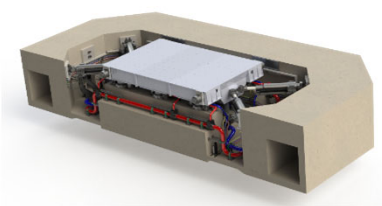
National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

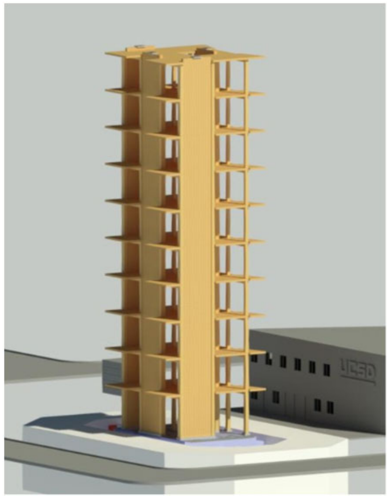
GEO-STRUCTURES
Earthquake Engineering Resilience

Sissy Nikolaou, WSP



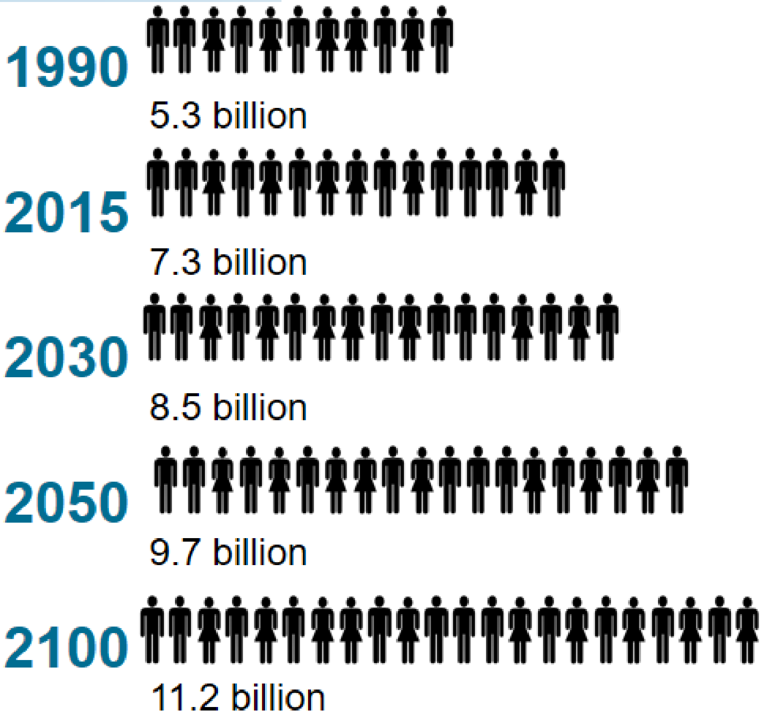
Joint Academia-Industry NHERI Workshop
NHERI@UC San Diego

September 21-22, 2020
University of California, San Diego



FACT : Smaller Events ≠ Less $ or ♥ Lost

increasing urbanization, climate change



2018 "unremarkable" for natural hazards with many smaller disasters

Immense toll :

13,500 ♥ lost (vs. 11,000 in 2016).
155B $ losses → 76B in pay-outs (Swiss Re), 4th highest ever

Trend : "new norm" of higher-frequency, more localized events, many related to extreme weather, causing ever greater damage.

With climate change, **if extreme events affect a new densely populated area,** what was once a small localized event **will become now a catastrophic event.**

wsp

R esilience

Foundation of a new Babel Tower ?

Google Searches past 15 years
Bruneau & Reinhorn (2019)

SEARCH	2016	2000	factor
Resilience	47,000,000	7,880.000	6
Engineering Resilience	**17,300**	**6,200**	**3**
Quantifying Engineering Resilience	**3**	**1**	**3**

Bruneau & Reinhorn, 2019

What do I think ?

Disasters: When/How not If

multi-hazard predictions
climate change
natural/urbanized environment

Resilience is a Choice

making *informed decisions* based on risk assessments with best knowledge, science, technology, while optimizing funding allocation.

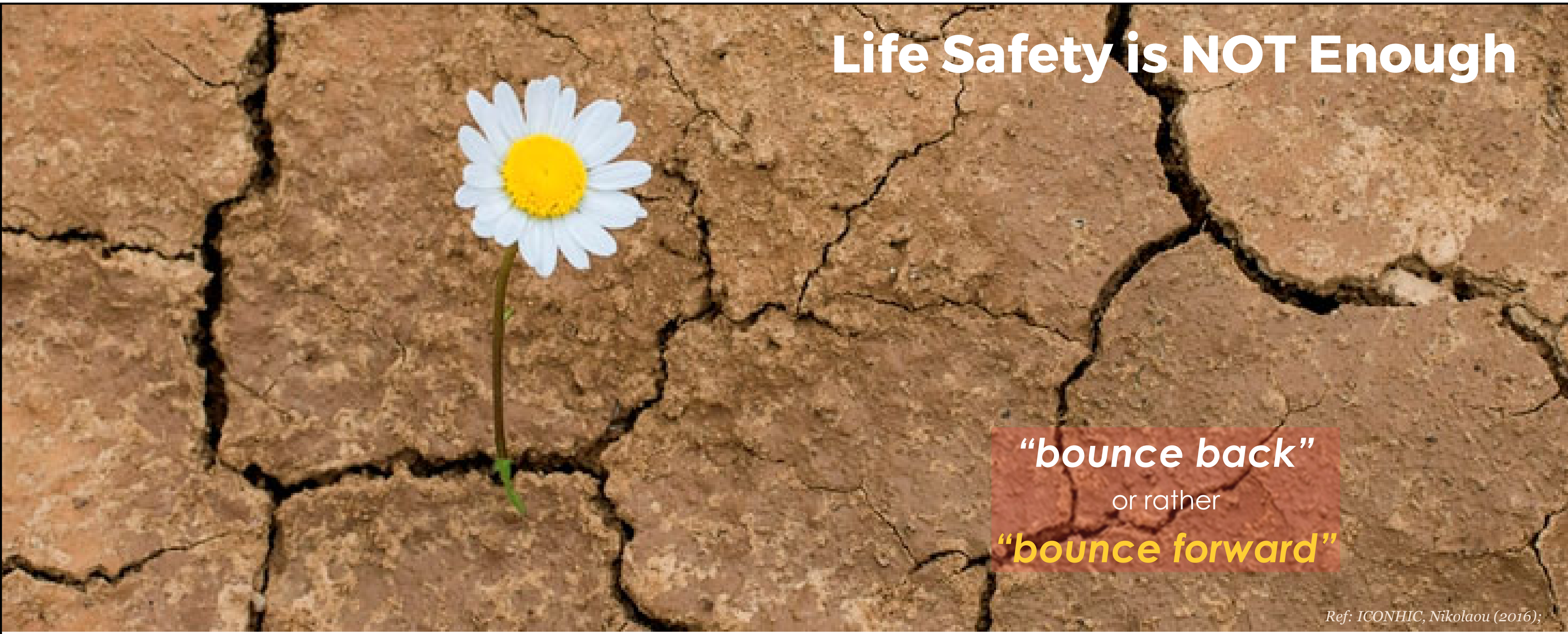
Simple: *it works* (6-fold return in federal investments)

