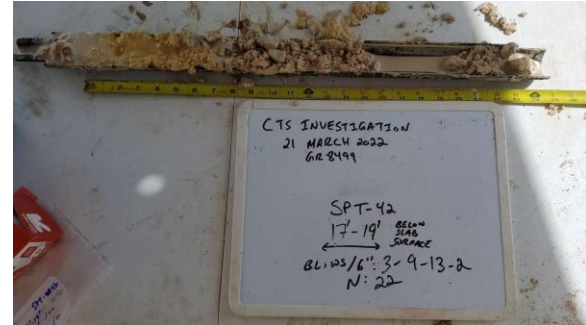
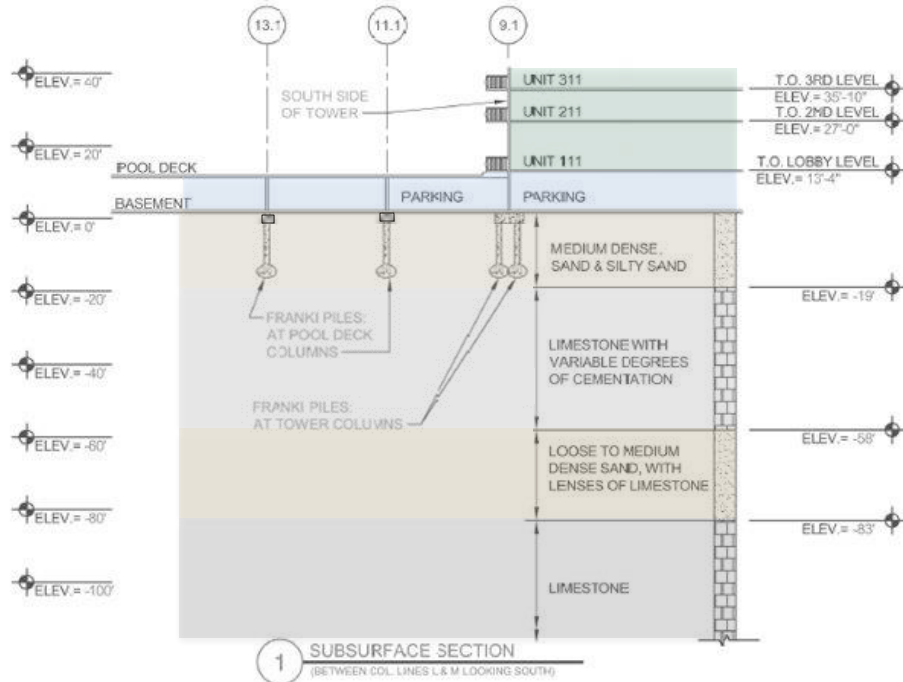
DEFINITIONS

- **Consultant** – Geosyntec Consultants, Inc., an independent consultant approved by the Receiver to coordinate, plan, oversee, and provide factual reporting as defined in this Protocol to the Experts/Participants. The Consultant will employ Testing Agencies and Contractors to meet the goals of the Protocol. Payment to Consultant for its fees and costs shall be paid by all Participants as defined in the "Payment of Costs" section below.
- **Contractor** – Company, or companies, approved by the Receiver to engage in providing construction, samples, borings, security, or other support for execution of the Protocol. The Contractors shall be engaged by the Consultant. Payment for services shall be remitted to Consultant for payment to Contractors. Payment for Contractors' services shall be paid by all Participants as defined in the "Payment of Costs" section below.
- **Court** – Circuit Court of the 11th Judicial Circuit in and for Miami-Dade County, Florida.
- **Expert** – Engineers (or other disciplines) investigating the collapse on behalf of Participants.
- **Litigation** -- *In Re: Champlain Towers South Collapse Litigation*, Case No. 2021-015089-CA-01, pending in the Eleventh Judicial Circuit Court in and for Miami-Dade County, Florida

