

# Ground Deformation and Lateral Spreading

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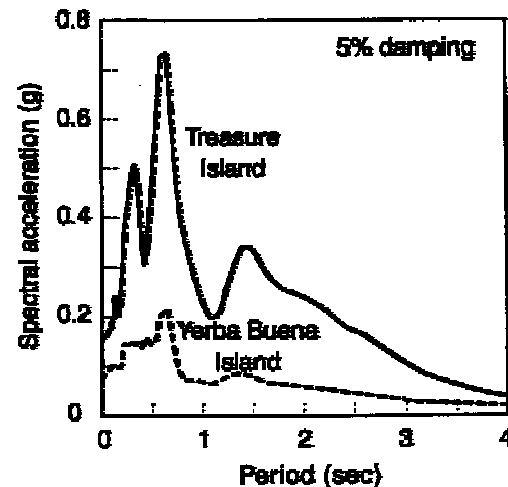
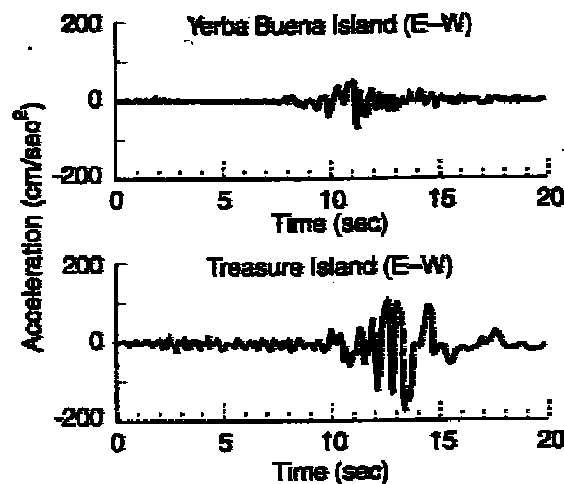


# Geotechnical Impacts on Structural Performance

## Response modification

Soil conditions can change:

- Amplitude
- Frequency content
- Duration



# **Geotechnical Impacts on Structural Performance**

Ground failure

Permanent deformations

# Geotechnical Impacts on Structural Performance

Ground failure

Permanent deformations

Flow failure



# Geotechnical Impacts on Structural Performance

Ground failure

Permanent deformations

Flow failure

Lateral spreading



# Geotechnical Impacts on Structural Performance

Ground failure

Permanent deformations

Flow failure

Lateral spreading

Settlement



## **Evaluation of Liquefaction Hazards**

Three primary questions to consider:

Is the soil susceptible to liquefaction?

Will the anticipated loading trigger liquefaction?

What will be the effects of liquefaction?

# Liquefaction Susceptibility

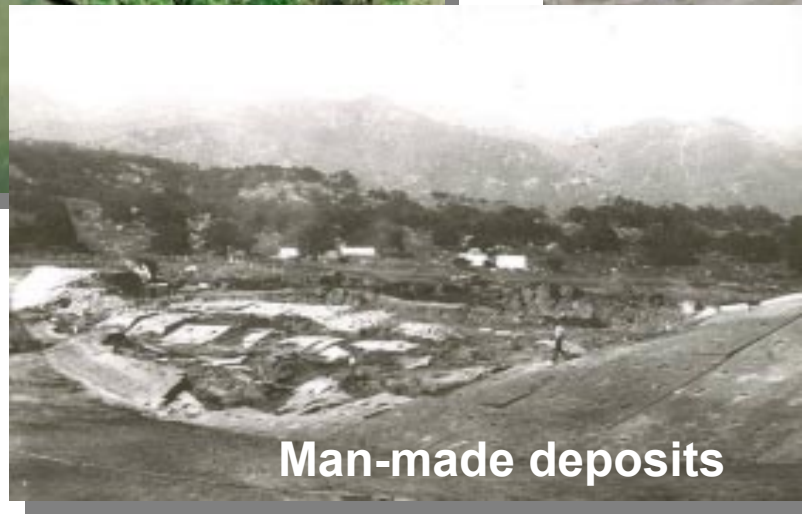
Geologic environments well established



Fluvial deposits



Alluvial deposits



Man-made deposits



## Liquefaction Susceptibility

Soil types well established:

- Clean sands
- Silty sands (up to ~35% fines)

Also observed:

- Silts
- Gravelly soils

### Conclusion:

Liquefaction susceptibility is relatively well understood – not a pressing issue for development of PBEE

## Initiation of Liquefaction

Current procedure:

Characterize [loading](#) by cyclic shear stress

$$CSR = 0.65 \frac{\tau_{\max}}{\acute{o}'_v}$$

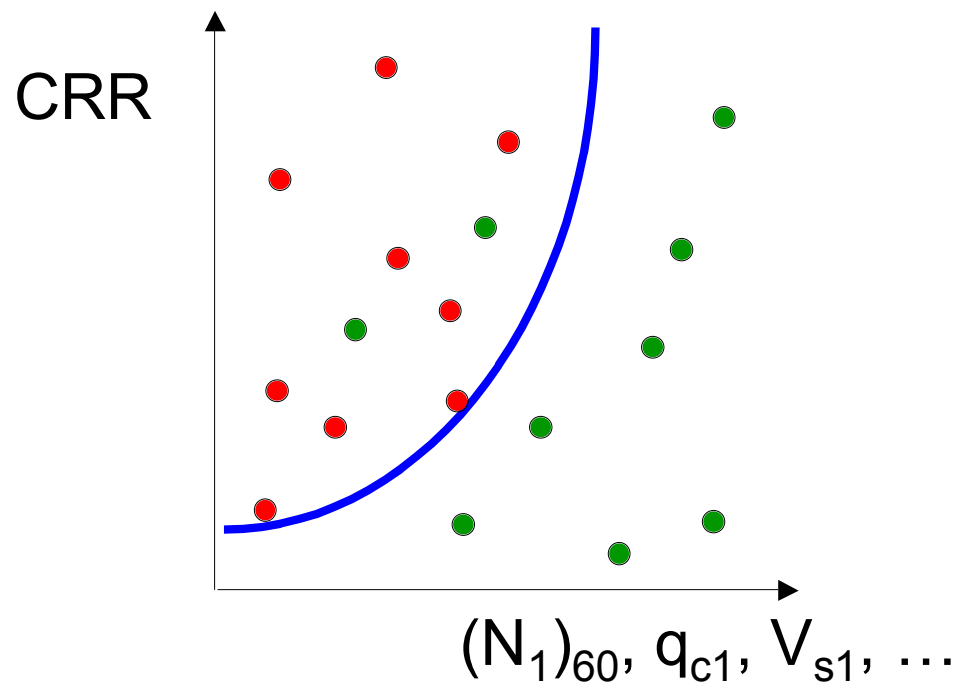
$$CSR = 0.65 \frac{a_{\max}}{g} \frac{\acute{o}'_v}{\acute{o}'_v} r_d$$

