ESG4 Conference @ UCSB

4th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion

ENHANCING SITE RESPONSE MODELING THROUGH DOWNHOLE ARRAY RECORDINGS

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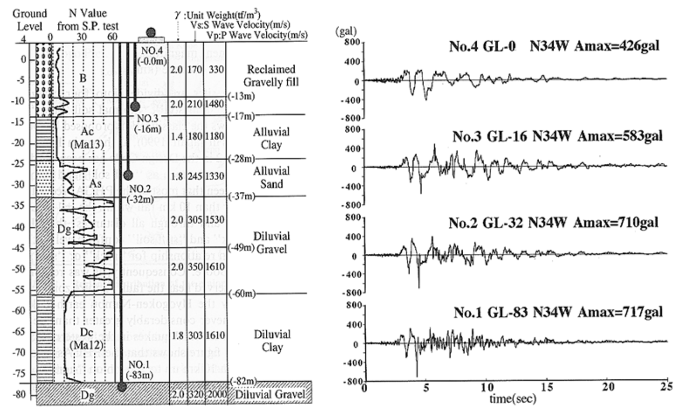
OUTLINE

- Motivation and background
- SelfSim inverse analysis framework development with porewater pressure development
- Learning soil behavior from synthetically generated downhole arrays
- Learning soil behavior from field array measurements – Wildlife array, CA
- Simulation of downhole arrays from 2011 Tohoku, Japan, earthquake.
- Concluding remarks

MOTIVATION – AVAILABLE VERTICAL ARRAYS

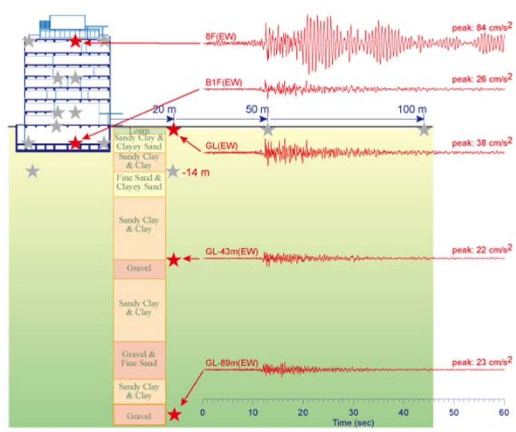


Soils & Foundations (1996)

Port Island, Kobe, 1995. Vertical Array

VERTICAL ARRAYS – WORLD WIDE

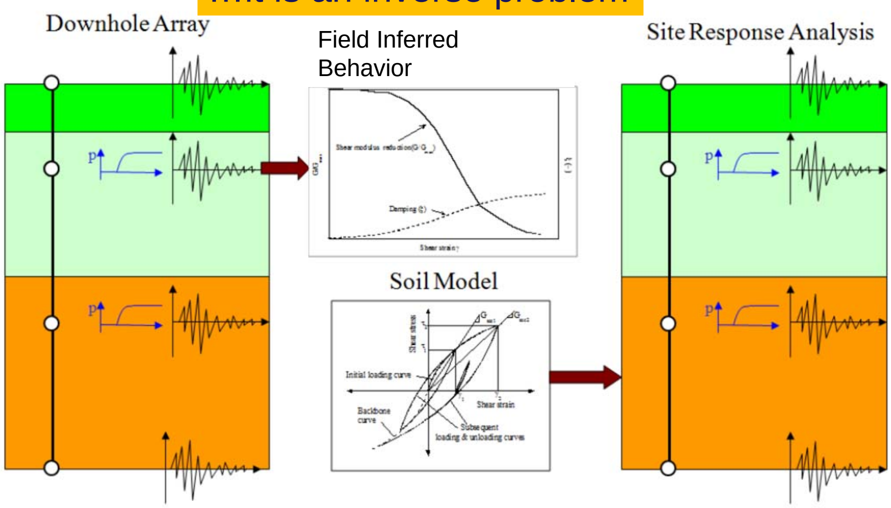
- US
- Turkey
- Taiwan
- Japan (Kik-net)
- …



Building Research Institute (BRI), Japan :
Urban Disaster Mitigation Research Center (annex) building