Society: building *trust in engineering* through performance

Do vs. Have Park et al. 2012

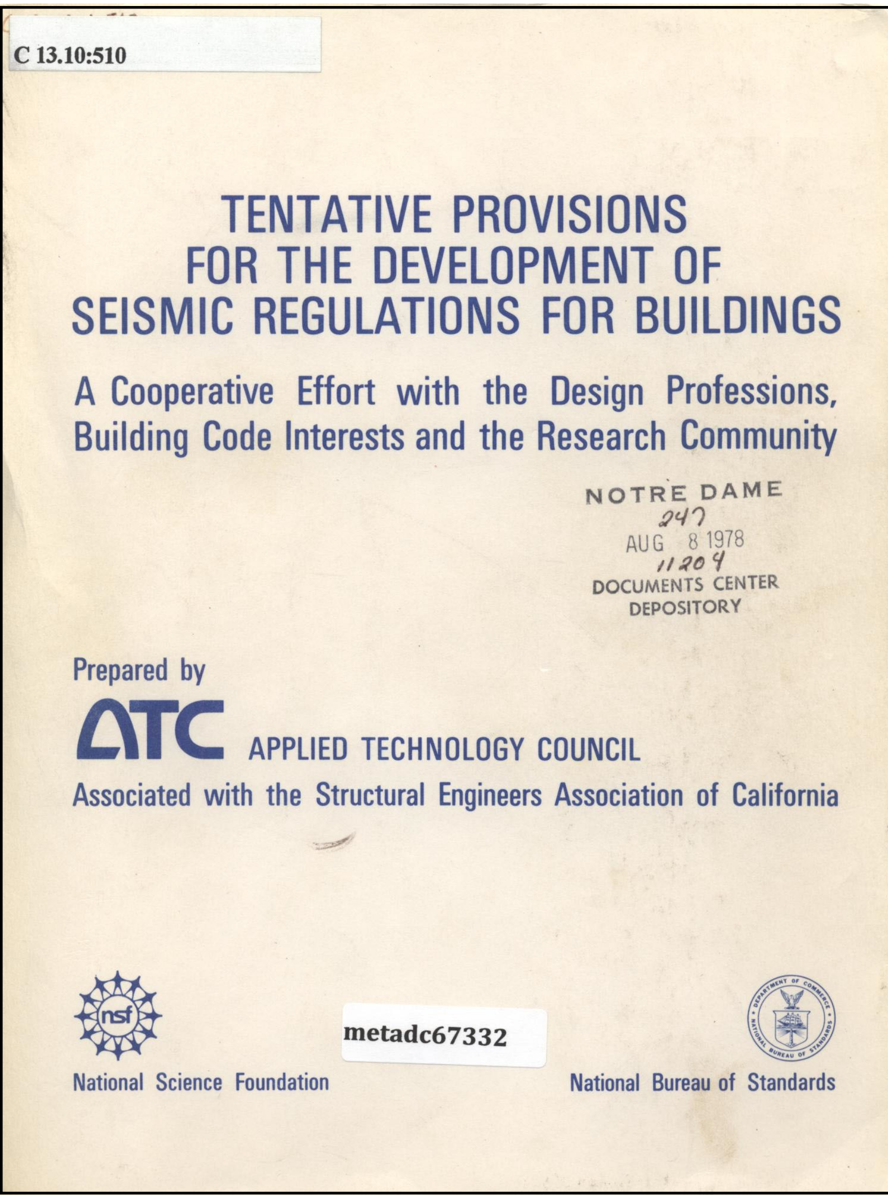
Emergent property of what an engineering system **does**, rather than a static property the system **has**; outcome of a **recursive process** wiht **sensing, anticipation, learning,** and **adaptation**, making it complementary to risk analysis with important implications for the **adaptive management of complex, coupled engineering systems**.

Life Safety is NOT Enough



“Life Safety” *objective → **no loss of life after an extreme event**. The structure gives the chance to get out of it alive, while it may be heavily damaged or need to be demolished later.*

Life quality, *rather than* **life safety** *represents* ***societal needs of resilience*** *as not a “bouncing back” but rather* ***“bouncing forward” strategy*** *that relies on* **Functional Recovery** *(NIST-FEMA, 2020) goals.*



TENTATIVE PROVISIONS
FOR THE DEVELOPMENT OF
SEISMIC REGULATIONS FOR BUILDINGS

A Cooperative Effort with the Design Professions, Building Code Interests and the Research Community

Prepared by
ATC APPLIED TECHNOLOGY COUNCIL
Associated with the Structural Engineers Association of California

National Science Foundation

National Bureau of Standards

WISDOM OF THE PAST

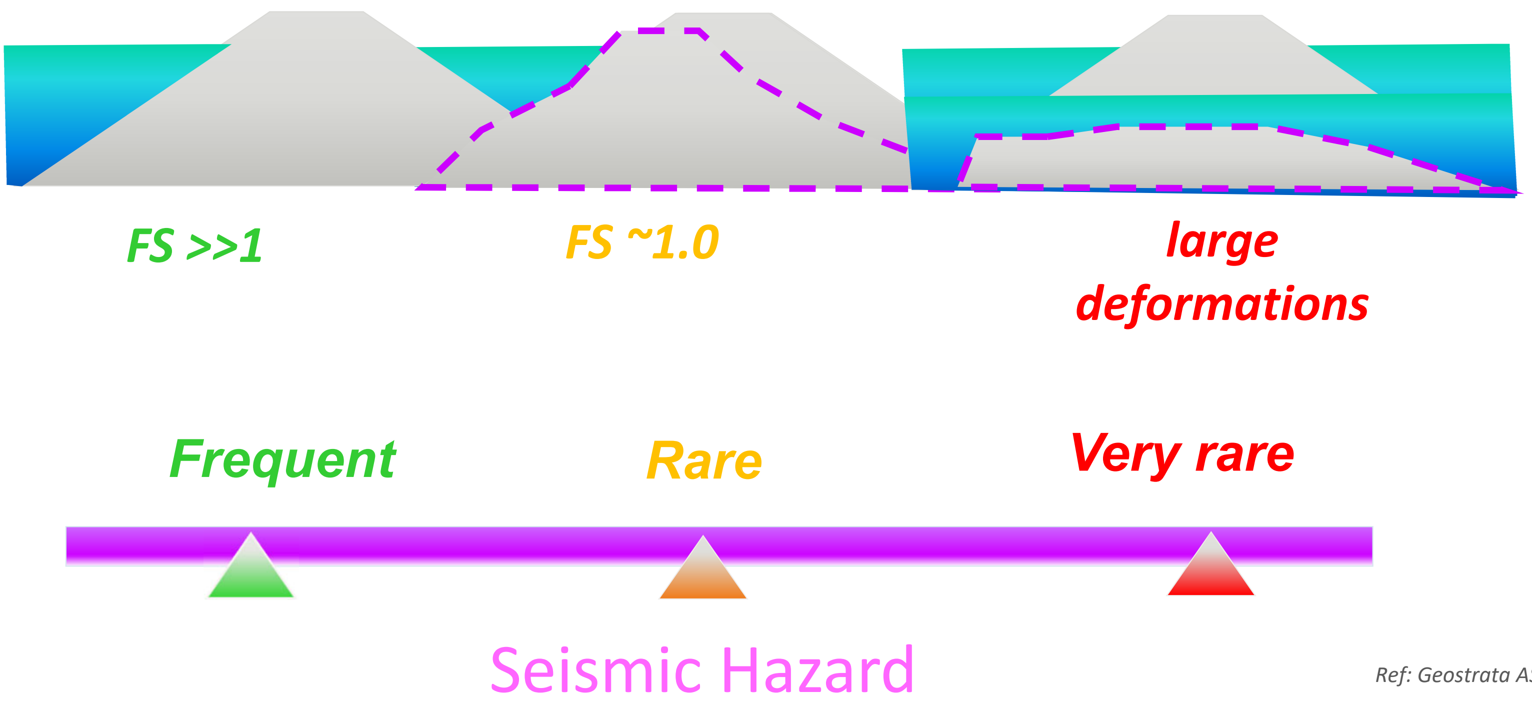
NBS [NIST] **ATC 3-06 (1978):** *It really is the* ***probability of failure*** *with resultant* ***casualties*** *that is of concern…….The geographical distribution of that probability is* ***not*** *necessarily* ***same*** *as the distribution of probability of exceeding some ground motion….*

FOUNDATION SEISMIC DESIGN

"Although.. Codes of Practice
begin with good intentions, they often
constrain innovation + ingenuity ... eventually
becoming the *only* basis of acceptable design."

