University of Nevada, Reno

# Large-Scale Shake Table Testing on the Effectiveness of Helical Piles to Mitigate Liquefaction-Induced Building Settlements

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# Acknowledgements


- Pacific Earthquake Engineering Research Center (PEER)
- Staff and a group of students at UCSD and Powell Lab
- Ram Jack

# Presentation Outline

- Background and Motivation
- Shake Table Testing Program
- Test Series #2 (with mitigation measure)
- Observations and Path Forward

# Background and Motivation

- 2011 M9.0 Tohoku Earthquake
- Widespread Liquefaction
  - 27,000 buildings damaged
  - Similar to Christchurch, NZ
- <u>Building foundation</u> performance varied
  - Deep foundations, good performance
  - Shallow foundations, extensive damage
  - 0 cm < 30 cm < 70 cm
  - Factor of 2.3


**Building (Pile Supported)**
**-No Settlement**

**Free field**
**-30cm Settlement**

**Building (Mat Foundation)**
**-70cm Settlement**

Photo:
Ashford et al. 2011

# 1994: NORTHRIDGE

"Structures damaged in the Marina District of San Francisco. The *first story of this three-story building was damaged because of liquefaction*; the second story collapsed. What is seen is the third story." 1989 Loma Prieta Eq

**Photo: USGS**

| | |
|---|---|
| Total Property Damage | $40 Billion |
| Residential | $20 Billion |
| Insured Residential | $10 Billion |

**50%!**

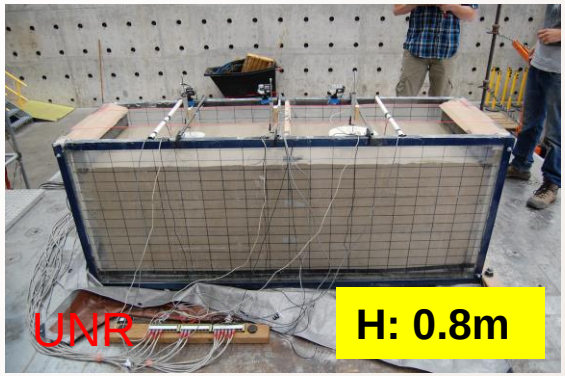
## Reference:
## Janiele Maffei (2019) – CEA

# Research Approach

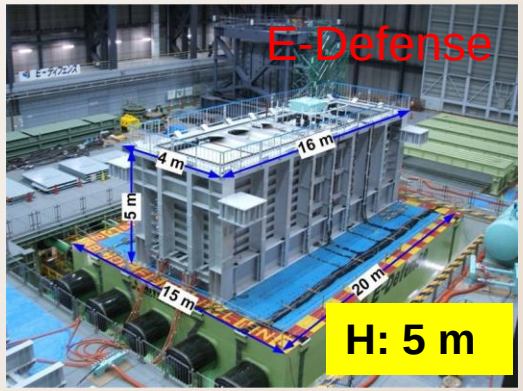
- Field case histories
- Centrifuge tests
- 1-g shaking table tests

