U-Link Renewal Project
Title: Space-geodetic monitoring of coastal structures

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1. Executive Summary

The goal of our U-link project is to develop a methodology for satellite-based monitoring of coastal structures to help the engineering community to assess and monitor the structural health of aging coastal structures in South Florida and coastal cities elsewhere in the country. Our team has collected pilot data and demonstrated the feasibility of the proposed approach and published a first paper on the data analysis approach. We also have developed a hypothesis to explain the subsidence observations based on the local geology. A research proposal to test this hypothesis is under review by the National Science Foundation (NSF).

We have experienced some roadblocks when attempting to gather construction records during phase 1 of our project. We have learned that accessibility to data for high-rise public buildings may be more easily achievable compared to privately-owned buildings. This is primarily due to the large body of property ownership and Homeowner Associations (HOA), and their lack of understanding of our project's mission resulting in mental distress regarding concerns about safety, liability and impacts on property values.

Here we propose a three-pronged research approach to lay the groundwork for a pilot project with Miami-Dade County on using InSAR information for building recertification. For this U-link extension project, *first,* we will acquire high-resolution data and extend our study area from Miami to the coasts of Broward and West Palm Beach counties. *Second,* we will identify country-wide news reports for buildings with structural damages and obtain InSAR data for these buildings to demonstrate that structural damages are detectable from space. *Third,* we will select public high-rise buildings for detailed study for which we anticipate less roadblocks than for privately-owned buildings.

2. Recap of original project

The project was motivated by the tragic collapse of the Champlain South condominium tower in Surfside, Florida in June 2021 that killed 98 residents. This event brought to attention (1) concerns about the structural safety of Florida's aged (> 30 years) beach condominium buildings, and (2) the need for new technology to monitor and assess the structural health of condominium high rises. Our project got a head start with InSAR data of the towns of Surfside and Bal Harbour which show a few centimeters of differential subsidence for several coastal structures. These data suggest that damages to structures can be detected from space and that the InSAR technology could contribute to structural health monitoring of structures.

3. Concept of proposed pilot project

In our concept of the proposed pilot project our team will provide InSAR data to Miami-Dade County. The County will then encourage properties undergoing the 30-year building recertification process to consult our database for subsidence. If subsidence is detected the property owner will have to demonstrate actions taken to mitigate the impacts of differential subsidence. Our team will be available to property owners to assist in the interpretation of the InSAR data.

Before we can start discussions with the County about the proposed pilot three conditions have to be met. *First,* our article on Surfside/Bal Harbour subsidence has to be published; *second,* known technical shortcomings of our data analysis approach are resolved; *third,* we are routinely receiving high-resolution data, and we have the software capability to automatically generate updated data when a new image has been received.

4. Proposed work

To prepare for designing the pilot project with the Miami-Dade County Office of resiliency we will pursue the following tasks::

Task 1. Acquire high-resolution SAR data. We will acquire high-spatial resolution data of the coastal area using the semi-commercial TerraSAR-X satellite operated by the German Space Agency which has a spatial resolution of 3x3 m^2. The spatial resolution is an order of magnitude better compared to the Sentinel-1 sensor which we are currently using, as shown by a comparison of the point density (Fig. 1). The acquisition of TerraSAR-X imagery requires satellite tasking, which is associated with costs. Establishing a smooth TerraSAR-X data flow is a top priority for our project going forward.