M. Puller (1998): "Deep Excavations"

RESILIENCE-BASED GEOTECHNICAL EQ DESIGN



Ref: Geostrata ASCE (Nikolaou, 2013)

RESILIENCE-BASED GEOTECHNICAL DESIGN

FUNCTIONAL RECOVERY GOALS

NIST-FEMA (2020)

Remain *operational* after medium-intensity earthquakes

Preserve *structural integrity* under extreme loading

Demonstrate *redundancies*

Resilient Foundation Design

Example - Earth Retaining Systems

RESILIENCE-BASED GEOTECHNICAL DESIGN

Example : Earth Retaining Systems

"equivalent" Walls → **Safety Factor (FS)**
strength-based

Shaking Levels → **Low intensity**
within design levels

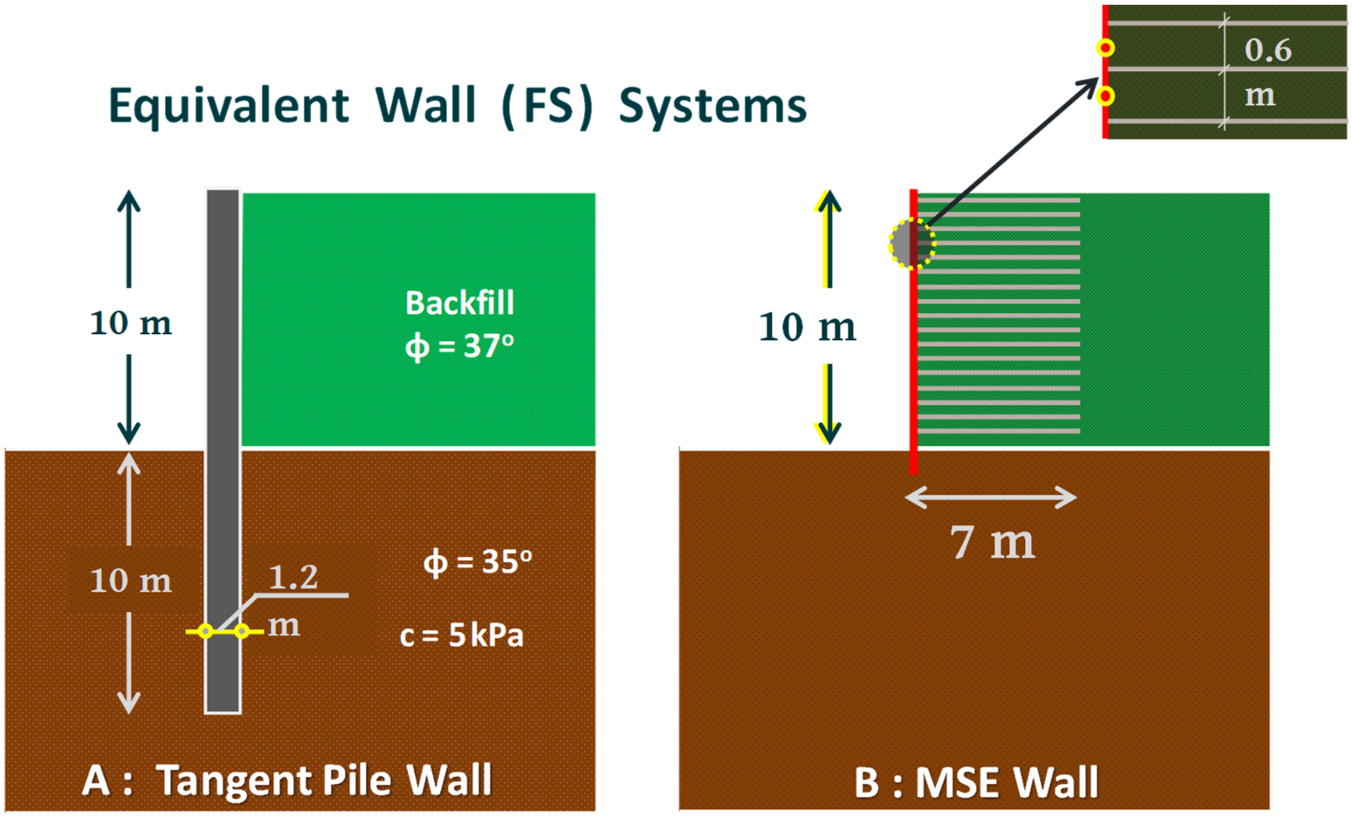
Shaking Levels → **Extreme Event**
well beyond design

FACTOR OF SAFETY (FS)

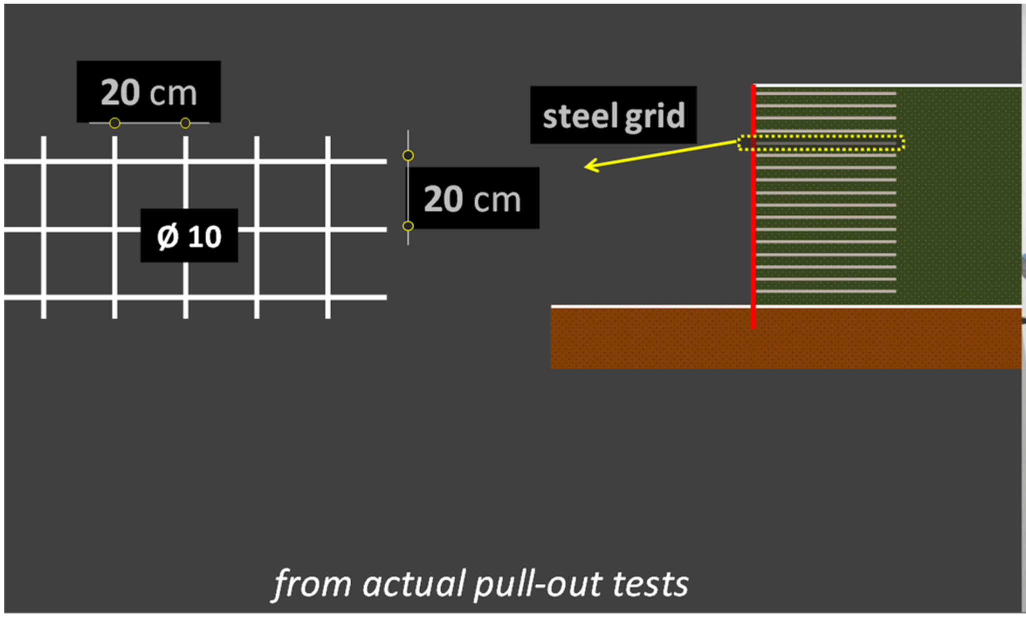
Static
FS_{st} = 1.8

Pseudo-Static
FS_{EQ} = 1.2
(α = 0.16 g)

Equivalent Wall (FS) Systems



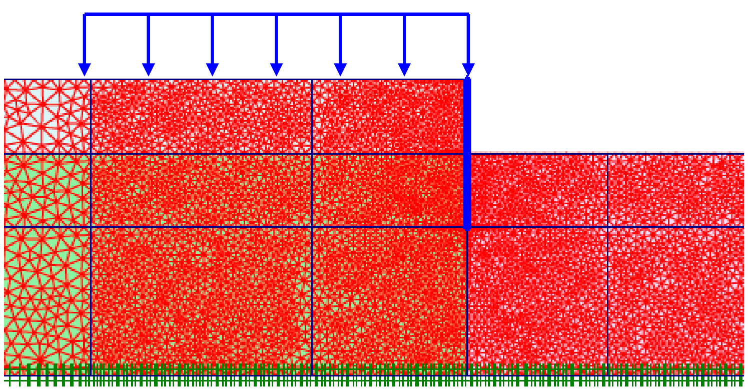
TRANSVERSE BARS



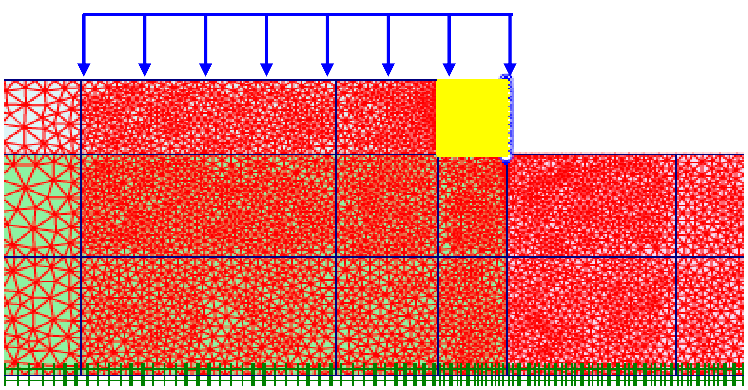
National Technical University of Athens, Soil Dynamics Laboratory

