“A Coastal Condo Climate Risk Primer”

By: Albert Slap, President, Coastal Risk Consulting, and Dr. Randall Parkinson

July 2021

Climate Change, a Risk Multiplier

INTRODUCTION

Humans love the oceans and the beaches. We love watching the play of light on the water, the sound of the waves, and the soft warmth of the sand. This is just in our nature and, it probably hasn't changed much from when our species first evolved. So, great numbers of us, a majority in fact, live close to the earth's coastlines. Some fortunate ones even live in coastal high-rise buildings that are along the ocean or the bays, with valuable, direct water views. But, in the aftermath of the horrific and tragic condo collapse in Surfside, Florida, many coastal condo owners, renters, HOAs and property managers are asking such appropriate questions as: "Is my building safe, now?" "How can we better understand routine inspection and engineering reports?" "I hear a lot about climate change, more frequent storms, more intense rainfall, and sea level rise. What do they mean for my building, now, and in the future?"

In order to provide some climate risk context to these issues and others that have been brought to the forefront by the Surfside condo collapse, Coastal Risk Consulting has teamed up with Dr. Randall Parkinson, a Research Associate Professor at Florida International University's Institute of Environment, to offer a complimentary, educational "Coastal Condo Climate Risk Primer". [1]

This primer is not meant to provide engineering, architectural or legal advice. Rather, it is meant to help you better understand the natural forces that affect many coastal condo buildings and act as "risk multipliers" on the maintenance, architectural and engineering problems that may arise over the course of time.

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[1] **Some links to resources that will help educate HOAs include**:
(1) https://www.theinvadingsea.com/2021/06/28/surfside-building-collapse-is-a-shocking-wake-up-call-for-coastal-condo-homeowner-associations/; (2) https://www.washingtonpost.com/video/national/expert-cautions-climate-change-could-destabilize-more-buildings/2021/06/27/b740dc7a-2385-467d-863d-6967c7e3cc30_video.html?tid=a_classic-iphone&no_nav=true; (3) https://www.youtube.com/watch?v=lXMAkEiuem4; (4) https://grist.org/climate/the-surfside-tragedy-could-be-a-bellwether-moment-for-managed-retreat/; (5) https://www.miamiherald.com/news/local/article252877743.html

Concrete and steel and salt water are not mortal enemies. Most coastal buildings are designed to live well with salt water. But major increases in global warming, more extreme weather, and heat, rising ocean and groundwater levels and saltwater intrusion are unprecedented in our modern era. Coastal buildings and their owners and operators, therefore, need to accommodate these climate changes in many aspects of their design, operation, maintenance, and planning for the future.

BACKGROUND

Traditionally, buildings and other structures (e.g., roads, bridges) constructed in the coastal zone were designed according to the physical and environmental conditions present at the time they were built. Along the coast, however, these conditions change with time because the area is very dynamic. The shoreline may erode or expand, storms come and go, and there maybe periodic flooding during heavy rainfall events or storm surge. Under conditions of climate change, our oceans are rising, and sea level will continue to rise ever faster. So, buildings and other structures located in the coastal zone will be subject to an increasingly hostile physical environment. It is not surprising then that some of these climate related changes are being discussed as possible contributing factors to the collapse of the Champlain Condominium in Surfside, Florida. To help condo HOAs, property owners and residents alike, we have prepared a summary of these phenomenon.

"Though the Champlain Towers South collapse is at the catastrophic level, failure of structural elements in coastal high-rise buildings, such as deck and balcony failures, has been an ongoing concern of the engineering and building official communities for decades," said Clifford Oliver, formerly an engineer with FEMA and now a Professor at University of Maryland and Principal of Nanticoke Global Strategies, ***"With the explosive development along the east coast of the U.S. since the 1970s, there are thousands of coastal buildings that have been exposed to corrosion associated with salt spray, periodic coastal flood water inundation, and seawater/ground water intrusion."***

In 2016, Miami-Dade County published a study entitled: "Report on Sea Level Rise and Saltwater Intrusion" (http://www.miamidade.gov/green/library/sea-level-rise-flooding-saltwater-

intrusion.pdf). The purpose of the study was to help the public and key stakeholders better understand the implications of sea-level rise on increased risks for flooding and saltwater intrusion on both public infrastructure and privately-owned buildings. The study also made recommendations to building owners on how to adapt to sea-level rise and saltwater intrusion. The study documented higher water-table elevations caused by rising sea level. It found: "Higher Sea levels increased the…percentage of time water-table elevations were less than 0.5 foot below land surface."

Some building experts are concerned that this kind of environmental assault could have played a role in the Surfside condo collapse. "Sea-level rise does cause potential corrosion and, if that was happening, it's possible it could not handle the weight of the building," Zhong-Ren Peng, Professor and Director of University of Florida's International Center for Adaptation Planning and Design, told The Palm Beach Post. "I think this could be a wakeup call for coastal developments." Greg Batista, an engineer who specializes in concrete repair projects, told the Miami Herald that he suspects concrete spalling, a process whereby saltwater seeps into concrete and ultimately causes support beams to rust, expand, and weaken, to be a factor in the building's collapse.

THE SCIENCE

Sea Level Rise and Tidal Flooding

"As sea levels rise, the risks of flooding increase. Just as there are multiple causes of flooding there are similarly many different impacts from rising sea levels. Higher average water levels can contribute directly to higher high tides and storm surges. This type of flooding can be observed most easily when water "overtops" existing sea walls and floods the urban areas during seasonally higher tides." "Report on Sea Level Rise and Saltwater Intrusion." (http://www.miamidade.gov/green/library/sea-level-rise-flooding-saltwater-intrusion.pdf)

Prior to the 1980s, it was not commonly known that sea-level was rising albeit at a very slow rate; almost imperceptible (<0.0787 inches per year). Many buildings that were constructed before then are still intact, having withstood the test of time. However, our climate has begun to change and more rapidly. Sea level is now rising at 0.13 inches per year and is expected to continue accelerating to as fast as 1 inch per year by the end of this century (Figure 1).