MOTIVATION

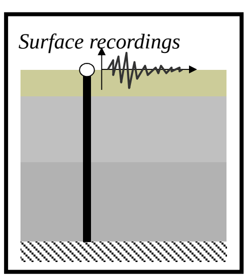
…it is an inverse problem

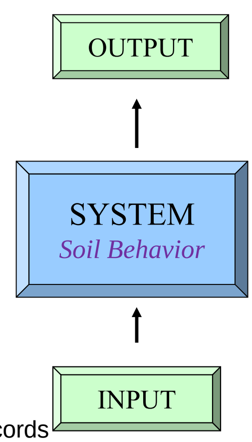


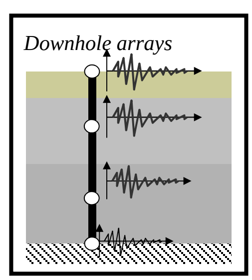
BACKGROUND – INPUT PROBLEMS

- Output is known (surface)
- Input is unknown
- System is unknown

- Output is known (surface)
- Input is known
- System is unknown

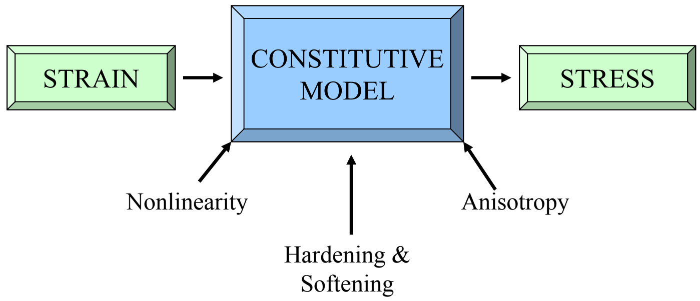






-Deconvolution
-Challenging
-Uniqueness? Need many records

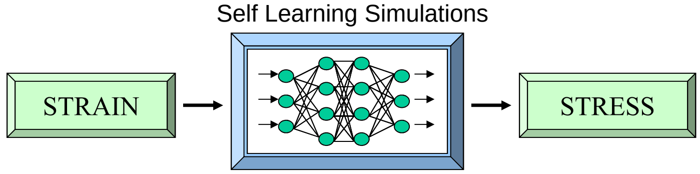
INVERSE ANALYSIS - OPTIMIZATION



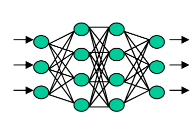
- Requires pre-defined constitutive model
- Difficult to develop & to refine for new loading conditions

INVERSE ANALYSIS – SELFSIM LEARNING

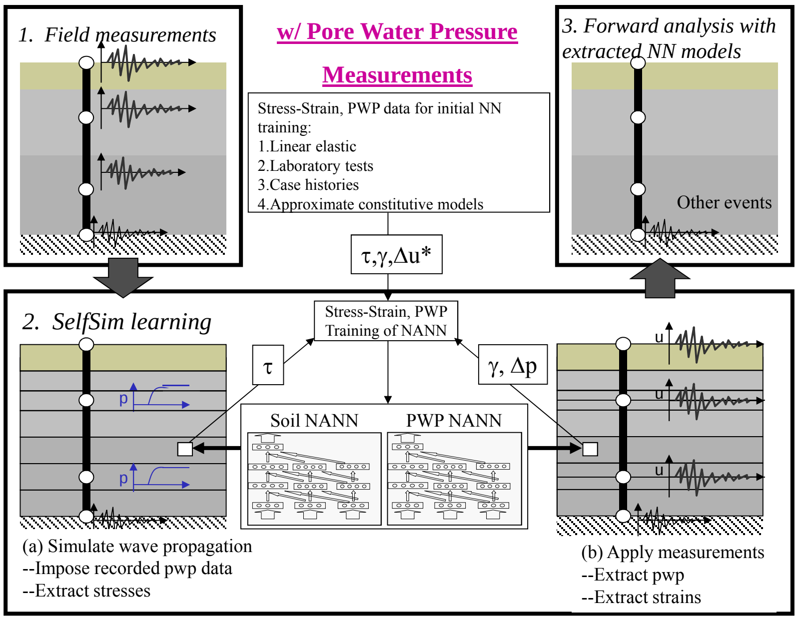
Self Learning Simulations



- Continuously evolving soil model (Artificial Neural Network, NN, Material Model)
- Material behavior in the form of a stress-strain-porewater pressure database
- Learn new behavior unconstrained by prior assumptions of soil behavior



SELFSIM ALGORITHM FOR DOWNHOLE ARRAY



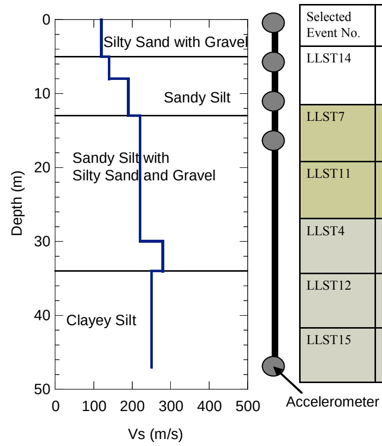
PRIOR DEVELOPMENTS

Tsai and Hashash: SelfSim inverse analysis application to Total Stress Site response Analysis