Resilience-Based Geotechnical Application

Numerical Analysis for FS



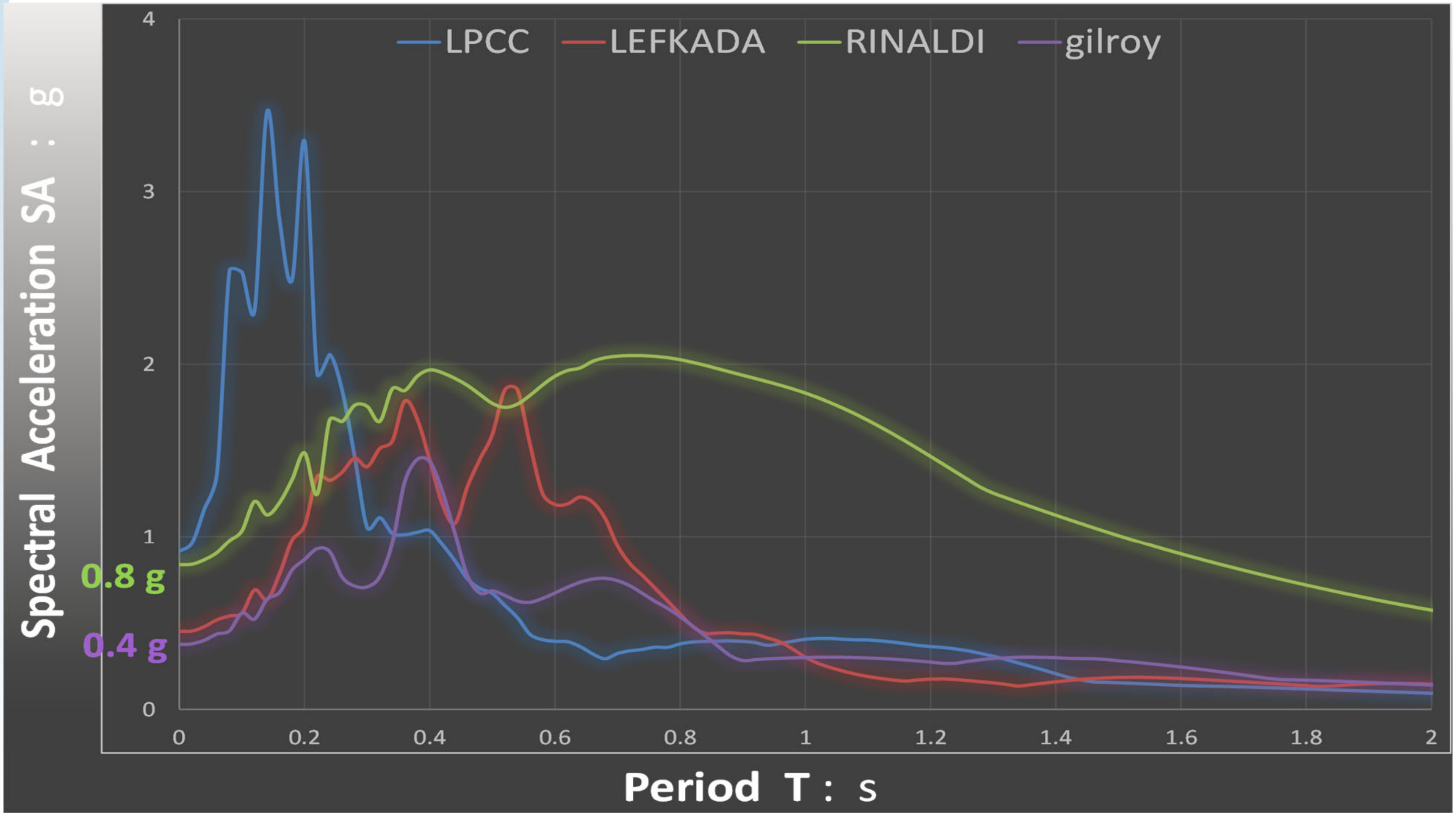
A : Tangent Pile Wall



B : MSE Wall

	A		B	
Static	$FS_{st} = 1.8$	=	$FS_{st} = 1.8$	
Pseudo-Static	$FS_E = 1.2$	=	$FS_E = 1.2$	*(α = 0.16 g)*

INPUT GROUND MOTIONS

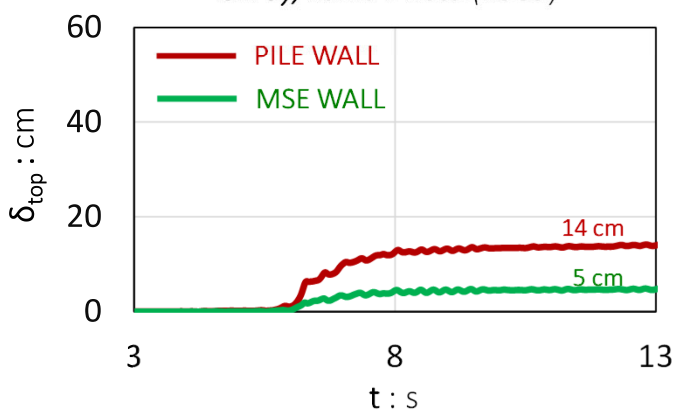


DYNAMIC RESPONSE

Top of Wall Displacement

PGA ≈ 0.4g

Gilroy, *Loma Prieta (1989)*

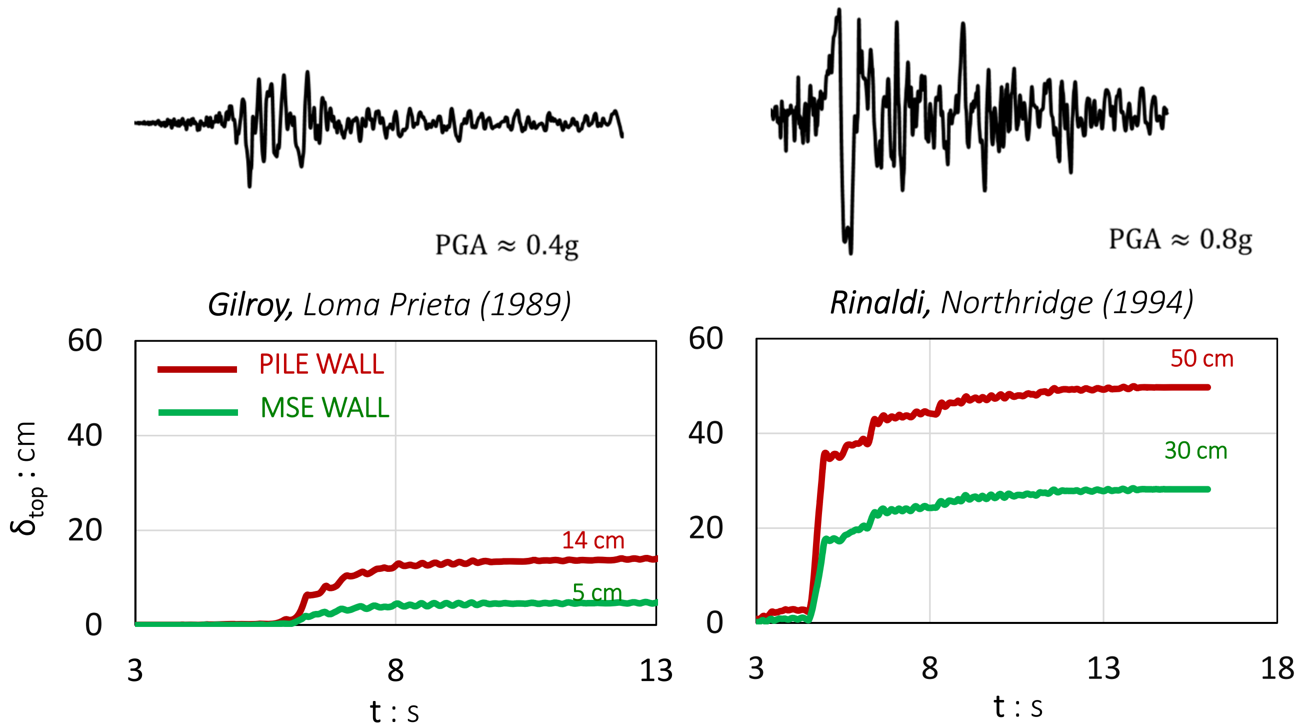


PGA ≈ 0.8g

Rinaldi, Northridge (1994)