[and](#) earthquake magnitude

## Initiation of Liquefaction

Current procedure:

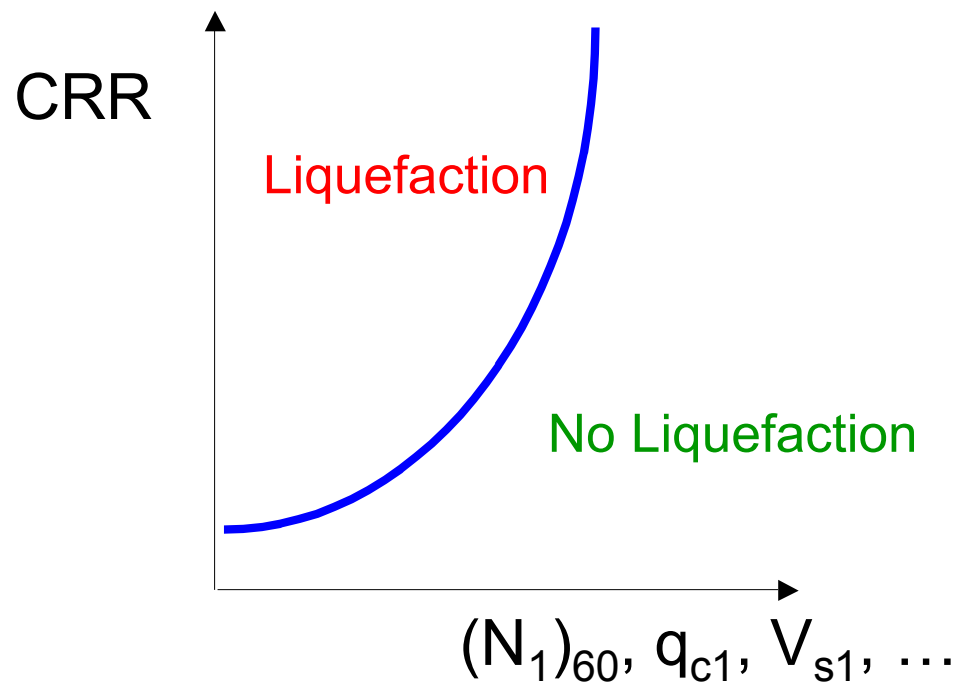
Characterize resistance by cyclic shear stress



## Initiation of Liquefaction

Current procedure:

Characterize resistance by cyclic shear stress



## Initiation of Liquefaction

### **Conclusion:**

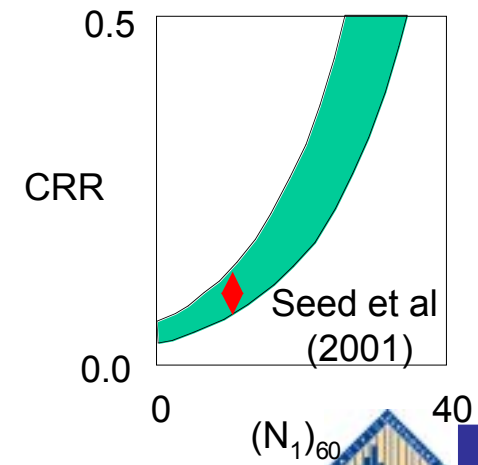
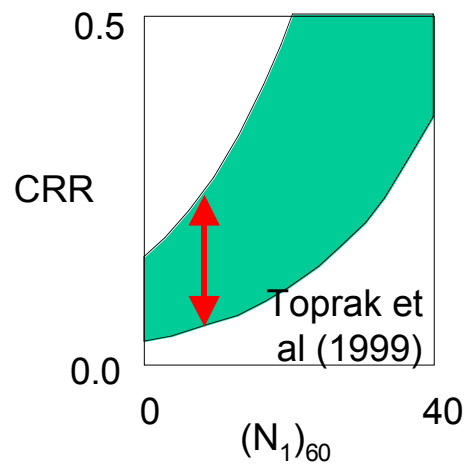
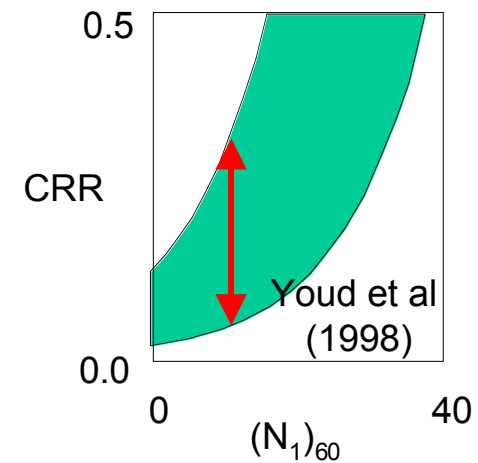
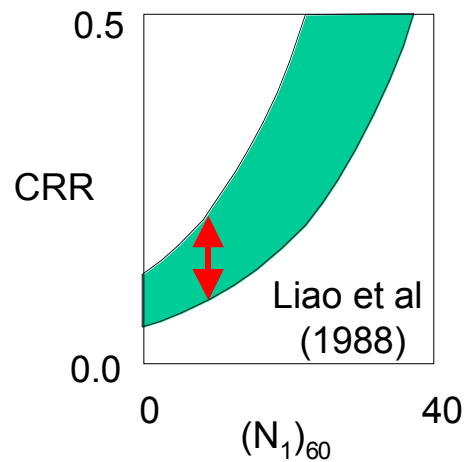
Practical procedures for evaluation of liquefaction potential exist, but are not readily suited to implementation in PBEE framework, in which unbiased estimates of probability of liquefaction are required.