SELFSIM APPLICATION TO REAL ARRAYS (TSA)

LOTUNG ARRAY, TAIWAN – Total Stress analysis

– Measurements: 0m, 6m, 11m, 17m, 47m



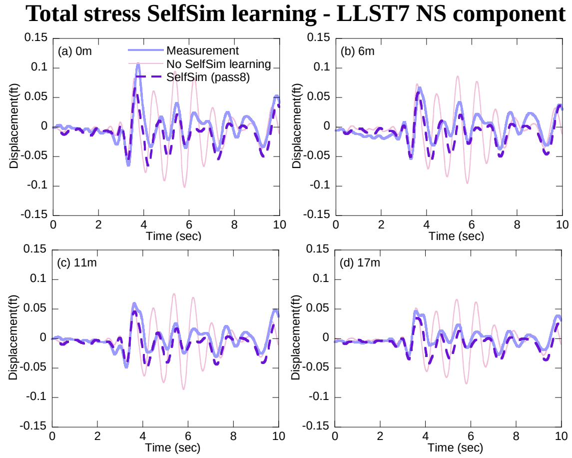
Selected Event No.	Date (M/D/Y)	M_L	Epicenter Dist. (km)	Measurement	Components	PGA (g)	Purpose
LLST14	7/30/1986	4.2	-	0m, 6m, 11m, 17m, 47m	NS	0.04	Calibration of small strain properties
					EW	0.03	
LLST7	5/20/1986	6.2	66.2	0m, 6m, 11m, 17m, 47m	NS	0.2	SelfSim Learning
					EW	0.16	Prediction
LLST11	7/17/1986	4.3	6	0m, 6m, 11m, 17m, 47m	NS	0.11	SelfSim Learning
					EW	0.06	Prediction
LLST4	1/6/1986	6.1	23.7	0m, 6m, 11m, 47m	NS	0.23	Prediction
					EW	0.15	
LLST12	7/30/1986	5.8	5.2	0m, 6m, 11m, 17m	NS	0.2	Prediction
					EW	0.15	
LLST15	8/5/1986	4.2	4.7	0m, 6m, 11m, 17m	NS	0.09	Prediction
					EW	0.1	

Tsai, 2007

SELFSIM APPLICATION TO REAL ARRAYS (TSA)

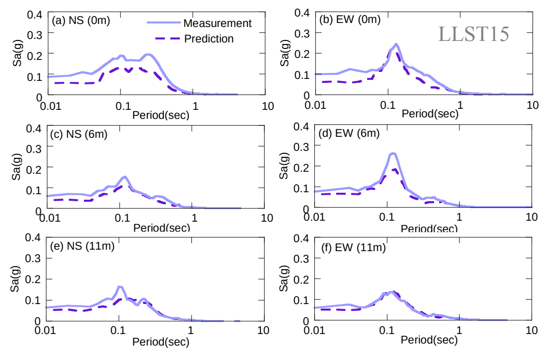
LOTUNG ARRAY, TAIWAN

Total stress SelfSim learning - LLST7 NS component



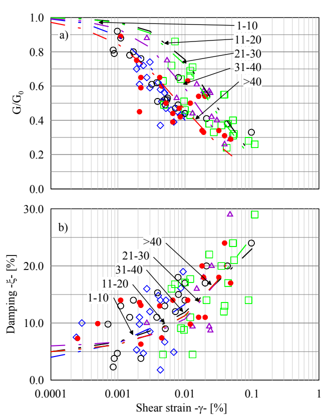
PREDICTION FROM SELFSIM MODEL (TSA)

LOTUNG ARRAY, TAIWAN

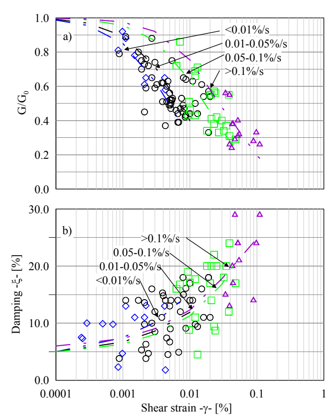


- Tsai (2007) found for total stress analyses…
- SelfSim is capable of reproducing downhole array measurements
- Learning from multiple records is required to capture nonlinear behavior over a wide range of strain

LEARNED DYNAMIC SOIL BEHAVIOR



Number of Cycles -N-	Data	Curve Fit
0-10	◇	— -
11-20	○	— -
21-30	□	— -
31-40	△	— -
>40	●	— -