DYNAMIC RESPONSE

Top of Wall Displacement



MSE wall behaves significantly better

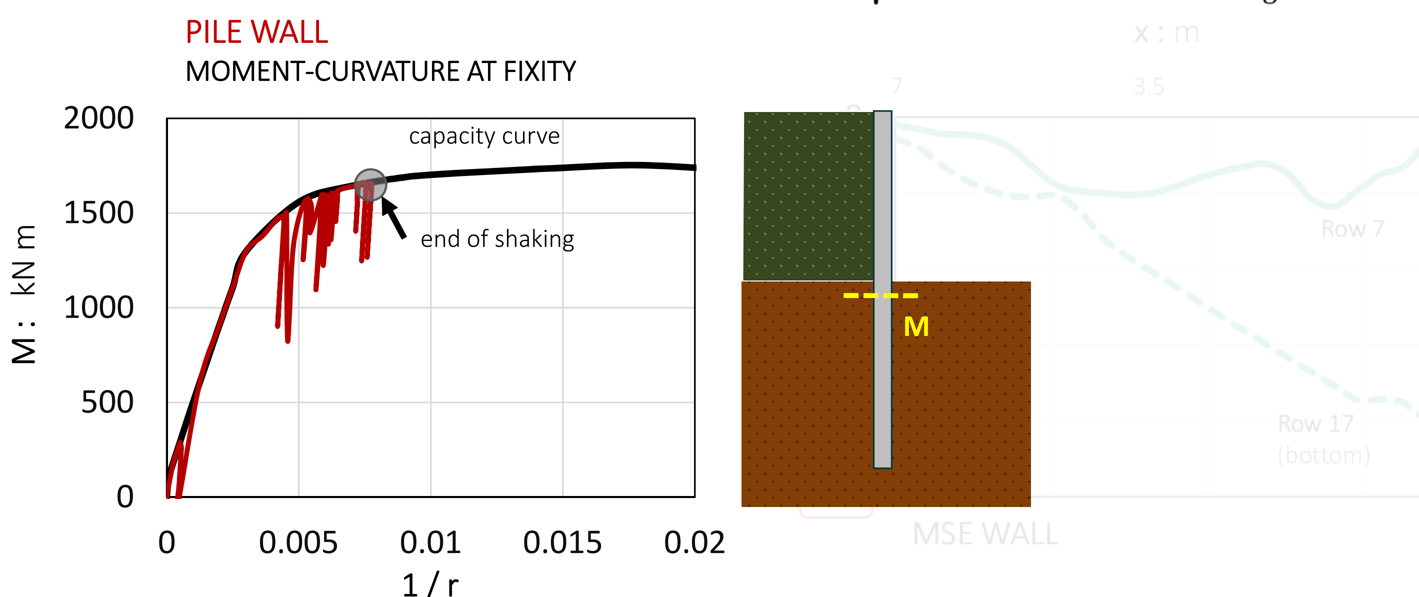
Bending Moment

PERFORMANCE QUANTIFIERS

Extreme Excitation (Rinaldi)

Quantification of Performance

Pile Wall: Moment-Curvature at fixity (left)



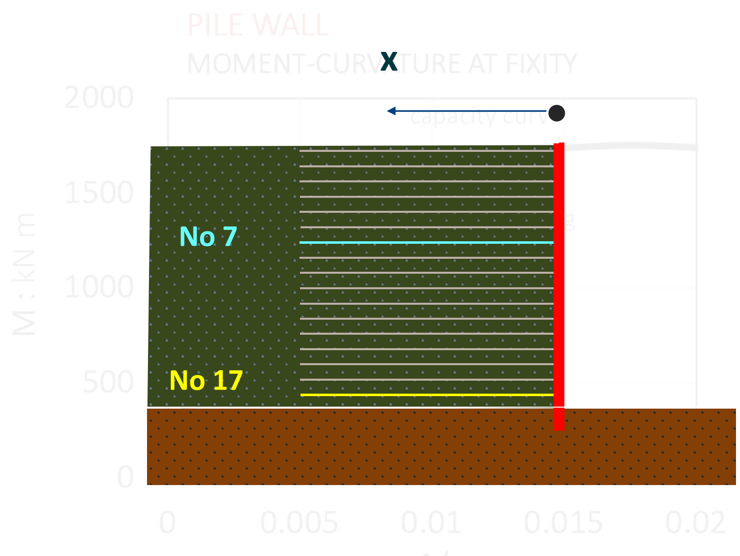
Axial Stress

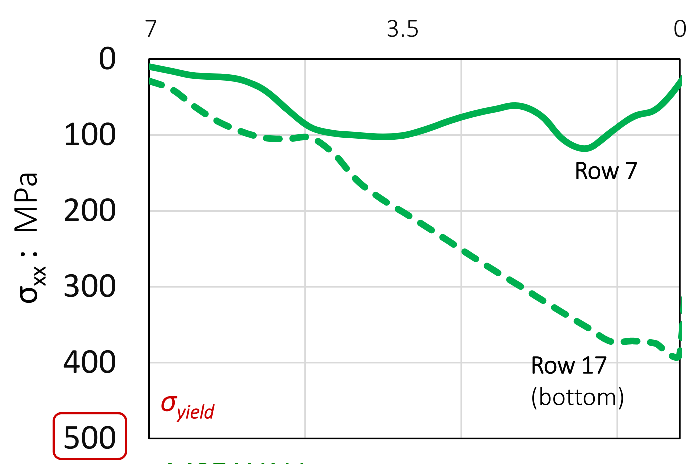
PERFORMANCE QUANTIFIERS

Extreme Excitation (Rinaldi)

Quantification of Performance

MSE Wall: Axial stresses along rib length
@ middle, bottom heights





MSE WALL
AXIAL STRESSES ALONG RIB

PERFORMANCE QUANTIFIERS

Extreme Excitation (Rinaldi)