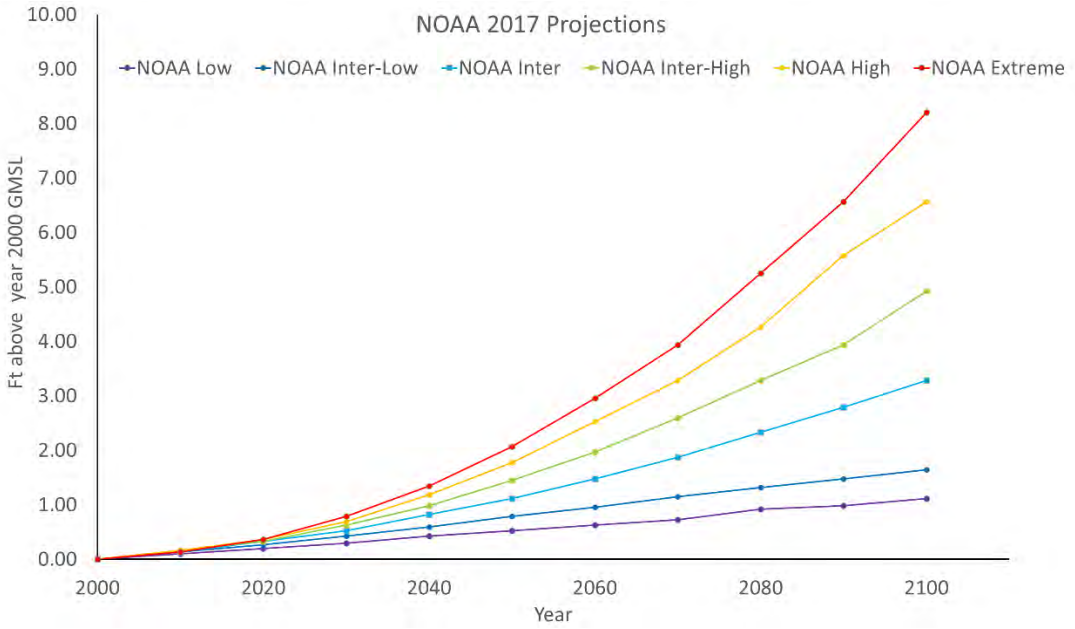


Figure 1. Sea-level rise projections as forecast by NOAA (2017).

The effects of sea-level rise on the structural integrity of a high-rise building are illustrated in Figure 2.

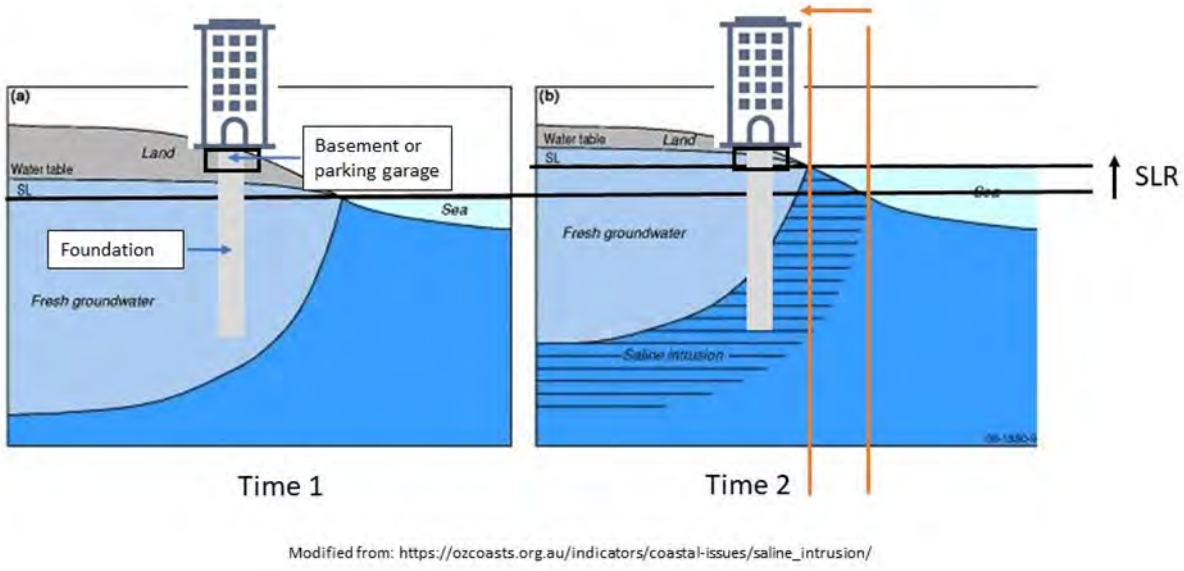


Figure 2. Subsurface hydrological conditions before (Time 1, left) and after (Time 2, right) sea-level rise.

The left panel represents the physical conditions of the subsurface at the time of construction. Beneath the building in this example is land (soils, sediment, limestone). Some of that land is above the groundwater table, but most of it is below the water table and, therefore, saturated

with freshwater. Under conditions of rising sea level, shown in the right panel, the water table rises, and the freshwater is combined or mixed with seawater by a process called saltwater intrusion. In this illustration, the basement or parking garage is now below the water table; a condition for which it may not have been initially designed. Furthermore, the building's foundation is now located in a saline environment. Again, a condition for which it may not have been not designed. These physical changes could lead to flooding of the subterranean portion of the building and accelerated corrosion of the foundation's rebar (Figure 3). Over the past 40 years, sea level has risen about 6 inches. Experts predict between 1 and 2 feet of sea level rise by the year 2050 and 3 to 10 feet by 2100.

Source: http://www.dot.ga.gov/BuildSmart/research/Documents/07-30.pdf

Figure 3. Structural integrity of pilings in seawater compromised by saltwater intrusion.

The intensity and frequency of major tropical storms and hurricanes are also predicted to increase as a consequence of climate change. That means flooding caused by heavy rainfall and storm surge will become more common. And, as sea level continues rising, surging seawater will penetrate ever further inland. All of this is expected to introduce new risks to coastal buildings and infrastructure.

But even now, flooding of low-lying areas during exceptional high tides is increasingly common. Also referred to as "sunny day" or "king tide" flooding, these are caused by years of relative sea

level increases. It occurs when tides reach anywhere from 1 to 2 feet above the daily average high tide and start spilling onto streets (Figure 4) or bubbling up from storm drains (Figure 5).