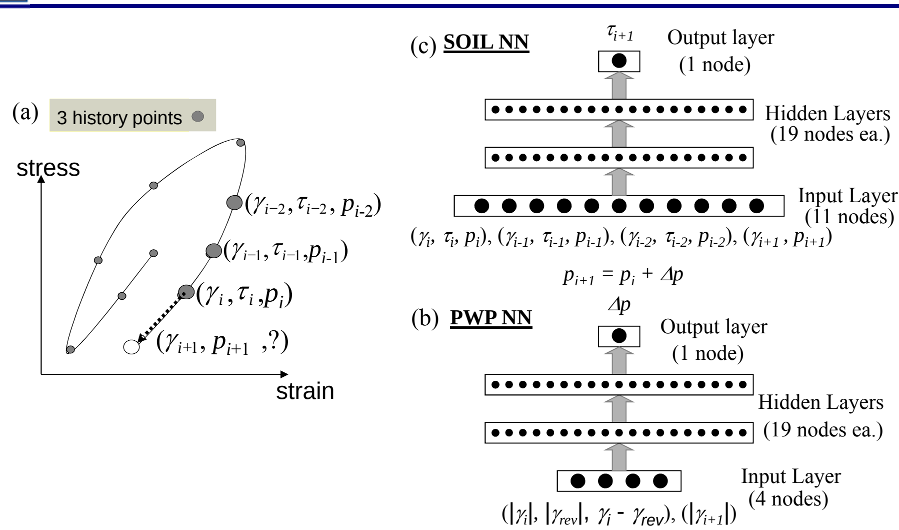


Strain Rate [%/s]	Data	Curve Fit
<0.01	◇	— -
0.01-0.05	○	— -
0.05-0.10	□	— -
>0.10	△	— -

…EXTENSION TO POREWATER PRESSURE GENERATIION

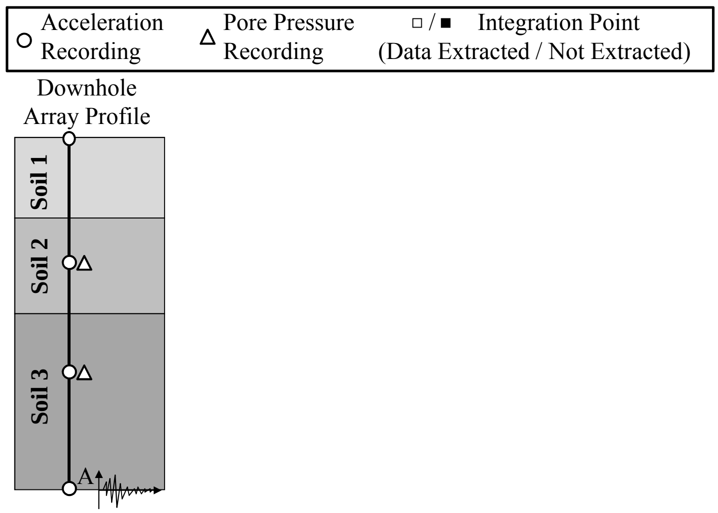
- Develop NN soil model with PWP generation capability
- Soil column discretization

NEURAL NETWORK MATERIAL MODEL



- 3-point model demonstrated for stress-strain-pore pressure coupled behavior (a).
- Proposed NN architectures for (b) pore pressure response model, and (c) stress-strain model illustrating how the pore pressure output is given as input to the soil model.

SELFSIM MESH GENERATION



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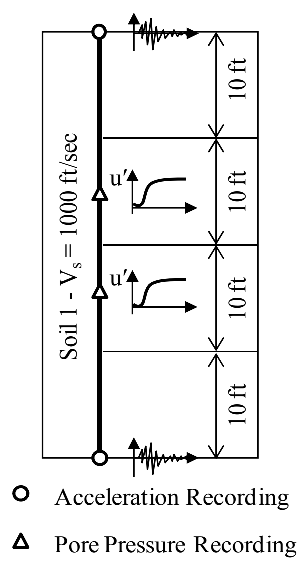
SYNTHETIC VERTICAL ARRAY

PROFILE

Development of synthetic vertical array data follows three steps:

1. Select a soil profile with known nonlinear soil behavior at the site.
2. Use DEEPSOIL to propagate a motion at bedrock through soil columns with known soil behavior using the hyperbolic soil model.
3. The output displacement, velocity, acceleration, and pore water pressure data of certain layers are used as synthetic array data.