Geotechnical Investigation



Estimated Subsurface Conditions



Column and Basement Slab Coring

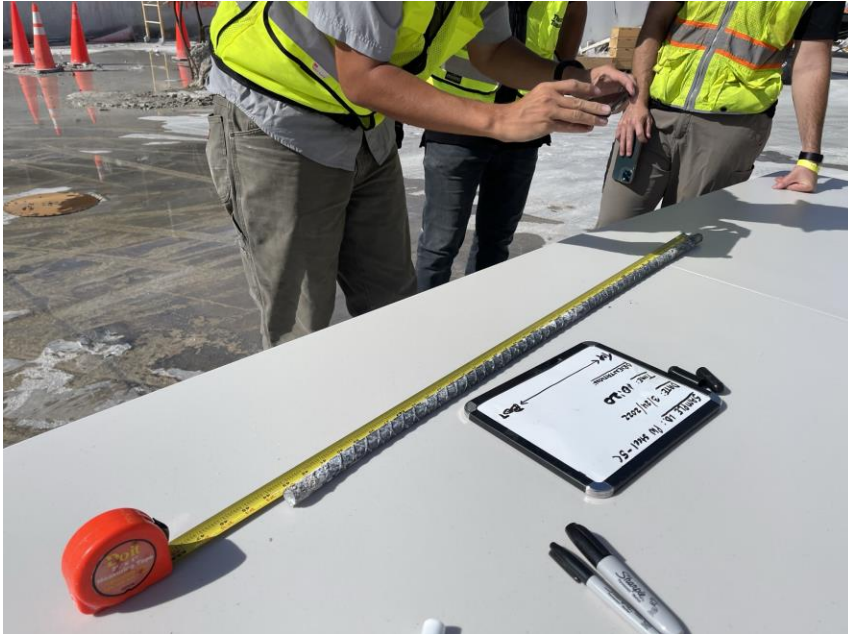


Concrete core collected from a column



Concrete core collected from the basement slab

Rebar and Waterproofing Sampling

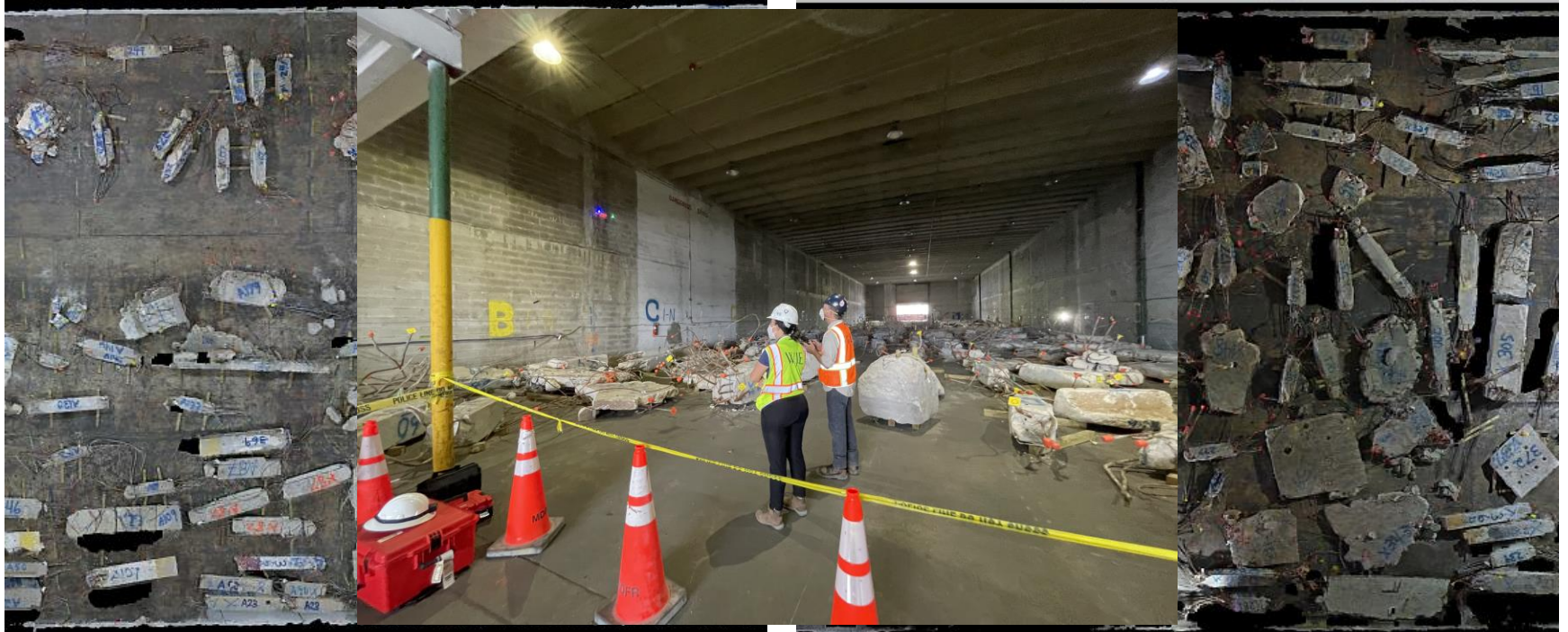


Steel sample collected from the south wall



Waterproofing testing at the pool deck

NIST/NCST - Primary Evidence Facility



Primary Evidence Facility – North Bay*

Item 14
Item 79
Item 352
Item 66-2
Item 48-2

Item 5
Item 6
Item 10
Item 13
Item 368
Item 344

* Items from Collapsed Portion



Item 217
Item 299
Item 65
Item 295
Item 364
Item 363

Item 333
Item 361
Item 362
Item 323
Item 312
Item 210
Item 323-2
Item 341



Primary Evidence Facility – South Bay

Majority of Items from
Collapsed Portion

Item 119
Item 128
Item 68
Item 999



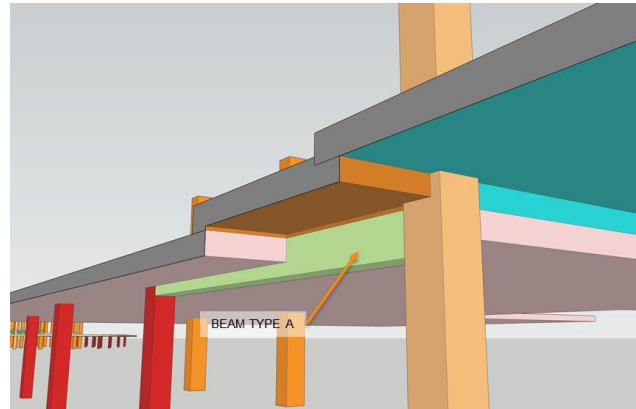
Majority of Items from
Imploded Portion



PEF – Item 344 "Punched Slab"



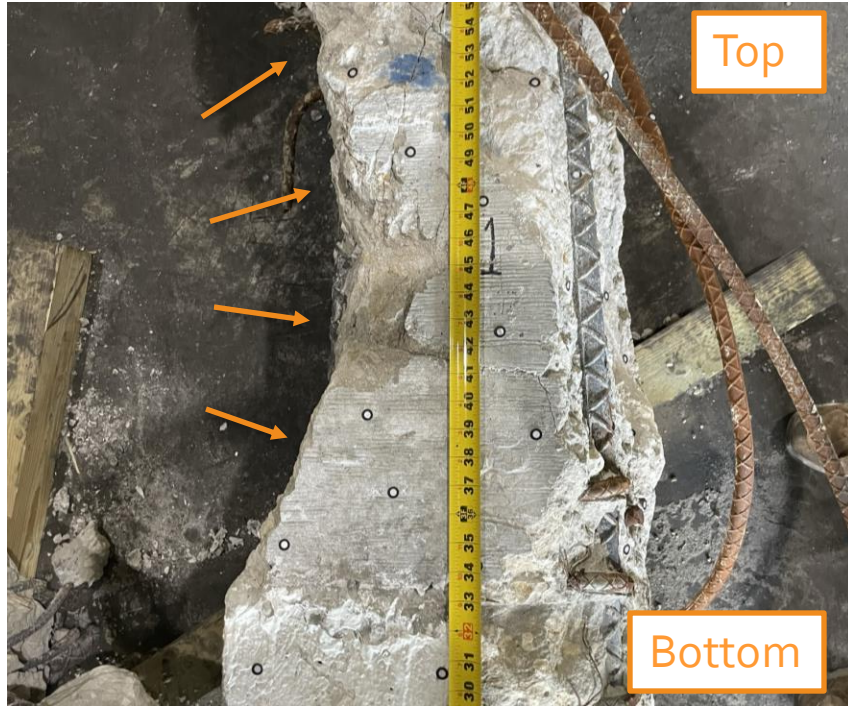
PEF – Item 299 "Beam A"



PEF— Item 323 "Beam A"



PEF – Item 341 - 16x16 Column



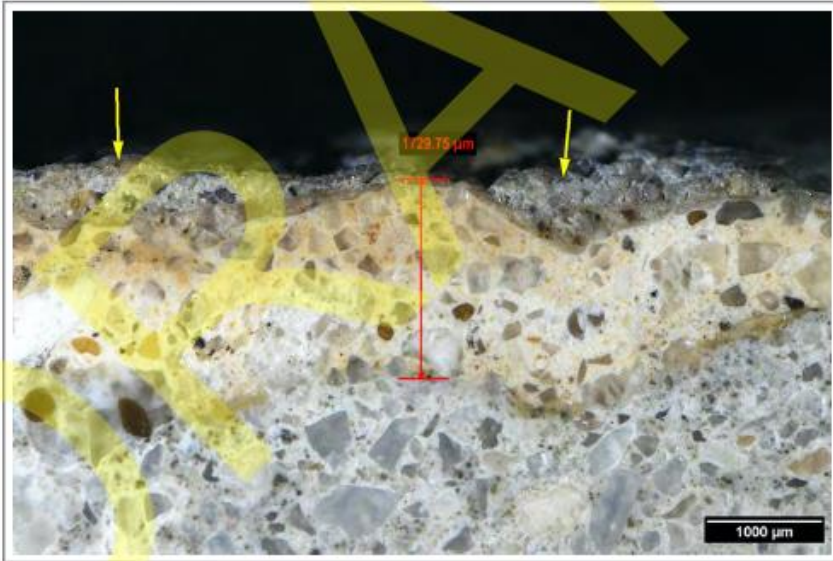
Findings & Observations

Laboratory Testing

Concrete Petrography and Testing

Basement Slab Samples

- Concrete typical to Florida
 - Moderate w/c ratio (0.35-0.45)
 - Well mixed
 - Non-air entrained
- Corrosion consistent with that at concrete placement
- Low chlorides and carbonation