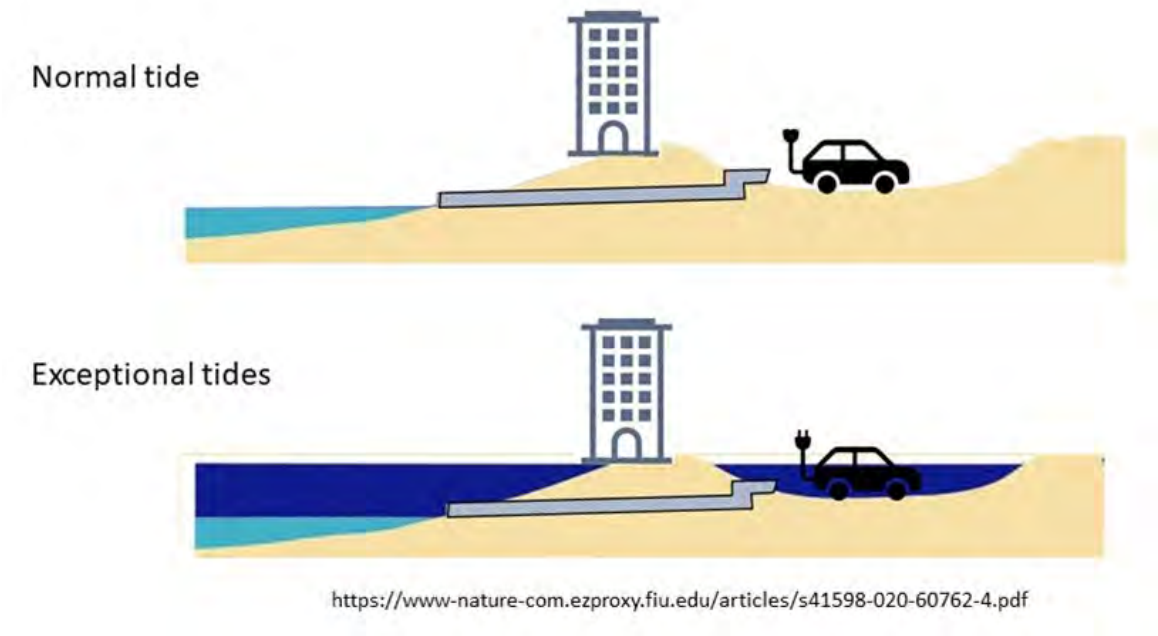


Figure 4. .When built, storm water generated during heavy rainfall drained by gravity into the ocean, even during exceptional tides (top). But because sea level has risen by more than a foot over since the 1920's salt water now flows through the aging stormwater pipes and into low-lying streets, sidewalks and yards (bottom) where it saturates the soils upon which they were constructed.

Figure 5. Saltwater bubbling onto the street from a stormwater drain during exceptional tide event.

As sea level rise continues, damaging floods that decades ago happened only during a storm now happen more regularly, such as during a full-moon tide or with a change in prevailing winds or currents (Figure 6). Eventually, the rising ocean may render gravity driven

stormwater infrastructure non-functional, if substantial and expensive adaptation investments are not made, and the ground is permanently saturated with sea water. Perhaps more importantly, higher sea levels also contribute indirectly to flooding by impacting groundwater levels and the drainage network. As groundwater levels rise, lands that were drained by stormwater drainage systems may be more difficult to protect from flooding. As the groundwater rises it is also possible to lose the storage capacity in the soil that typically helps alleviate flooding after rain events. With some loss of the capacity to infiltrate, water levels may remain higher for longer periods of time, particularly during the rainy season. Higher groundwater and sea levels may also incrementally reduce the effectiveness of the drainage infrastructure meaning that the extent or duration of flooding may last longer than it has in the past. For example, if French drains in underground parking garages or basements or other exfiltration systems become saturated, this may compromise their effectiveness.

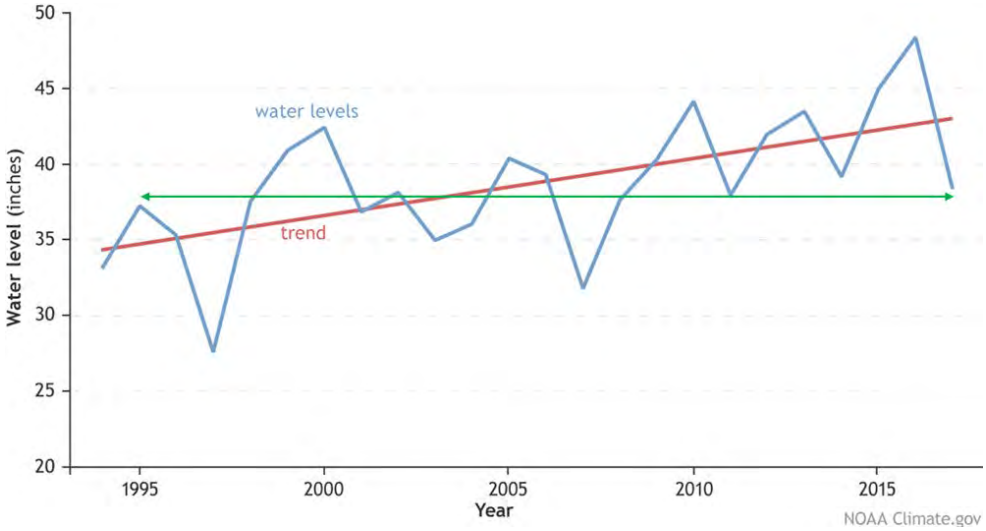
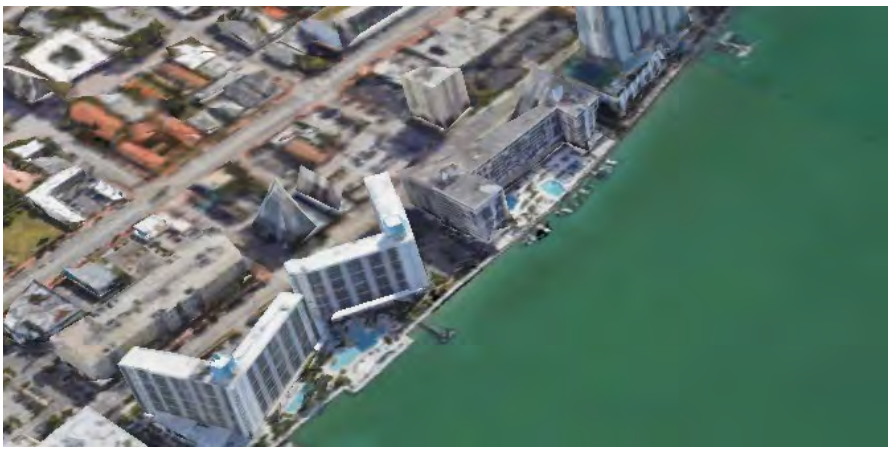


Figure 6. Virginia Key between 1994 and 2017 has risen by more than 5 inches because of sea-level rise (red line). Water level elevations during low tide are now greater than the high tides that occurred 20 years earlier.

Finally, as sea levels rise they affect beach profiles and erosion rates. While beach nourishment can help slow these changes to the adjacent beaches and dunes and provide important storm protection benefits, these are often expensive and not guaranteed to occur when most needed.