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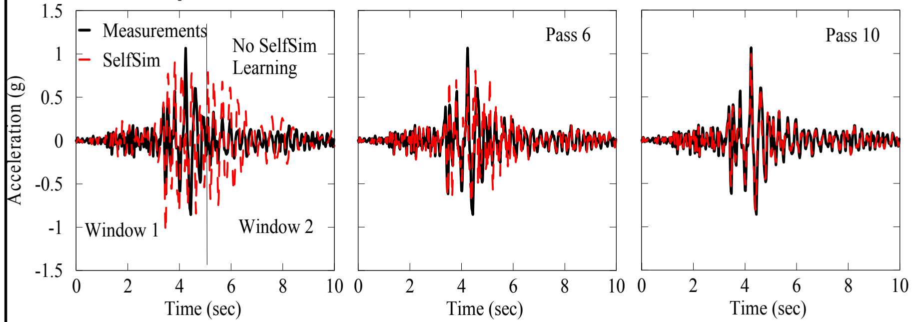
SYNTHETIC VERTICAL ARRAY

SELFSIM LEARNING

Loma Gilroy broadband motion

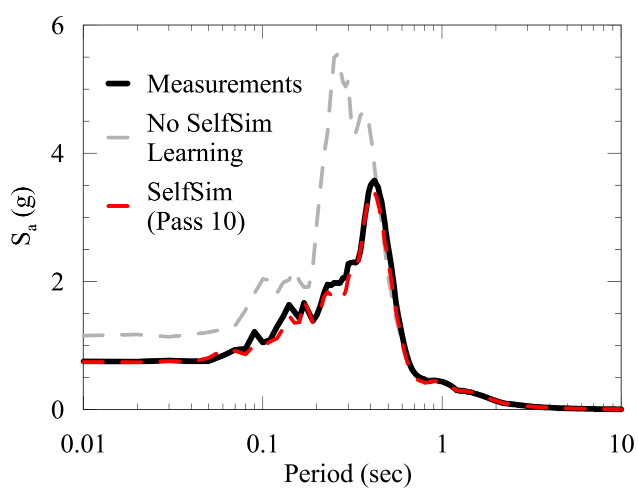


SelfSim Learning, window 1: After six SelfSim learning passes, calculated surface accelerations approach the target measurements within this window and can well predict the response at later shaking stages.

SelfSim Learning, window 2: Four additional SelfSim learning passes are then performed using window 2 data (the entire period of shaking). The computed response (Pass 10) matches acceleration measurements and the surface response very well.