Concrete Chlorides

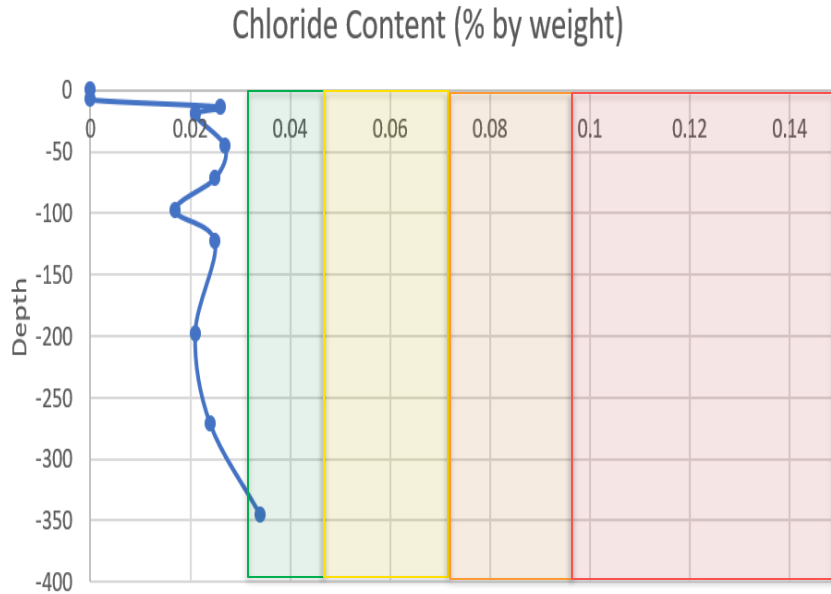
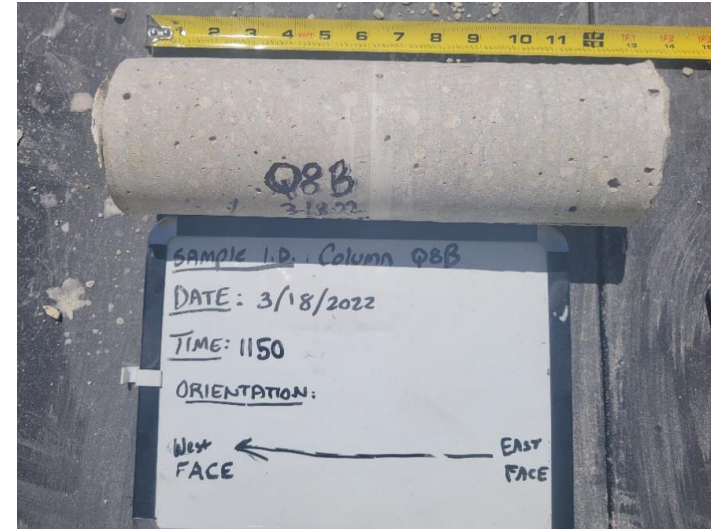


Table F1. ASTM C1218 Water Soluble Chloride Results for Core BS-3F

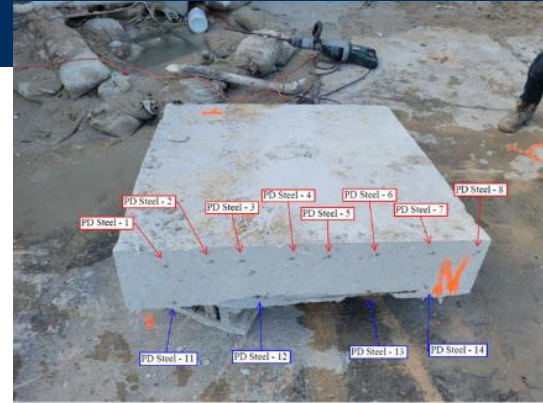
Core ID	Subsample ID	Depth	Chloride Content	
			weight percent (wt %)	parts per million (ppm)
(26YD13295) BS-3F	YD13295-1	0-3 mm	not detected	not detected
	YD13295-2	6-9 mm	not detected	not detected
	YD13295-3	12-15 mm	0.026	264
	YD13295-4	18-21 mm	0.021	212
	YD13295-5	44-47 mm	0.027	269
	YD13295-6	70-73 mm	0.025	247
	YD13295-7	96-99 mm	0.017	167
	YD13295-8	122-125 mm (depth of bar)	0.025	250
	YD13295-9	196-199 mm	0.021	213
	YD13295-10	270-273 mm	0.024	241
	YD13295-11	344-347 mm	0.034	340

Concrete Material Properties

Location	Average Compressive Strength (psi)	Min. Specified Compressive Strength (psi)
Transfer Girder	3560	4000
Column M15.1	3785	6000
Column Q8	5820	6000
Pool Deck	4475	4000
Perimeter Wall	4280	4000
Shear Wall East	6600	6000
Shear Wall West	8155	6000



Steel Reinforcement

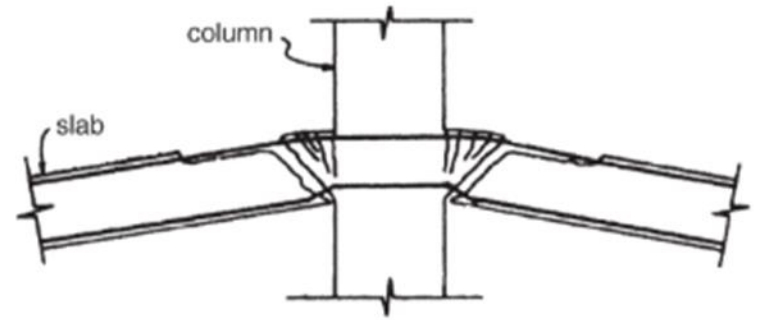
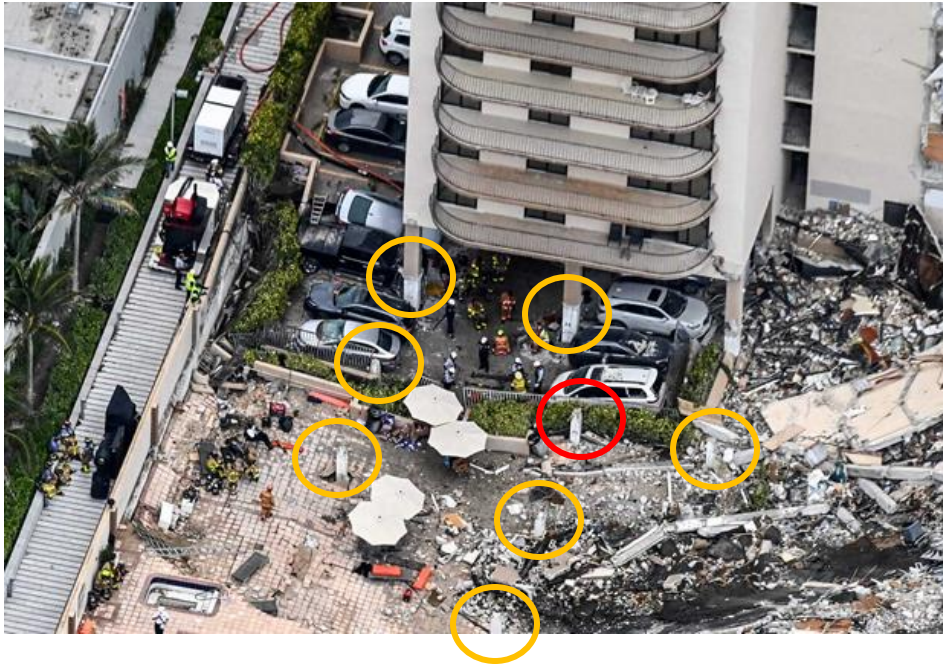


	Min. Specified (ASTM 615 Gr. 60)	Perimeter Wall (avg.)	Pool Deck (avg.)
Yield – F_y (psi)	60,000	69,948	77,012
Ultimate – F_u (psi)	90,000	106,814	110,300
Elongation (%)	7-9 depending on bar size	12.4	12.9

