Friday, May 30th 2014

CalGeo Expo @ UCLA

"Centrifuge Experiments to Investigate Levee Deformation Potential in the Sacramento-San Joaquin Delta"

Riccardo Cappa & Samuel Yniesta

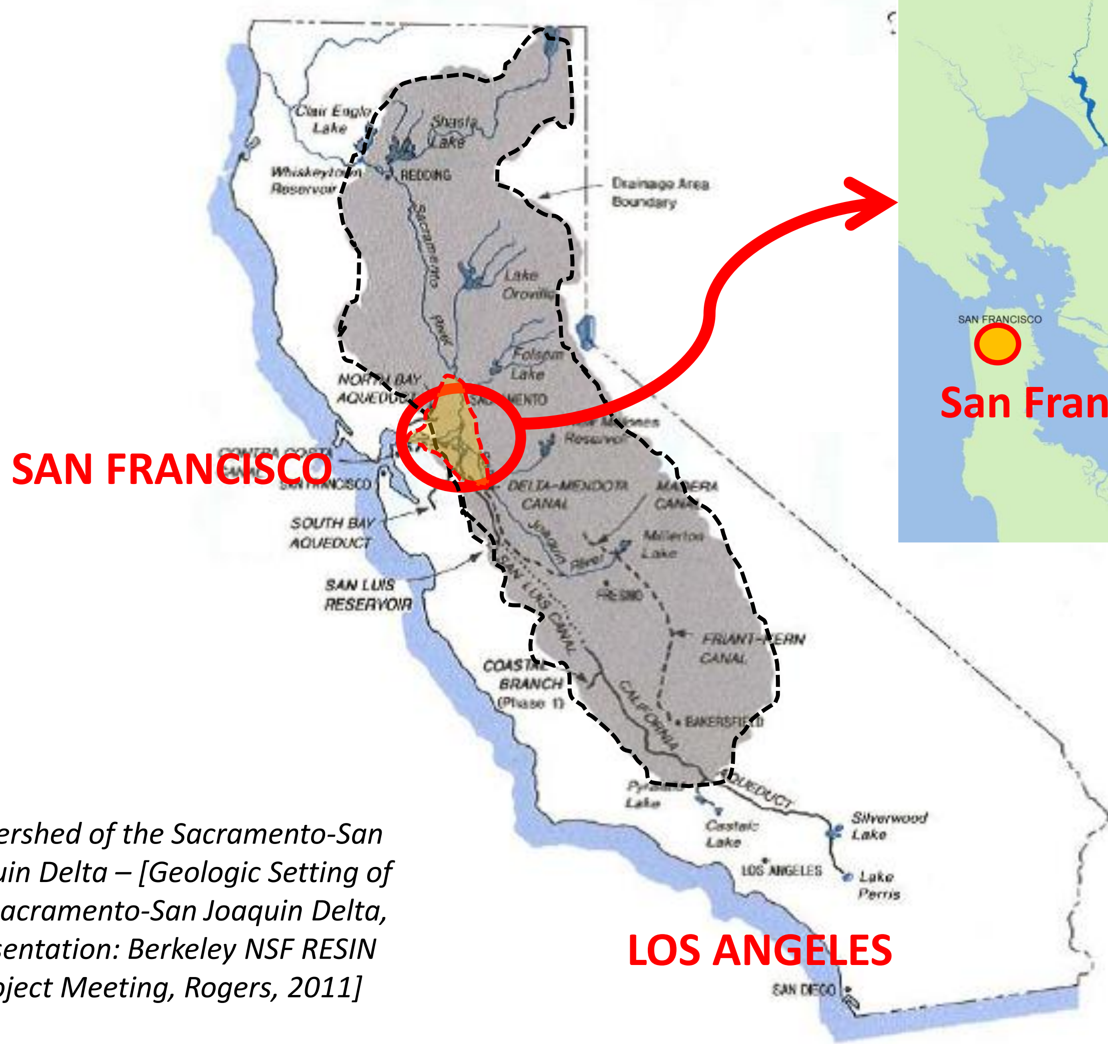
OVERVIEW

- **Introduction of the Delta**
  - Construction of the Levees
  - Seismic Hazard
  - Consequences of levee failure
- **Project**
  - Objectives of the Project
  - Research Program
- **Centrifuge Test of a Clayey Levee**
  - Model Construction
  - Testing
  - Preliminary Results
- **Centrifuge Test of a Sandy Levee**
  - Testing
  - Preliminary Results
- **Future Work and Summary**

Photo by Ian Kluft

Photo courtesy of Roy Tennant

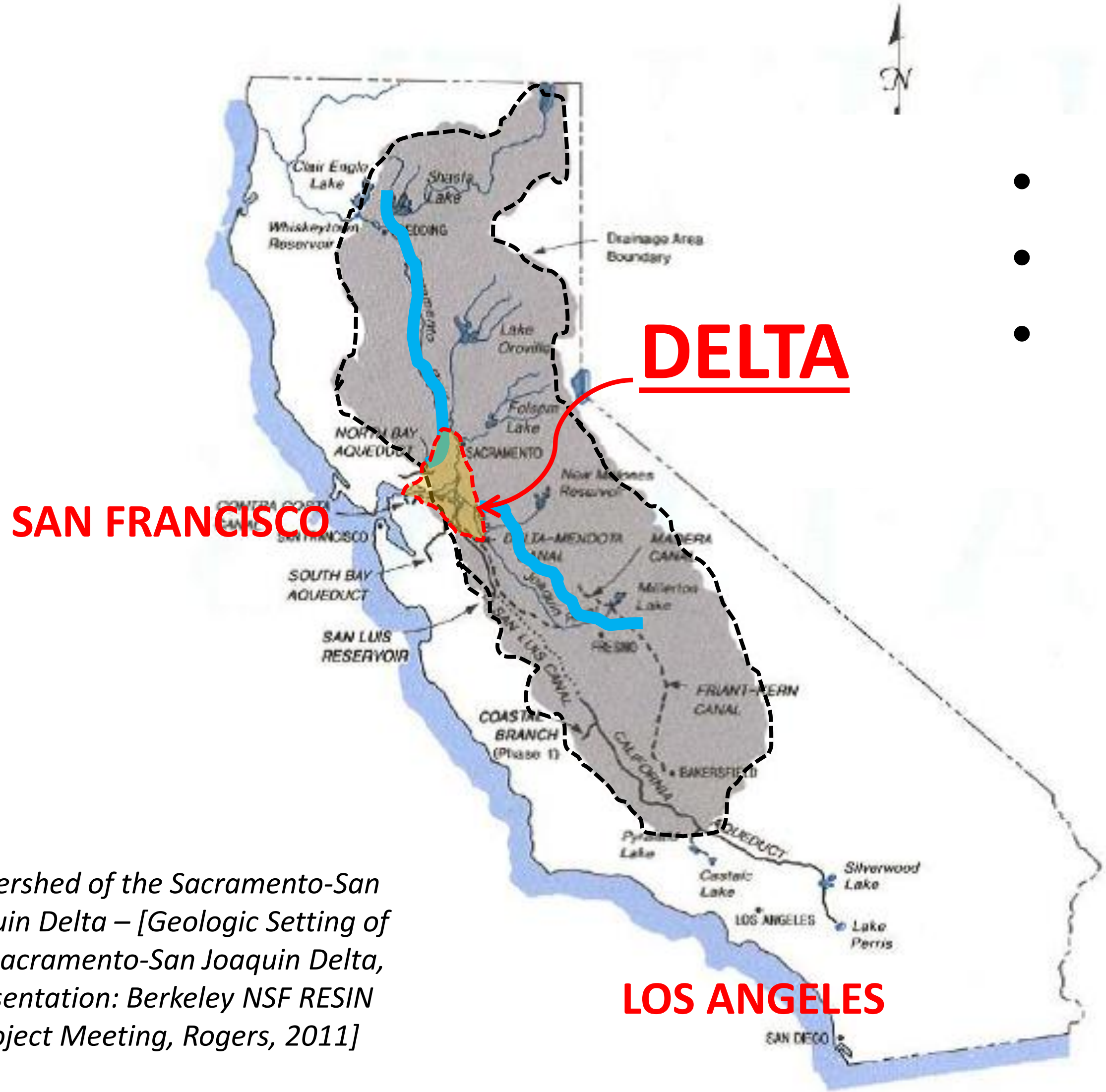
DELTA LOCATION



Watershed of the Sacramento-San Joaquin Delta – [Geologic Setting of the Sacramento-San Joaquin Delta, Presentation: Berkeley NSF RESIN Project Meeting, Rogers, 2011]

http://mavensnotebook.com/wp-content/uploads/2013/11/Meral-basic-slides_Page_3.jpg

DELTA LOCATION



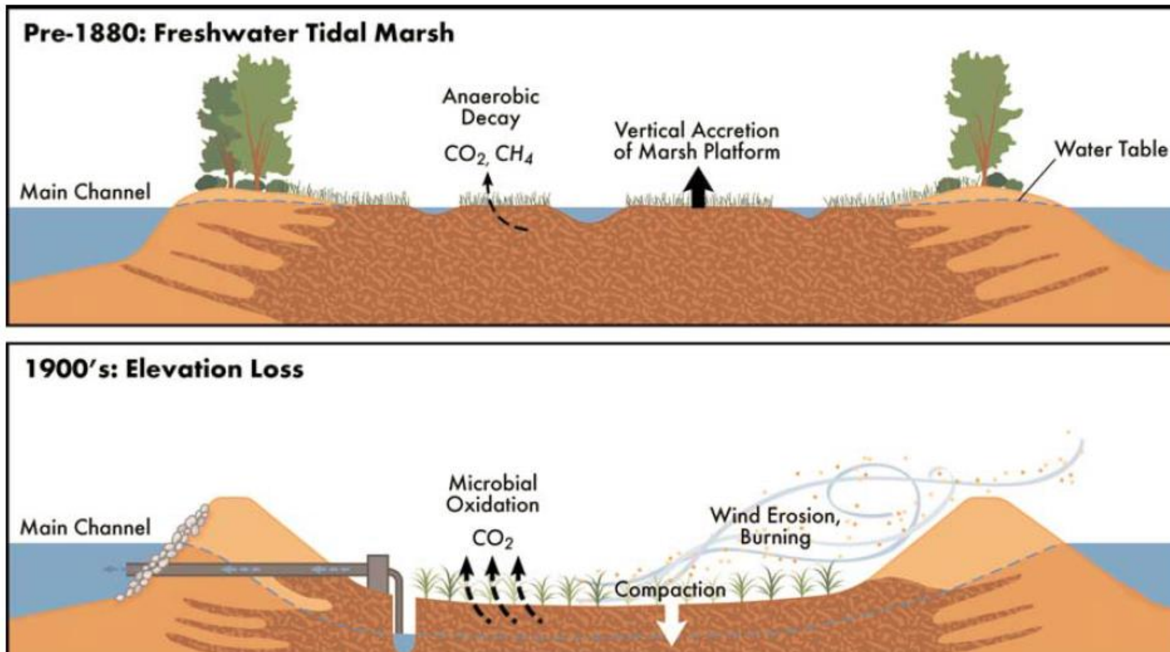
Watershed of the Sacramento-San Joaquin Delta – [Geologic Setting of the Sacramento-San Joaquin Delta, Presentation: Berkeley NSF RESIN Project Meeting, Rogers, 2011]

- **70 islands**
- **2,800 km^2**
- **1800 km levees**

HOW DID THE DELTA CHANGE?

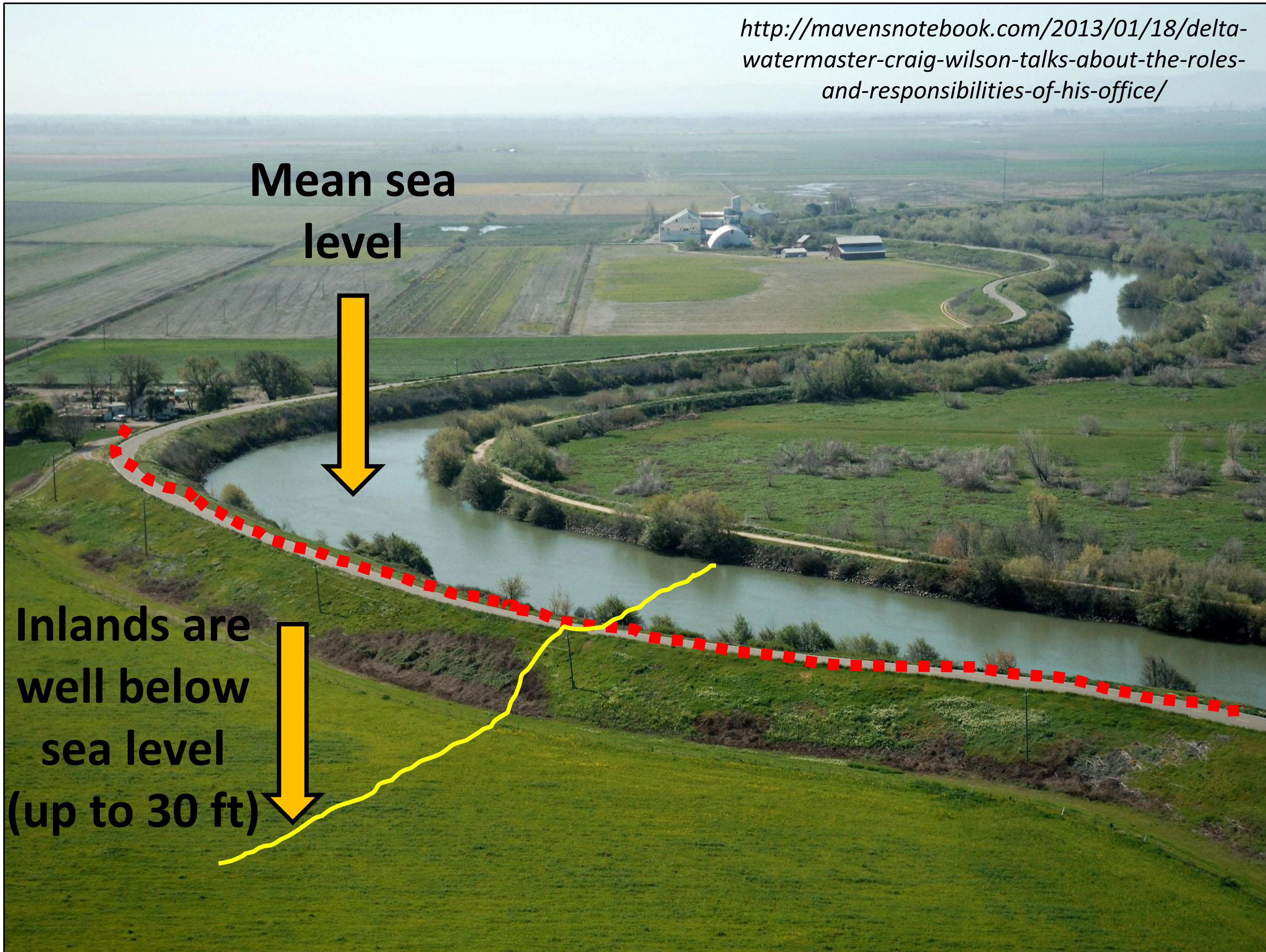
- 1880's Y reclamation started Y levees were raised
- Beginning of a subsidence process due to:
  - Mechanical settling
  - Land burning
  - Erosion
  - Oxidation
  - Decomposition
  - Shrinking

Clamshell Dredge Building a Levee – [SFEI, 2012]