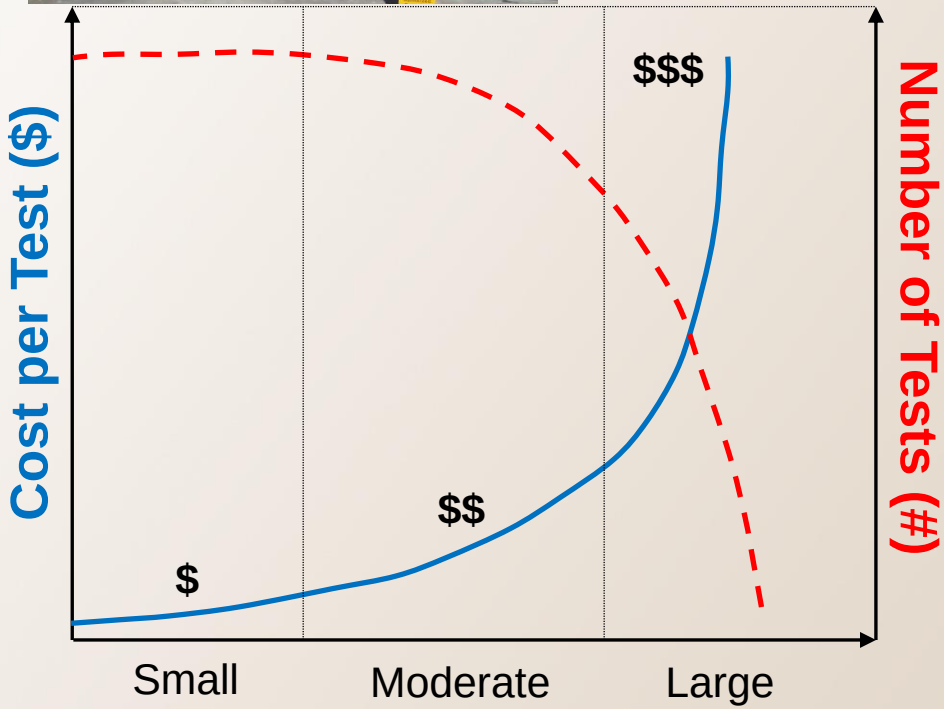
# Shake Table Testing

- Model size vs. cost



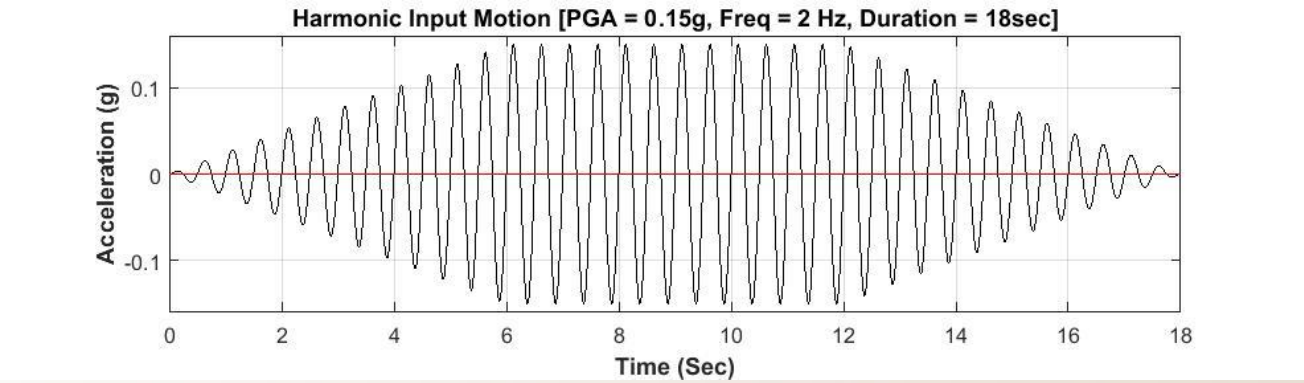


# Testing Program

- Two series of tests
  1. Without any mitigation (baseline test) – Completed June 2018
  2. With helical piles as a countermeasure – completed in April 2019
- Multiple shakings including white noises during each test

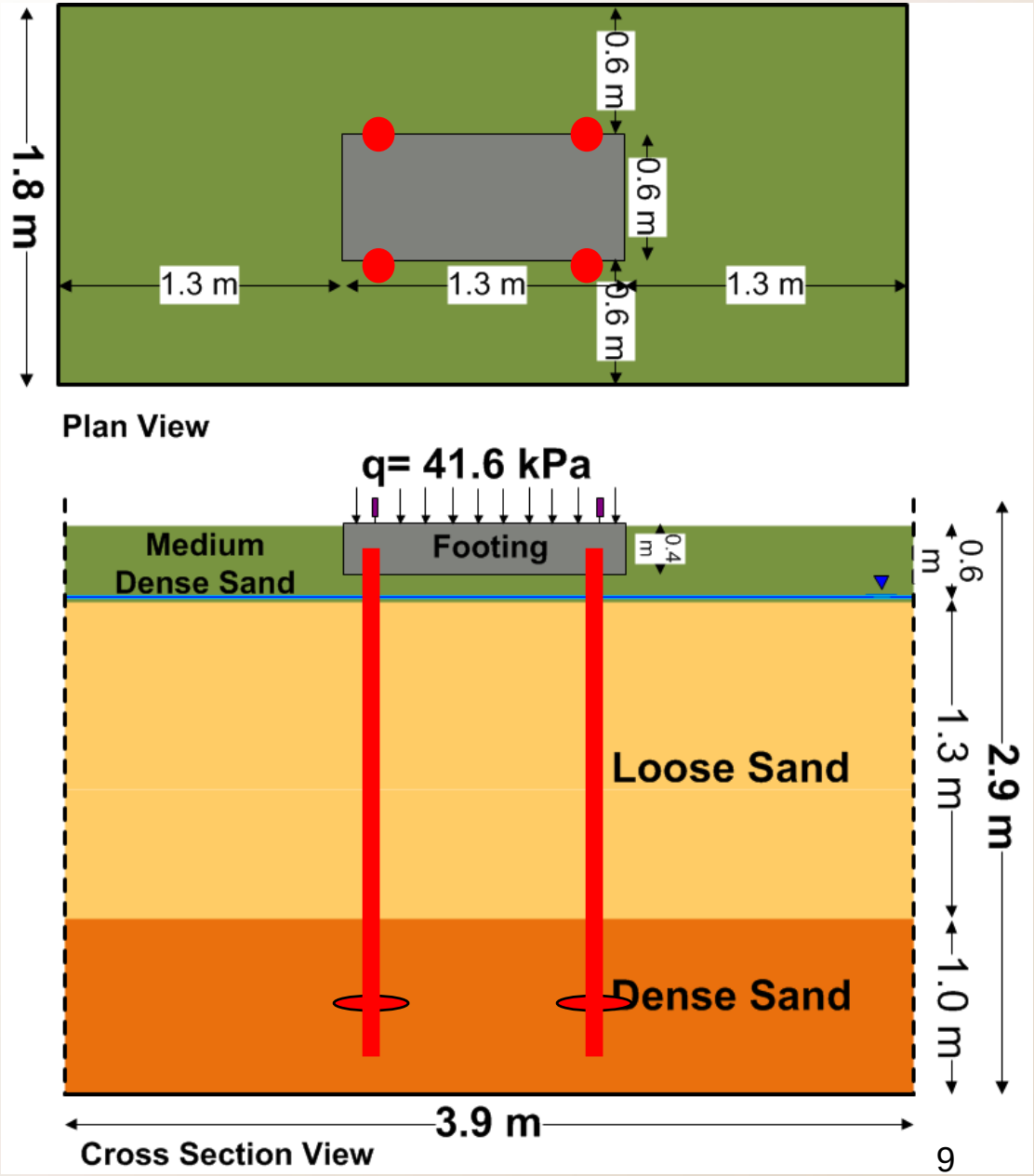
| Test # | PGA (g) | GWT (m) |
|---|---|---|
| 2-1 | 0.15 g | 0.6 |
| 2-2 | 0.3 g | 0.6 |