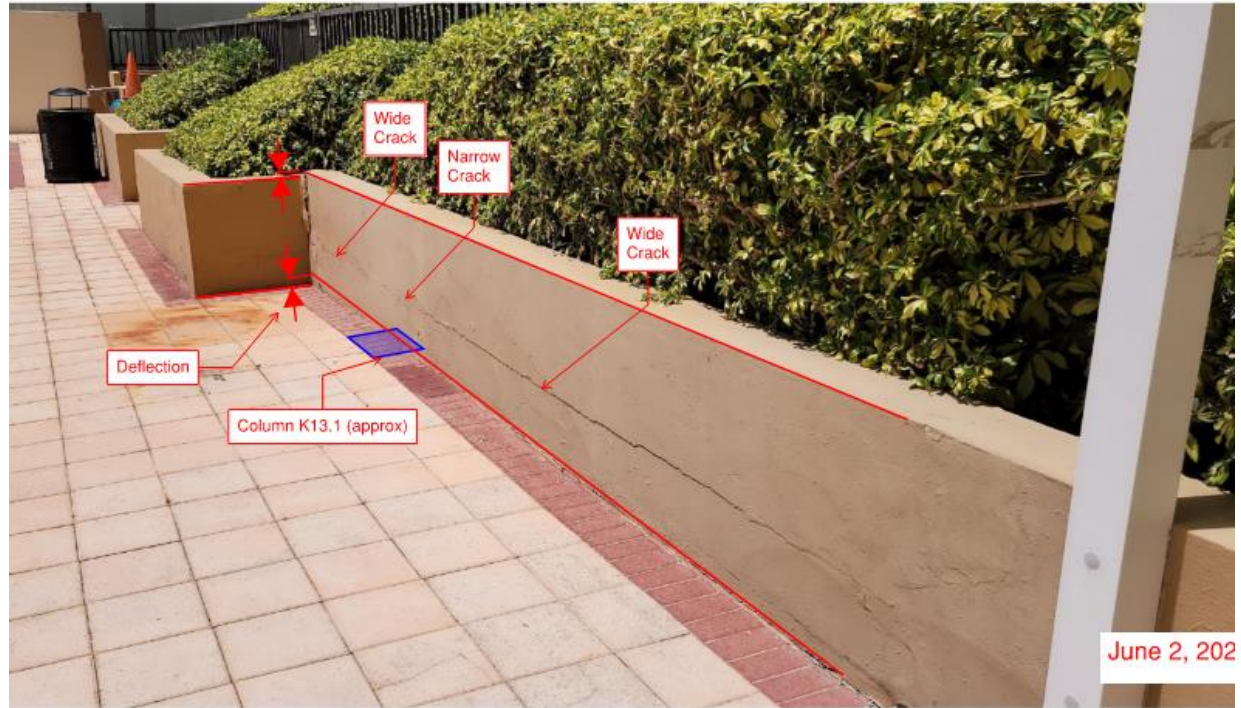
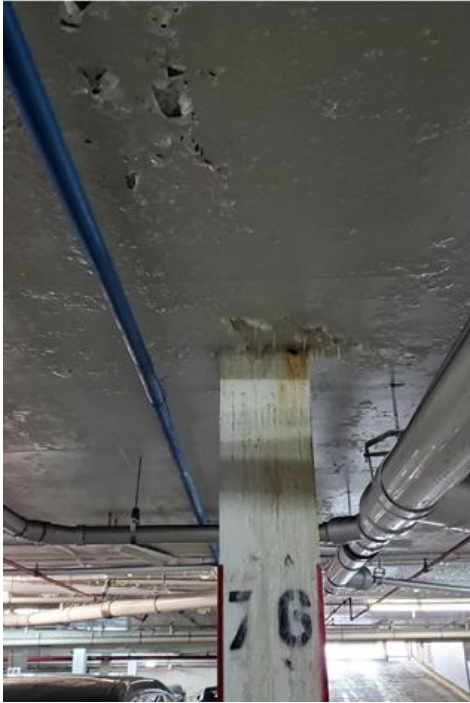
Findings & Observations