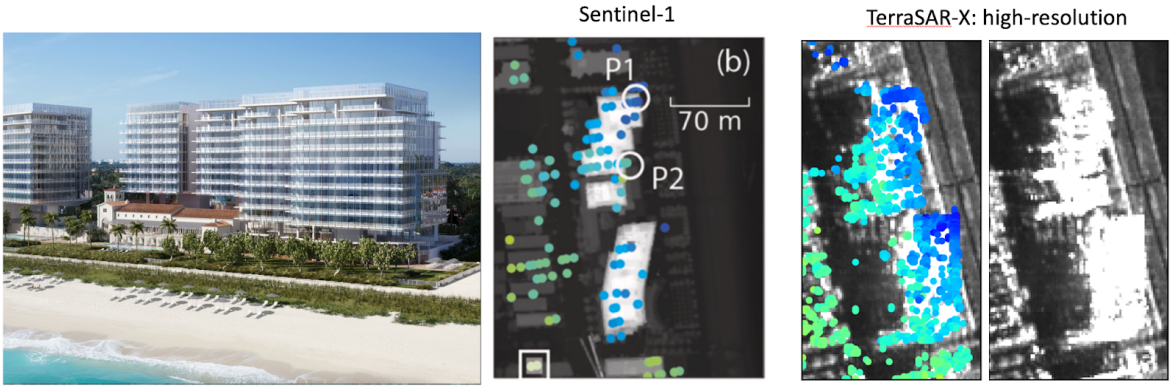

Fig. 1. *InSAR-detected subsidence of the Surf Club hotel, Surfside, demonstrating the difference in spatial resolution between (center) the open access Sentinel-1 satellite, and (right) the restricted TerraSAR-X satellite. TerraSAR-X provides an order of magnitude better spatial resolution but is associated with costs.*

Task 2. Extending to Broward and West Palm Beach counties. The next task is to extend our study area northward to cover entire South Florida. We expect additional subsidence

hotspots because the shallow limestone has more abundant sand layers. In fact, the strongest subsidence signal that we have detected is in Sunny Isles in northeastern Miami-Dade where construction was associated with significant vibrations that were litigated in court.

Task 3. Algorithm improvements. Another task is to improve our data analysis approach. Our approach works for structures up to ~50 meters tall (such as the Surf Club Hotel), but has limitations for taller structures (see Fig. 2). The reasons are differences in the travel path of the radar signal reflected from the ground and from the roof of structures.

Task 4. Country-wide search for condominium damages. Next we will conduct a country-wide search of news media for reports about damages to condominium buildings. We then will acquire InSAR data for these structures to test for precursory displacement signals. This will demonstrate that the InSAR technology can detect structural damages of condos.

Task 5. In-situ measurements of long-term settlement. A learning outcome of the first year are the complexities of ground-based measurements at privately-owned buildings. This year we will focus on public property anticipating that it is easier to obtain permission to install reflectors. Our target is the new Miami-Dade county courthouse which is under construction. We are also in discussion with Broward County on placing a GNSS receiver on their courthouse to validate our subsidence observations (Fig. 2). Recently, the top floors of the courthouse were closed over structural concerns.

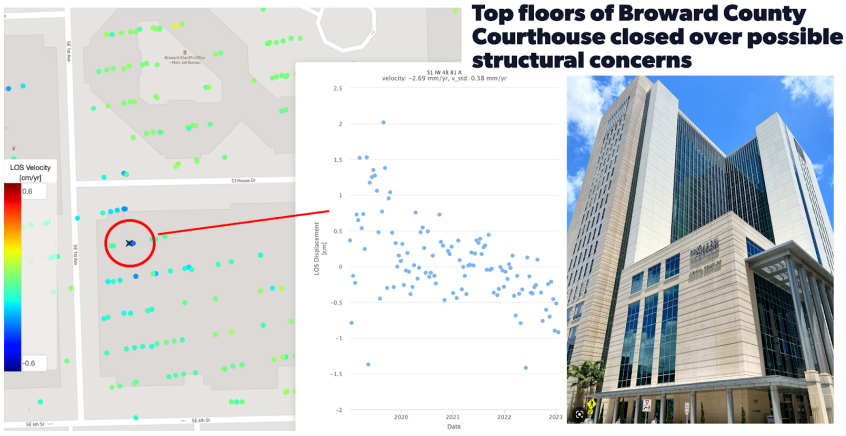

Fig. 2. *InSAR-detected subsidence of the Broward County courthouse in Fort Lauderdale. We hope to place a GNSS receiver on the courthouse for data validation. Another building for validation is the new Miami-Dade county courthouse currently under construction.*

5. Achievements

The *first* achievement of this project is the publication of a first technical method paper featuring the Miami subsidence results (Mirzaee et al., 2023).