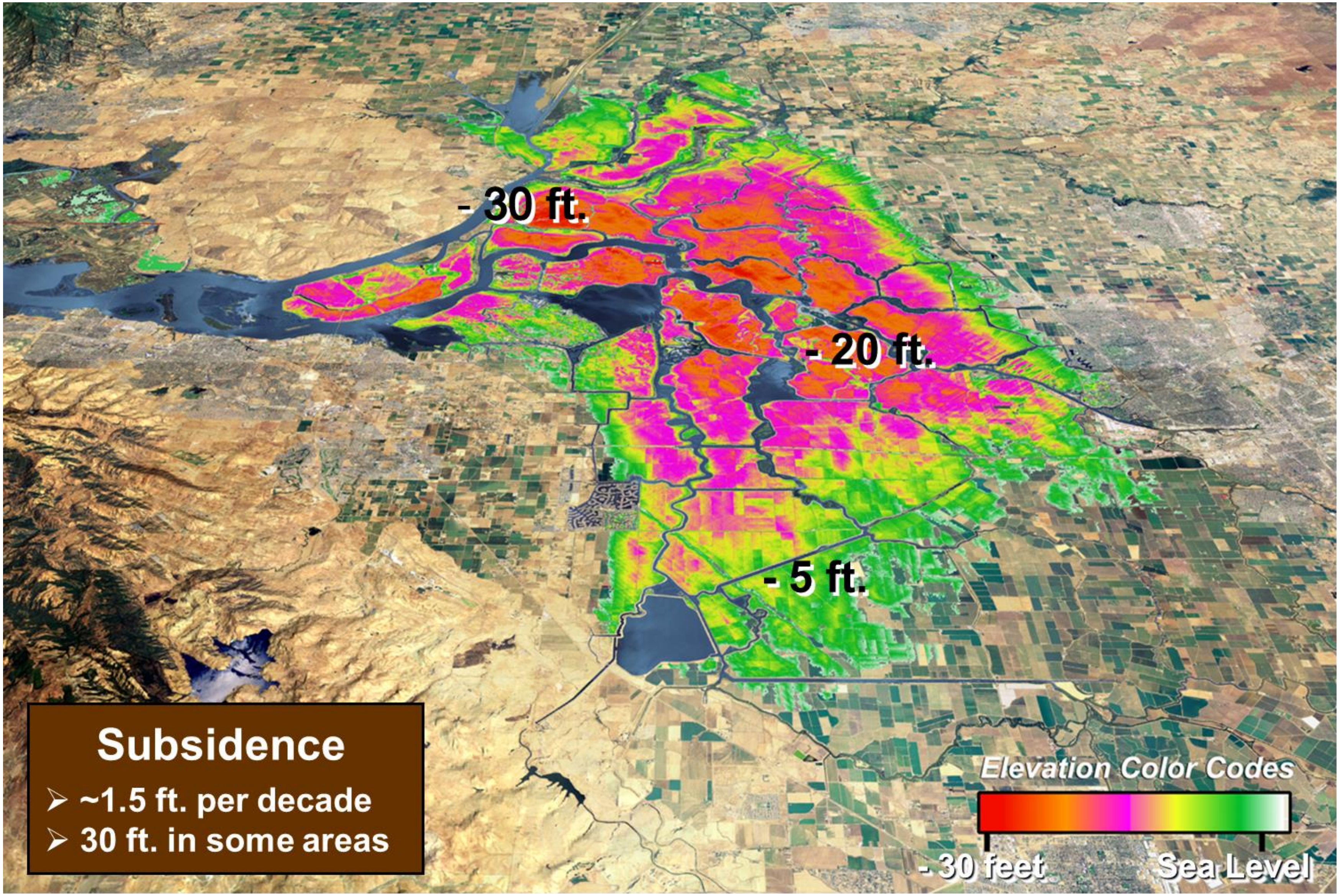


Evolution of Delta islands due to levee construction and island subsidence - [Subsidence, sea level rise, and seismicity in the Sacramento-San Joaquin Delta, Mount and Twiss, 2005]

SUBSIDENCE IN THE DELTA



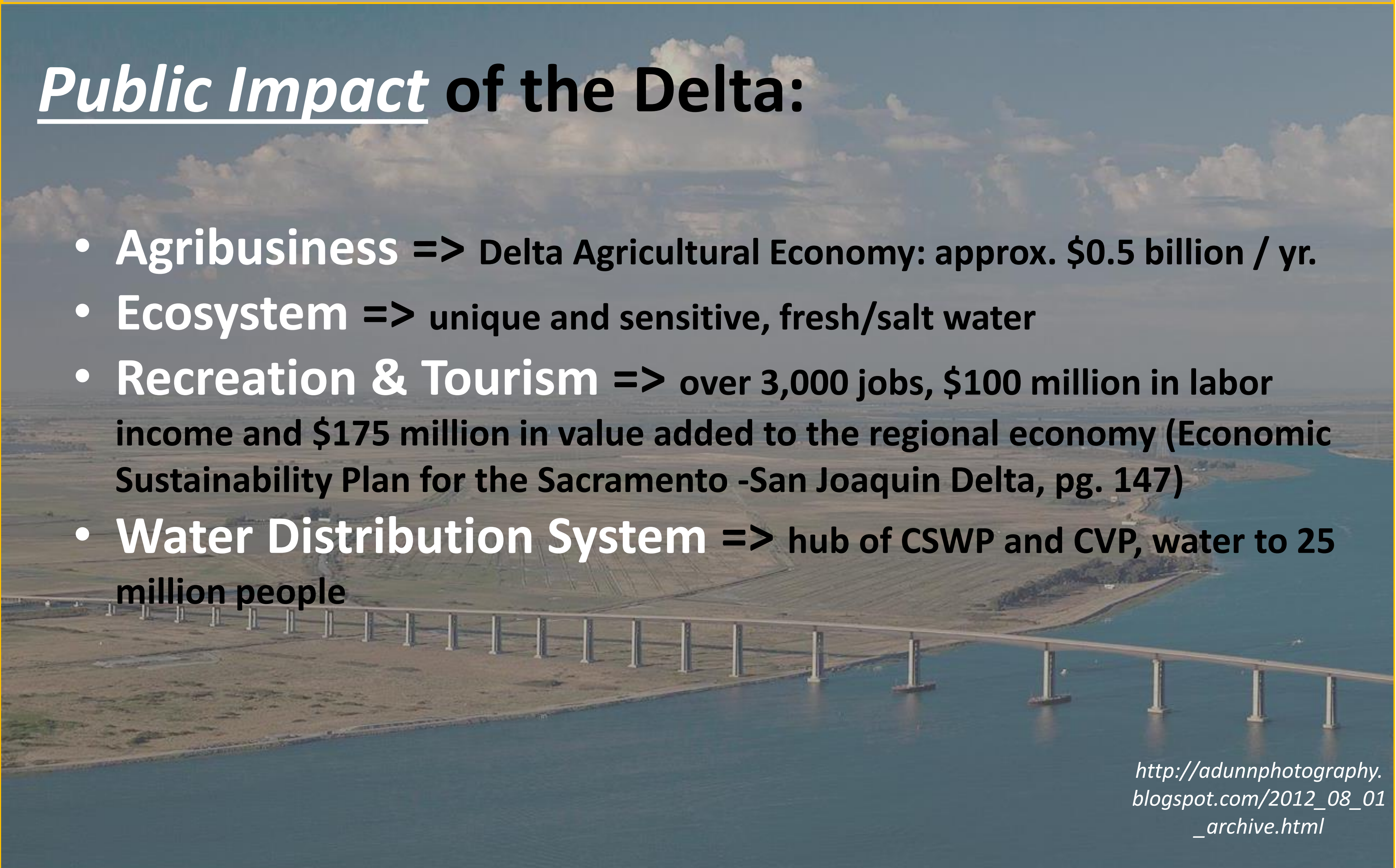
SUBSIDENCE IN THE DELTA


- 30 ft.
- 20 ft.
- 5 ft.
Subsidence
➢ ~1.5 ft. per decade
➢ 30 ft. in some areas
Elevation Color Codes
- 30 feet
Sea Level

IMPORTANCE OF DELTA

Public Impact of the Delta:

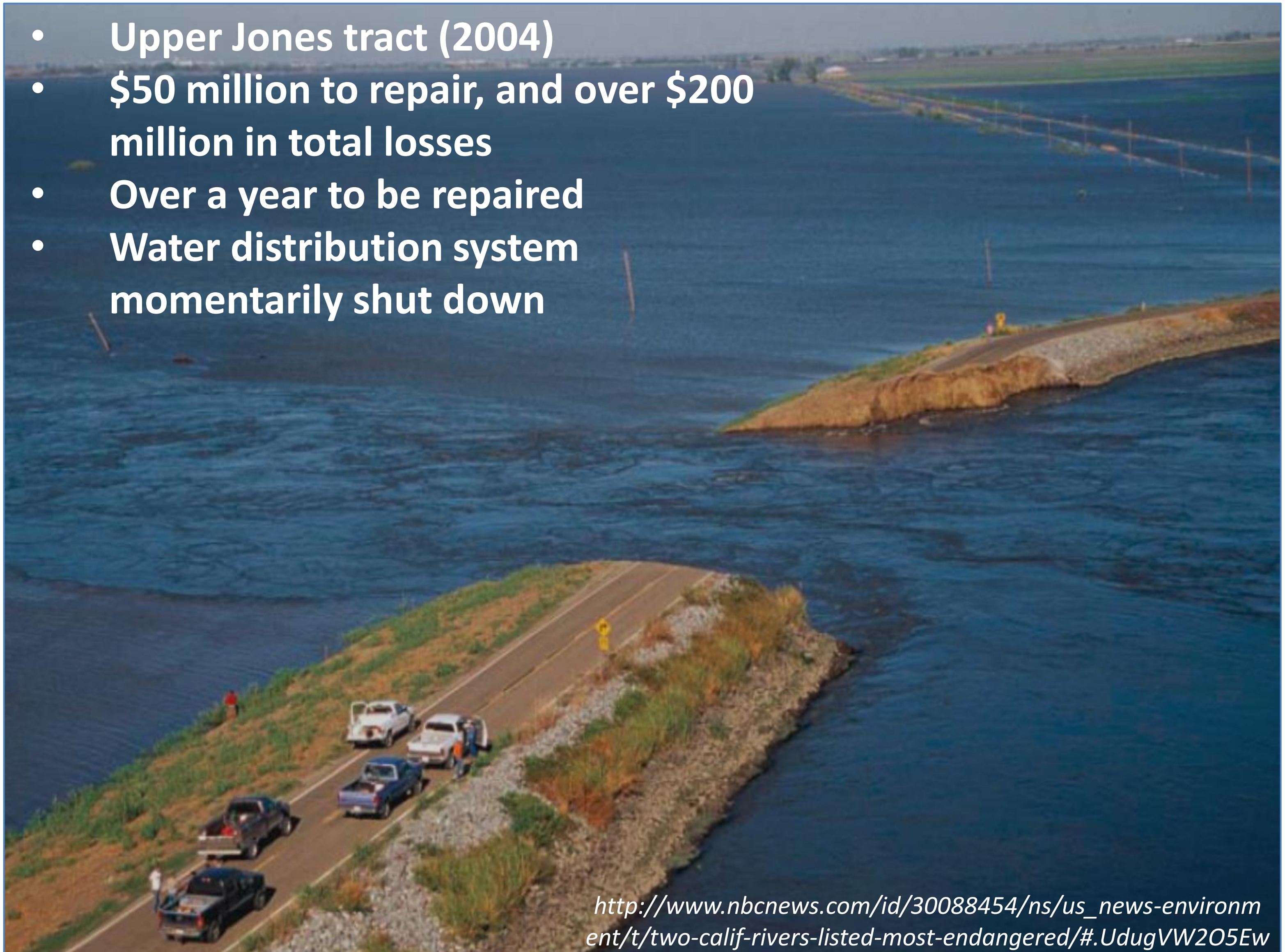
- **Agribusiness => Delta Agricultural Economy: approx. $0.5 billion / yr.**
- **Ecosystem => unique and sensitive, fresh/salt water**
- **Recreation & Tourism => over 3,000 jobs, $100 million in labor income and $175 million in value added to the regional economy (Economic Sustainability Plan for the Sacramento -San Joaquin Delta, pg. 147)**
- **Water Distribution System => hub of CSWP and CVP, water to 25 million people**



http://adunnphotography.blogspot.com/2012_08_01_archive.html

WHEN A LEVEE FAILS…

- Upper Jones tract (2004)
- $50 million to repair, and over $200 million in total losses
- Over a year to be repaired
- Water distribution system momentarily shut down

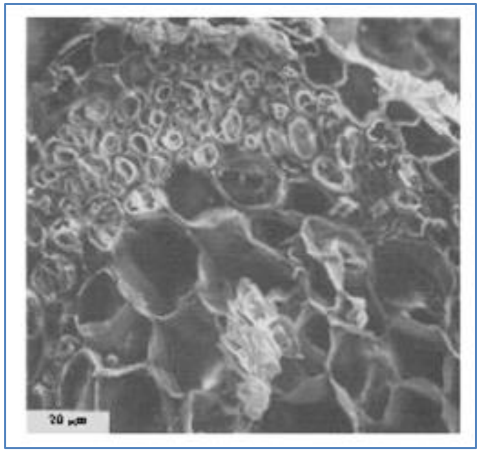


http://www.nbcnews.com/id/30088454/ns/us_news-environment/t/two-calif-rivers-listed-most-endangered/#.UdugVW2O5Ew

Peat has unique characteristics:

- High water content (w= 400-800%)
- Low unit weight (γ = 10-12 KN/m^3)
- Small shear wave velocity (V_s = 25 m/s)
- High organic content (OC ~ 64%)

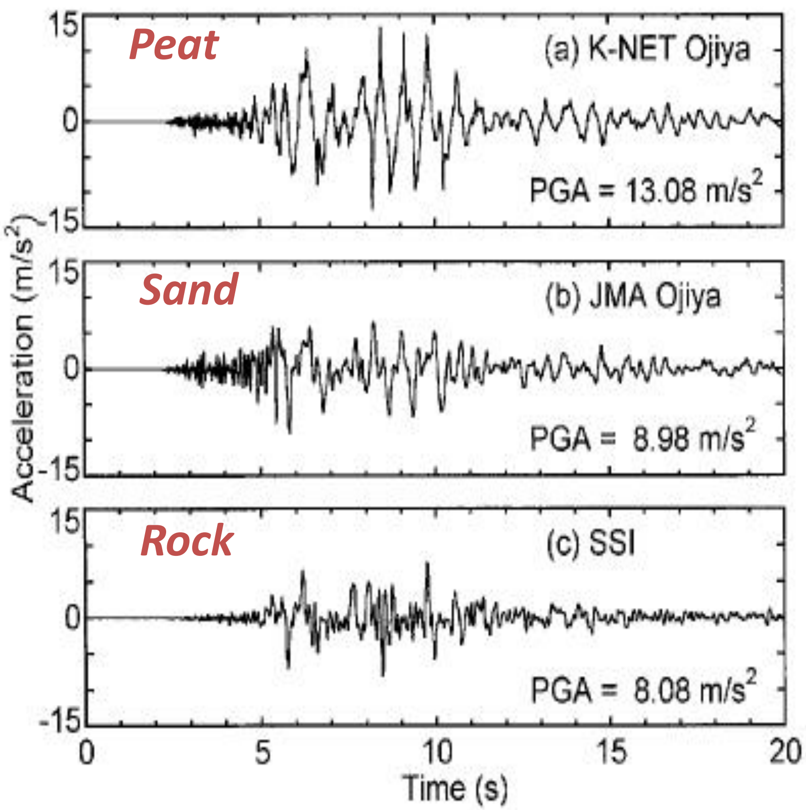
[Shafiee et al., 2007]



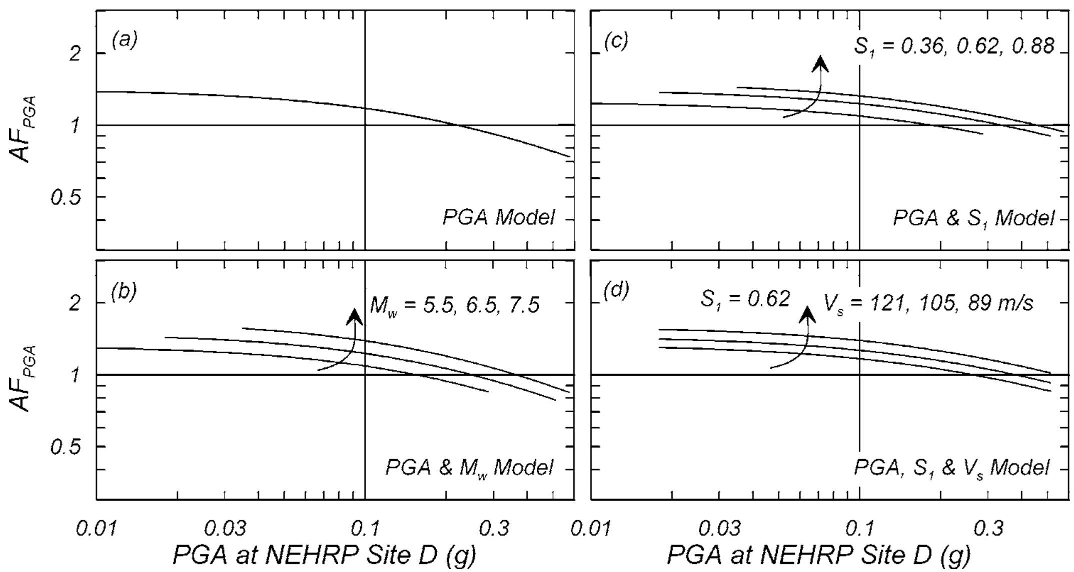
Transverse section of a peat fiber at x800 – [Secondary Compression of Peat with or without Surcharging, Mesri et al., 1999]