Structural Analysis

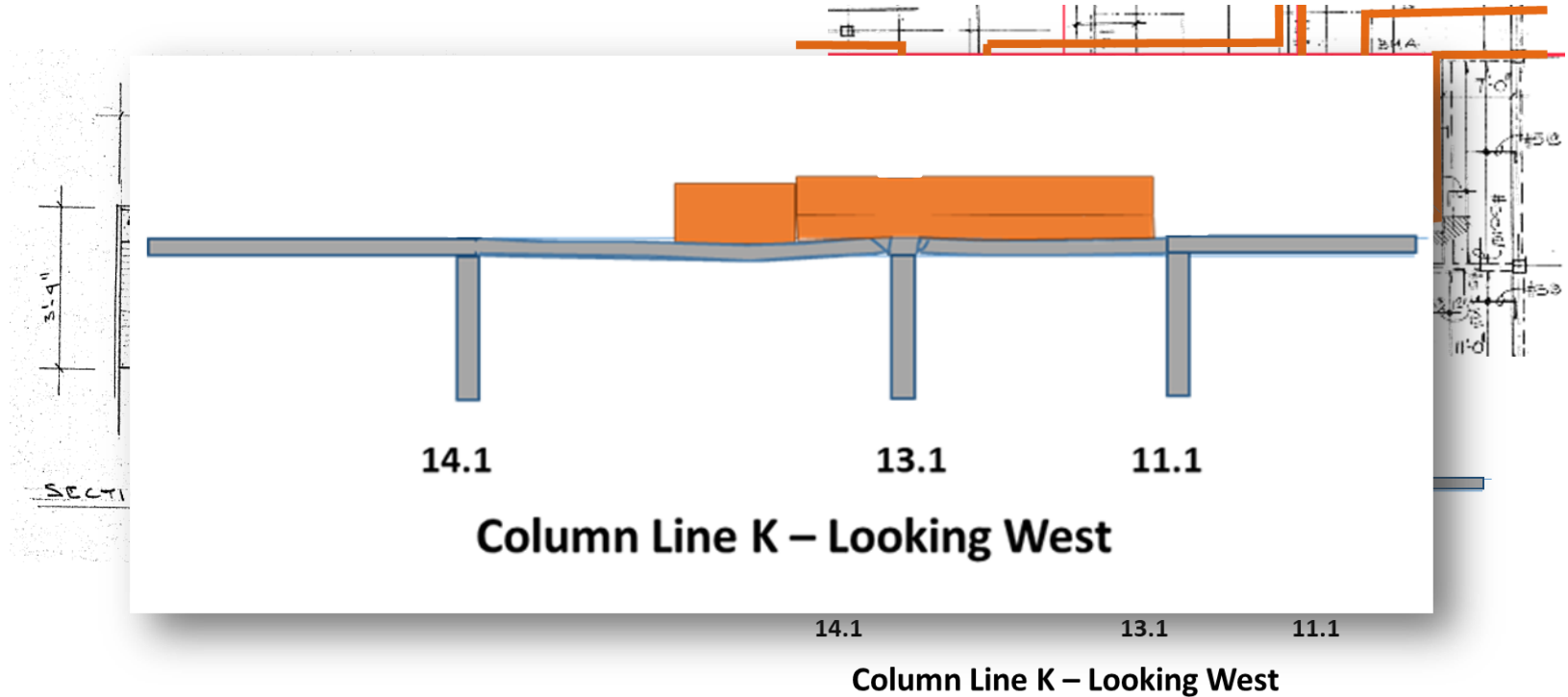
Punching Shear Failures



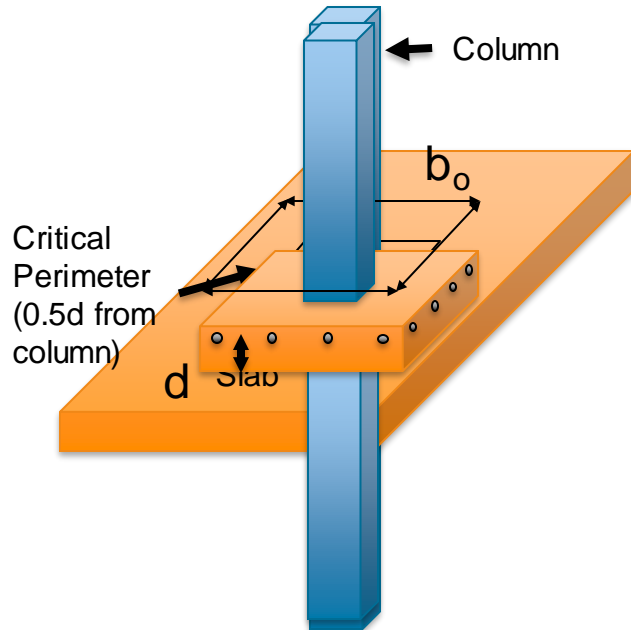
Pool Deck Slab Distress



K/13.1 Likely Slab Distress Mechanism

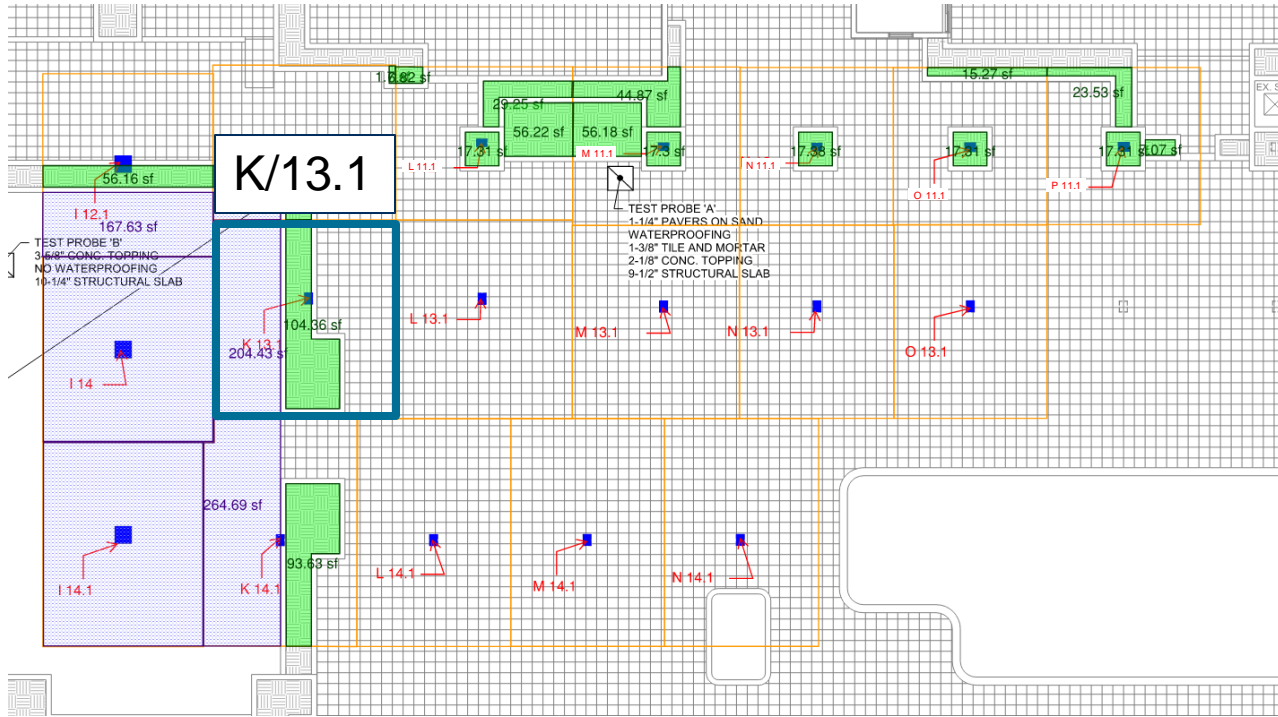


Punching Shear



- Punching Shear
 - Dependent on concrete strength (f'_c)
 - Effective depth (d) and critical perimeter (b_o)
 - $V_c = 4\sqrt{f'_c}b_o d$
- Current research shows that:
 - Dependent on amount of reinforcement and slab thickness
 - A coefficient of 4 may be unconservative for low reinforcement ratios

Pool Deck – At Collapse



Pool Deck Punching Shear (K 13.1)

As designed

Column Number	K 13.1
Size (in x in)	16x12
Nominal f'_c (psi)	4000
Clear Cover (in)	0.75
Factored Load (kip)	266
Reduced Nominal Capacity (kip)	155
Demand to Capacity Ratio	1.72

At collapse

Column Number	K 13.1
Size (in x in)	16x12
Estimated f'_c (psi)	5000
Clear Cover (in)	2.13
Estimated Load (D) (kip)	128
Nominal Capacity (kip)	113
Demand to Capacity Ratio	1.13

$$3\sqrt{f'_c}$$

Sustained Load Effects

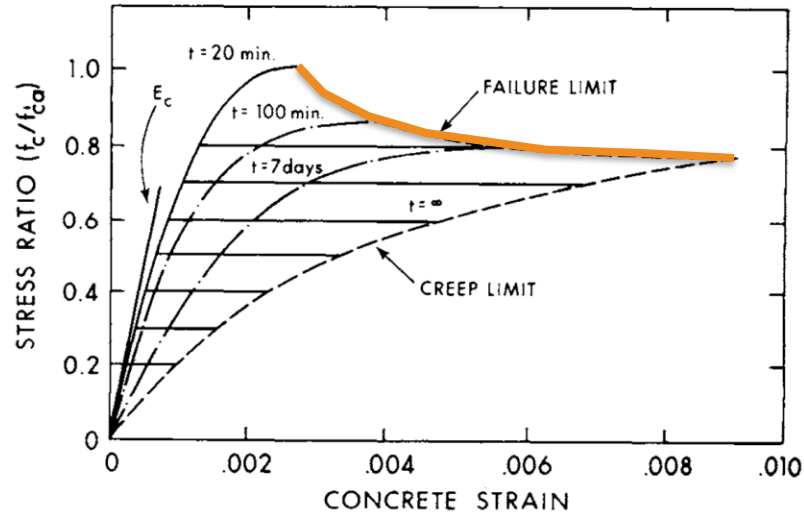
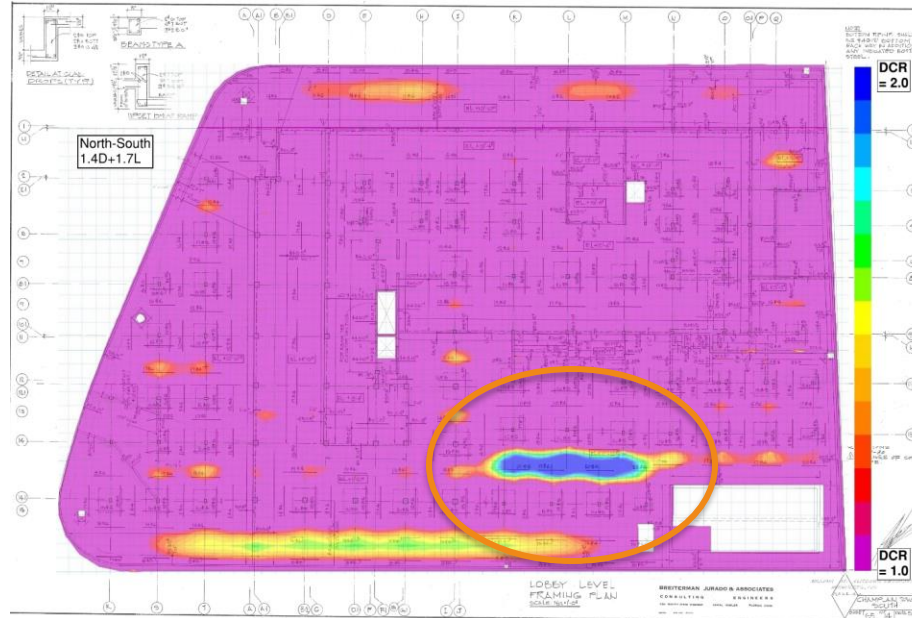