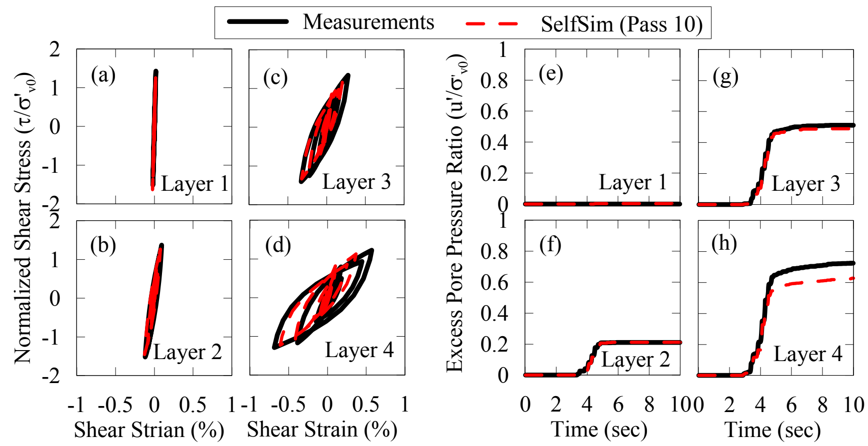
SYNTHETIC VERTICAL ARRAY

RESPONSE SPECTRA



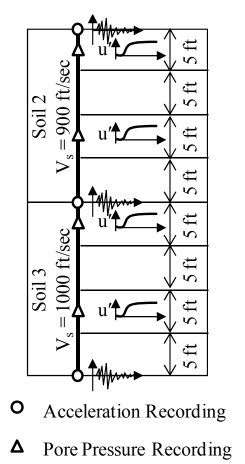
SYNTHETIC VERTICAL ARRAY

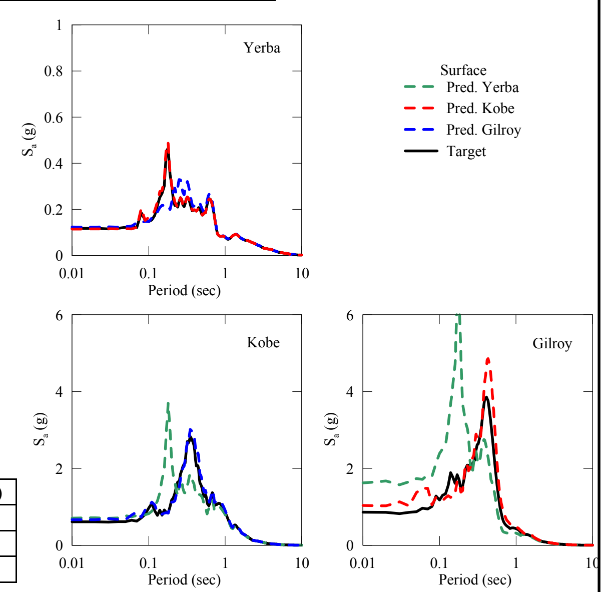
STRAIN-STRESS CURVE AND PORE PRESSURE RESPONSE



SYNTHETIC VERTICAL ARRAY

MULTIPLE EVENTS

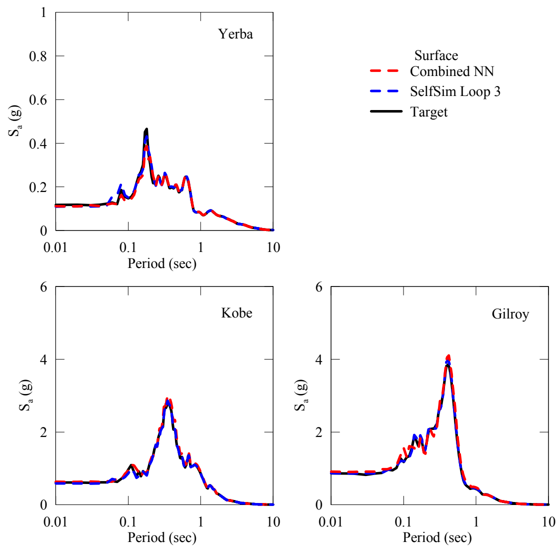




Symbol	Earthquake	Station	PGA(g)
LY	Loma Prieta	Yerba Buena	0.065
KK	Kobe	KJMA	0.4
LG	Loma Prieta	Gilroy	0.45

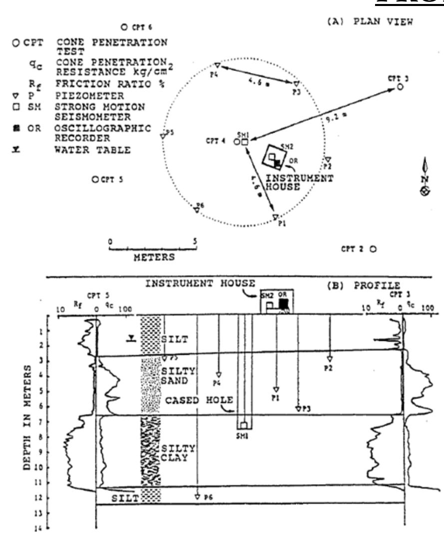
SYNTHETIC VERTICAL ARRAY

MULTIPLE EVENTS

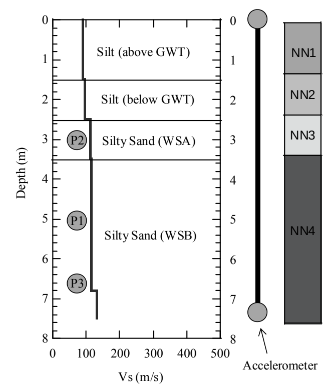


WILDLIFE LIQUEFACTION ARRAY

PROFILE



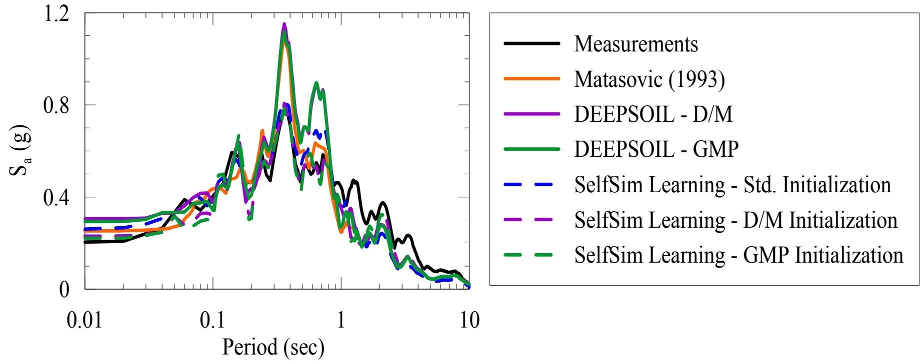
(from Matasovic, 1993; after Benett et al., 1984)



- Located in the flood plain of the Alamo River in the Imperial Valley, CA.
- The original array was installed by the USGS in 1983.
- The ground water table at 1.5 m from the ground surface.