More high-quality field data from sites of liquefaction and non-liquefaction are needed.

Improvements are possible through the identification of better parameters with which to characterize loading and resistance.

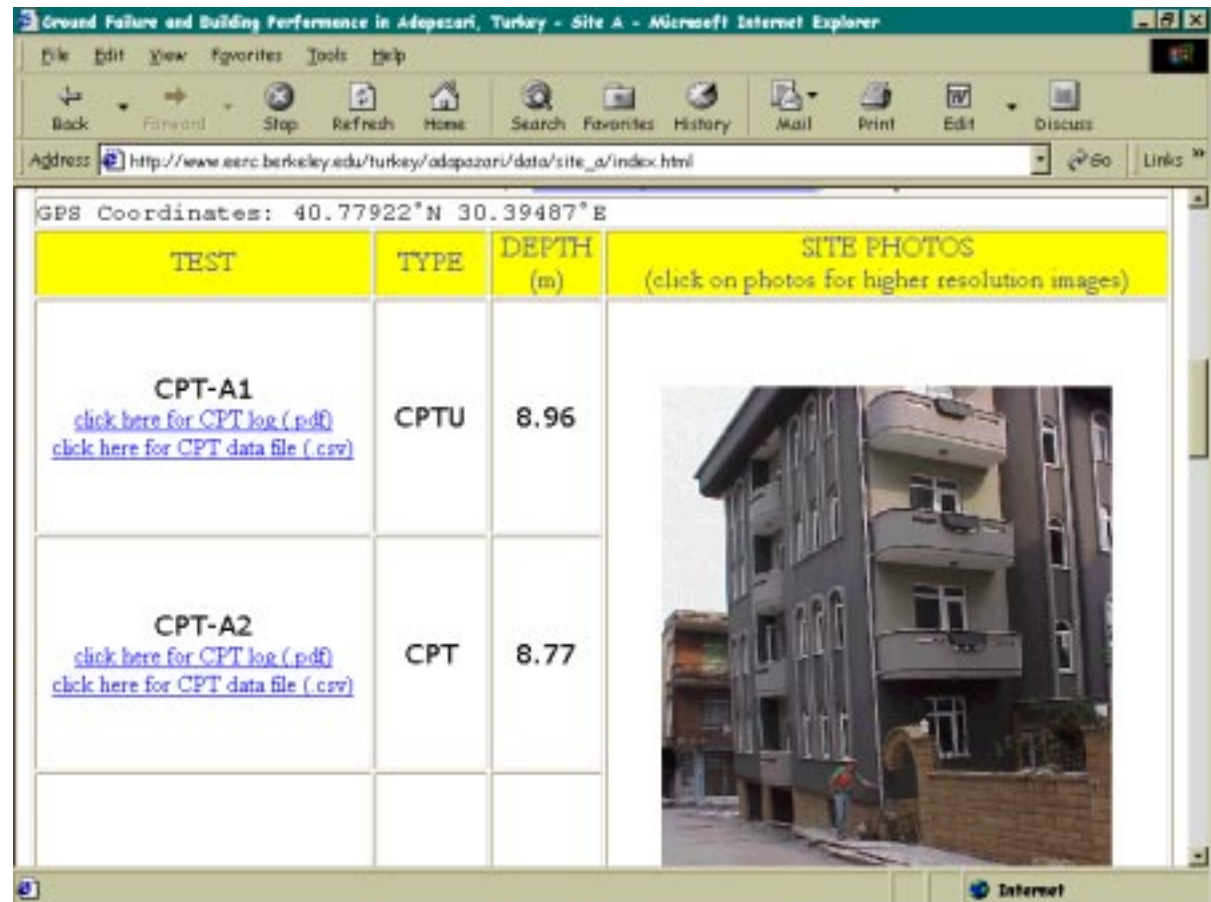
# What are we doing about these issues?

Probabilistic  
evaluation of  
liquefaction potential  
Seed, Der  
Kiureghian, et al.




## What are we doing about these issues?

Ground Failure and  
Building  
Performance in  
Adapazari, Turkey  
Bray et al.



The screenshot shows a Microsoft Internet Explorer browser window. The title bar reads "Ground Failure and Building Performance in Adapazari, Turkey - Site A - Microsoft Internet Explorer". The address bar contains the URL "http://www.eerc.berkeley.edu/turkey/adapazari/data/site\_a/index.html". The main content area displays the following information:

GPS Coordinates: 40.77922°N 30.39487°E

TEST	TYPE	DEPTH (m)	SITE PHOTOS (click on photos for higher resolution images)
CPT-A1 <a href="#">click here for CPT log (.pdf)</a> <a href="#">click here for CPT data file (.csv)</a>	CPTU	8.96	
CPT-A2 <a href="#">click here for CPT log (.pdf)</a> <a href="#">click here for CPT data file (.csv)</a>	CPT	8.77	

[http://www.eerc.berkeley.edu/turkey/adapazari/data/site\\_a/index.html](http://www.eerc.berkeley.edu/turkey/adapazari/data/site_a/index.html)

## Effects of Liquefaction

Effects can be divided into two categories:

### Response

- Amplitude
- Frequency content
- Duration

### Ground Failure

- Lateral deformations
- Vertical deformations

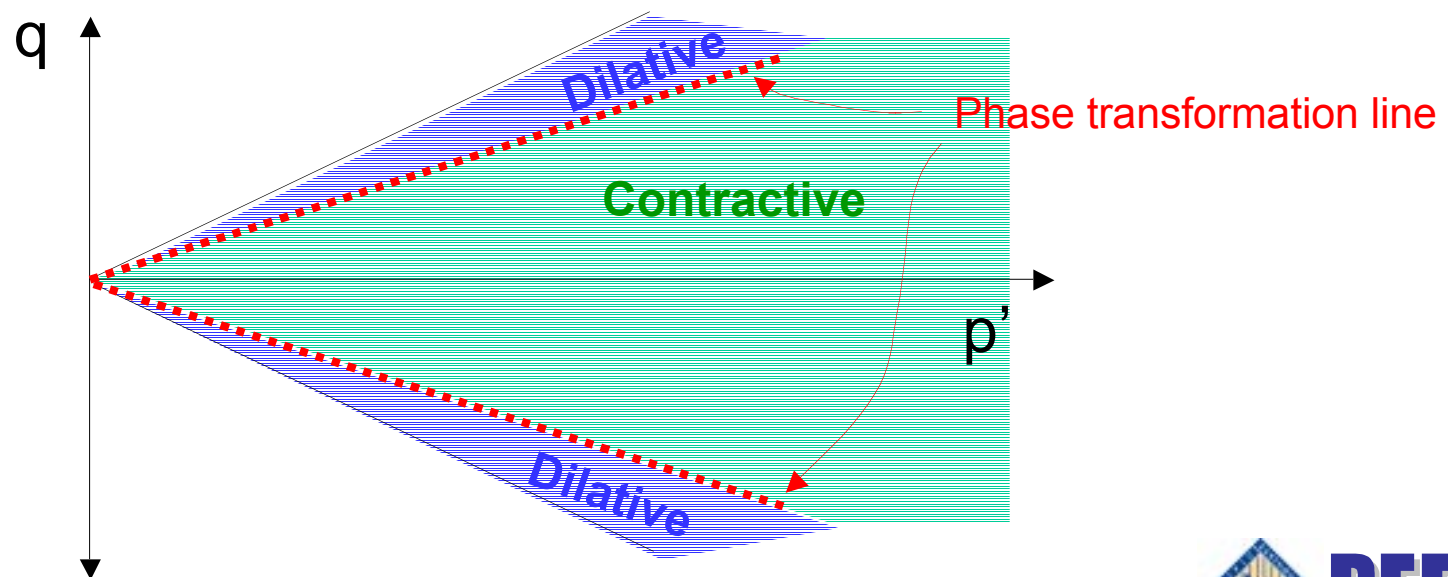
**Both are influenced  
by phase  
transformation  
behavior of soil**