Fig. 2—Stress-strain curves for concrete loaded in compression in various periods (Rusch)

- Concrete weaker under sustained loads
- Typically ignored in design
- Different stresses (i.e., shear, comp.) may have different behavior

Lobby Level Slab – Finite Element Model

As-Designed Positive Bending, 1.4D+1.7L, $\Phi = 0.9$

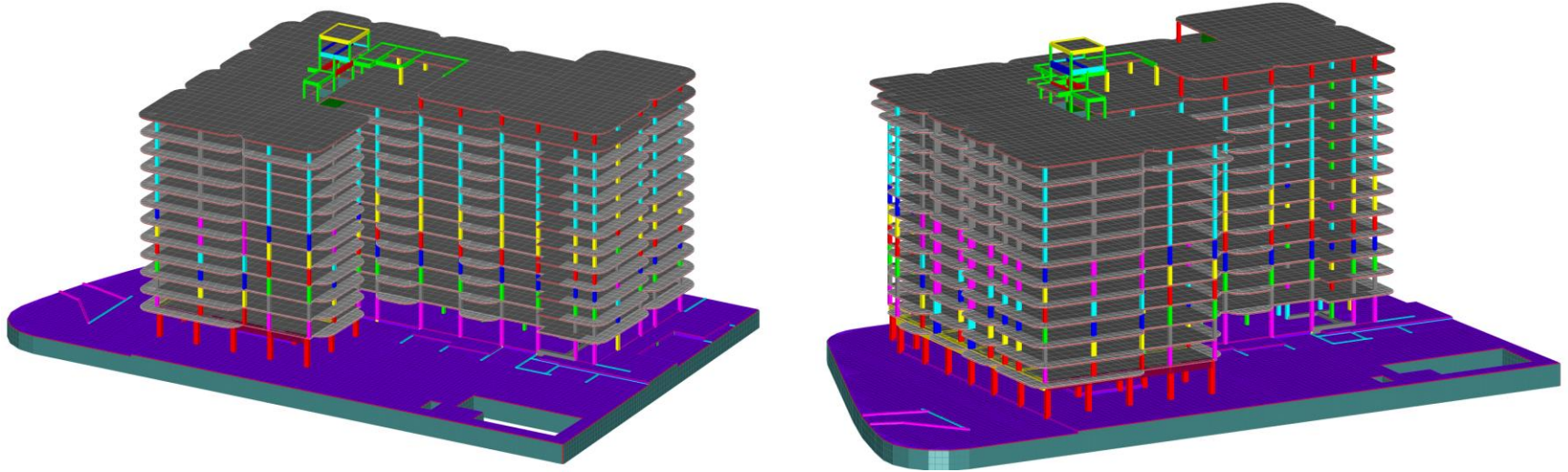


As-Designed Pool Deck

- Demand-capacity ratios for negative bending, one-way shear, and punching shear at columns of interest
- Demands:
 - As-built planter geometry
 - Assumed dead loads subject to change
- Capacities:
 - As-designed
 - clear cover = 0.75"
 - $f'_c = 4000$ psi
 - $F_y = 60$ ksi

Grid X	Grid Y	Direction	1.4D+1.7L		
			DCR_M_neg ($\phi = 0.9$)	DCR_V ($\phi = 0.75$)	DCR_Punch ($\phi = 0.75$)
14.1	I	N-S	2.09	0.99	1.71
14	I	N-S	1.38	0.75	1.28
14.1	K	N-S	2.00	1.31	1.91
13.1	K	N-S	1.32	0.71	1.85
14.1	L	N-S	1.96	1.36	1.80
13.1	L	N-S	1.35	0.56	1.89
14.1	M	N-S	1.61	1.19	1.75
13.1	M	N-S	1.22	0.52	1.79