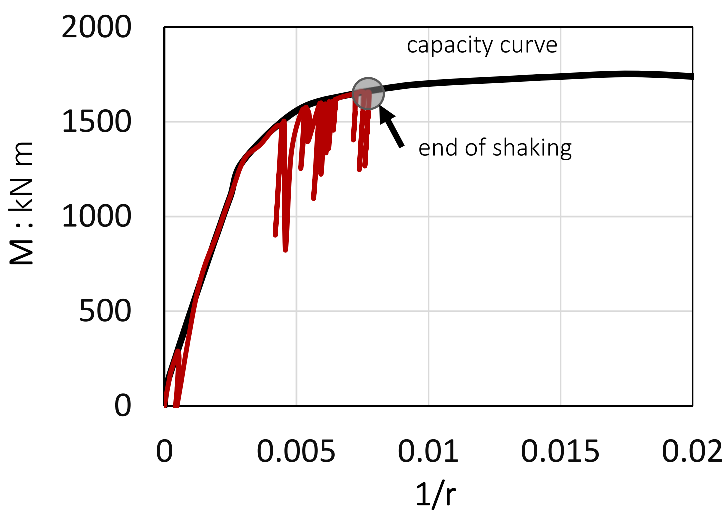
Quantification of Performance

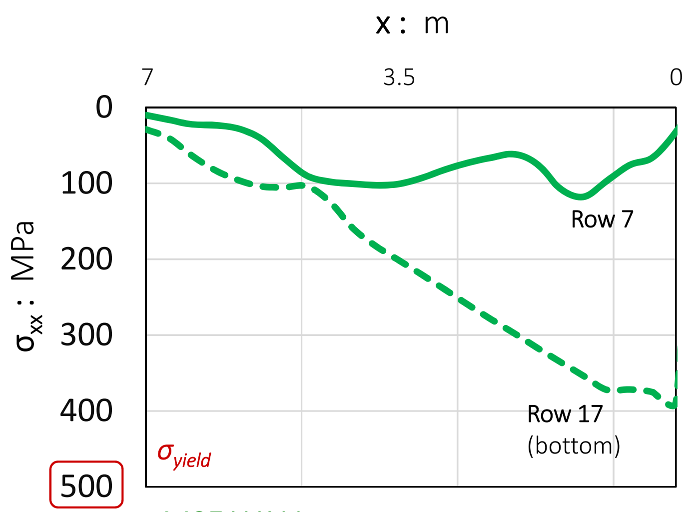
Pile Wall: Moment-Curvature at fixity

PGA ≈ 0.8g

PILE WALL

MOMENT-CURVATURE AT FIXITY



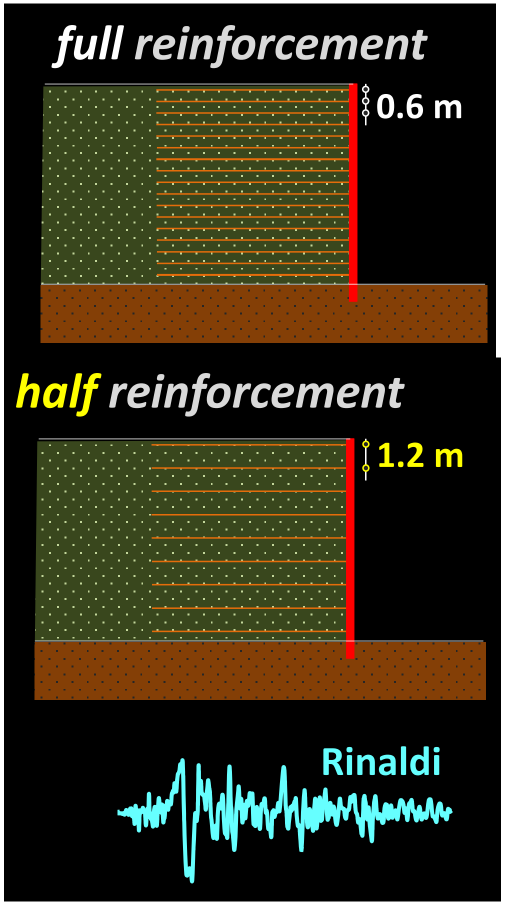


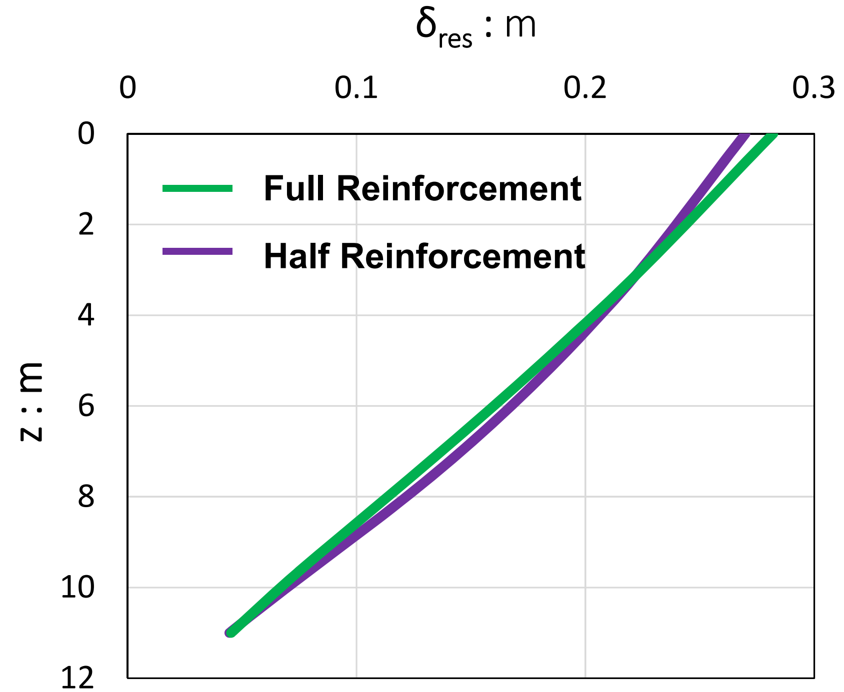
MSE WALL

AXIAL STRESSES ALONG RIB

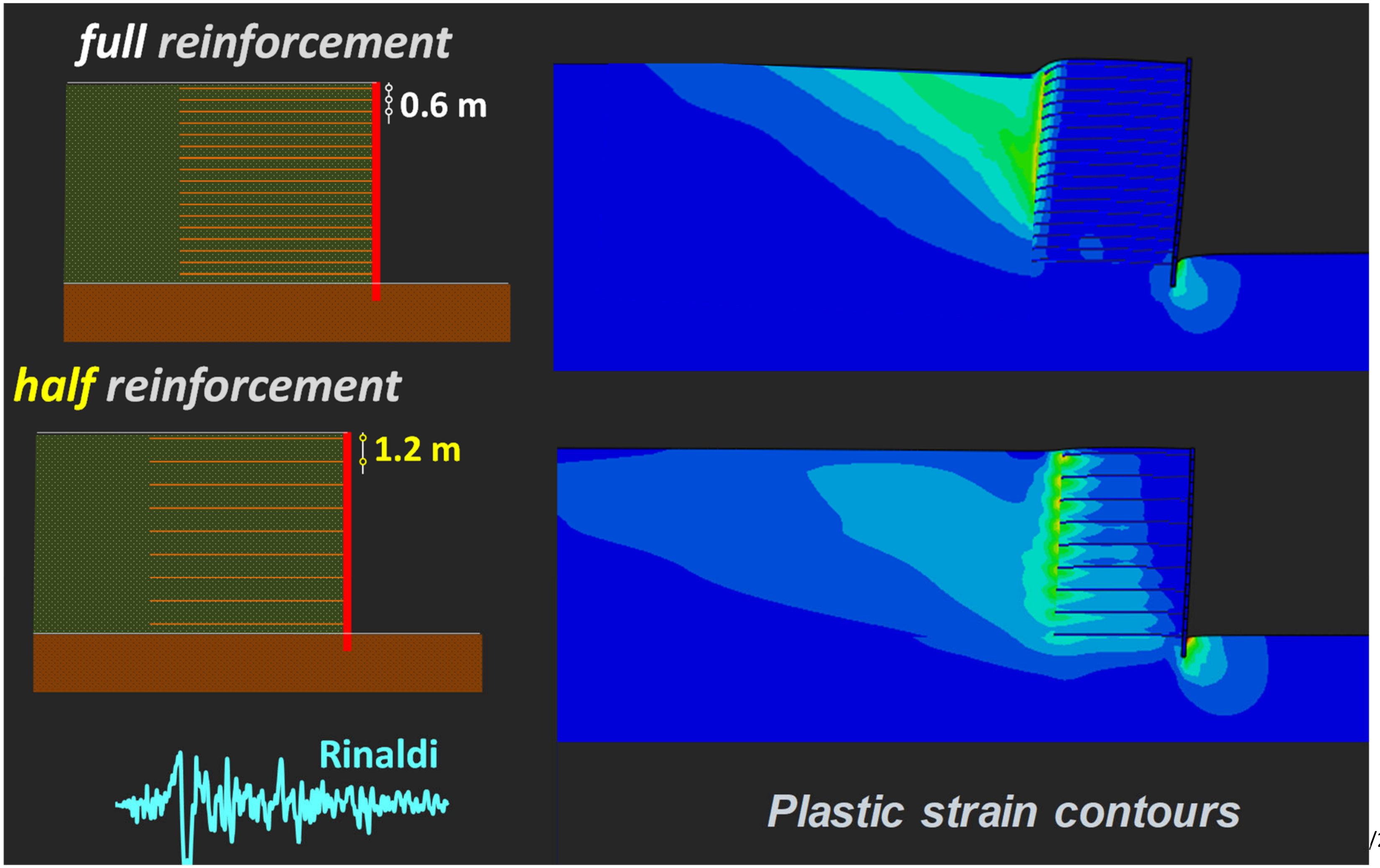
REDUNDANCY EVALUATION

MSE Wall





MSE Wall Redundancy Evaluation



RESILIENCE-BASED GEOTECHNICAL DESIGN

Example : Earth Retaining Systems

Conclusions

Both systems ***may avoid collapse*** during strong earthquakes, but the ***pile wall deformation*** would be unacceptable.

The ***MSE system*** is more ***redundant***, making it likely to sustain multiple & smaller events offering both risk optimization and cost-effectiveness

Reviewing in-depth ***numerical results*** provide valuable insight in the behavior of the system

Actual Observations

Ref: Kuwano et al. (2014)


This could save me money !


This could sponsor my research

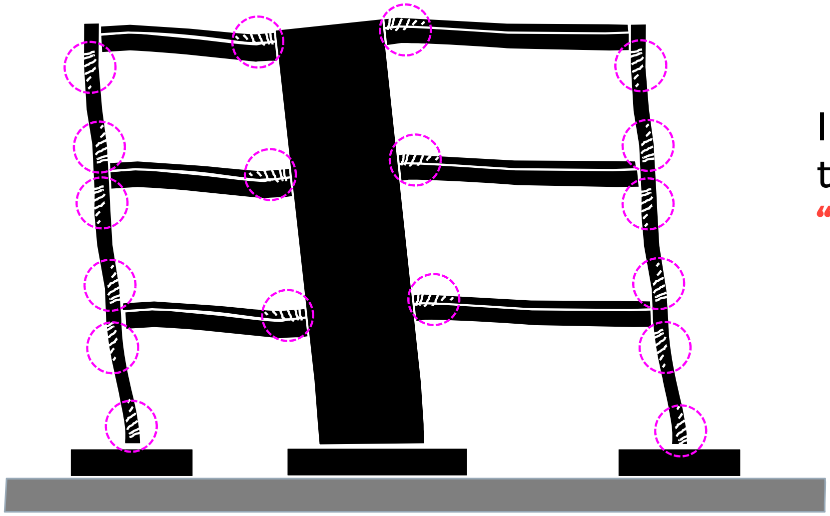
DARE

to Think Differently, Beyond Codes

Is Stronger Better?