High Settlements and Low Strength

PEAT RESPONSE



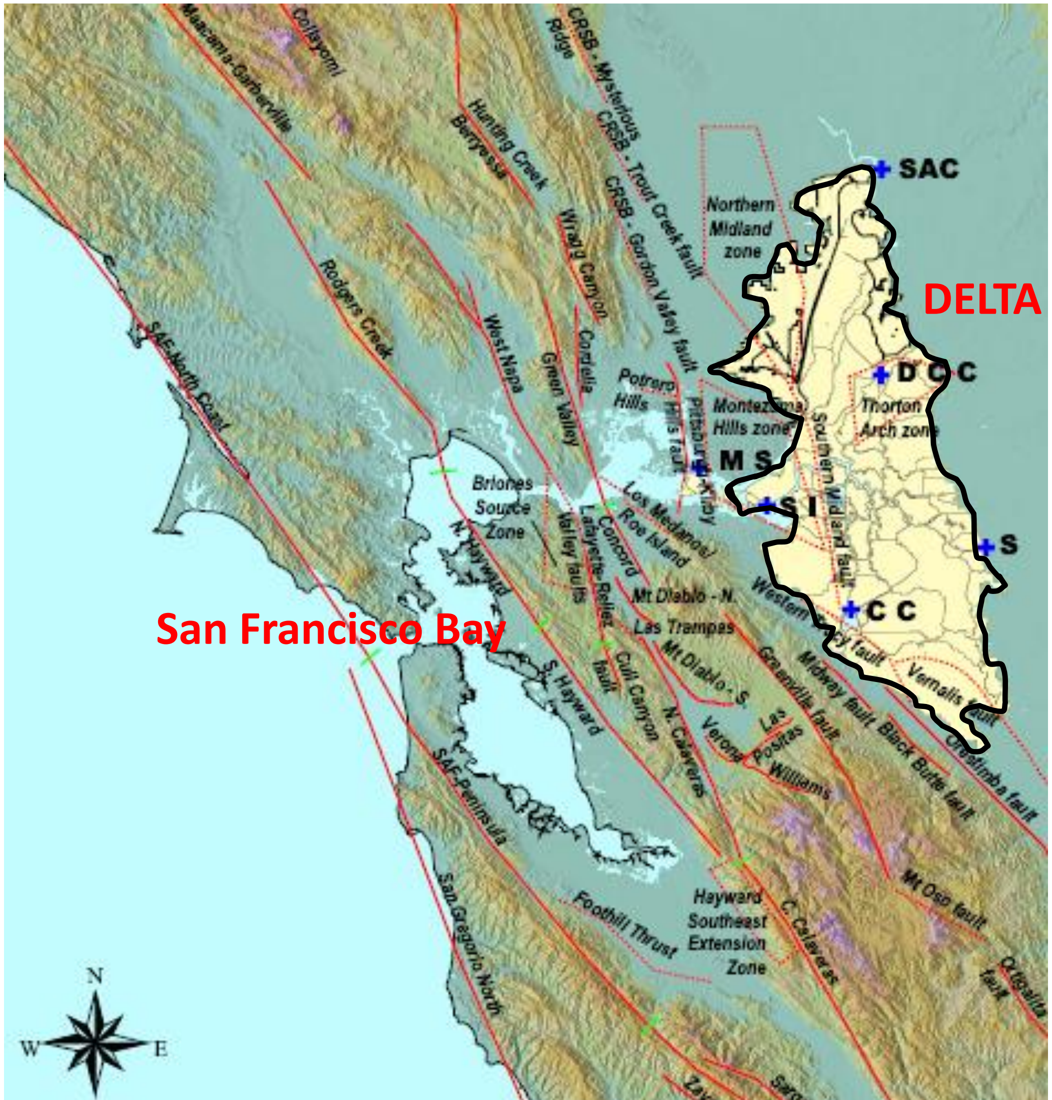
Tokimatsu and Sekiguchi (2006)



Kishida et al. (2009)

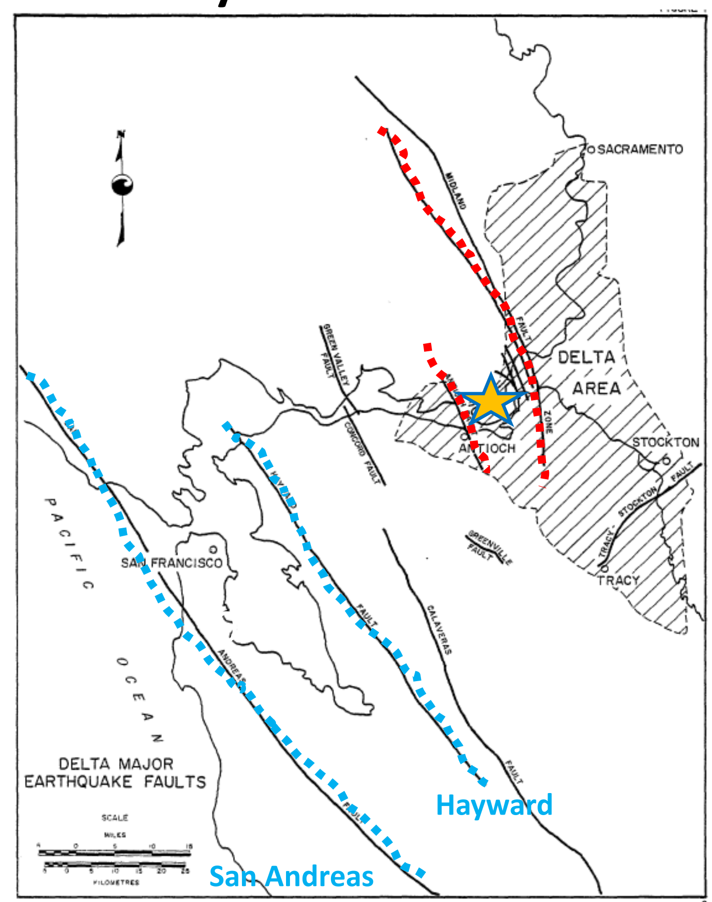
Ground motions can be amplified by peat

FAULT SYSTEM IN THE DELTA



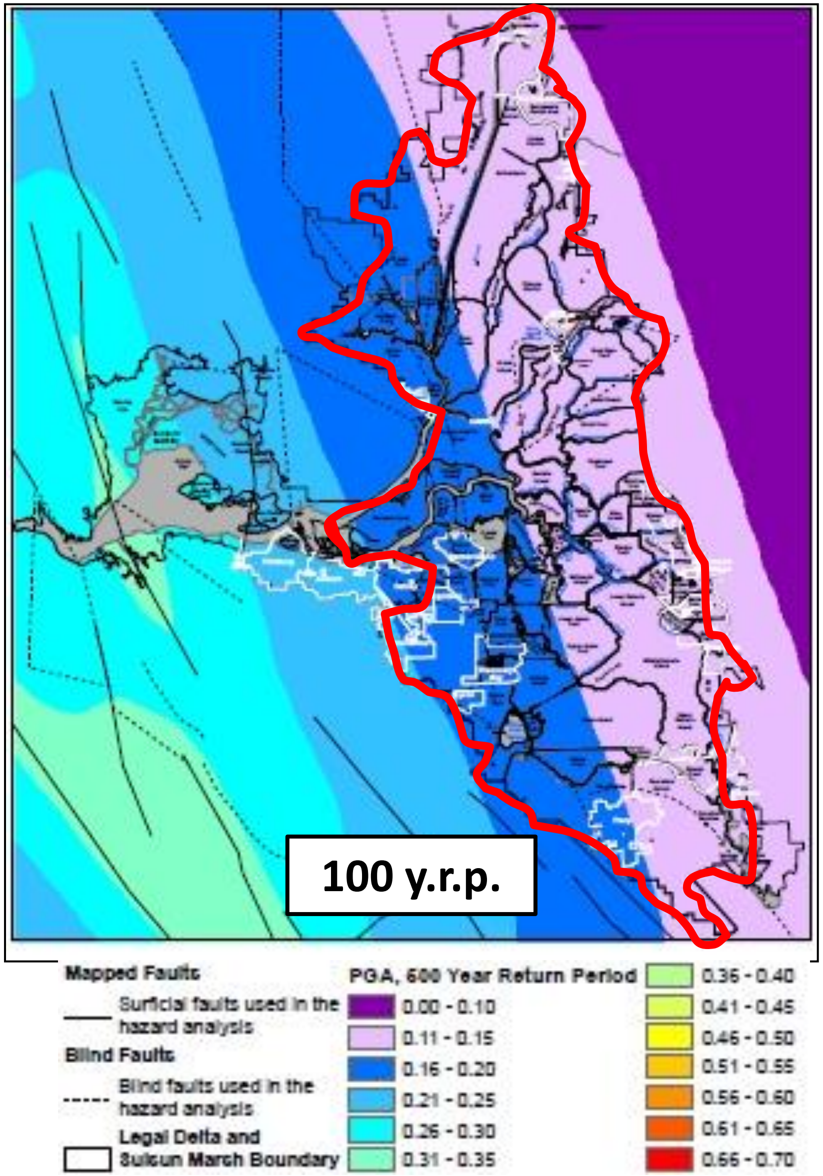
Seismic risk controlled by:

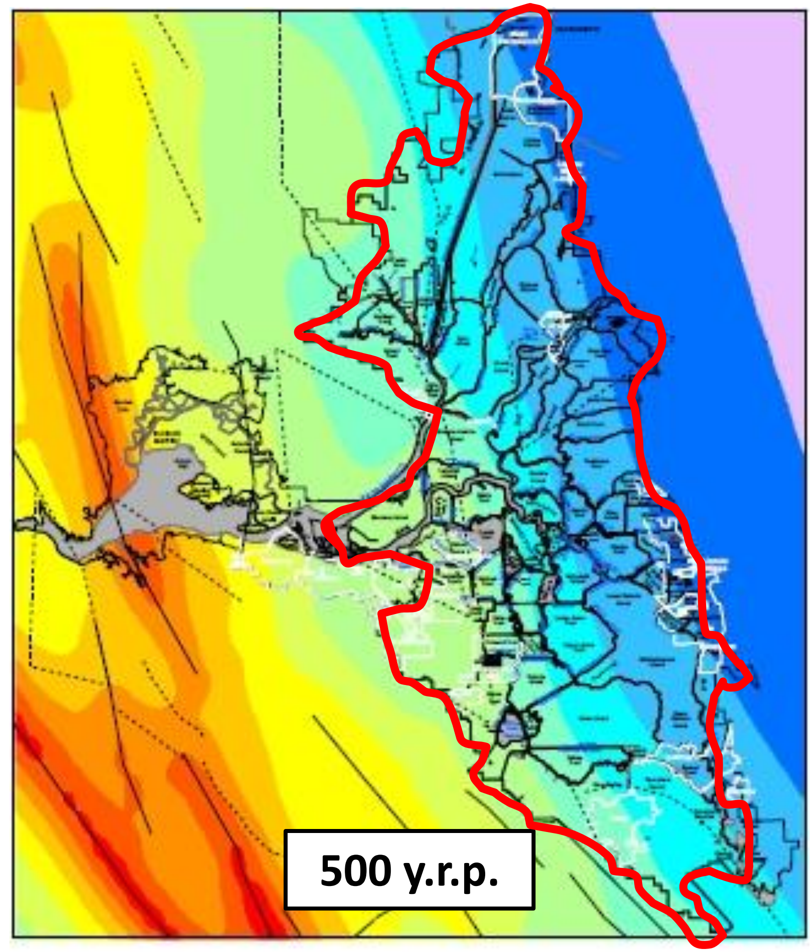
- **6.5-7.0 M earthquakes**
- **Nearby faults**



Major and Minor Faults in the Delta – [Seismic Hazard in the Sacramento-San Joaquin Delta, CDWR, 1980]

100 & 500 YEAR RETURN PERIOD (Y.R.P.) SCENARIOS





- **0.4 g PGA for 500 y.r.p. (DRMS,2009)**

POSSIBLE DISASTER

Multiple Failures Υ "BIG GULP" Υ Salinity Intrusion Υ Reduced water exports Υ $ 40 billion in economic losses (DRMS, 2009)

Video 1

Levees ⇔ Earthquakes Υ little understanding

Our project: *"NEESR: Levees and Earthquakes: Averting an Impending Disaster"*

PREVIOUS WORK

- **Ted Reinert**: Field Test of Model Levee on Sherman Island
- **Ali Shafiee**: Lab Testing of Peat, Seismic Deformation Potential
- **Dong Yeop Kwak**: Fragility Functions of Levees in Japan
- Also involved: **Sean Ahdi, Seema Barua, Pavlo Chrysovergis, Rob Moss, Yi Tyan Tsai**

Field test of a levee

PROJECT TEAM

UCI – Civil and Environmental Engineering Department:

- Professor Anne Lemnitzer
- Riccardo Cappa, Graduate Student


UCLA – Civil and Environmental Engineering Department:

- Professor Scott Brandenberg
- Professor Jonathan Stewart
- Samuel Yniesta, Graduate Student



University of Bristol, UK – Civil Engineering Department:

- Professor George Mylonakis

Special thanks to:

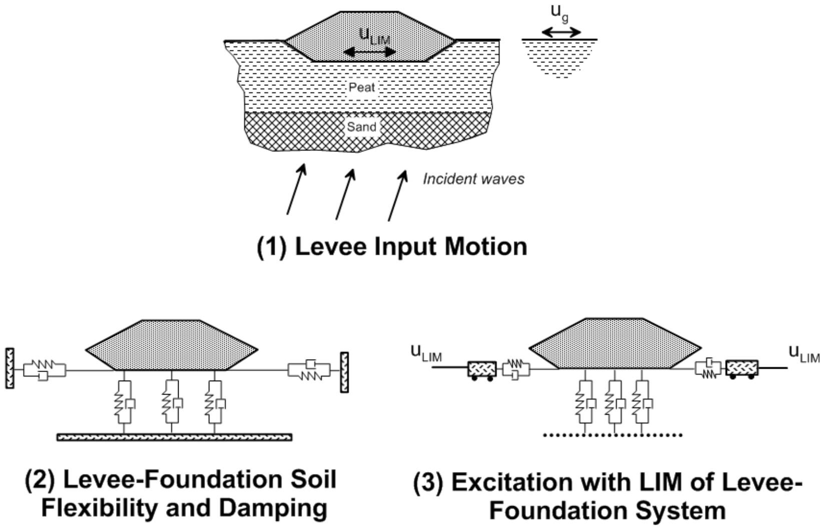
Bahareh Heidarzadeh, NEES@UCDavis team: Anatoliy Ganchenko, Chad Justice, Tom Kohnke, Lars Pedersen, Peter Rojas, Dan Wilson

Project Funding: NSF Award #1208170 (July 2012)

OBJECTIVES OF THE PROJECT

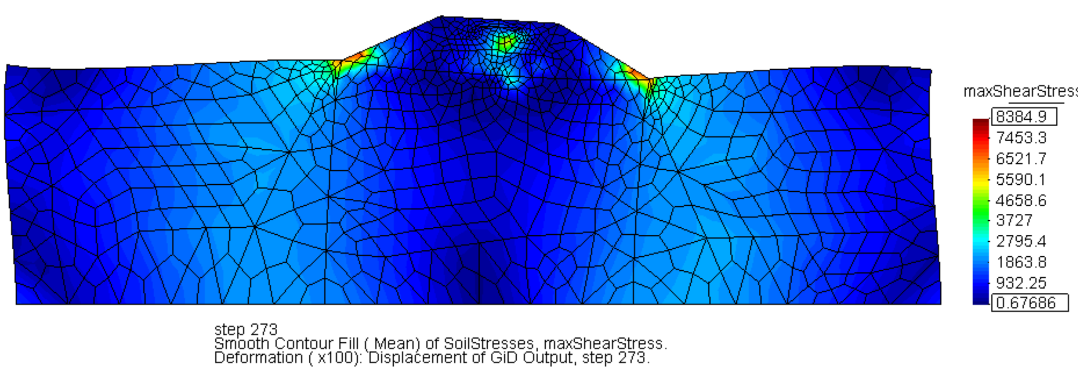
Peat – points of interest:

- post-cyclic volume change potential in peat
- cyclic pore pressure development in the peat
- levee-peat interaction



Levee – points of interest:

- Investigation of the liquefaction potential of the levee
- Development of an analysis framework for levee response

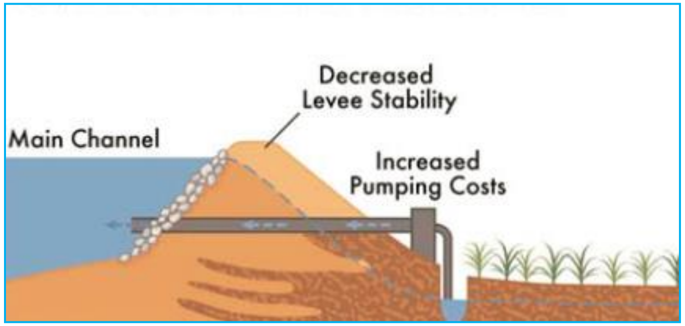


RESEARCH PROGRAM

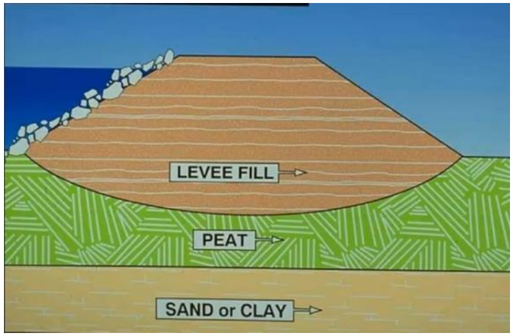
Laboratory Investigations → Small Scale Centrifuge Tests

Large Scale Experimental Test Program

- Test 1
  - Phase 1: Clayey Levee
  - Phase 2: Sandy Levee
- Test 2
  - Phase 1: Clayey Levee
  - Phase 2: Sandy Levee



Simplified Levee Section

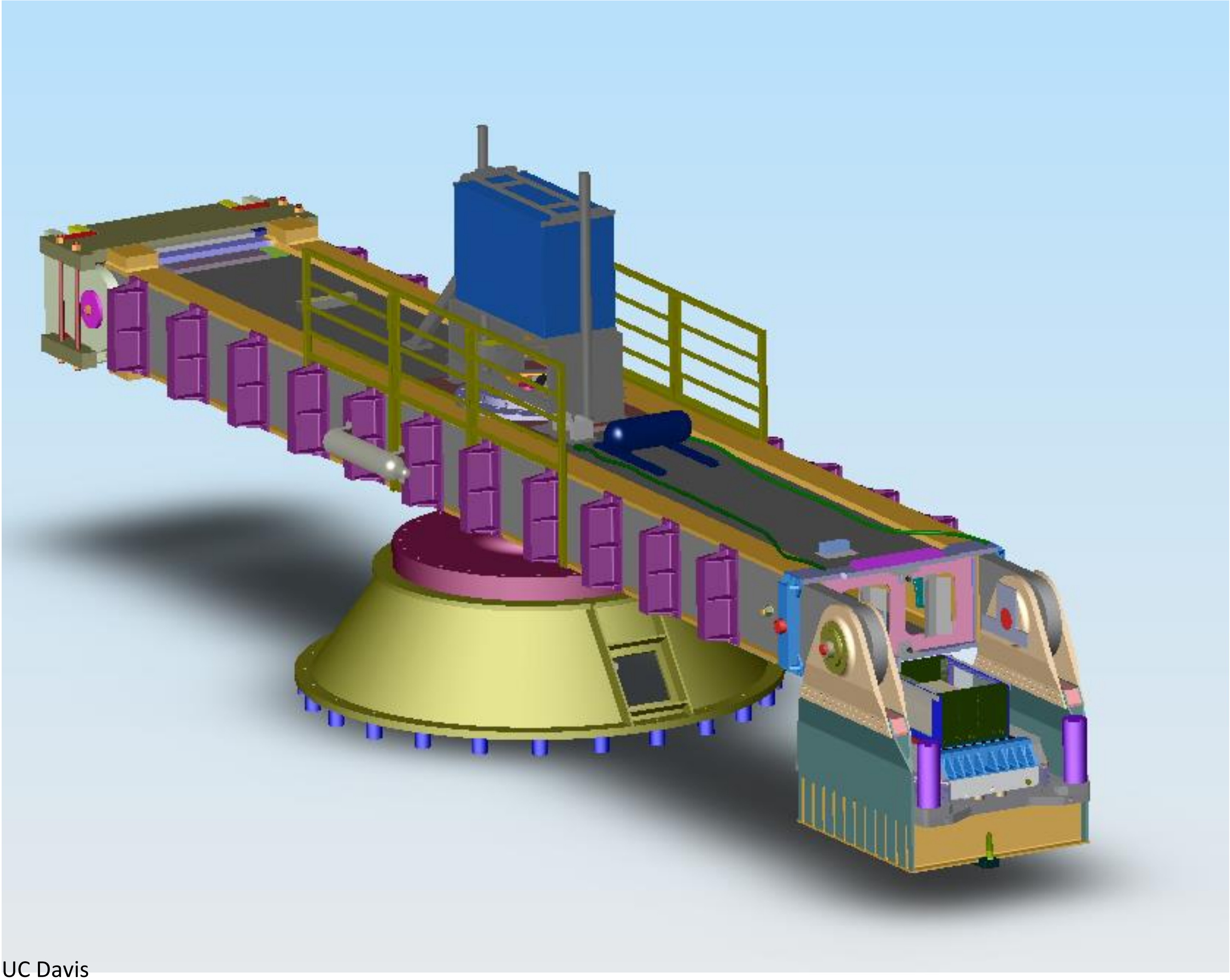


Idealization in Centrifuge Experiments

CENTRIFUGE PRINCIPLES

Slide courtesy of UC Davis

CENTRIFUGE PRINCIPLES



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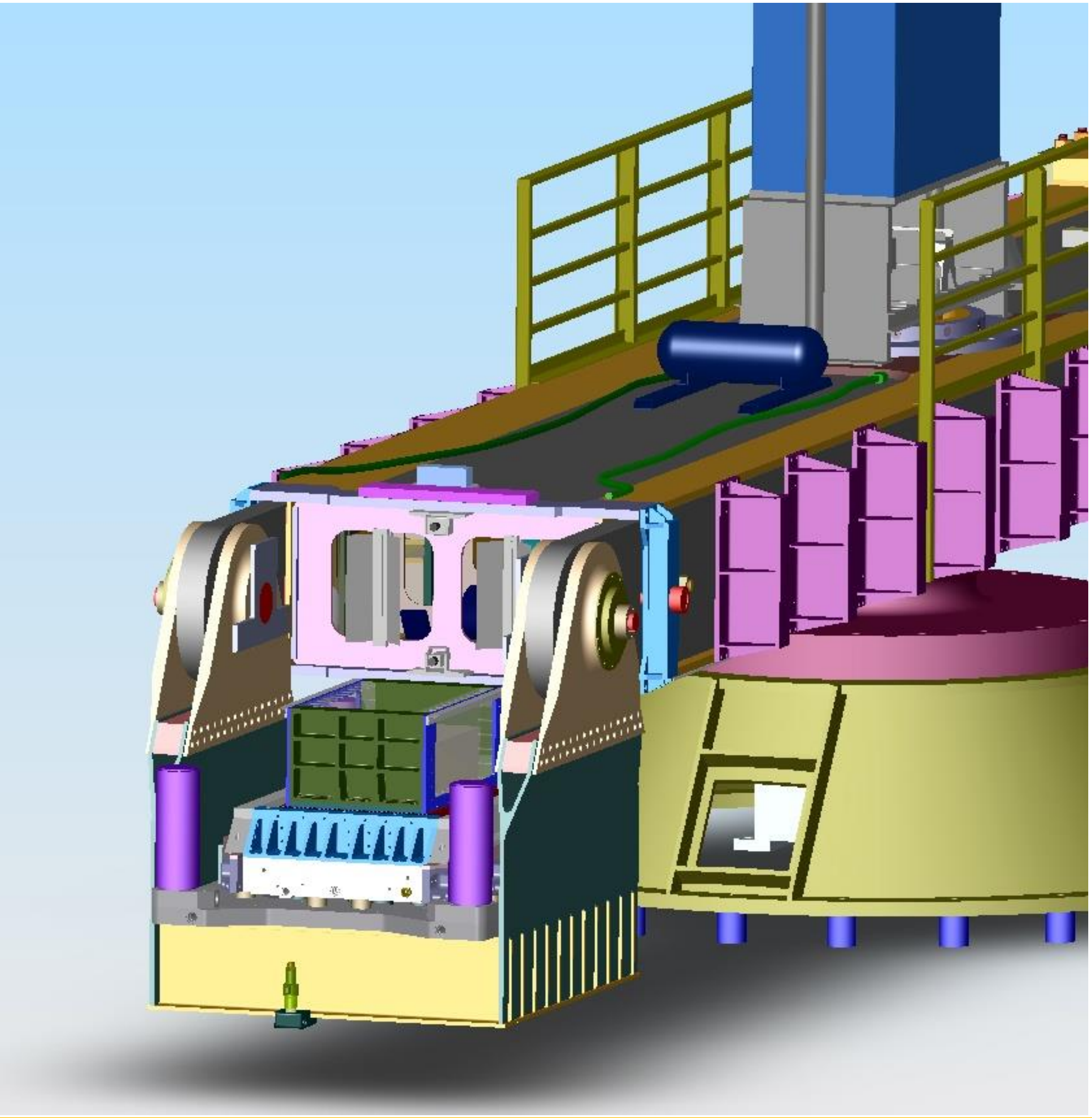
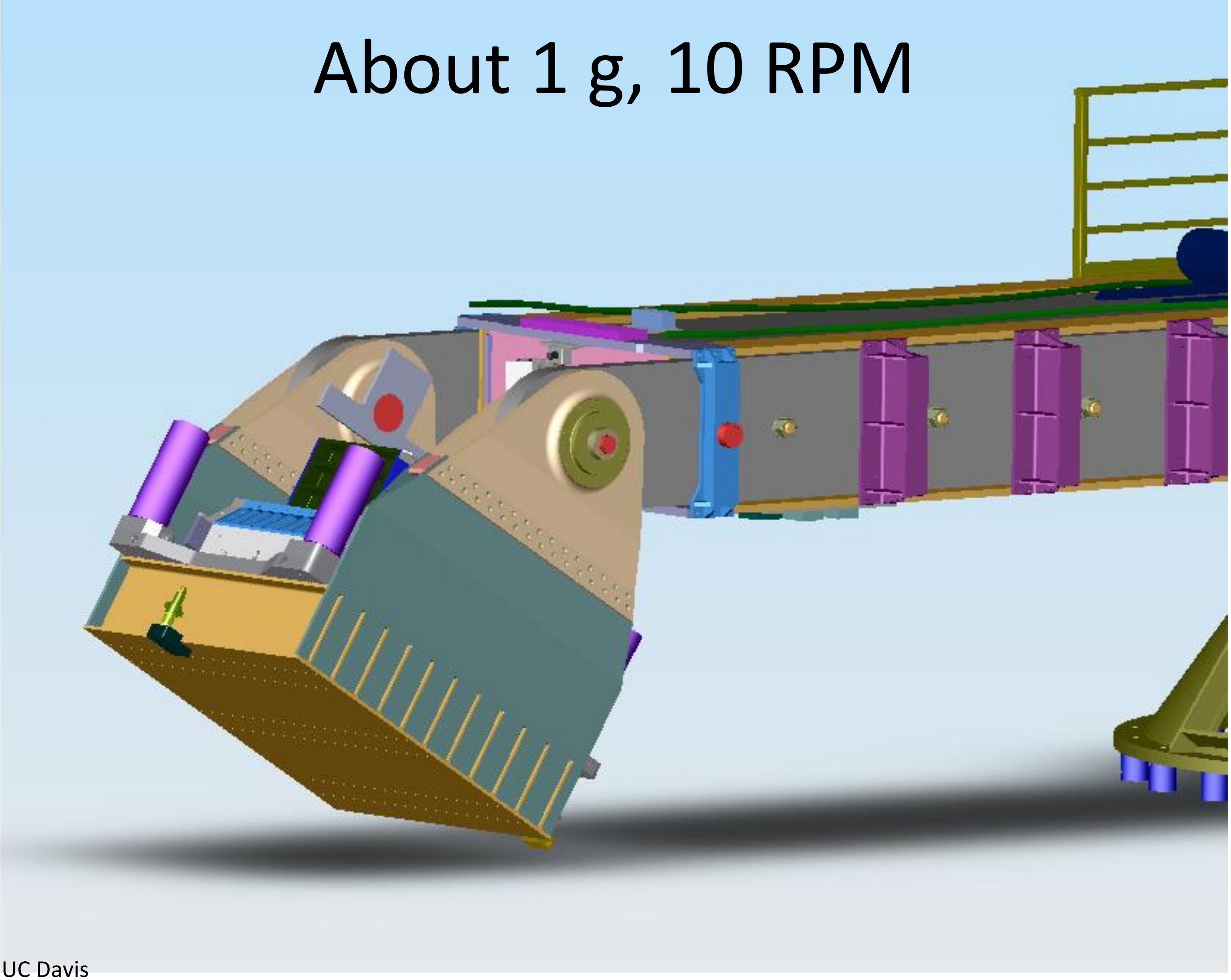
CENTRIFUGE PRINCIPLES