Full Building – Finite Element Model



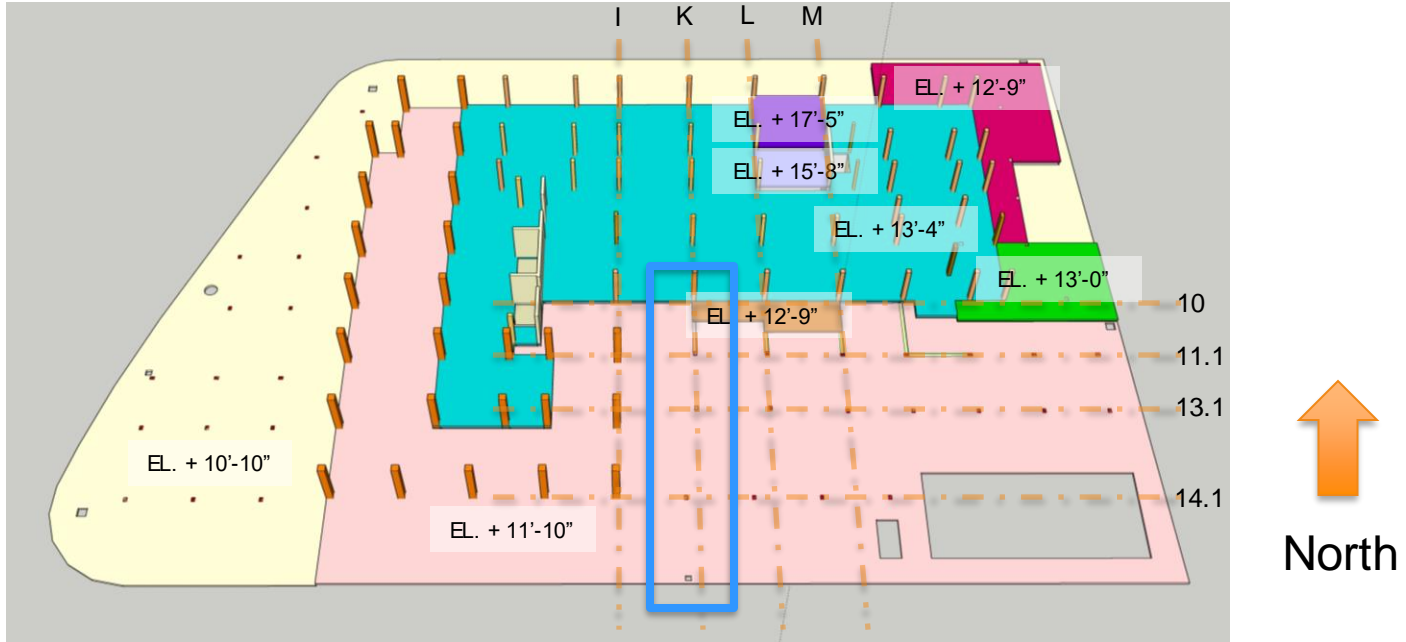
Findings & Observations

Theory of Collapse

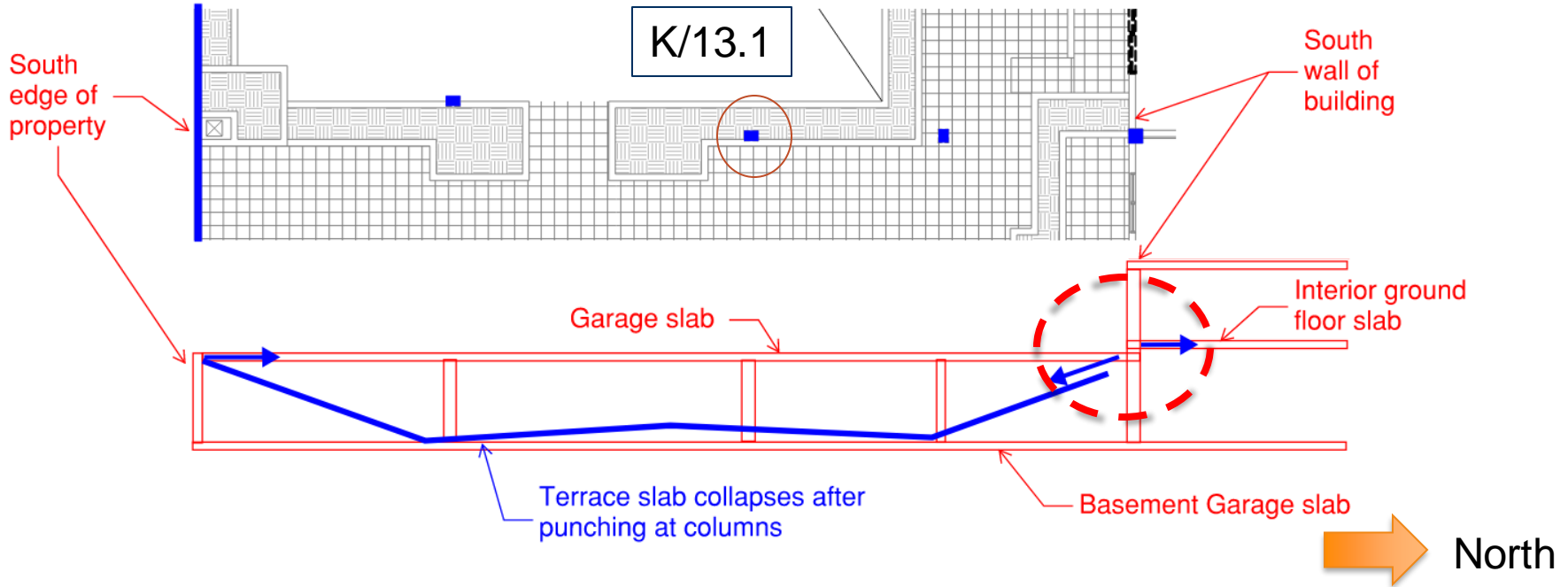
Theory of Collapse

1. The pool deck to the south of the building fails
 - Reported by the residents and in video documentation
 - Observable punching shear failures
2. The failure of the pool deck applies horizontal forces to the building columns
 - Horizontal forces are a result of bending forces and a possible catenary
 - Strength is diminished by the step in the slab at the building
3. These forces fail the column at the south exterior wall resulting in a progressive and partial collapse of the tower
4. The remaining western portion remains due to the shear wall at the elevator core

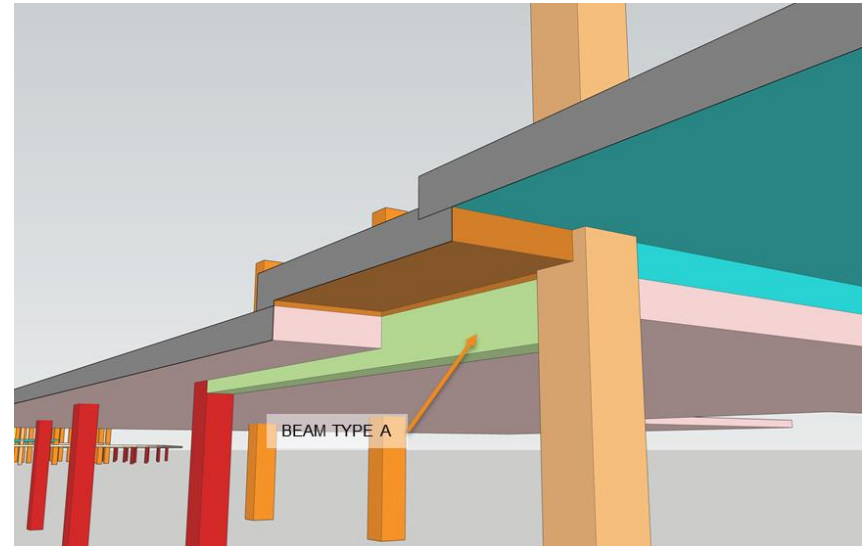
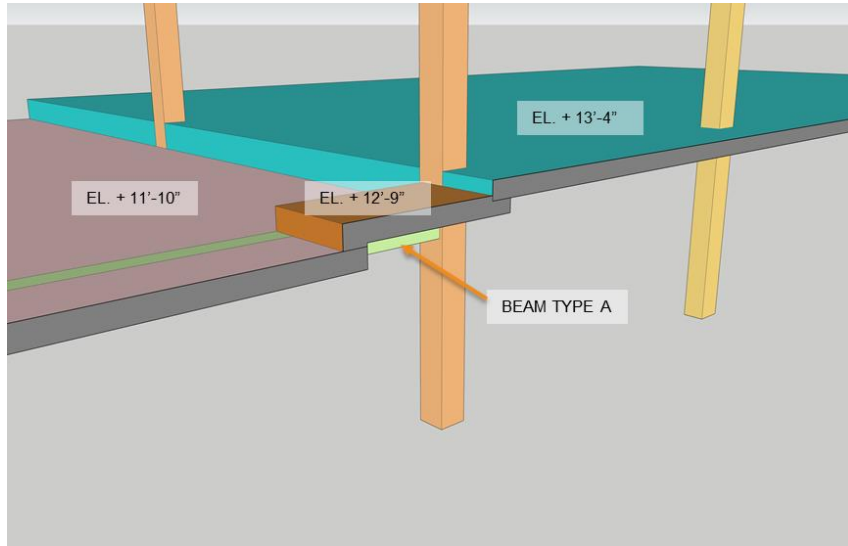
Pool Deck/Lobby Level



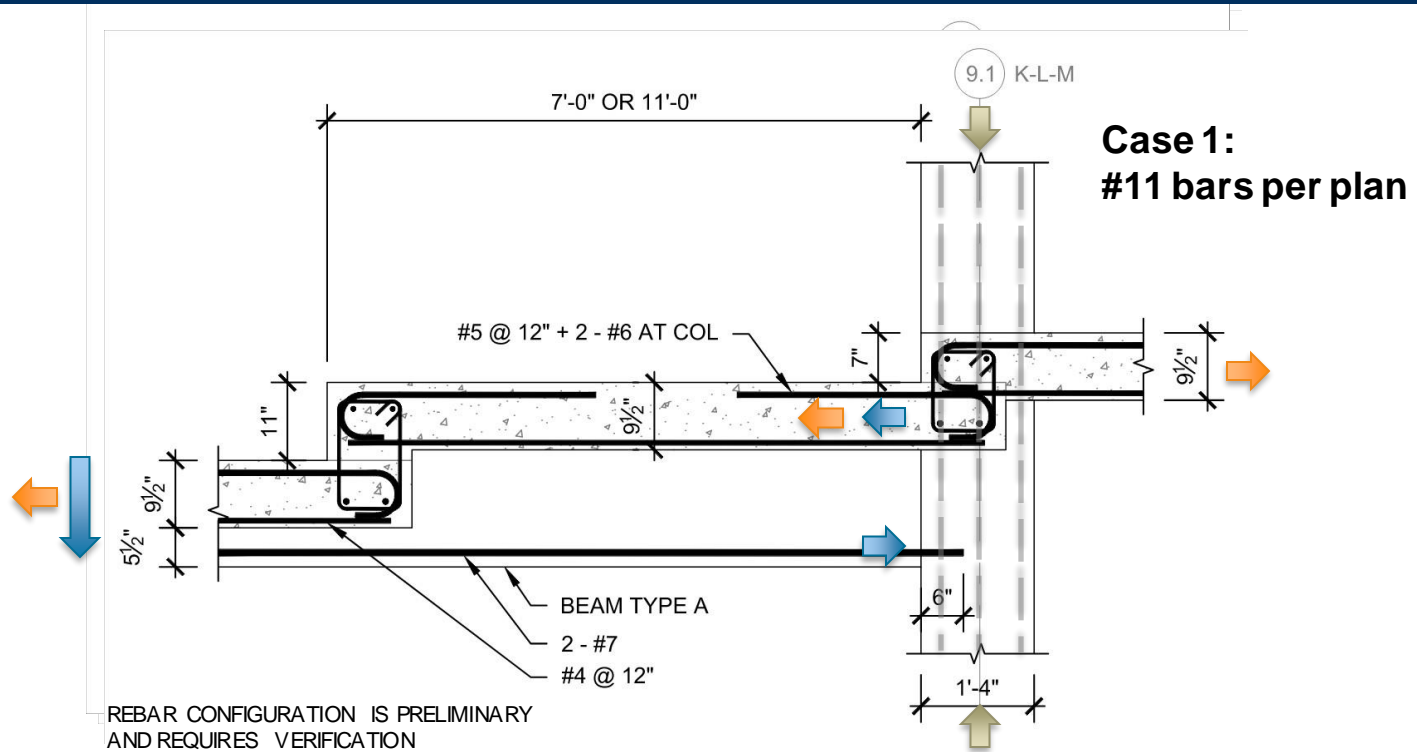
Behavior of Slab after Punching Failures