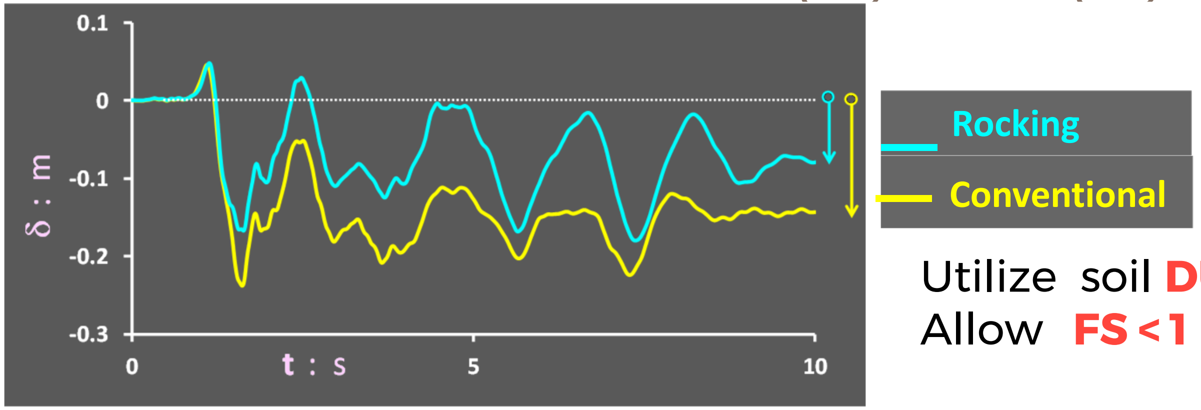
IS STRONGER BETTER?

Resilience by Geo-Design



Intentionally **UNDER-design** the foundation so **plastic "hinging"** will develop at **soil**

Gazetas et al. (2018); Kutter et al. (2017)



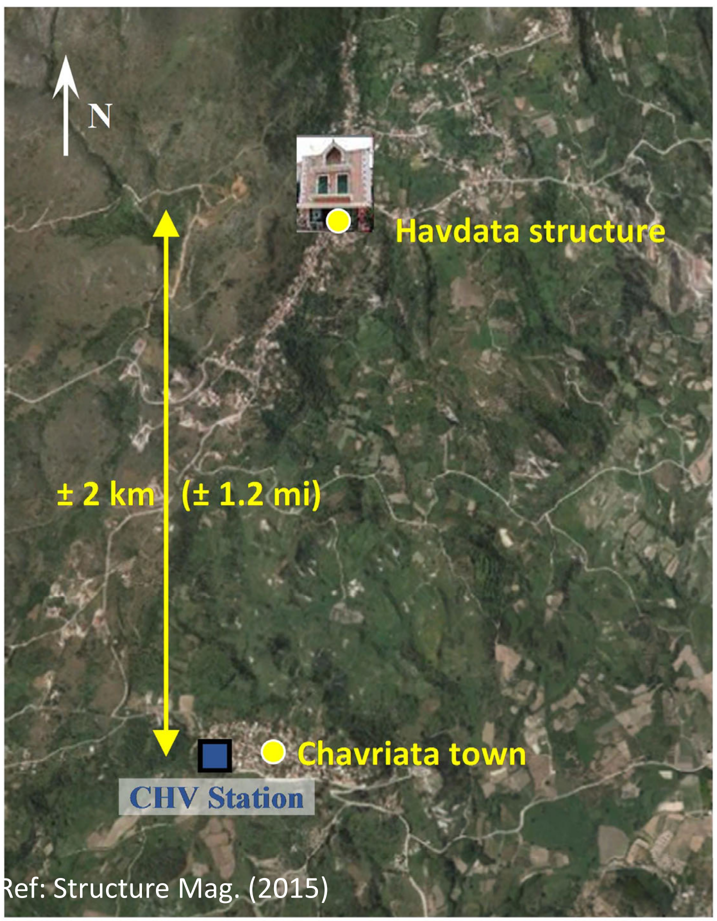
Utilize soil **DUCTILITY,**
Allow **FS < 1** !!!

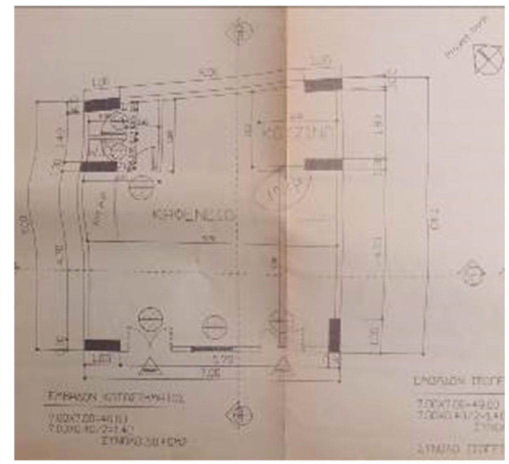
LEARNING from EARTHQUAKES

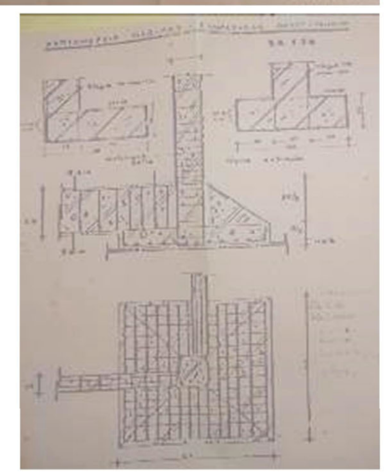
Why Did this Work?

2014 Greece EQs

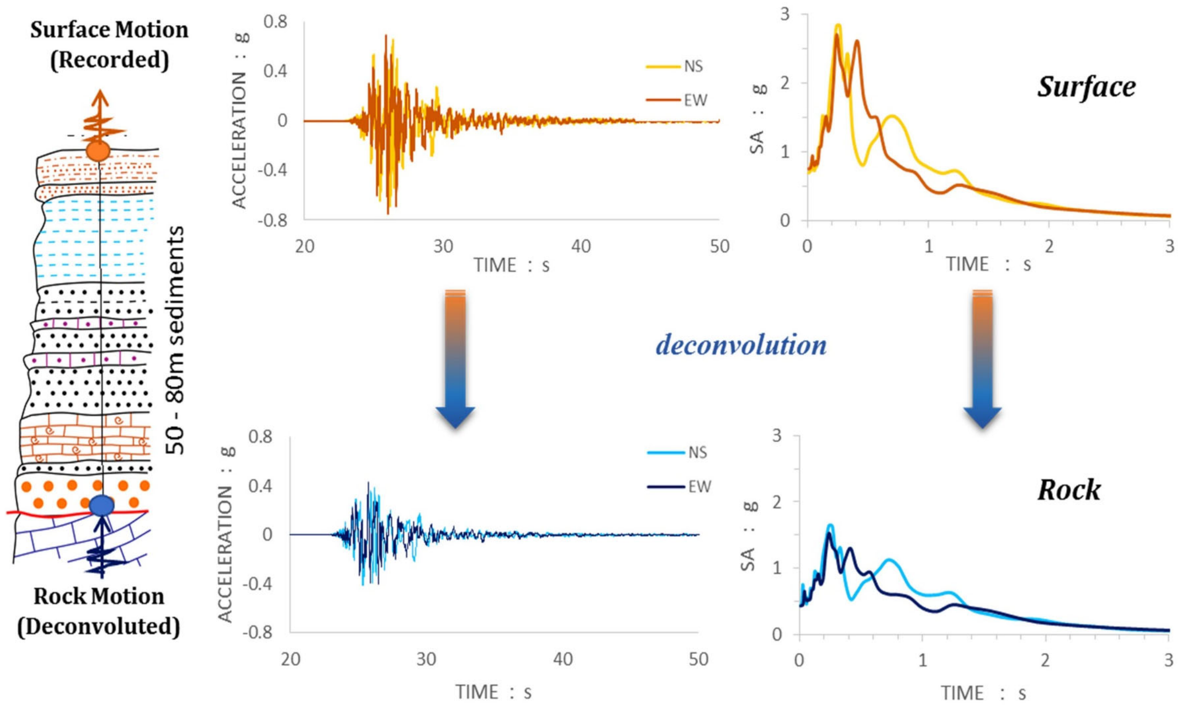
1995 Havdata RC Structure ~ 2 km north of CHV1