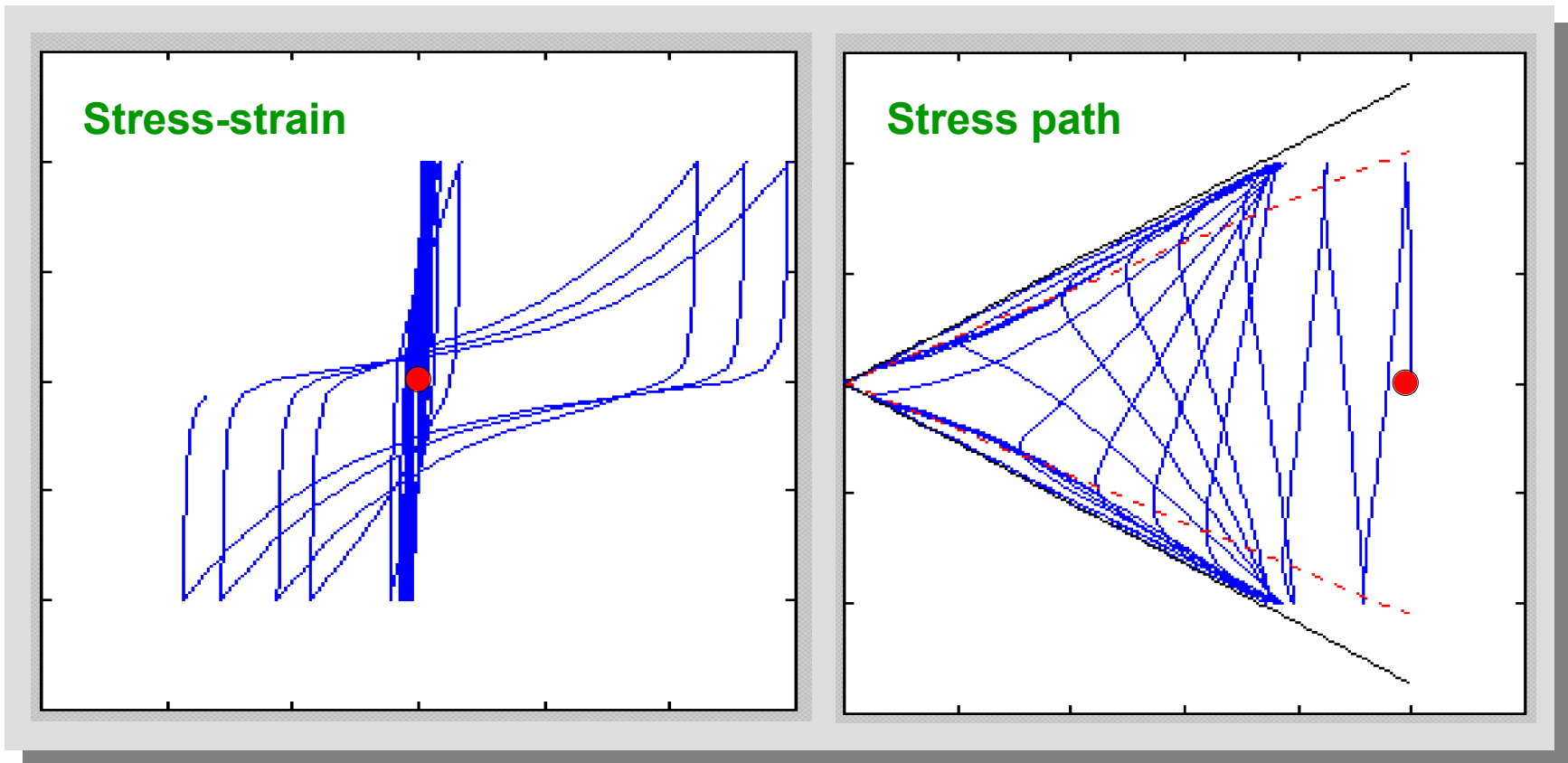
## Effects of Liquefaction

### Phase transformation

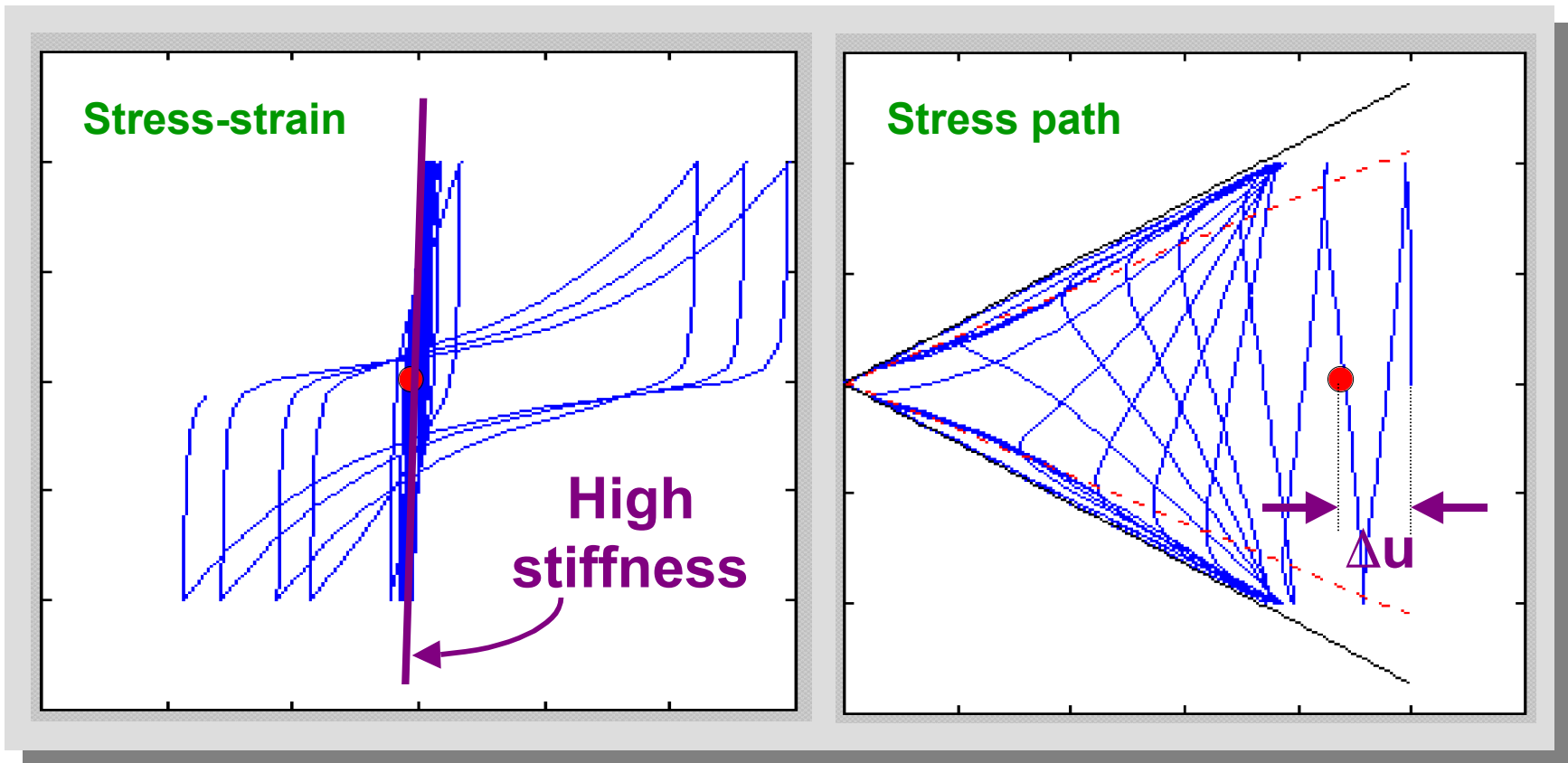
- Contractive behavior –  $u$  increases,  $p'$  decreases
- Dilative behavior –  $u$  decreases,  $p'$  increases