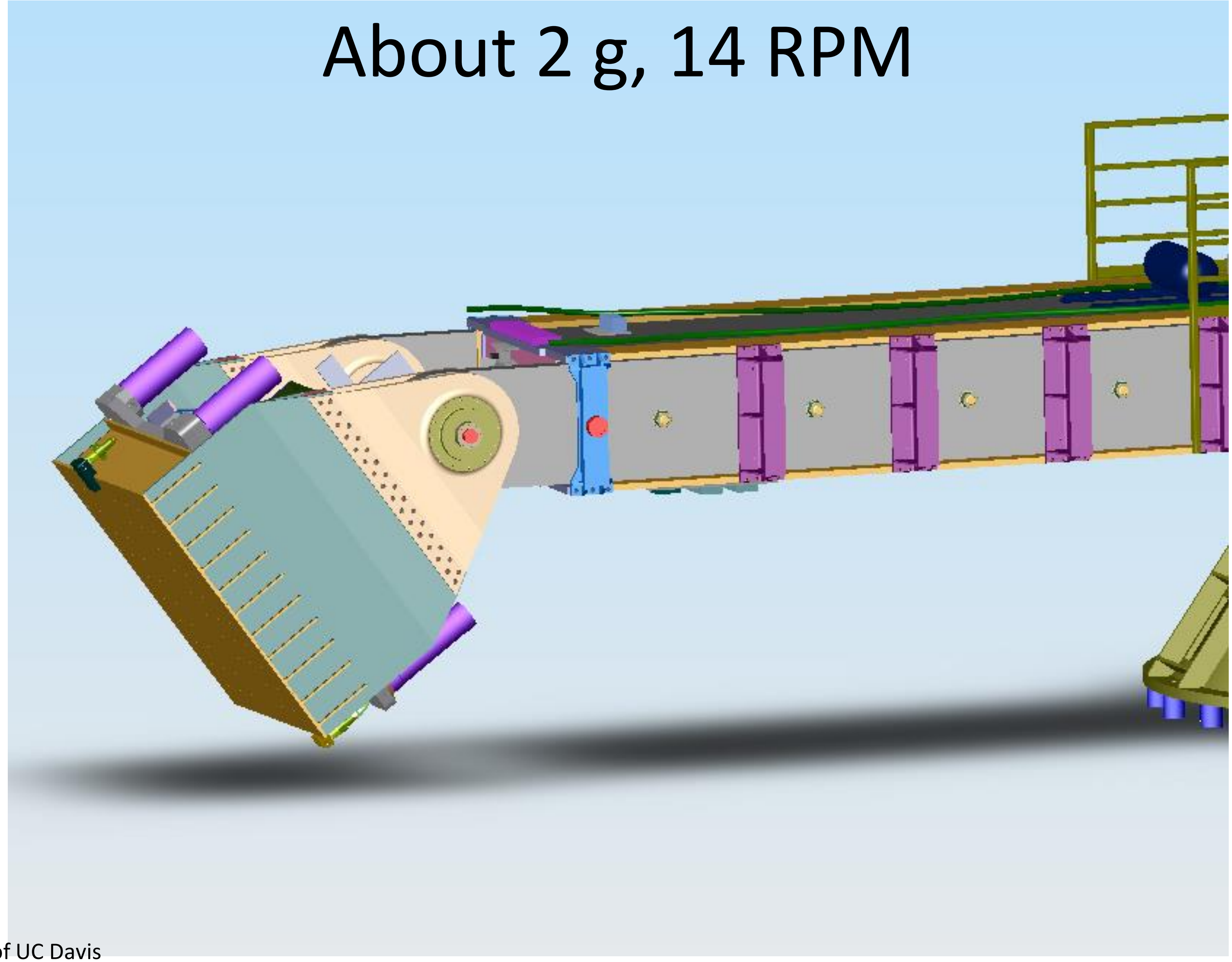


Slide courtesy of UC Davis

CENTRIFUGE PRINCIPLES



Slide courtesy of UC Davis



Slide courtesy of UC Davis

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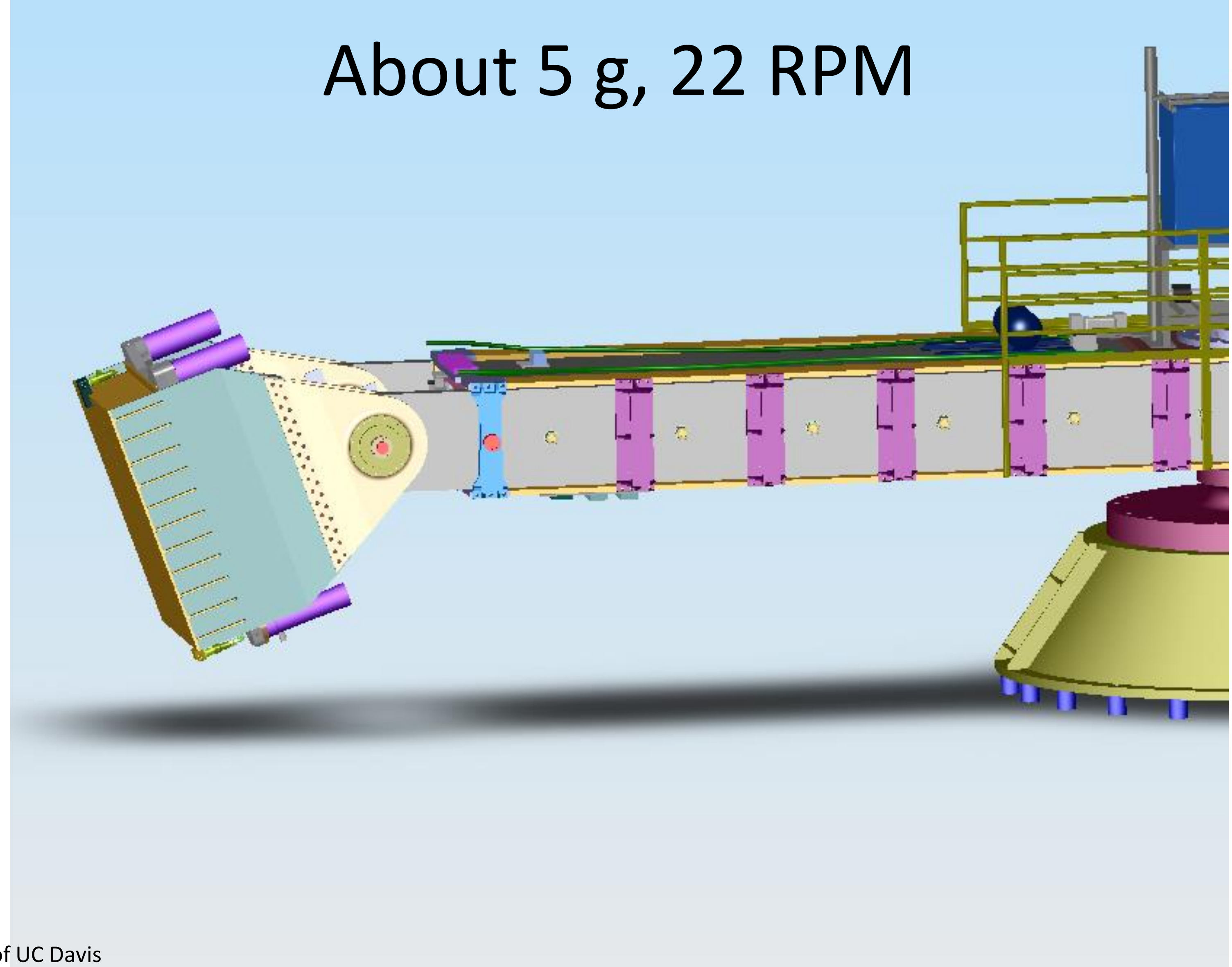
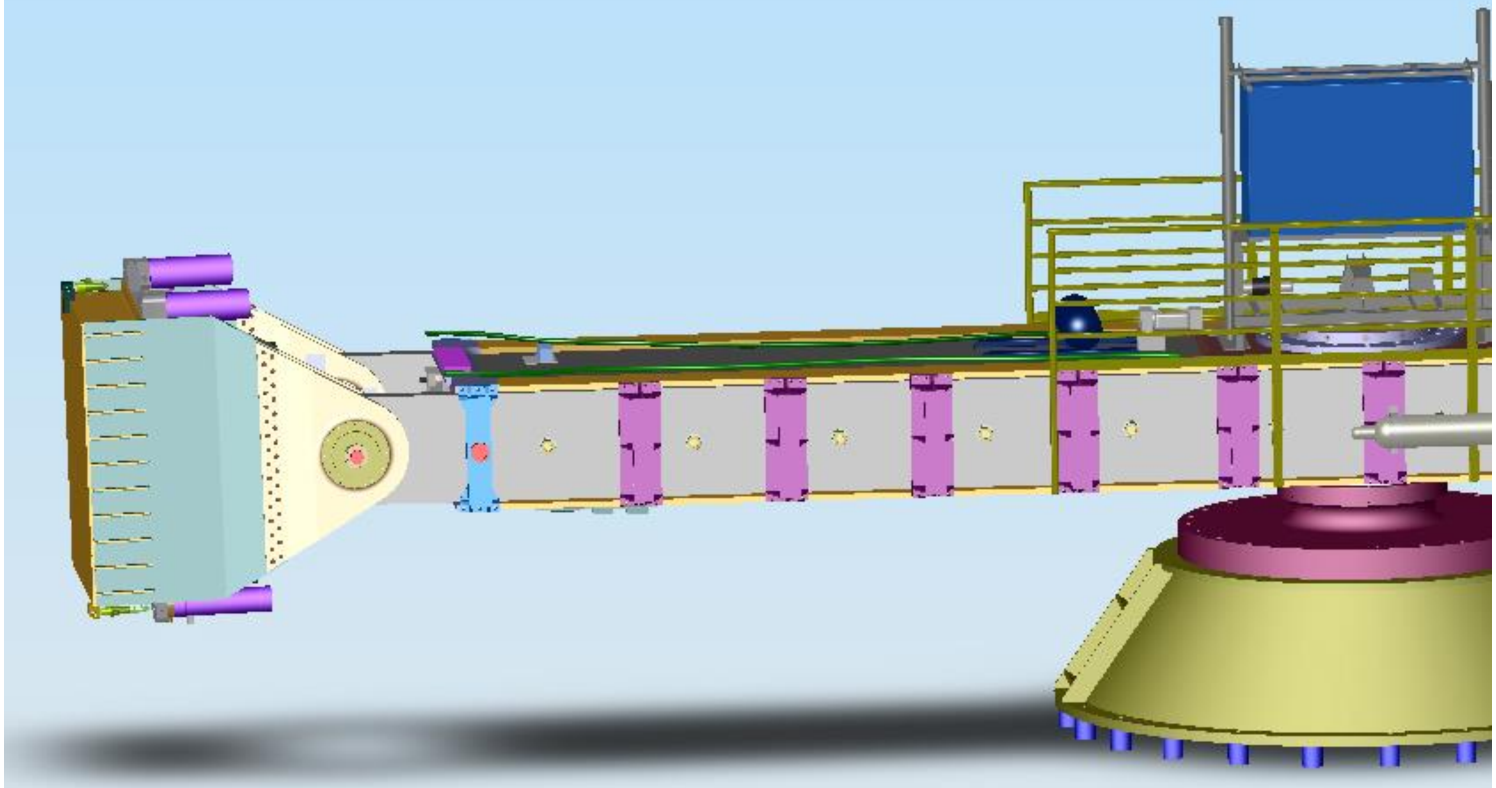


Slide courtesy of UC Davis

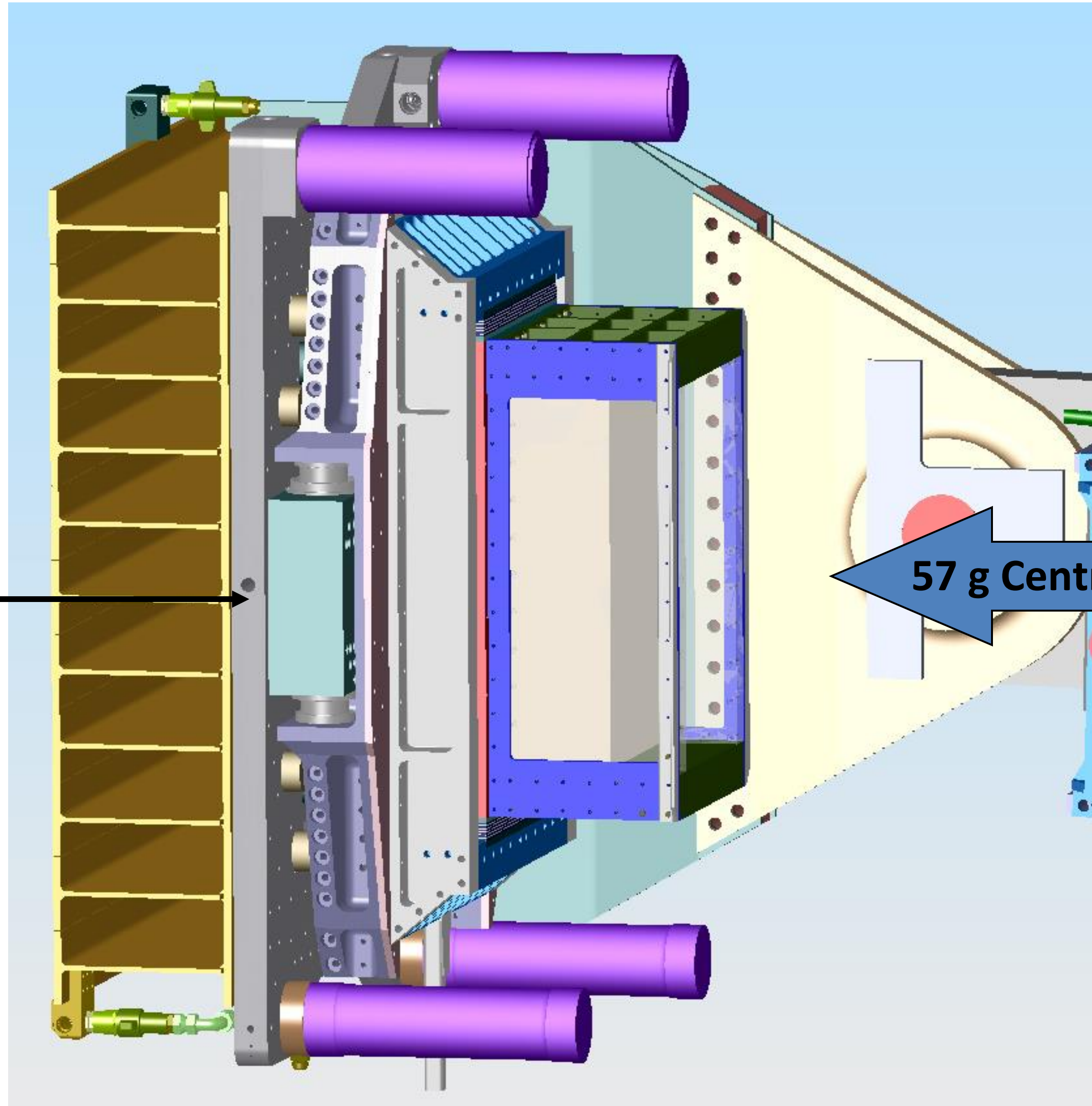
About 57 g, 76 RPM, 160 MPH



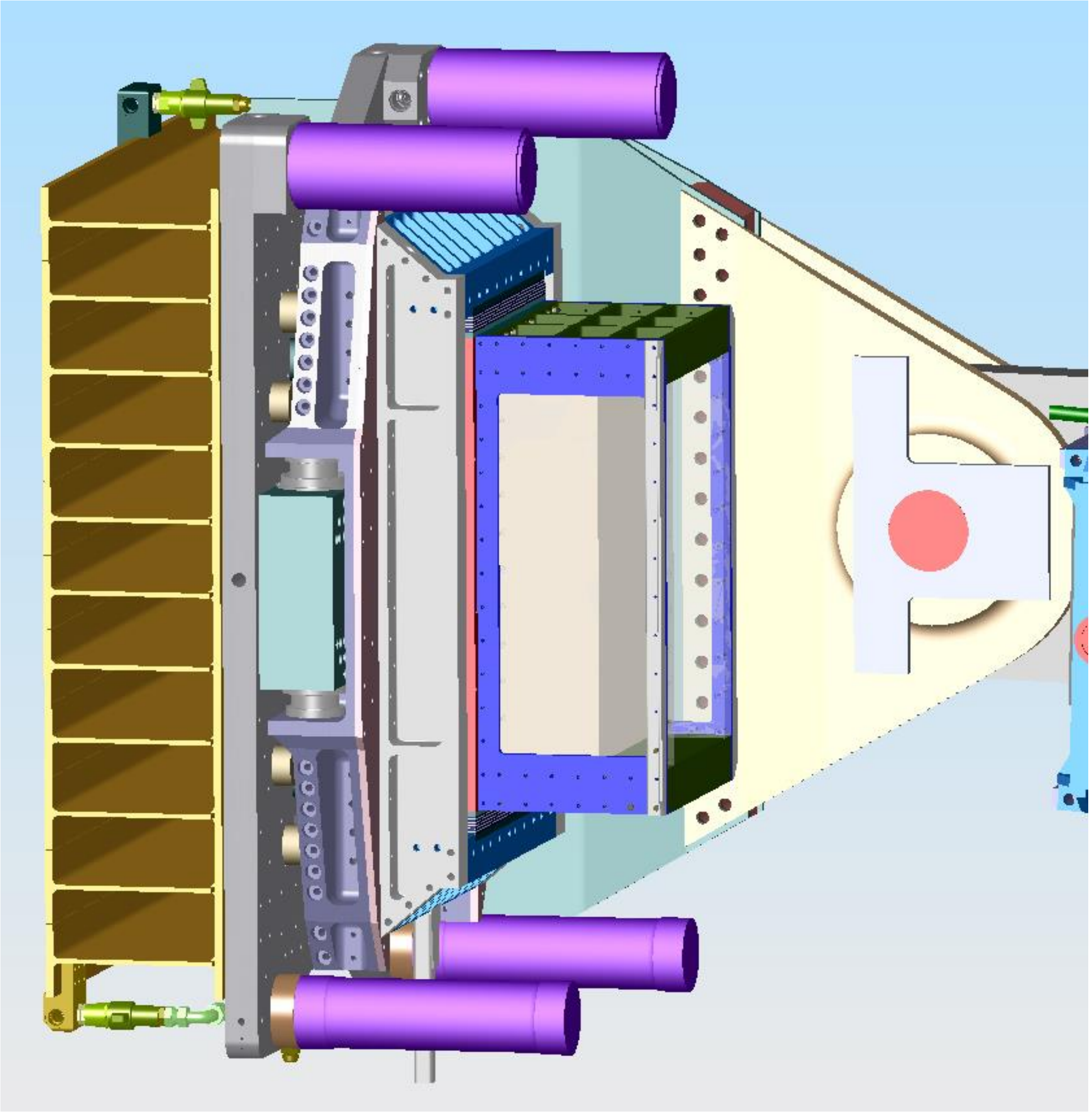
The centrifugal force increases the "weight" of the model to simulate weight of full scale Civil Structures