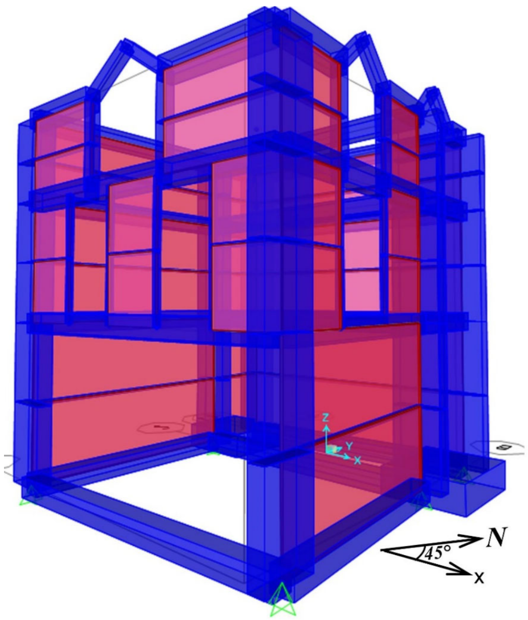


Ground Motion Simulation



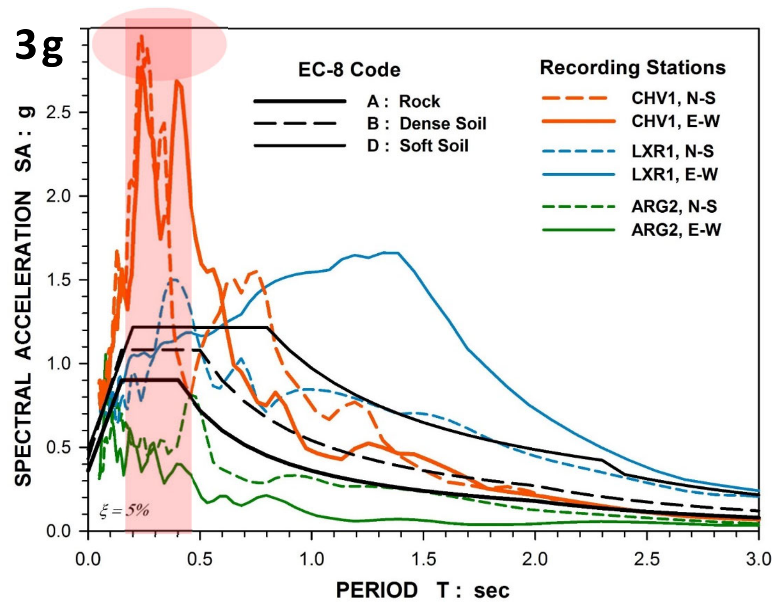
Ref: Structure (2015); GEER-034 (2014)

Resilient Behavior Explained



Structural Period (with infill)

T_1 ~ 0.08 s; T_2 ~ 0.05 s



without infill

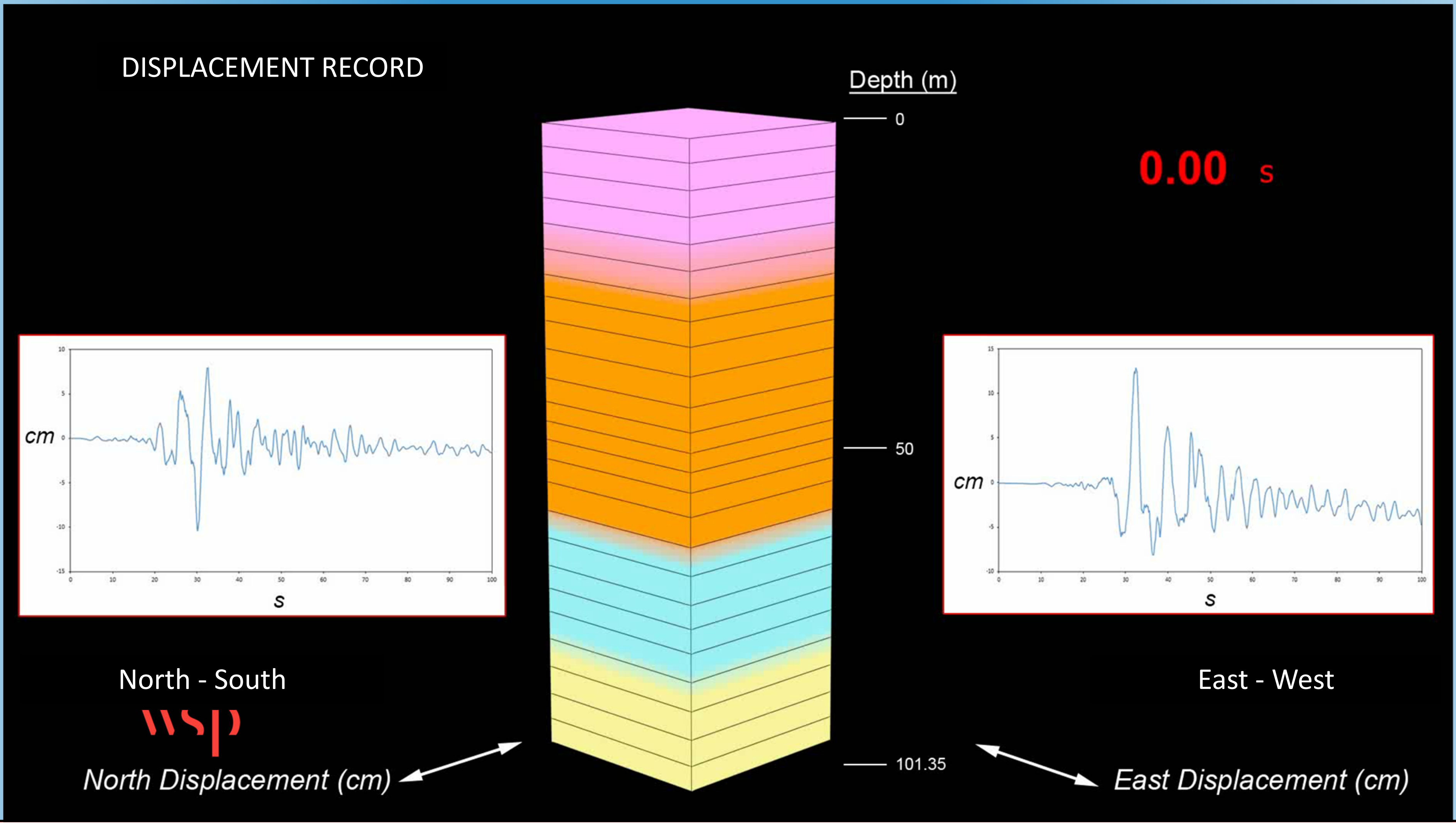
T_1 ~ 0.31 s; T_2 ~ 0.26 s

What are you Talking About?

COMMUNICATION IS KEY

wsp

VISUALIZATION TO COMMUNICATE WITH OTHER DISCIPLINES



RESILIENCE-BASED GEOTECHNICAL DESIGN

Needs for NHERI @UCSD Shake Table

Understand ***fundamental behavior*** of both systems

Perform ***experiments in various scales*** and the laboratory to ***calibrate and validate*** computational models.

Incorporate ***reconnaissance lessons*** of success

Innovate with materials, concepts and construction methods that can provide ***redundancy***

Prove concepts with extreme and ***multiple & smaller multi-hazard events*** offering both ***risk optimization*** and ***cost-effectiveness***.

Communicate and ***collaborate*** with practice

“Never, ever, think outside the box.”

THE NEW YORKER

Many thanks for your attention

and to the

NSF-Funded NEHRI Program at UCSD

for this great opportunity to present my views

My mentors

Prof. G. Gazetas, NTUA
Dr. A. Rahimian, WSP

My collaborators

Dr. R. Kourkoulis, NTUA
Dr. F. Gelagoti, NTUA
Dr. I. Georgiou, NTUA
Dr. Ilya Shleykov, WSP

Sissy Nikolaou
M: +1-917-301-2507 | S.Nikolaou@outlook.com