West Ave. Condos Miami Beach (Google Earth)



Modeling of Sea Level Rise flooding at West Ave. Condos by RiskFootprint™, www.riskfootprint.com

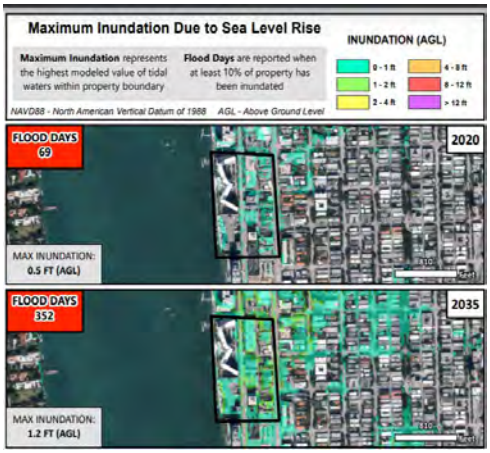
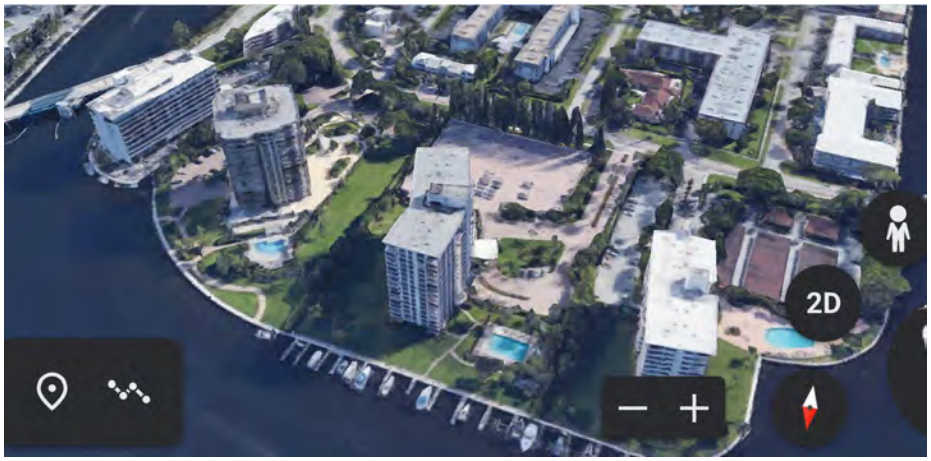


Image of King Tide or "sunny day" flooding, Miami Beach

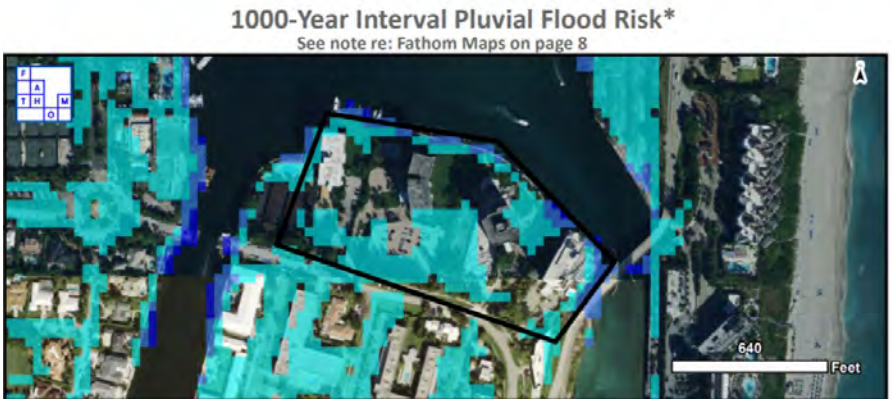
Increased Heavy Rainfall and Hurricane Storm Surges

Lake Boca Condos, Boca Raton, FL (Google Earth)

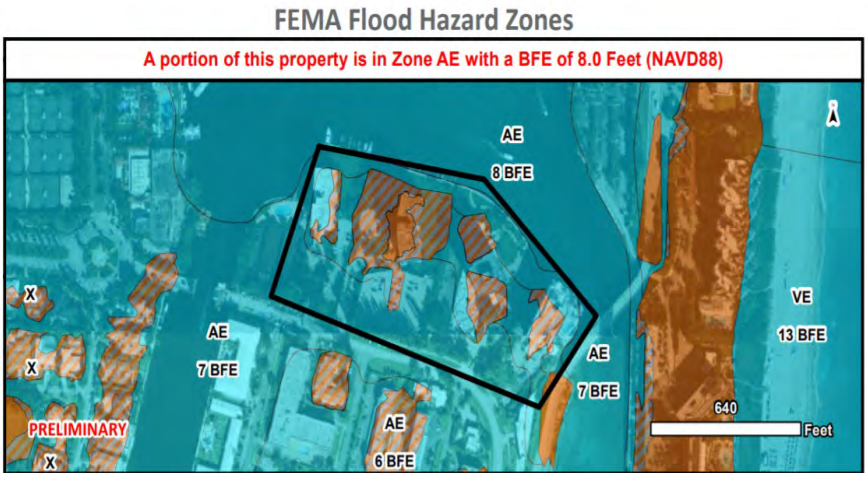


Heavy Rainfall Flood Risks Increasing

Modeling of Pluvial or Heavy Rainfall flooding at Lake Boca Condos by RiskFootprint™, www.riskfootprint.com