The *second* achievement is the development of a hypothesis for the observed subsidence. In this hypothesis subsidence is due to creep deformation of the sand interbedded in the coralline limestone and initiated by construction-related vibrations. We have a pending proposal with the NSF to test this hypothesis by drilling two 100-m long sediment cores in Surfside for geotechnical testing (collaborative proposal with Florida Atlantic University).

The *third* achievement is the detection of 2-3 cm of subsidence at the 87th Park tower south of the collapsed condo (Fig. 3). Vibrations from construction of this tower are suspected to have contributed to the collapse. Pre-construction geotechnical investigations have documented a sand layer at 21-23 meters depth (Fig. 3D). This suggests that we are following the correct lead, and that vibrations cause creep deformation of interbedded sand layers, resulting in subsidence at the Earth's surface.

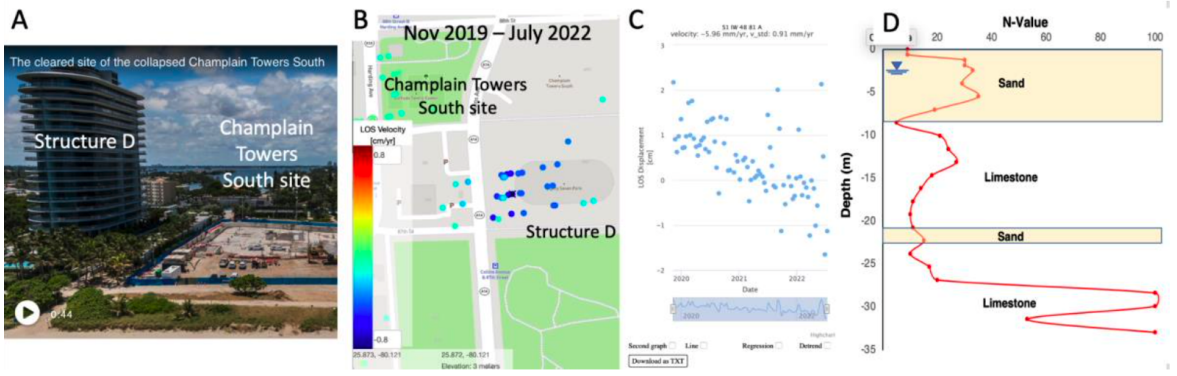

Fig. 3 *(A-C) InSAR detected subsidence of 2-3 cm of the 87th Park Tower south of the collapsed condo. (D) Lithology depth section and Standard Penetration Test (SPT) N-values. We hypothesize that vibration-induced slow creep in the sand layer at 21-23 m depth caused the subsidence.*

6. Efforts to secure external funding

In the first year of the project we have submitted 4 grant proposals with different Co-PIs:

Agency	Requested amount	Submission date	Status
NASA	$1250k	May 2022	declined
Florida Legislature FY2023 complimentary funding	$300k	July 2022	declined
National Science Foundation	$550k	Oct 2022	pending
State Fire Marshal	$300k	Dec 2022	declined

We also have submitted a White Paper to the Florida Legislature via the city of Miami Lakes to investigate structural damages and human health impacts from mine blasting ($1,740k). There is a distinct possibility of contracting with the Florida Department of Transportation now that UM has signed a Master Agreement with the Department. At a recent meeting with FDOT officials, the possibility of a pilot project was discussed. Finally, we have recorded a video to introduce our project: https://www.youtube.com/watch?v=1qZKXl7cNTk

7. References

Mirzaee, S., Amelung F., Fattahi, H. (2023). Non-linear phase linking using joined distributed and persistent scatterers, Computers & Geosciences, Volume 171