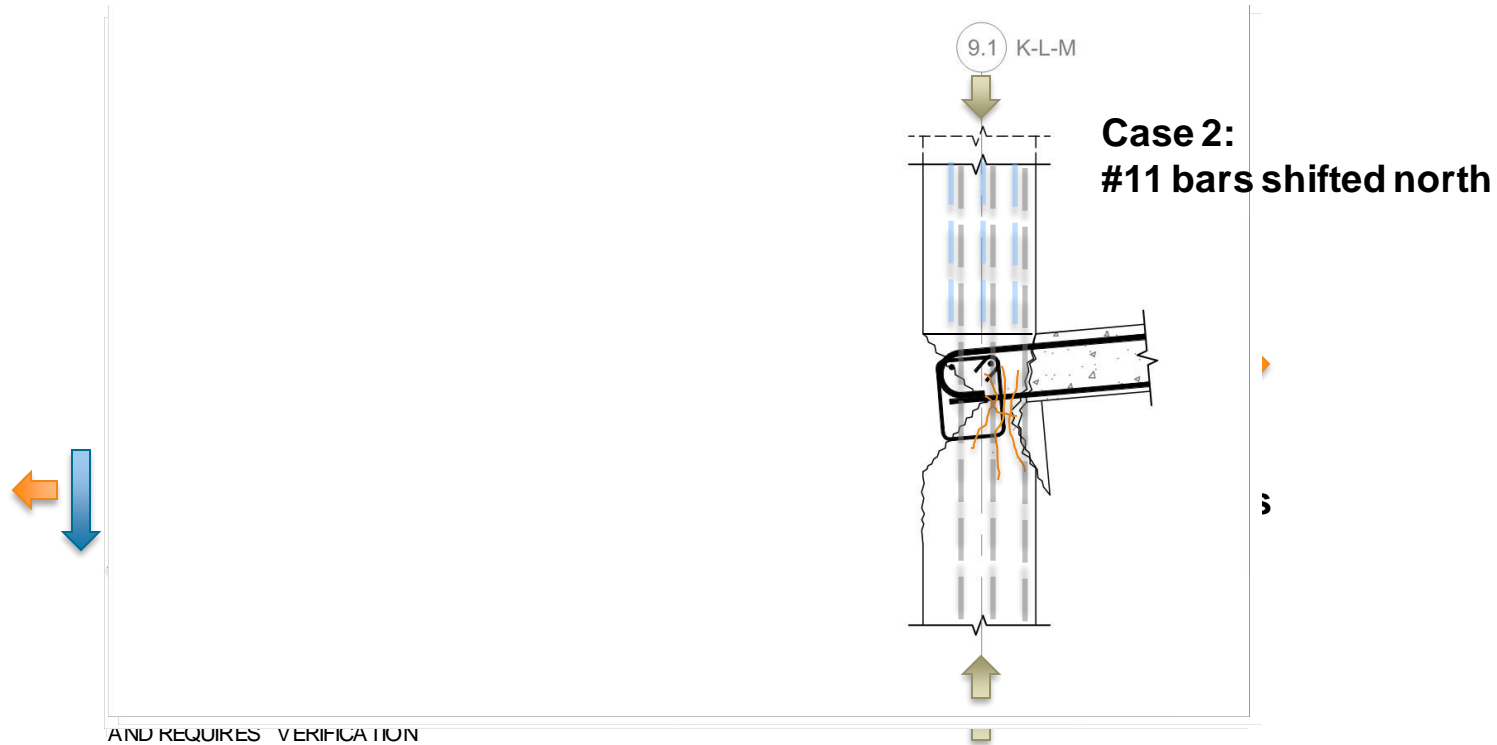
Slab Elevations



Progressive Collapse Mechanism



Progressive Collapse Mechanism



Summary



Mistakes that Appear to have Contributed

- Inadequate design of pool deck slab (especially punching shear)
- Excess weight on pool deck
 - Original concrete overlay not shown on drawings
 - Addition of pavers
 - Larger planters than shown on design drawings
- Shallow top reinforcement (decreasing effective depth)
- Engineers responsible for repairs failed to identify deficiency

Other Contributing Causes

- Long-term sustained load effects
- Low top reinforcement ratio (Code now requires more reinforcement)
- Water buildup in planters
- Corrosion (significance unclear)



\$~1+ Billion Dollar Settlement

- ~\$1 billion from defendants
- ~\$120 million for the sale of the land
- Economic loss: \$96 million dollars for property damage
- Wrongful death: ~\$900 million
- Attorney fees: ~\$100 million

Defend

- S
- E
- V
- C
- M
- .



Judge gives final approval to 'remarkable' \$1 billion Surfside condo collapse settlement

BY LINGA ROBERTSON

UPDATED JUNE 24, 2022 8:48 AM



Judge Michael Hanzman gestures on May 11, 2022, as he speak to attorneys in court where a settlement has been reached for Surfside collapse victims. JOSE A. IGLESIAS/jgilesias@miamiherald.com



One day before the one-year anniversary of the Surfside condominium collapse that killed 98 people, Miami-Dade Circuit Court Judge Michael Hanzman made his deadline and gave final approval to a \$1 billion settlement of the second-largest class-action lawsuit in Florida history, which he praised in court on Thursday as "remarkable not only in terms of its size but for its speed."

million
25 million

Structural Engineering Going Forward...

- Awareness of our practice
 - ACI 318-77
 - Importance of checking with peers and mentors
- Law and Code Changes
 - Do more inspections matter?
 - Punching shear
- Future research needs
 - Punching shear, progressive collapse, etc.

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BY DOU

UPDATE

PART 3: MEMBERS

CODE COMMENTARY



Centerline bay

upse

↑



Reaction frame

Load cell

Markers

500 k (2 MN) hydraulic jack

Specimen

Support block

Optotrak Cameras

A (see

increases if A_{smin} is not satisfied. A_{smin} was developed for an interior column, such that the factored shear force on the critical section for shear equals the shear force associated with local yielding at the column faces.

To derive Eq. (8.6.1.2) the shear force associated with local yielding was taken as $8A_{smin}f_y/b_{col}$ for an interior column connection (Hawkins and Ojima 2017) and generalized as $(\nu/5)A_{smin}f_y/b_{col}$ to account for edge and corner conditions. A_{smin} also needs to be provided at the periphery of drop panels and shear caps.

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May 11, 20
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