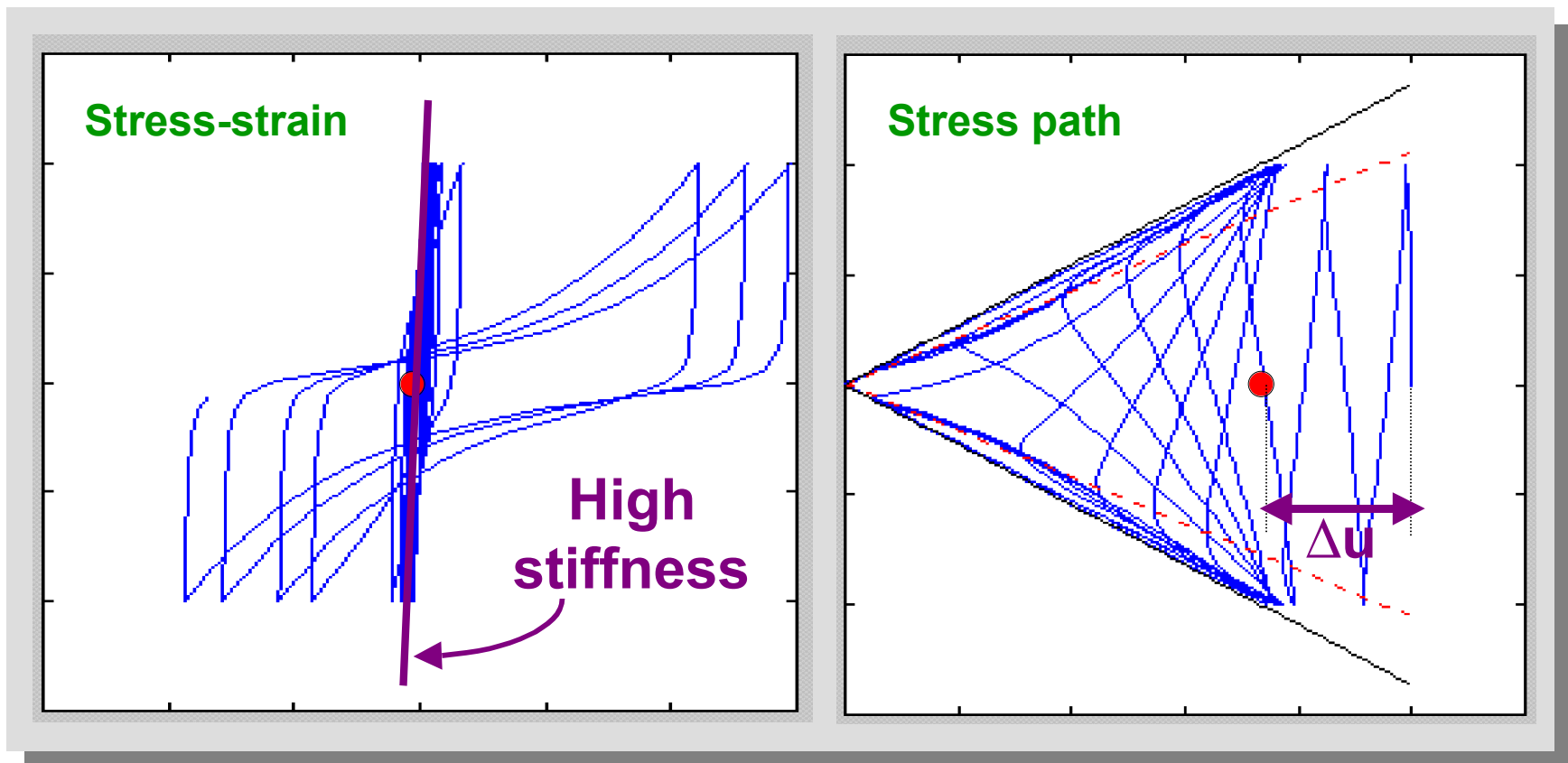
## Effects of Liquefaction



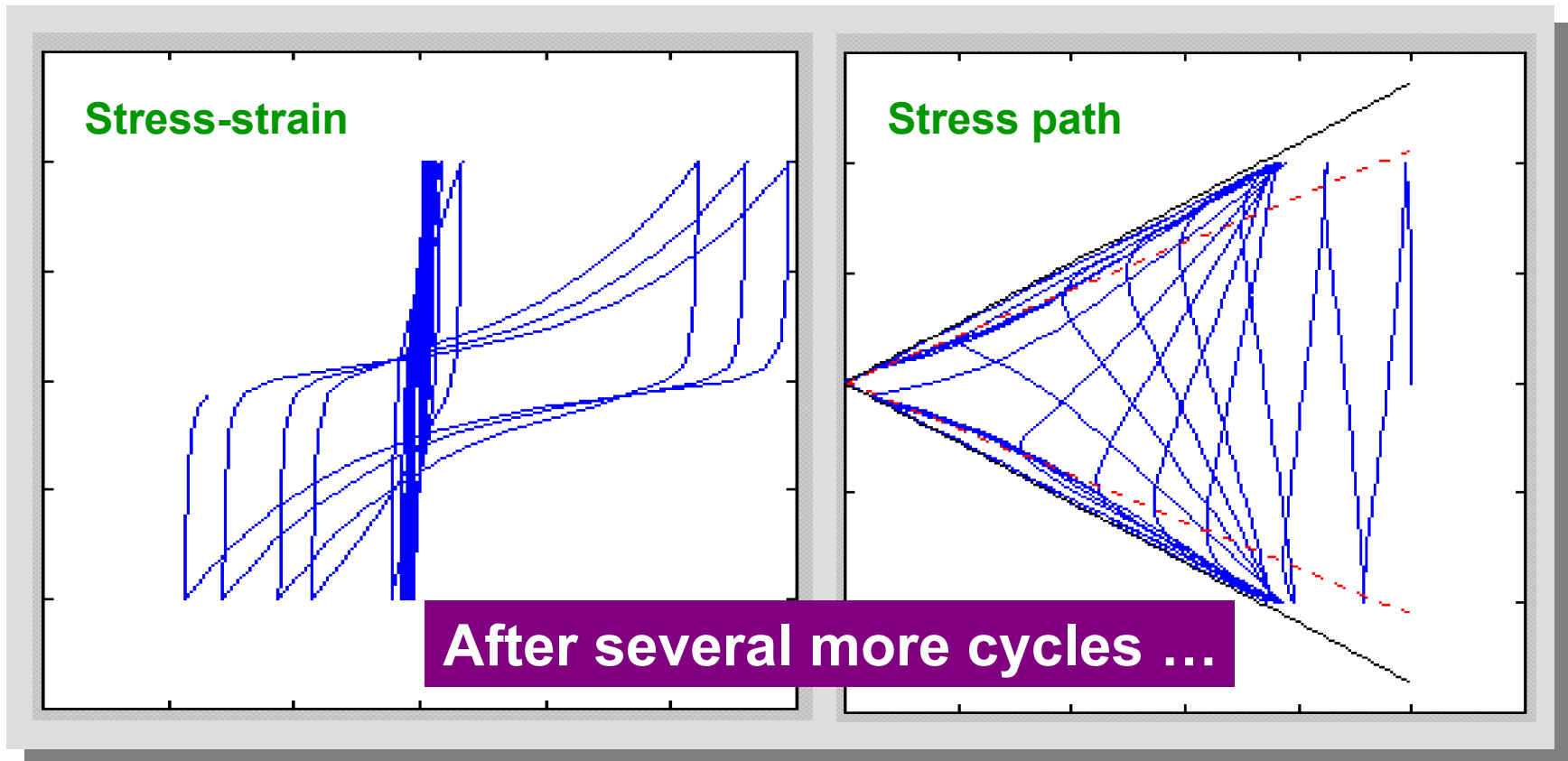