Slide courtesy of UC Davis

CENTRIFUGE PRINCIPLES



Slide courtesy of UC Davis



Slide courtesy of UC Davis

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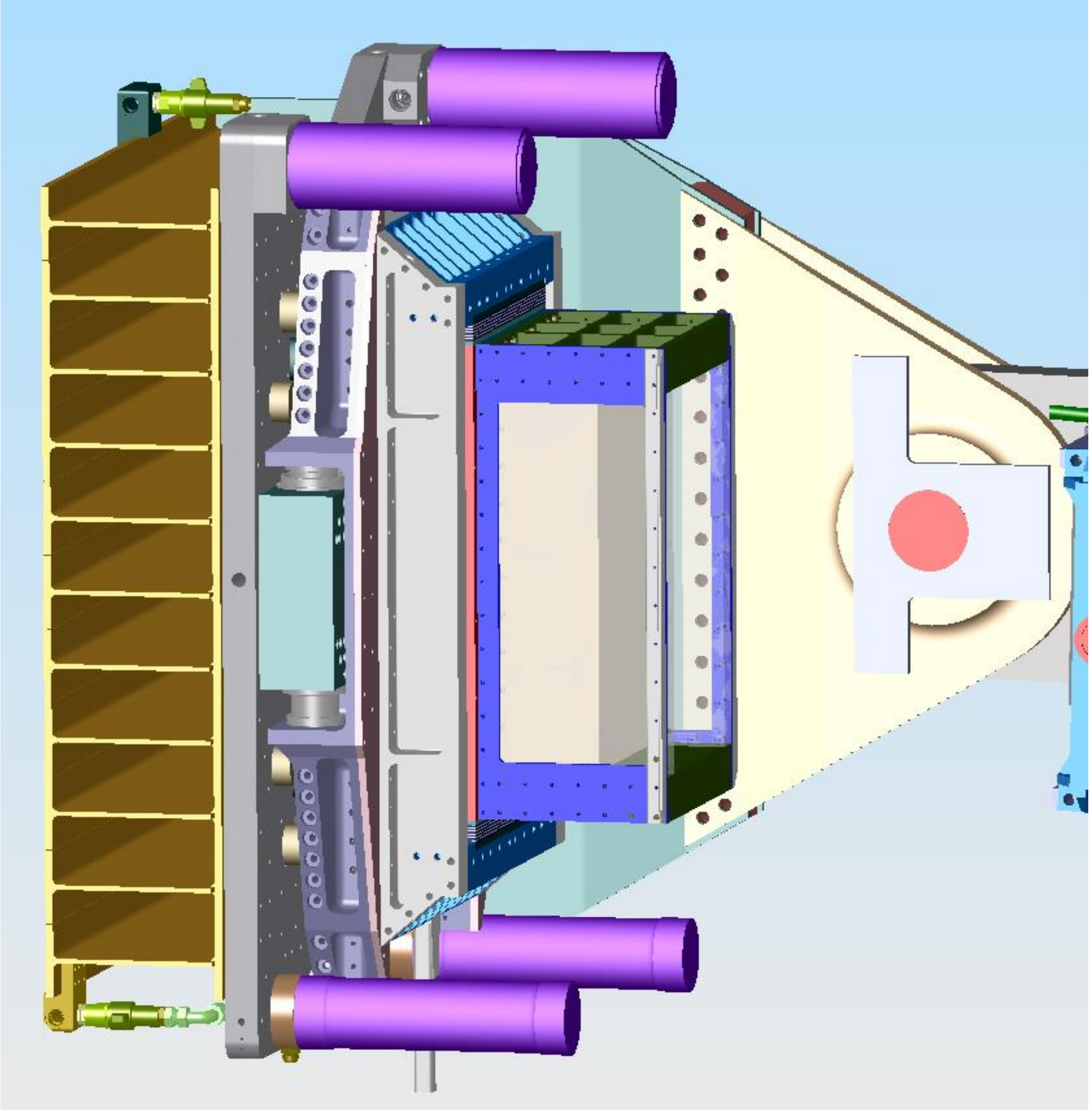


Slide courtesy of UC Davis

CENTRIFUGE PRINCIPLES

- Soil strength and stiffness depend on effective stress

- Increased gravity increases the weight of the model and increases the stresses

- Stresses in the reduced scale model are equivalent to those in a full scale prototype

- Relationship between model and prototype:

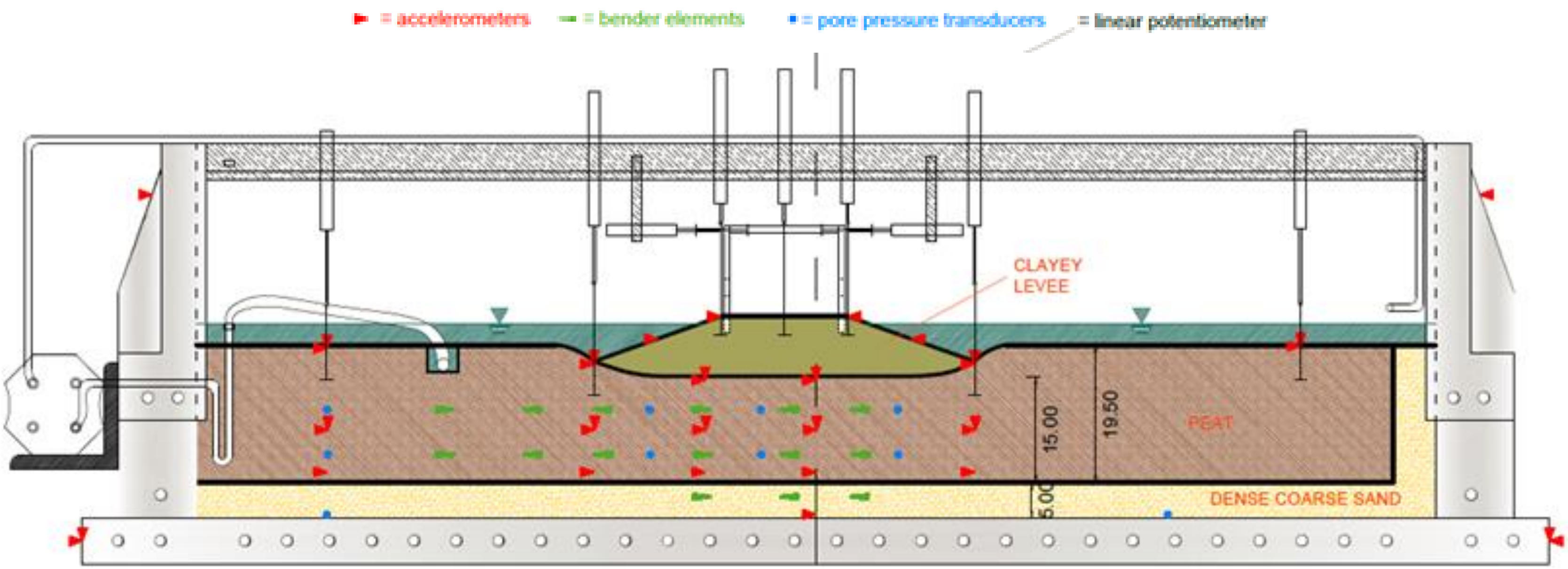
$$\frac{g_p}{g_m} = \frac{1}{N}$$

$$\sigma^* = \frac{\sigma_p}{\sigma_m} = 1$$

Quantity	Prototype Dimension /Model Dimension
Dynamic Time	N/1
Dynamic Frequency	1/N
Displacement, Length	N/1
Velocity	1/1
Acceleration, Gravity	1/N
Force	$N^2/1$
Pressure, Stress	1/1
Diffusion time	$N^2/1$
Mass	$N^3/1$

Kutter et al. (1992)
http://nees.ucdavis.edu/principles.php

LARGE SCALE 9m RADIUS INVESTIGATIONS



PHASE 1 - CLAYEY LEVEE:

- **Ground motions and sine sweeps**
- **Peat seismic performance**
  - **Wave propagation**
  - **Strains**
  - **Pore pressures**

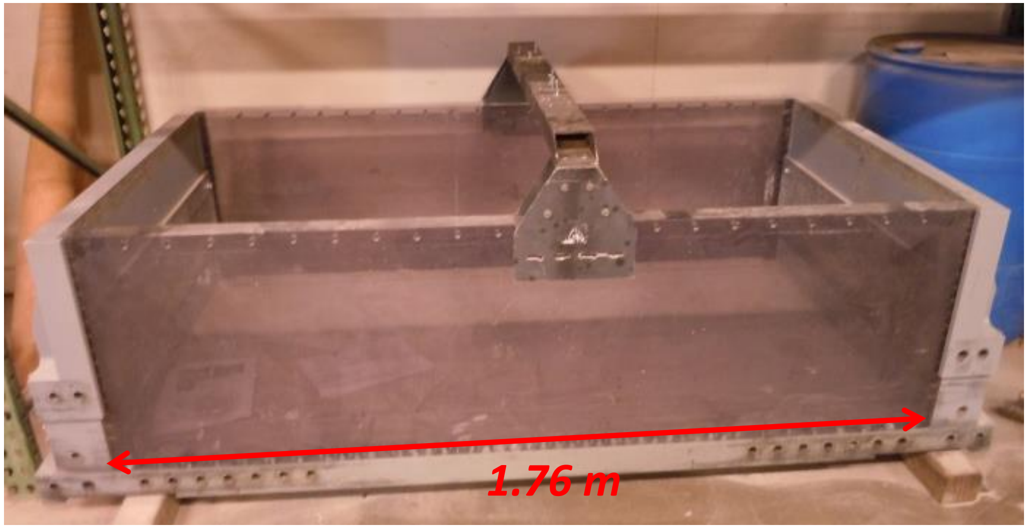
TARGET DIMENSIONS FOR RCK01

Prototype Dimensions (target)

Peat Layer Thickness: 11 m
Levee Height: 5 m

Model Dimensions (target in flight)

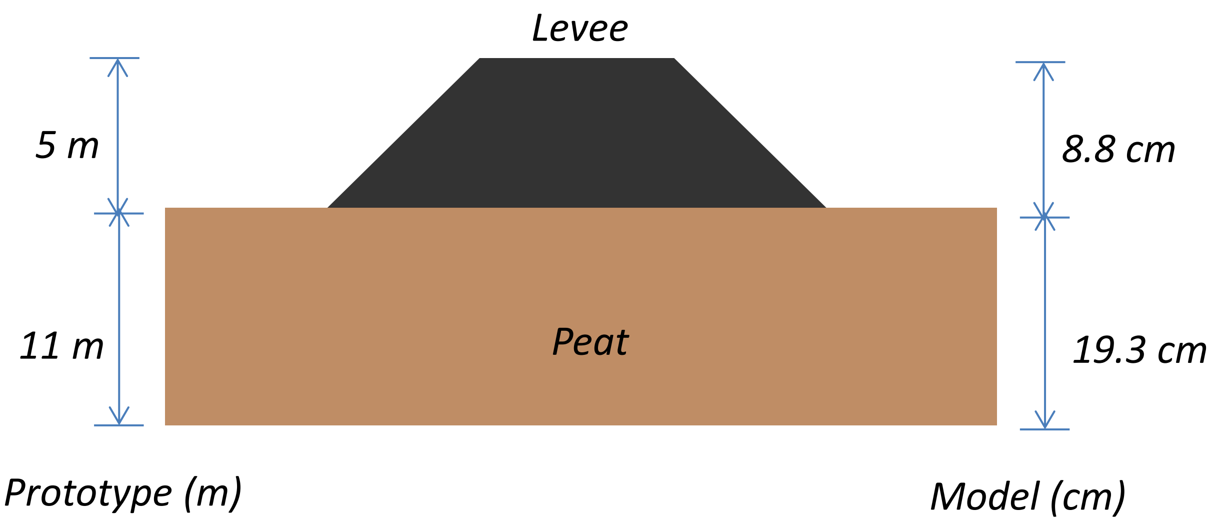
Peat Layer Thickness: 19.3 cm
Levee Height: 8.8 cm