WILDLIFE LIQUEFACTION ARRAY

RESPONSE SPECTRA

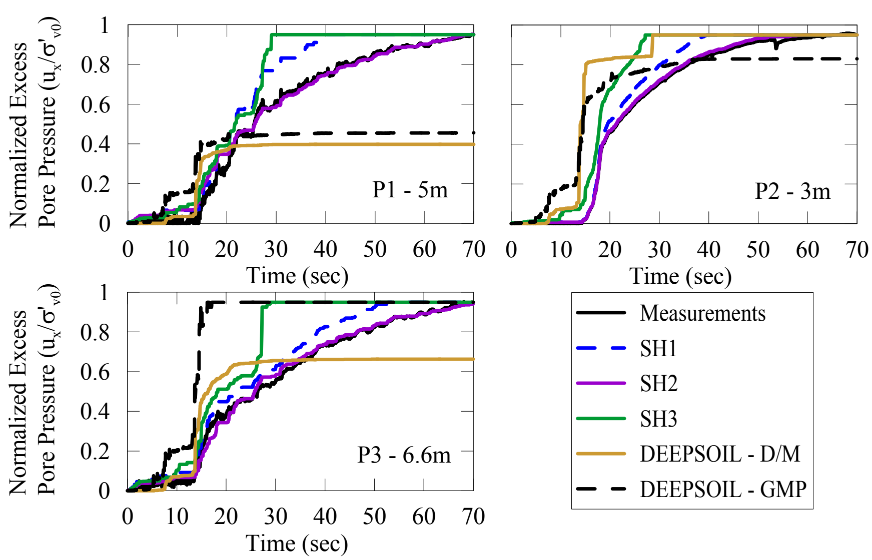


Three scenarios using the Superstition Hills N-S earthquake measurements

- SH1 – Imposed Recordings, Linear Elastic NN Initialization
- SH2 – Imposed Recordings; PDHM / D-M PWP Computed Values NN Initialization
- SH3 – Imposed Recordings; PDHM / GMP PWP Computed Values NN Initialization

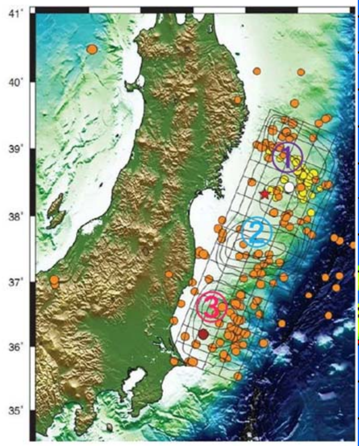
WILDLIFE LIQUEFACTION ARRAY

PORE PRESSURE RESPONSE

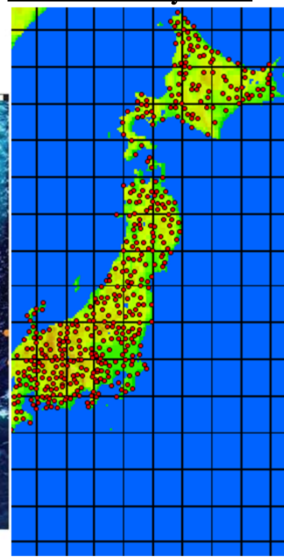


2011 M_W 9.0 JAPAN EARTHQUAKE

Kik-net array data



(Tokyo Tech CUEE)



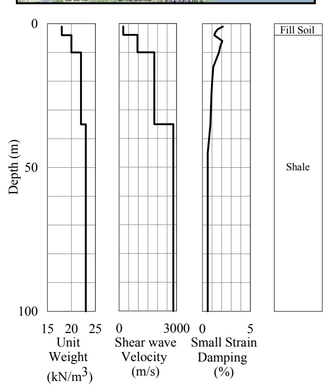
Questions:

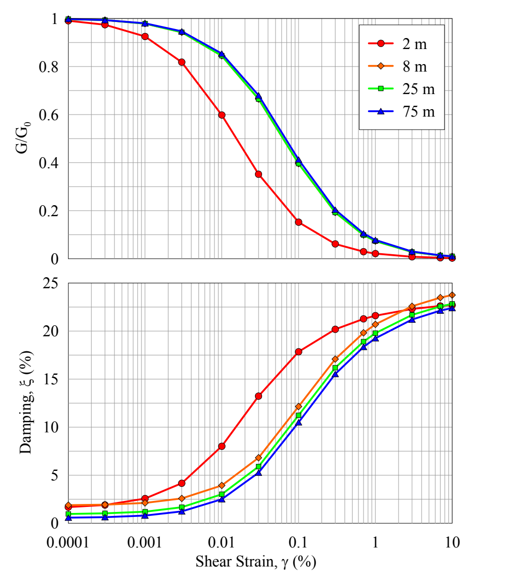
-How well do our conventional site response models work for long duration motions?

-How significant is cyclic degradation due to large number of cycles?