**Target Input Motion**

# Test Layout

- Isolated footing
- GWT @ 0.6m
- Uniform liquefiable layer (4.5') w/ 2' of crust
- 41.6kPa contact pressure
- Extensive instrumentation
- A group of 2×2 helical piles
- w/ and w/o mitigation



# Laminar Box at UCSD's Powell Lab


- Height= 2.9m (9.5 ft), Width= 1.8m (5.9 ft), Length= 3.9m (12.8 ft)

# Model Design and Construction Challenges

- Extensive instrumentation of helical piles
- Design of pile-footing connection
- Used bracket connection, no specifications for lateral capacity
- Suitable for dynamic Loading?

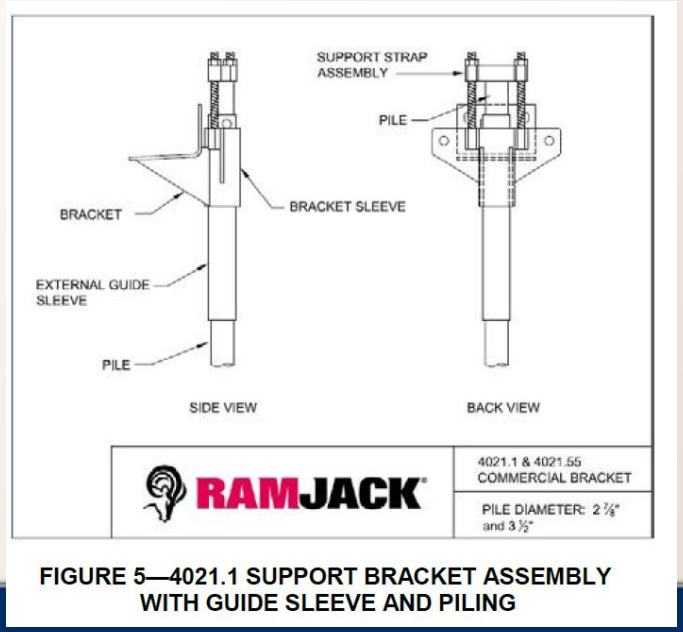



FIGURE 5—4021.1 SUPPORT BRACKET ASSEMBLY WITH GUIDE SLEEVE AND PILING


a
SG55


b


c


d


e

# Completed Model Prior to Shaking


Side View

Top View

Before Test


After Test

# Observed Sand Ejecta


Photo 13. Differential settlement of 4 story RC apartment house due to liquefaction.

Ref: Yamagichi et al. (2012)

CPT Mounting

CPT Setup

Model prior to shaking

# Observations and Path Forward

- Helical piles performed very well (settlement reduction)
- Extensive liquefaction and sand ejecta were achieved in both tests
- Data interpretation to continue
  - Test series#1 (baseline) results were submitted for publication
  - This scale testing on a shallow foundation on liquefiable soil: first-of-its-kind => greater opportunities!
  - Industry support was key to our success
  - Collaborative projects are unique: opportunities and complementing expertise and facilities => coordination is key!


# Thank you!