## Effects of Liquefaction



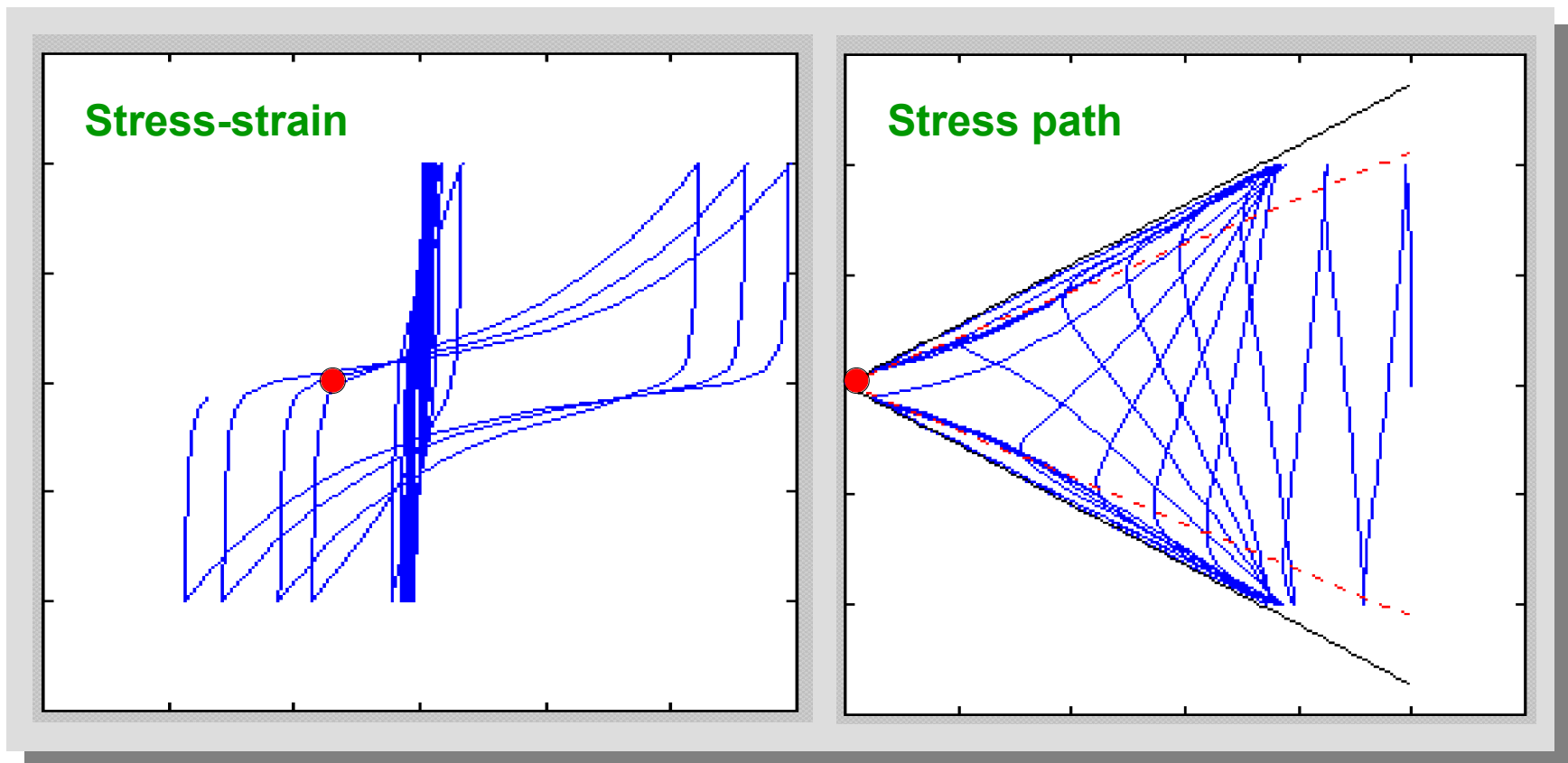
## Effects of Liquefaction



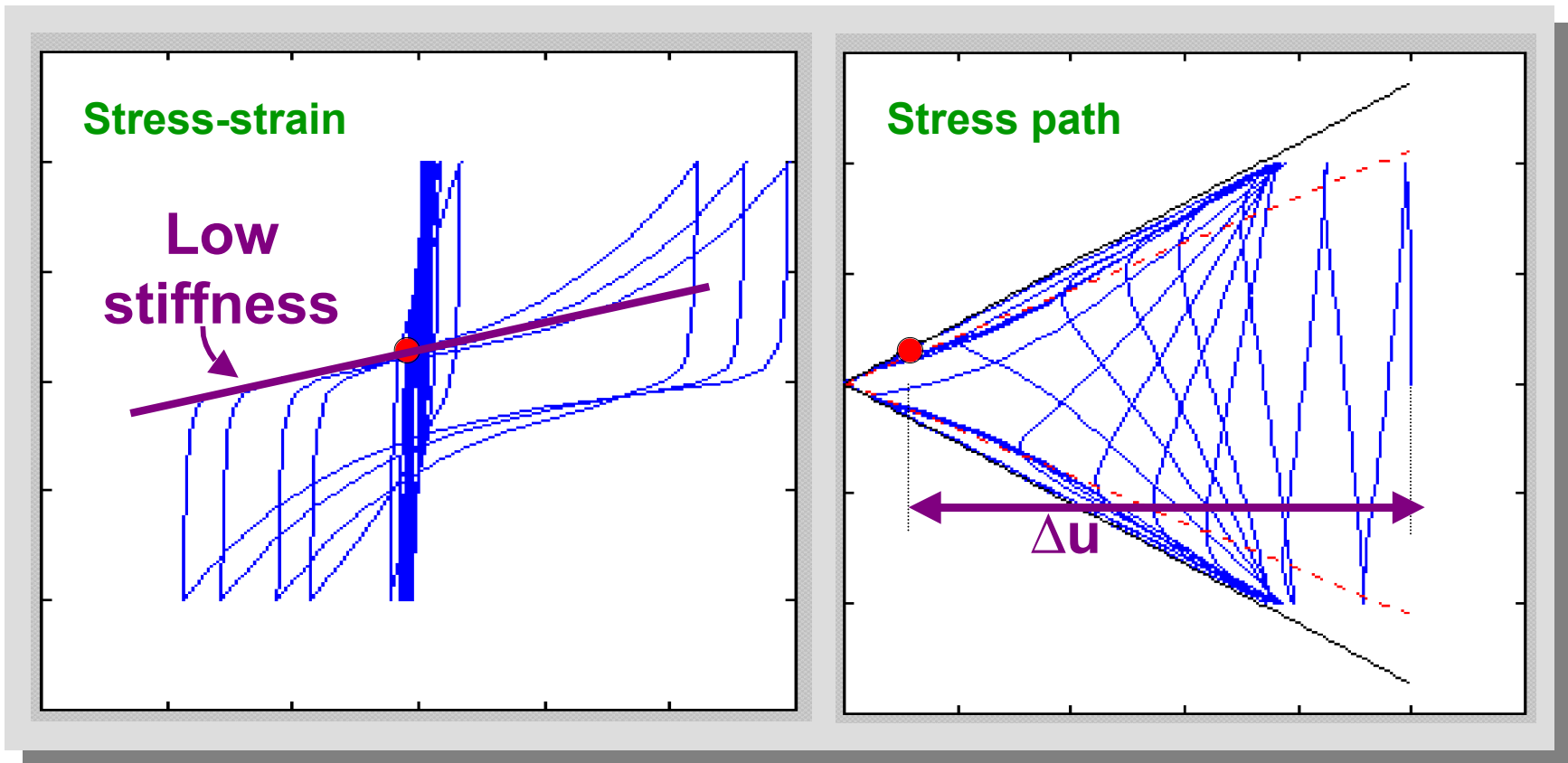