FEMA Flood Map and Base Flood Elevations (BFEs) Lake Boca Condos

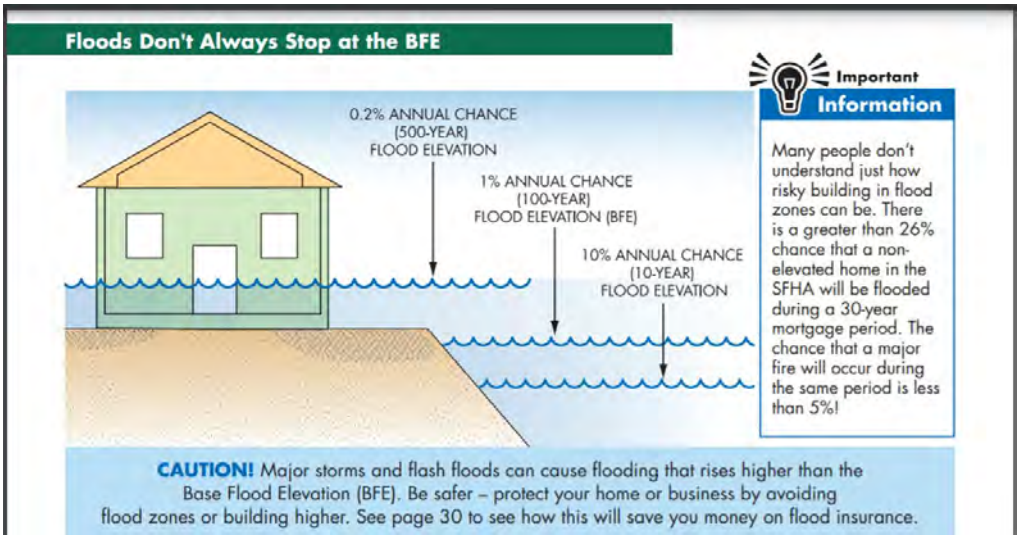


FEMA Flood Zones and the BFE

Communities must join the National Flood Insurance Program (NFIP) and administer floodplain management requirements before residents and businesses can purchase Federal flood insurance and to be eligible for some types of Federal assistance, including flood mitigation grants. In partnership with communities and the States, FEMA produces flood maps in accordance with FEMA standards. The maps are used by communities, insurance agents, real estate professionals, and others. The FEMA flood maps detail various risk zones and Base Flood Elevations (BFEs). Generally, the pricing of flood insurance is set by NFIP, and private insurance companies based in part on the height of the elevation of the building's first floor (usually the ground floor) in relation to the established BFE. Condo HOAs and owners can determine the "effective" BFE applicable to their building from the most recent FEMA flood maps. The height of the building's first floor can be determined from the building's Elevation Certificate.

In the example above, the condos on Lake Boca are located in a FEMA AE Zone (a "so called" 100-year flood zone) with a BFE of 8-feet above sea level. The AE zone is shaded blue. The brown shaded areas are FEMA X zones, where FEMA has modeled the rise to be less than a .2% annual risk (a "so called" 500-year flood zone). But floods don't always stop at the BFE. "Floodplain Management in Florida, A Quick Guide (2017)," (https://www.floridadisaster.org/contentassets/5a671dfdfadf45ab9a2c61635e2a4fed/quick-guide-for-floodplain-management.pdf). Many people do not realize that, in the 100-year FEMA

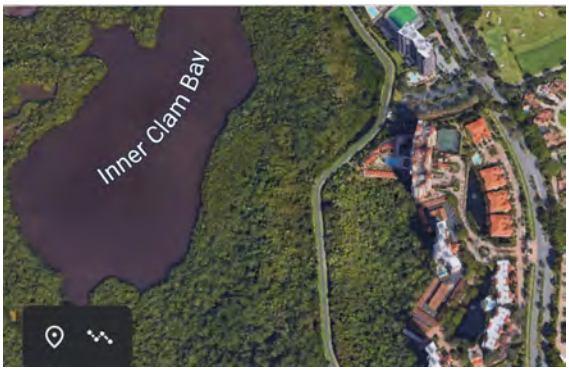
flood zone, there is a greater than 26% chance that a non-elevated, home or condo lobby will be flooded during a 30-year period. During the same period, the risk that a major fire would occur in the building is less than 5%.



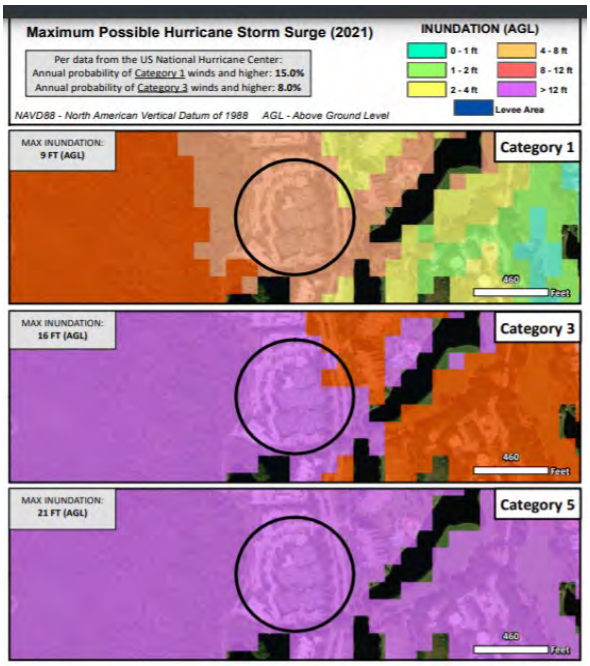
Storm Surge

Storm surge is the abnormal rise of water created by a strong storm. In South Florida, a significant storm surge is typically associated with a tropical storm. The storm surge results in temporarily higher water levels that recede after the storm has passed. Changing ground water levels and sea level rise water impacts storm surge heights. Higher water levels contribute to higher storm surges and potential wider area of land inundated by such a surge.

Condos, Naples, FL



Modeling of Hurricane Storm Surge flooding at Naples, FL condos by RiskFootprint™, www.riskfootprint.com



Land Subsidence

Another process that may compromise the structural integrity of roads, bridges, and buildings is subsidence. Subsidence is the lowering of the land's surface caused by surface loading or the withdrawal of fluids (e.g., groundwater, etc.). The result is a reduction in the void space or porosity of the soils or sediments. This causes compaction and is expressed at the surface as subsidence, which is expressed as distance of displacement over time (e.g., inchers per year). The potential effects of compaction on buildings or other structures are illustrated in Figure 7.

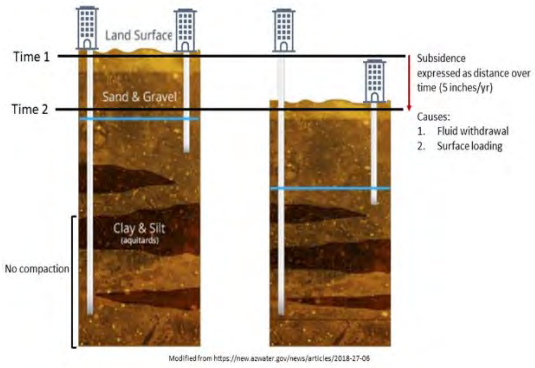


Figure 7. Effects of subsidence on two buildings with different foundations.

The two panels above depict conditions of the subsurface and surface before (time 1, left) and after subsidence (time 2, right). Two buildings are shown, one with a deep foundation (left) and the other with a shallow foundation (right). They respond differently to the same amount of subsidence because the structural attributes of each are different. This is referred to as differential subsidence, which occurs at spatial scales of 10s of feet to 100s of miles.

Our changing climate is causing an acceleration in the rate of sea-level rise, but also warmer temperatures, changes in precipitation patterns and intensity, and an increase in the frequency and intensity of tropical storms and hurricanes. All of these will alter the physical and environmental conditions of the coastal zone and have the potential to compromise the structural integrity of our buildings, bridges, and roads; either over time or in an instant.

CONCLUSIONS AND RECOMMENDATIONS

The Miami-Dade study made important recommendations for building owners to which the condo HOAs, owners and residents should be aware, along with local governmental staff and elected officials.