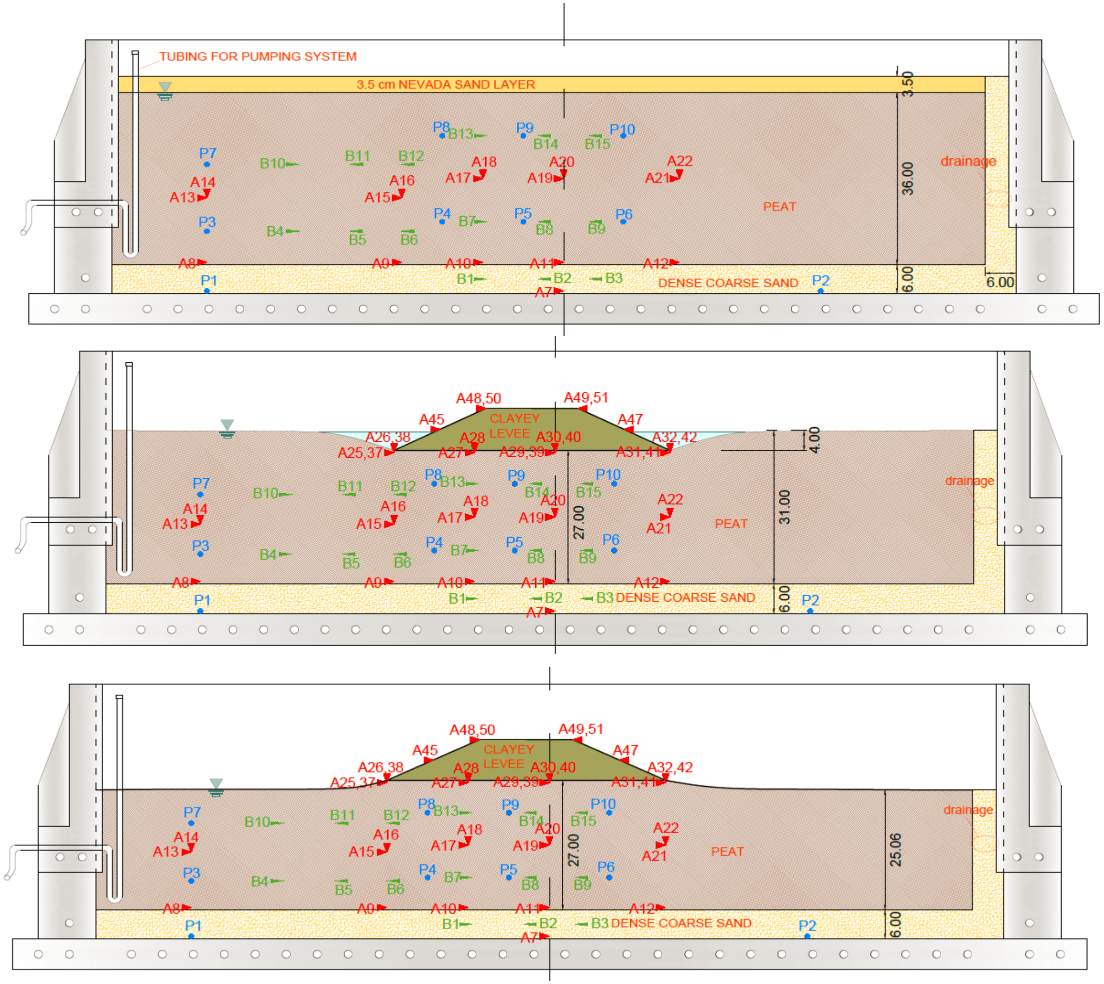
Target Acceleration => 57 g

Container Geometry

Length: 1.76 m
Width : 0.91 m
Height: 0.54 m

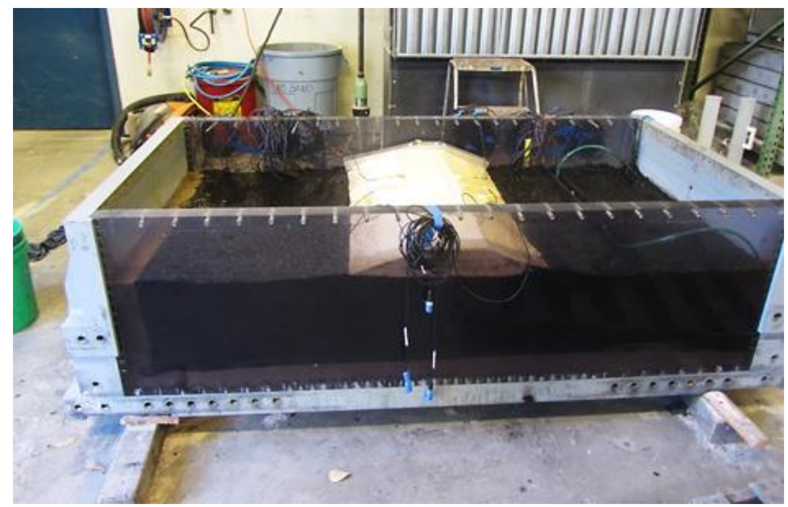


MODEL CONSTRUCTION



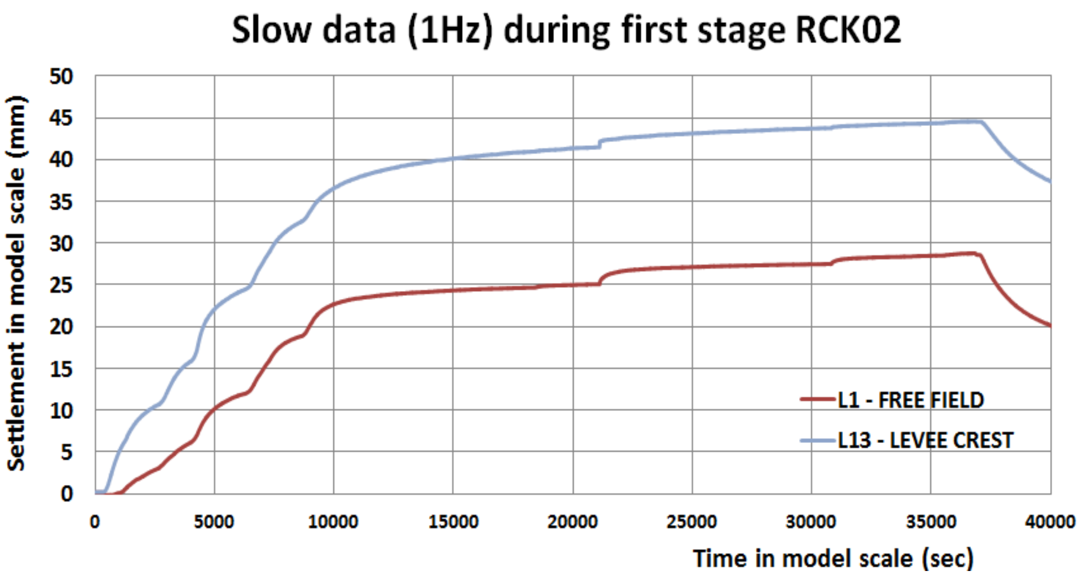
Sand layer on top of the peat:

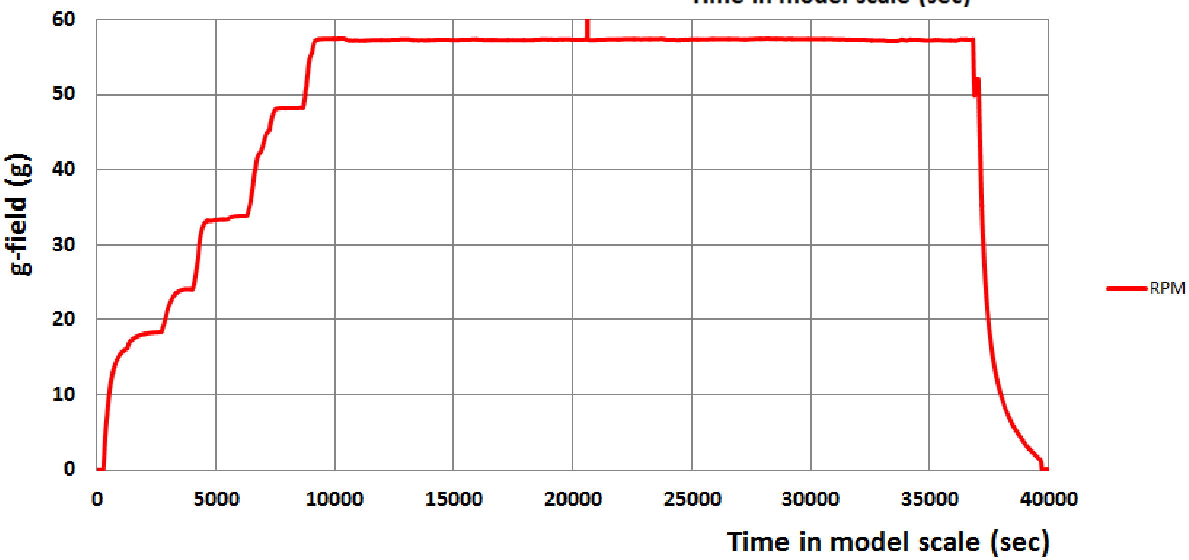
- Consolidation of peat
- Increased bearing capacity
- Peat settled by 5cm (14%)



Time lapse of the first stage => 5 weeks before spinning

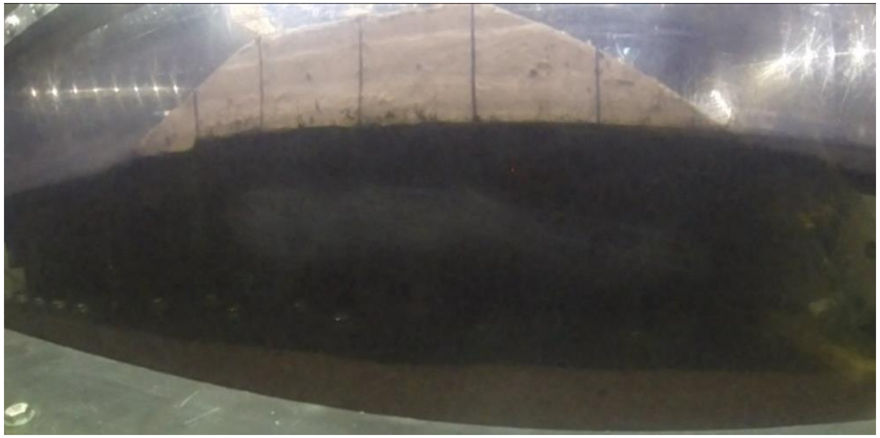
VERTICAL STRAINS RECORDS



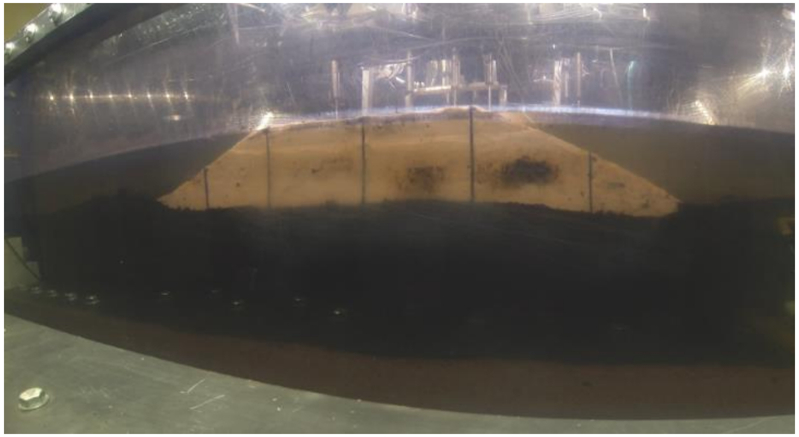


Settlement during second large scale investigation RCK02 for the first clayey levee phase

Settlements during spinning => vertical strains of 40 %



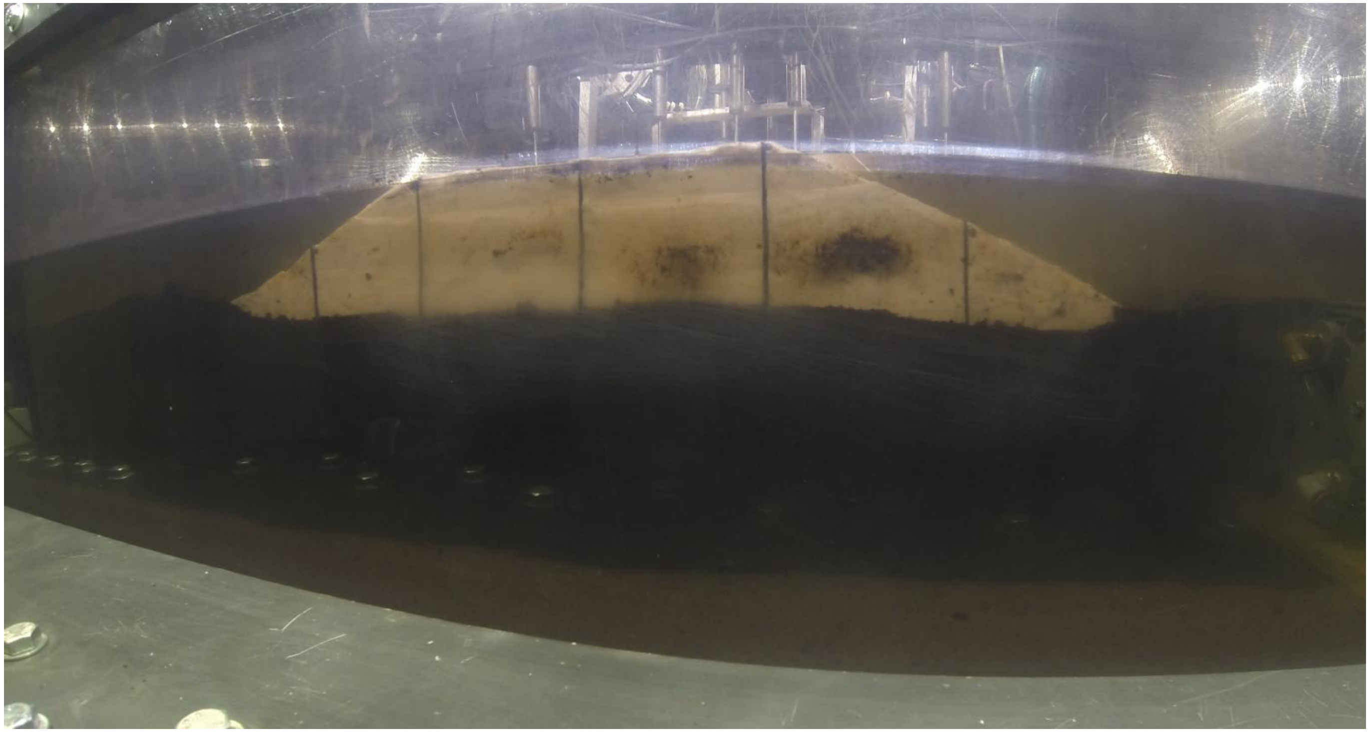
1 g condition



57 g condition

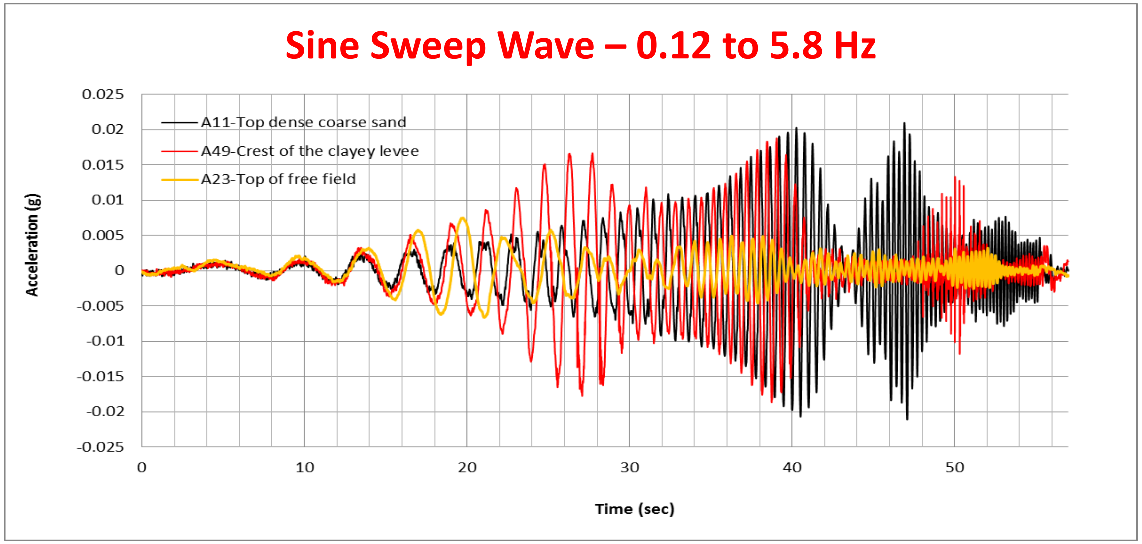
[Video 3 – Time Lapse Spinning Down from 57 g to 1 g]

Model vs. Prototype Scale



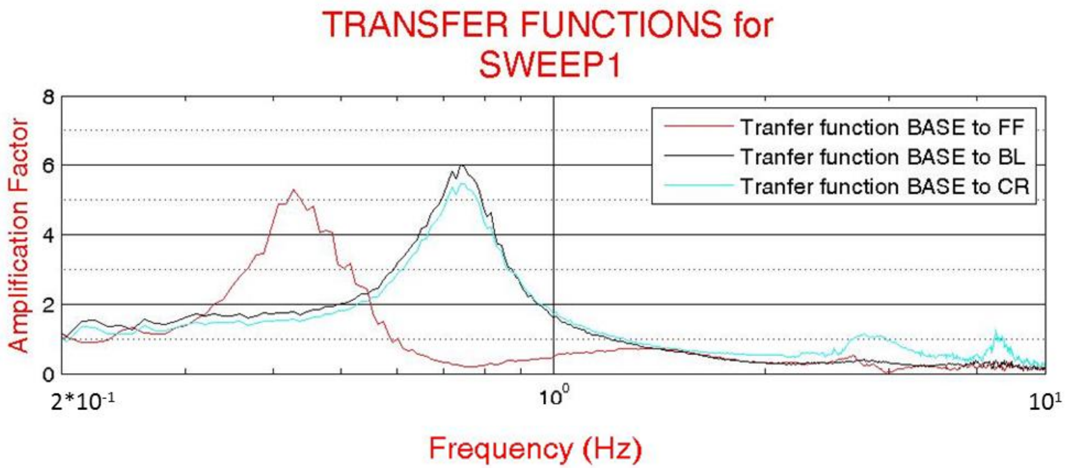
Video 4a,b – Slow motion 0.6g PBA ground motion on the clayey levee