-Site response with DEEPSOIL V4.0

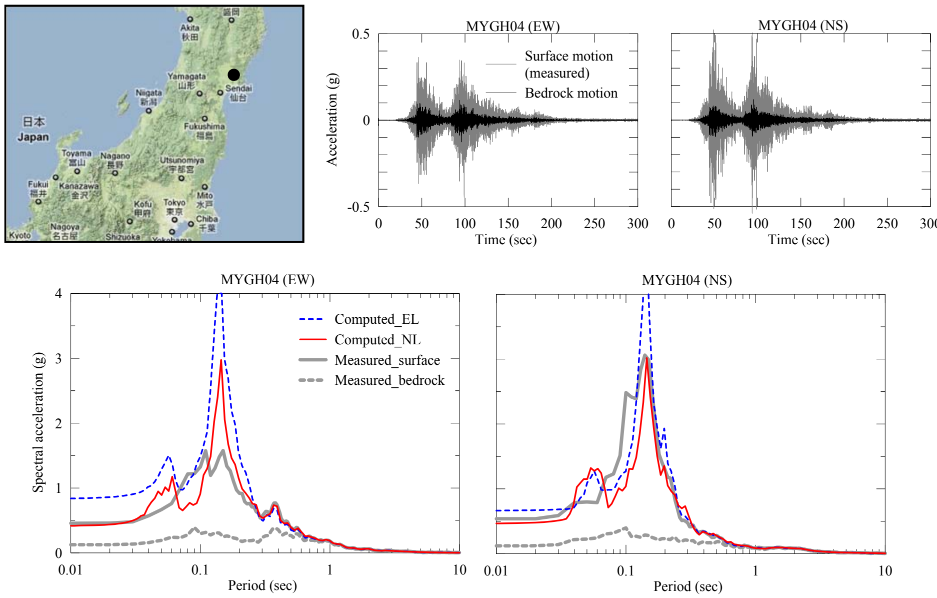
MYGH04





Modulus reduction and damping curves by Darendeli (2001)

MYGH04



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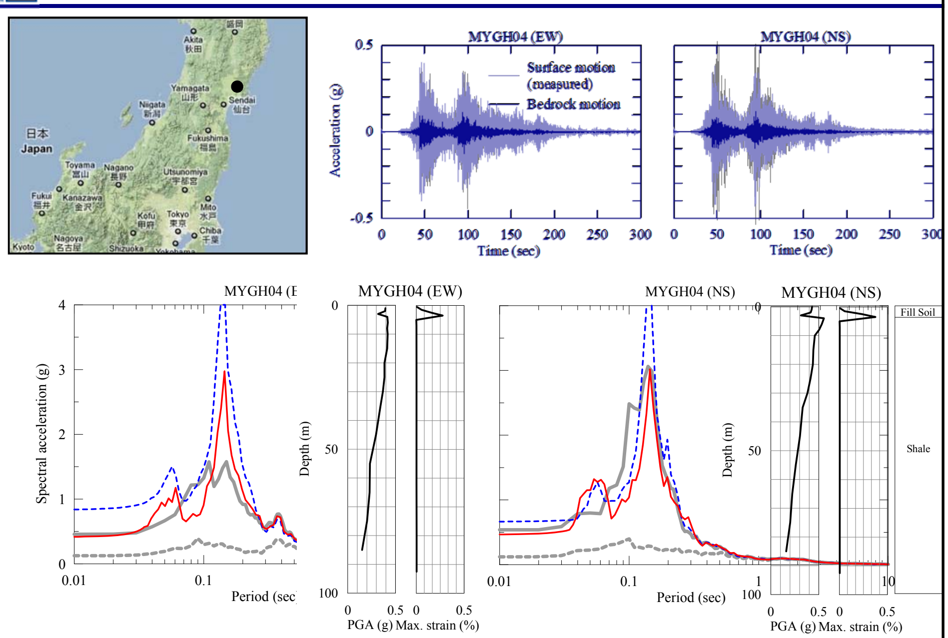
MYGH04



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CONCLUDING REMARKDS

•Vertical Arrays provide valuable information for improving our site response models

•SelfSim inverse analysis framework has been extended to learn from vertical arrays with pore water pressure (PWP) measurements.

•Need more array data with PWP to evaluate and improve the reliability of our models.

• Preliminary one-dimensional site response analyses were conducted using the program DeepSoil v4.0 to reproduce the soil response from the downhole arrays for the March 11 2011, Tohoku, Japan, earthquake.

- •Current site response analysis are able to capture key features of the response at some of the stations.
- •Need for more detailed characterization of the sites
- •Influence if cyclic degradation?
- •There is much to learn from the data.