Some of the recommendations included:

— Elevate buildings;

— Flood-proof buildings with wet flood-proofing; dry flood-proofing; passive flood barriers; improvised flood protection (sandbags or moving equipment to higher elevations); deployable flood panels;

— Elevate the height of the interior finished floor elevation;

— Elevate mechanical systems;

— Avoid below grade parking or basements;

--Construct flood barriers to protect specific infrastructure;

---Elevate seawalls and bulkheads;

--Install backflow preventers to restrict the flow of seawater into the stormwater system;

--Increase the use of porous pavements in areas where infiltration is possible;

-- Increase the use of green roofs and facades to reduce urban run-off;

--Additional floodproofing for critical facilities;

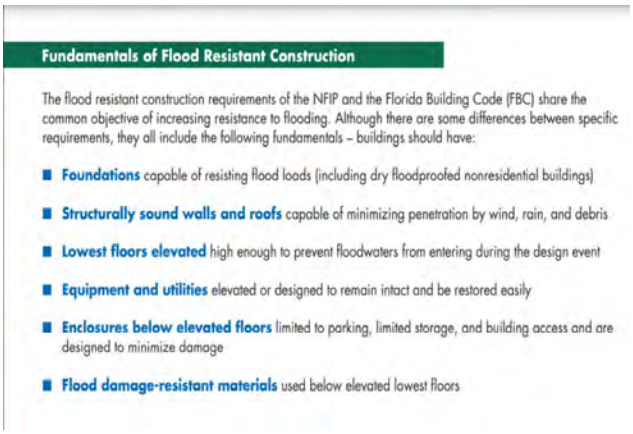
--Install additional stormwater pumps, as required;

--Install seepage barriers to reduce the flow of groundwater;

--Disclose building hazards and vulnerability to potential condo purchasers.

The goal of these recommendations is to reduce both short-term and chronic flooding of buildings from extreme weather and climate change-induced sea level rise.

The "Floodplain Management in Florida, Quick Guide," https://www.floridadisaster.org/contentassets/5a671dfdfadf45ab9a2c61635e2a4fed/quick-guide-for-floodplain-management.pdf, also provides guidance to building owners from NFIP and the Florida Building Code:



Fundamentals of Flood Resistant Construction

The flood resistant construction requirements of the NFIP and the Florida Building Code (FBC) share the common objective of increasing resistance to flooding. Although there are some differences between specific requirements, they all include the following fundamentals – buildings should have:

- **Foundations** capable of resisting flood loads (including dry floodproofed nonresidential buildings)
- **Structurally sound walls and roofs** capable of minimizing penetration by wind, rain, and debris
- **Lowest floors elevated** high enough to prevent floodwaters from entering during the design event
- **Equipment and utilities** elevated or designed to remain intact and be restored easily
- **Enclosures below elevated floors** limited to parking, limited storage, and building access and are designed to minimize damage
- **Flood damage-resistant materials** used below elevated lowest floors

Coastal condo HOA boards, management companies and residents can better understand current and future impacts of flooding, sea level rise, rising groundwater, saltwater intrusion, and hurricane storm surges by obtaining physical climate risk assessments for their buildings. Armed with this information, the boards, owners, and residents can make more informed decisions about risk mitigation investments, plan for needed reserve funds, and identify other adaptation actions that may be appropriate for their specific location and building, including infrastructure upgrades needed by the local/county/state governments that provide services to their buildings.

QUICK SUMMARY

BUILDING OWNERS AND MANAGERS NEED TO:

- **HAVE THEIR BUILDINGS ASSESSED FOR CURRENT AND FUTURE RISKS OF CLIMATE CHANGE AND SEA LEVEL RISE. PROPERLY EDUCATE THEMSELVES AND RESIDENTS ABOUT BOTH CURRENT AND FUTURE CONDITIONS, SO THAT THEY CAN TAKE NECESSARY AND APPROPRIATE ACTIONS IN A TIMELY MANNER.**
- **HAVE THEIR BUILDINGS INSPECTED MORE FREQUENTLY FOR THE IMPACTS OF CORROSION DUE TO FLOODING, SALTWATER INTRUSION, SEA LEVEL RISE AND OTHER FACTORS.**
- **MAKE NEEDED INVESTMENTS FOR REPAIRS AND STRUCTURAL SAFETY.**
- **COASTAL CONDO RESERVE FUNDS SHOULD BE REVIEWED FOR ADEQUACY BOTH FOR NORMAL AND PLANNED MAINTENANCE AND REPAIRS AND THE FUTURE IMPACTS OF CLIMATE CHANGE, EXTREME WEATHER, RISING SEA LEVELS AND GROUNDWATER AND HIGHER HURRICANE STORM SURGES.**

For further information, please contact: customerservice@riskfootprint.com or call 844-Sea-Rise (732-7473), www.riskfootprint.

APPENDIX

https://www.miamiherald.com/news/local/article252877743.html

Sea rise under scrutiny in condo collapse: Corrosion likely, but no sign of sinkhole

BY ALEX HARRIS| AHARRIS@MIAMIHERALD.COM

August 2, 2021

Scraped clean of tons of rubble late last month, the bare garage floor of Champlain Towers South appears to rule out at least one early suspect in its catastrophic collapse.

There were no telltale signs of a sinkhole.

The garage floor, the building's lowest level, remains in one piece with no craters or potholes suggesting unseen geological forces were at work. The "sinkhole" a doomed resident saw opening from her balcony in a final phone conversation was likely not erosion beneath the building but the implosion of the concrete pool deck above the garage floor — the seeming trigger event of a massive and still unresolved structural failure.

"The slab appears to be intact and there is no obvious sink hole," said Jennifer Huergo, a spokesperson for the National Institute of Standards and Technology, the federal agency investigating the cause of the collapse. "That said... our experts will be looking at every aspect, above and below ground, for potential triggers."

RELATED CONTENT

- Sea rise makes septic tanks 'ticking bombs.' Why does Miami-Dade still allow them?
- Miami-Dade's new sea rise strategy: build higher and back away from the water

Those aspects will include the effects of rising seas on the 40-year-old building, which remain on the long list of contributing factors for structural engineers and other experts trying to piece together the causes of the unprecedented disaster. If increasing tidal flooding didn't undermine the building, it may have pushed corrosive brine into the parking garage.

Even now, time-lapses of the empty garage floor show flooding that rises and falls with the tide throughout the day. And a former maintenance manager described to Herald news partner CBS4 regular pumping of salt water from the garage — conditions experts say would likely exacerbate the effects of rust on reinforcing steel in concrete slabs and columns.