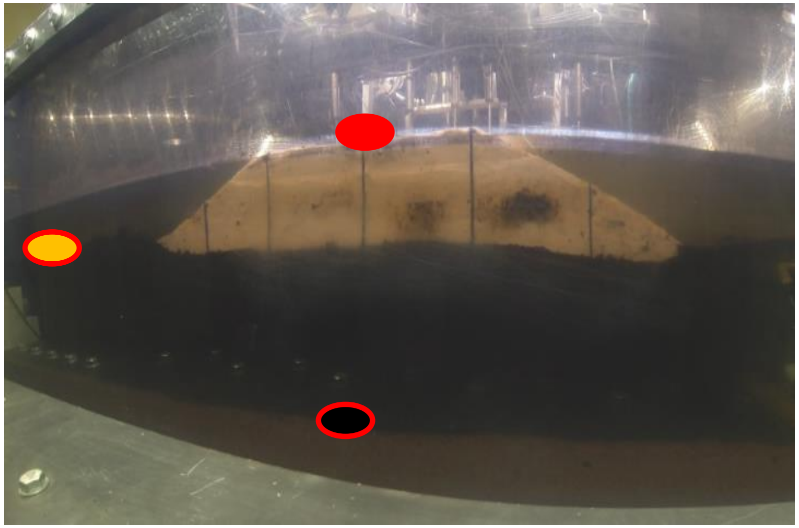
ACCELEROMETERS' RECORDS



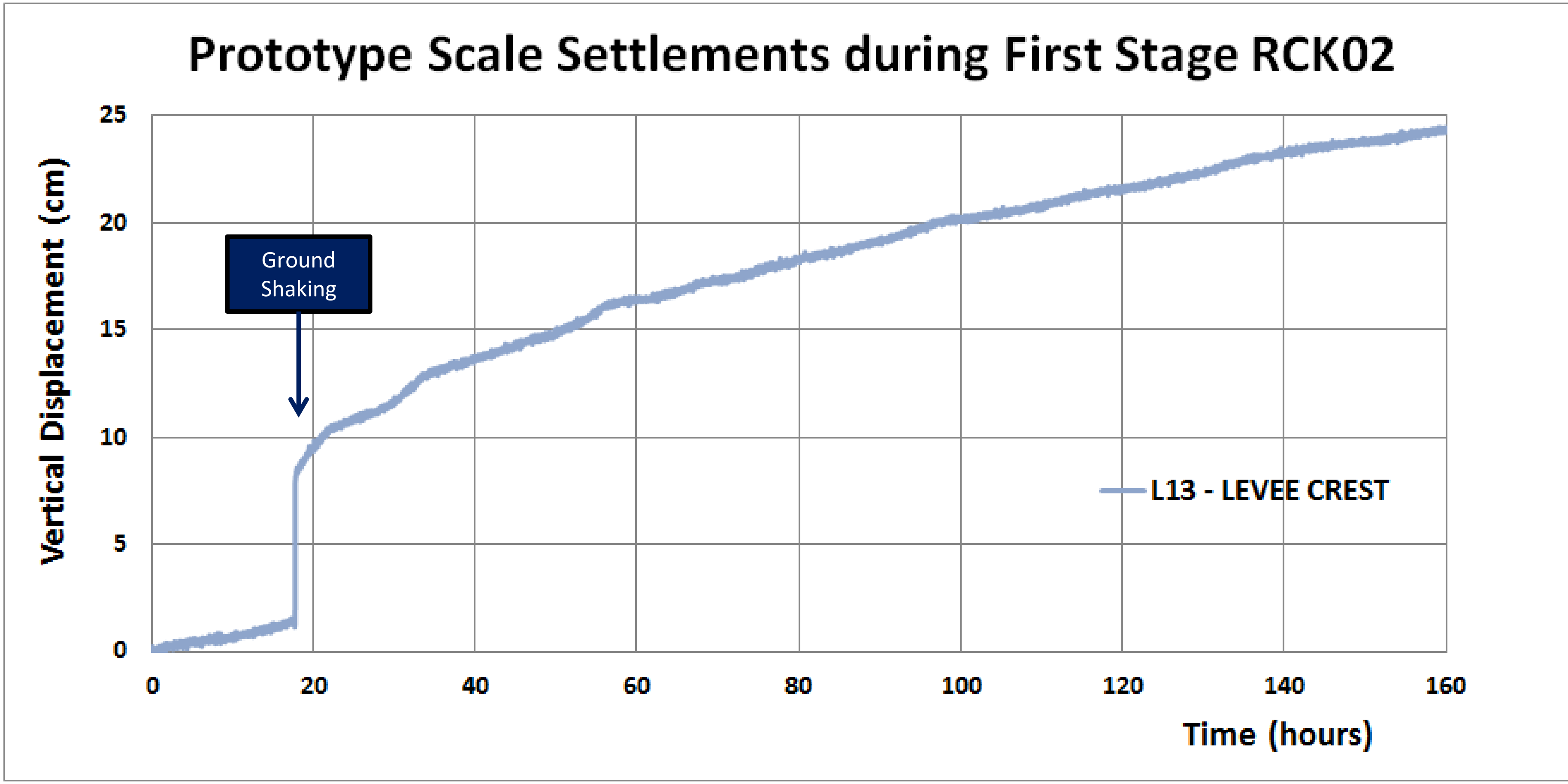
Compare response:

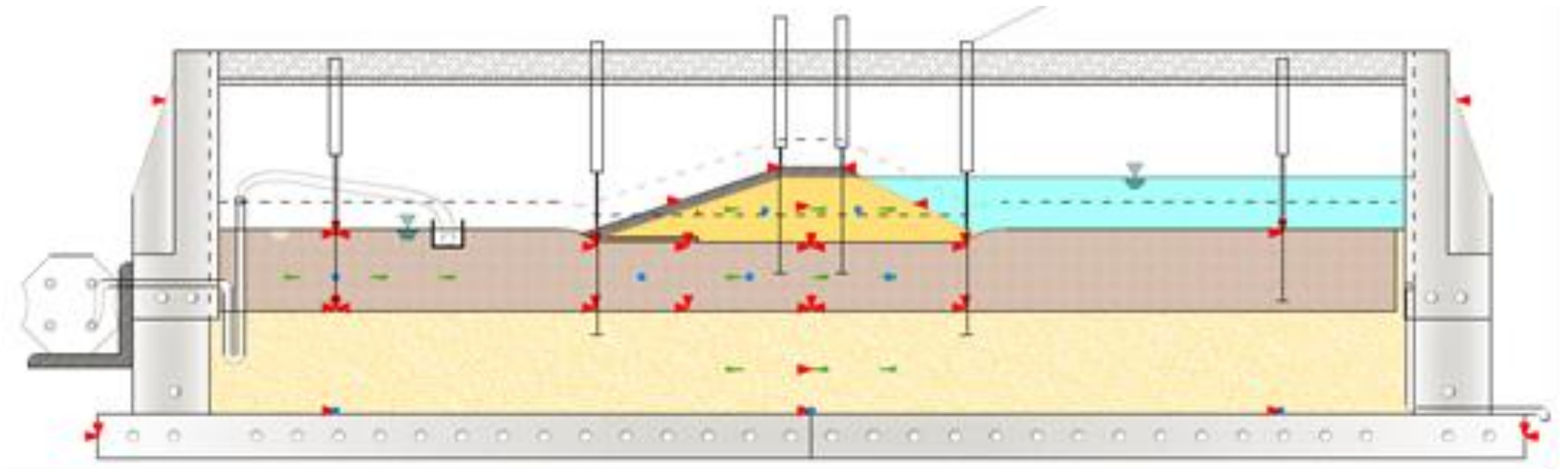
- ***Peat base***
- ***Free field***
- ***Levee Crest***





SETTLEMENTS DUE TO GROUND MOTIONS

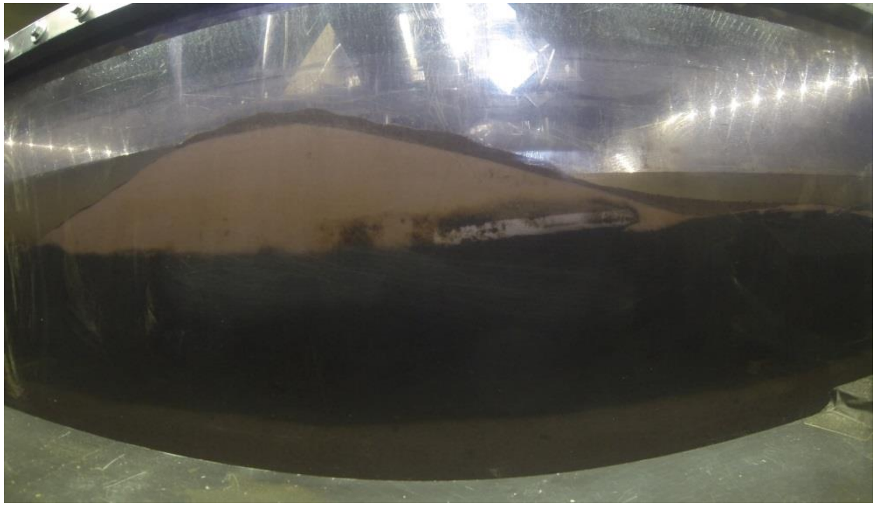


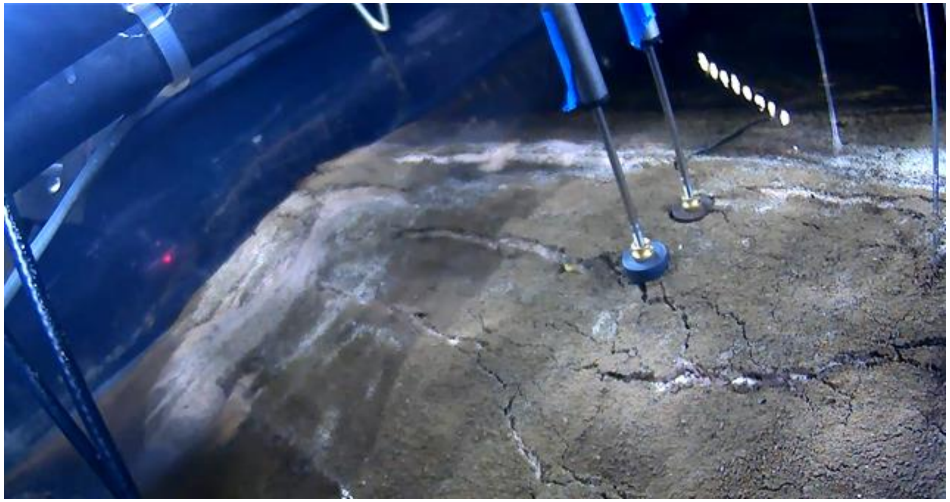


PHASE 2 – SANDY LEVEE:

- **Levee deformation potential**
- **Target 0.4 g PBA**
  - **Liquefaction of the levee fill**
  - **Deformations**

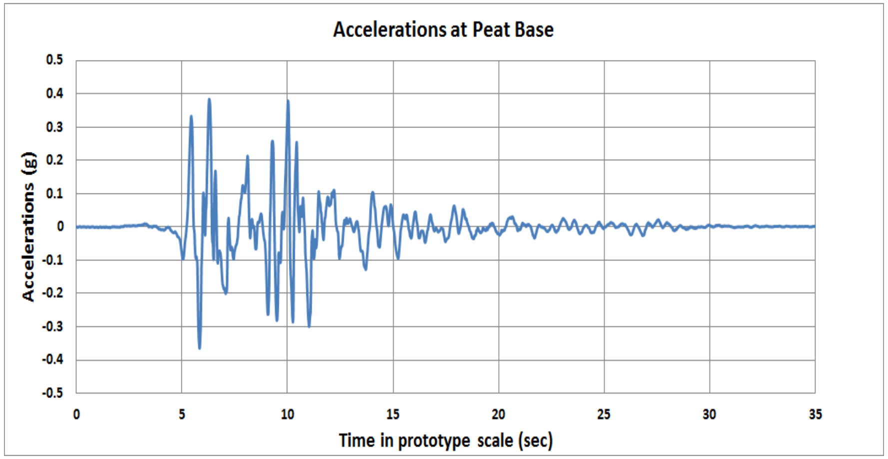
Liquefaction of the sandy levee is a real threat

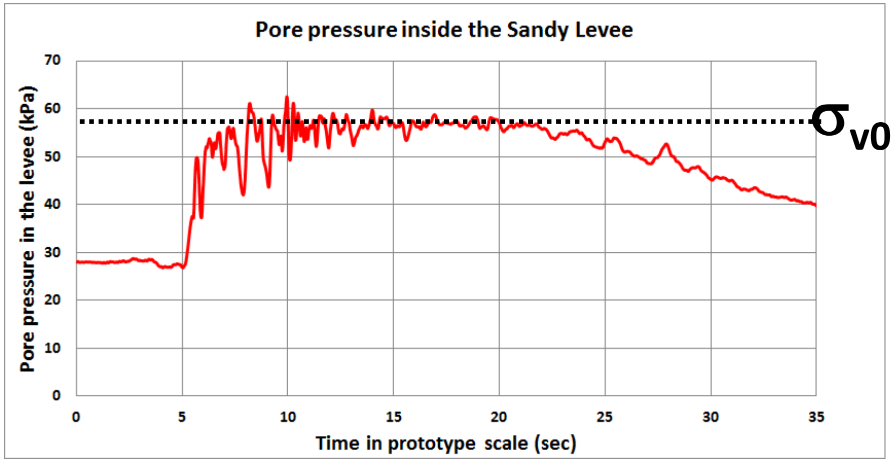


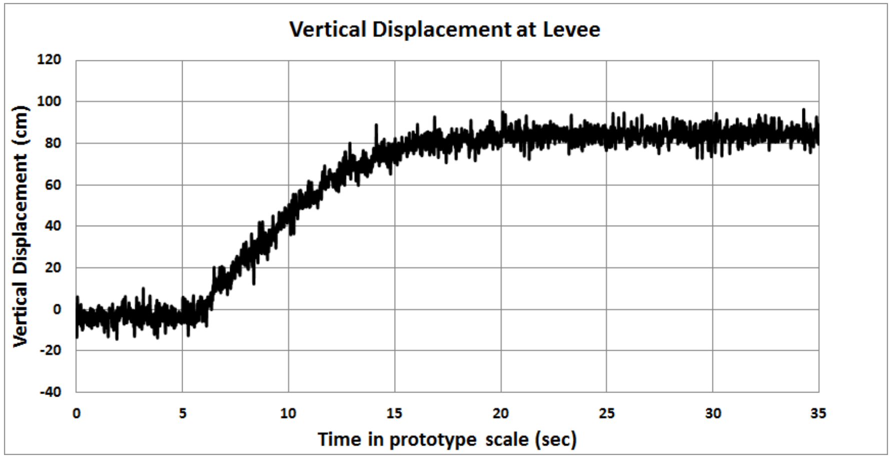


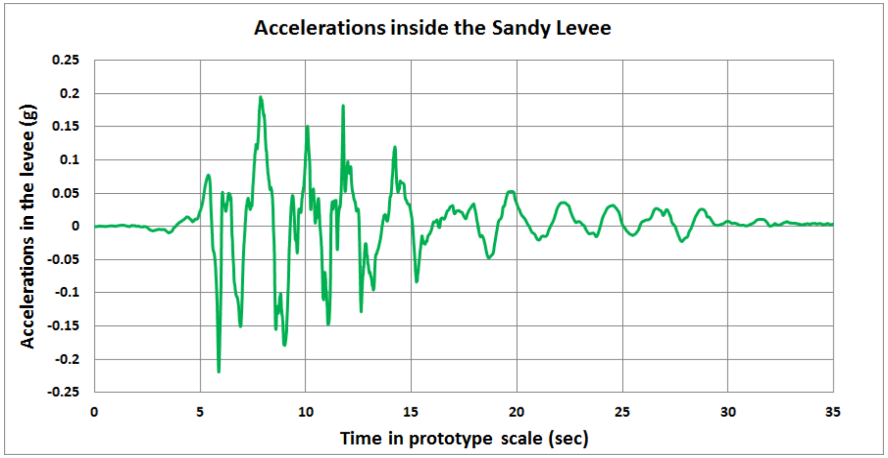
Video 5 and 6 – Target 0.4g PBA Ground Motion on Sandy Levee

Liquefaction of the sandy levee is a real threat









Records in Prototype Scale

SUMMARY AND CONCLUSION

- 0.4 g PGA is expected for 500 y.r.p => “Big Gulp” would jeopardize the state economy
- Centrifuge testing provides insights on S.S.I. and cyclic behavior of peaty soils
- Centrifuge testing shows a potential for levee liquefaction
- More analysis to come…

FUTURE WORK

- **Data analysis**:
  - Analyze the response of the peat during earthquakes
  - Analyze the post seismic behavior of the peat
- **Numerical simulations**:
  - Create a constitutive model for peat
  - Observe the influence of different parameter variations
- **Make comparisons between lab testing, field testing, centrifuge testing and numerical simulations**
- **Eventual application of our research**:
  - Develop an analysis framework to evaluate the stress demands under the levee and estimate the probability of failure
  - Develop fragility functions and risk map for levees in the delta

QUESTION TIME!

Thanks!