“We’re chasing like 50 different things and trying to understand them one at a time,” said Allyn Kilsheimer, the independent structural engineer that the town of Surfside hired to investigate the collapse.

Kilsheimer himself isn’t ready to rule anything out, including sea-rise impacts and possible undetected voids or sinkholes under the building. Among the many things he wants to assess are the effects of tides and full moons on the underground water table. He will drill a hole near the north building (a few blocks from the south building) and insert a device called a piezometer, which measures groundwater levels. That, he said, is a challenge in an underground garage on a barrier island — one that also underlines the looming threat of sea-rise to South Florida.

“We can’t drill through the basement of the garage because it could create a geyser at high tide,” he said.

A rising threat

What, if any, role rising seas played in the collapse, there is no escaping the rising risks to Surfside and other coastal communities up and down the Florida coast. Low-lying garages in South Florida have flooded for years, some famously so. Recall the 2016 photo of an octopus finding its way up a drainpipe into a Miami Beach condo’s garage.

READ MORE

- Octopus in the parking garage is climate change’s canary in the coal mine

The two feet of sea level rise expected by 2060 will swamp septic tanks, homes, parks and roads. And as waters keep rising, it will eventually render some places permanently uninhabitable.

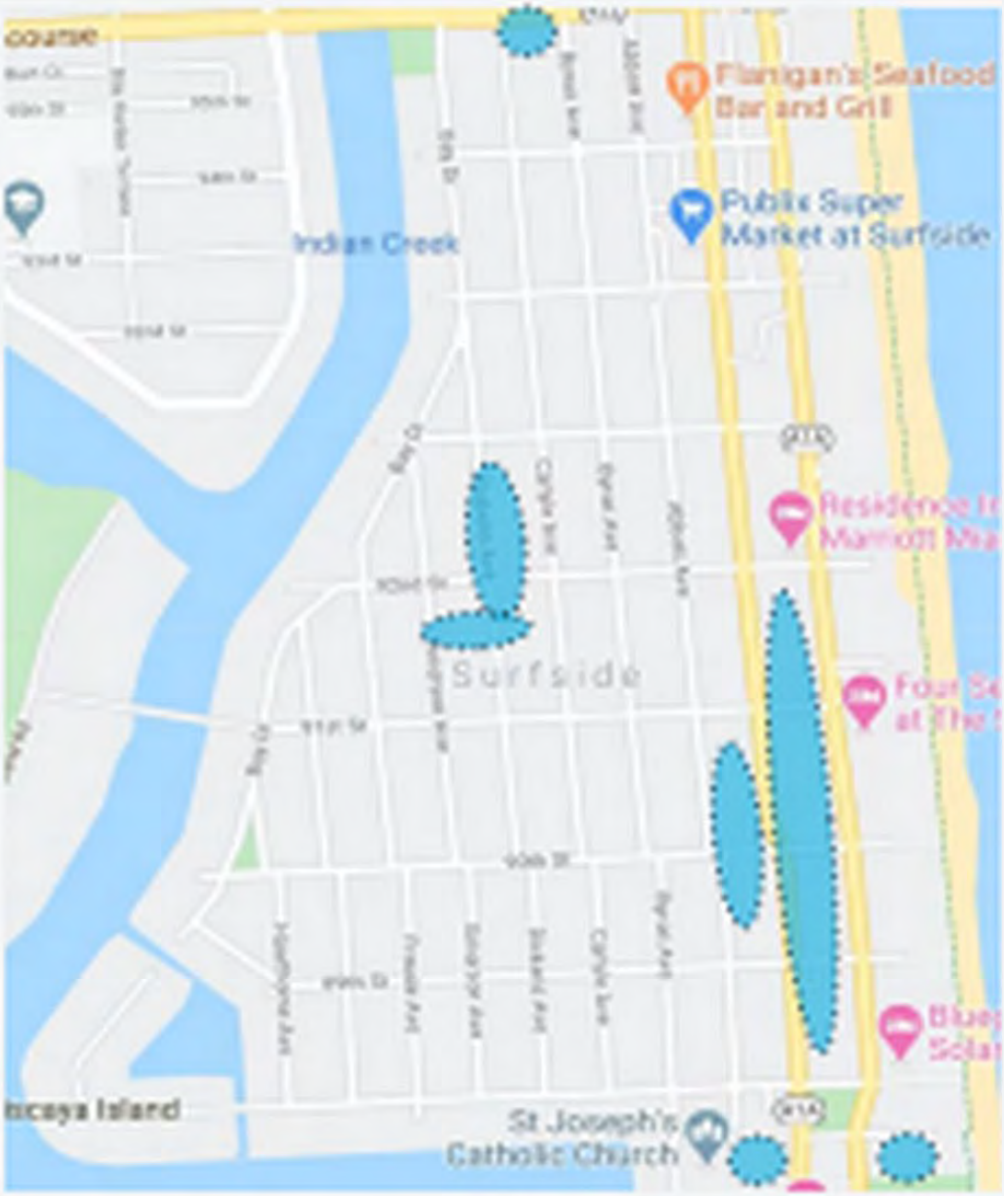
In a meeting just last year, the town heard from consultants that it faces structural threats from sea rise. The most pressing risk is not along the higher elevations of the beach where Champlain Towers was but on the low-lying side adjacent to north Biscayne Bay.

Streets in the single-family home part of town nearer to the Intracostal Waterway flood so deeply after heavy rains that the water has been reported ruining cars and soaking into houses, garages and crawl spaces. Residents even floated the idea of installing “No Wake” signs to protect their homes.

The meeting was the public debut of a flood model the city commissioned from Atkins Engineering through a partnership with the American Flood Coalition. Caroline Resor, a strategy associate with the flood coalition at the time, told residents that sea-rise-driven flooding could occur as often as 100 days per year by 2030. She said the more extreme of those floods could cause $400,000 to $2 million in damage to homes.

“That is obviously a risk that is increasing,” she said. “Other parts of town are far less at risk from tidal flooding.”

Project close-up: Flooding hot spots



Flooding hotspots were estimated in meetings with Town staff and based on a typical 10-year rain event

Atkins Engineering made a map of flooding hot spots in Surfside, which consultants presented to the city in a November 2020 meeting on sea level rise impacts. (Atkins Engineering)

The tiny town hasn't ignored the threat and actually has a brief history of pioneering climate change policy. In 2019, Surfside created a fund developers paid into designed to help buy out future residents when their homes became unlivable. But it was immediately overturned by the new mayor, Charles Burkett, and slate of commissioners. At a meeting in November, Burkett gave a presentation on his preferred solution to avoiding the floods — elevating single-family homes with federal grant money.

There was no discussion on what to do with seaside condominiums.

Sea rise a first suspect

Nevertheless, the effects of sea rise almost instantly emerged as a suspect in the immediate aftermath of the collapse — fueled by both the "sinkhole" report and national news coverage of a 2020 Florida International University survey of the coast that showed that the condo had slowly been sinking. Though the FIU professor himself downplayed the connection, noting it was a small shift at one point in time, the specter of sea rise taking down entire buildings made headlines for weeks.

The sinkhole theory was serious enough that a trade publication, New Civil Engineer, produced an inconclusive report about it in early July.

Investigators have since dismissed most of those theories.

Was the building built on an old inlet that was slowly reclaiming the land? No, that seemed like a misread of an old and poorly written map. Was it built on wetland that was slowly settling? No, old development maps show that Champlain Tower South went up on an original section of the island, and wasn't filled in with mowed-over mangroves and dirt like the western side.

But the corrosive effect of routine flooding at the building's base remains an unanswered question — and very much part of the forensic analysis.

Water, especially saltwater, can worm its way into concrete, creating pockets of air that eat away at the adhesive between the components of cement, eventually reaching (and destroying) the reinforcing steel rebar embedded within.

Rubble and debris of the Champlain Towers South condo can be seen in Surfside, Florida on Tuesday, July 6, 2021. The rubble shown here is from the front portion of the condo towers, which was demolished 11 days after the back part of the tower collapsed with people inside. (MATIAS J. OCNER | mocner@miamiherald.com)

Corrosion from salt spray, storm surge and tidal flooding is an old foe in coastal areas, often the biggest and most expensive repair faced by aging buildings. Buildings constructed in the 1980s — before tougher codes and improved construction techniques — are particularly vulnerable. One pool maintenance worker told the Miami Herald the garage had standing water in it 36 hours before the building collapsed, and he was told that the underground pool maintenance room ran through a new water pump every two years to keep the room dry.

Still, many experts, including Dawn Lehman, a professor of civil and environmental engineering at the University of Washington retained by the Herald as a consultant, stress that corrosion alone is unlikely the reason the building failed. Buildings, she said, are designed to have structural redundancies.

“We know corrosion is an issue for many buildings on the coast and it must be addressed, but we do not expect it to lead to full building collapse without other serious structural deficiencies,” she said

But flooding episodes also have become more common as sea levels have risen, including in the Champlain Tower underground garage, which sits about 10 feet below ground in a part of the barrier island where the water table is only about two feet below the surface. In the 40 years since the towers were constructed, sea levels have risen about eight inches at Virginia Key, the nearest official tidal gauge.

Water from below

That tidal rise can have significant impacts in a place like South Florida, which is built on porous limestone that allows water to flow freely below the surface. It's why sea walls are ineffective at holding rising tides at bay.

The top layer of that water is a small lens of freshwater that floats on top of the denser saltwater pushing in from below. In the case of Miami Beach, the lens gets shallower near the edges, which means saltwater is closer to the surface. But just how close is hard to know.

And that could be important in the Champlain Towers probe because of potential impacts on piles — the concrete columns shoved deep underground that help hold up buildings. It remains unclear how deep the piles under Champlain Tower were. It's not recorded in the original plans the city of Surfside released to the public, and the town's consulting engineer Kilsheimer said it would require sonic testing at the site to know for sure.

That testing, of the concrete caps on the piles and the dirt around them, can determine what condition the piles are in, as well as if there are any voids or sinkholes underneath the building. Underground issues certainly aren't unheard of in South Florida and the underlying limestone geology is pocked with holes. There are anecdotal stories of individual buildings in Miami with secret underground canals undermining their foundations, or old Miami Beach hotels that look perfect on the surface but had crumbling foundations underground.

But sinkholes capable of swallowing cars, homes and buildings are far more common in Central Florida, and can even occur in mainland Miami, but they're rare on barrier islands, according to Florida's sinkhole report database.

Photos taken of the scraped-clean floor of Champlain Towers South show water pooling in the area. (Robert Lisman)

John Pistorino, a long-time Miami-Dade structural engineer hired by attorney Stuart Grossman for a lawsuit representing the survivors and victims of the collapse, said in his 50-year career investigating building failures in South Florida he couldn't recall a time where sinkholes were a major issue.

"In my experience with the soil conditions along the coast where all these high rises are, sinkholes are not a concern. The bigger concern would be storm surge, scour... which would undermine shallow foundations but not deep foundations like these buildings have," he said. "But there's a first for everything."

Hunting for corrosion

With corrosion the more likely contributing factor, investigators are looking for clues in the now exposed garage, where regular flooding occurred, and the remains of the pool deck and ground floor above it.

At least six engineering experts told the Herald it appeared as if the initial failure that triggered the building collapse happened in that concrete slab that supported both the outdoor pool deck and the first floor of the building itself. Why it failed remains the big question — did the slab simply crack at a weak spot or did the failure occur in the connection to the garage floor columns supporting it from below?

Previous engineering reports revealed the slab had serious deterioration of the concrete and reinforcing steel and was in line for multi-million dollar repairs. Video obtained by the Miami Herald from minutes before the collapse also showed what appeared to be concrete rubble assumed to have fallen from the pool deck slab to the floor of the underground garage below.

Herald consultant Lehman, after examining dozens of photos, videos, documents and all available design plans for the building, considers the slab itself a leading suspect.

That's where regular garage flooding comes in. Lehman said it's possible that could have kept the garage humid and salty, a bad environment for most metals. She said her examination of reports on concrete cores and other repairs indicates that the amount of concrete cover over the reinforcing steel may have been insufficient for that type of exposure to the elements.

She noted that photographs and prior repairs show the reinforcement in the pool deck had corroded and was not replaced.

"The cause of that corrosion is probably in the garage," she said. "Because they designed that bottom cover as if it were an interior slab, but the exposure of the garage to regular flooding is deteriorating the ceiling of the garage, the bottom of the pool deck."

Lawrence Kahn, a professor emeritus of structural engineering at Georgia Tech, said the rainwater collecting on the pool deck, which a consulting engineer noted had a design flaw that retained water, could be a more likely culprit.

"If there hadn't been seawater inundation that reached the bottom of the slab then it's more likely that it came from the top," he said. "The humidity carries a lot of salt with it, but generally, it'd be much slower to absorb from the bottom."

But he said it is also possible that rust could have spread from the garage floor up through steel in the columns into the pool deck above.

Planned materials testing may help piece together the puzzle and how tidal flooding and rust fit in.

Kahn said investigators can tap columns with a geologist pick and listen to the results. A clear ringing is a sign the column is structurally sound, while a dull thud hints that it's cracked or deteriorated.

"That's the first sign that something's wrong," he said.