## Effects of Liquefaction



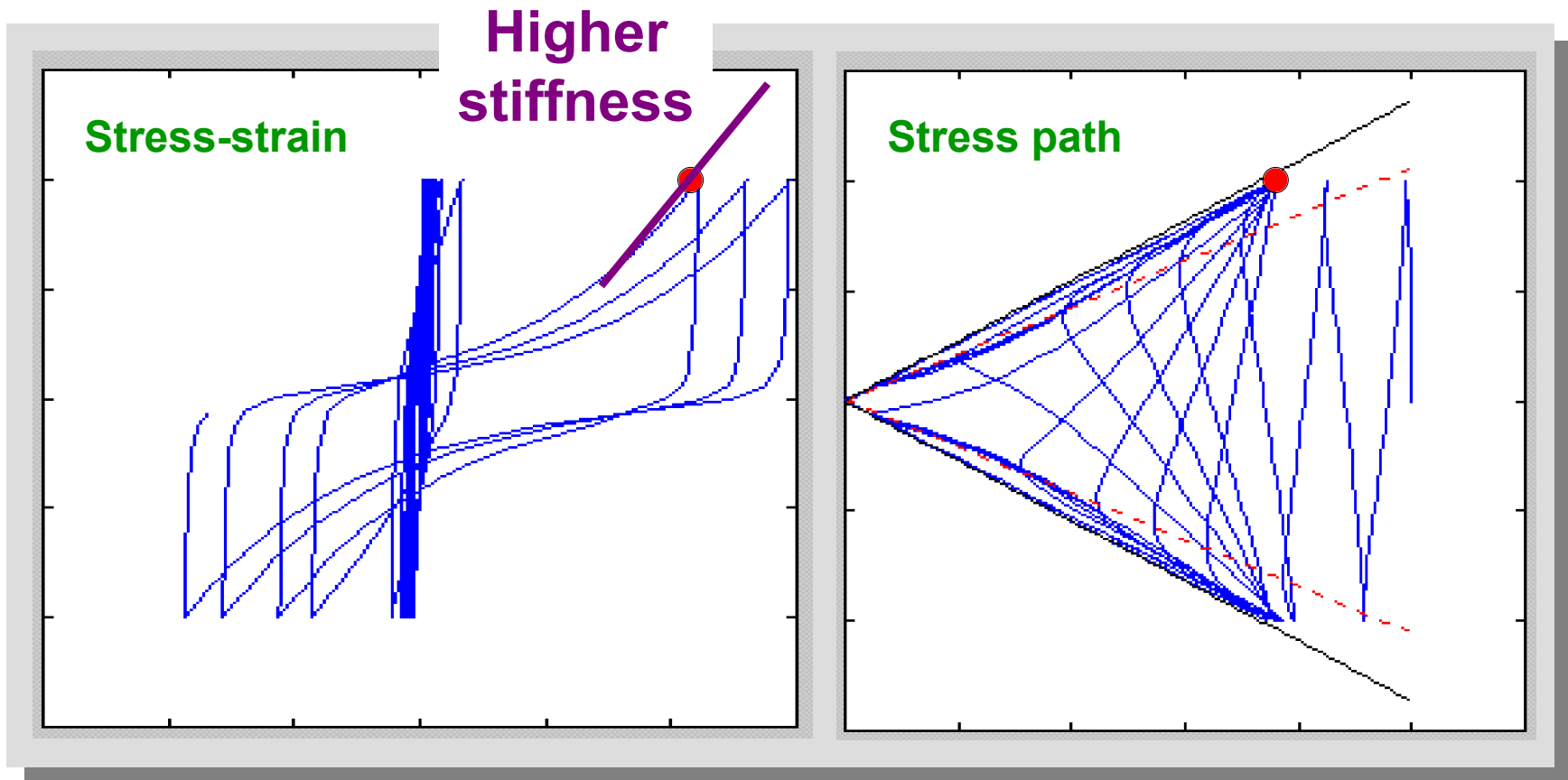
## Effects of Liquefaction



# Effects of Liquefaction

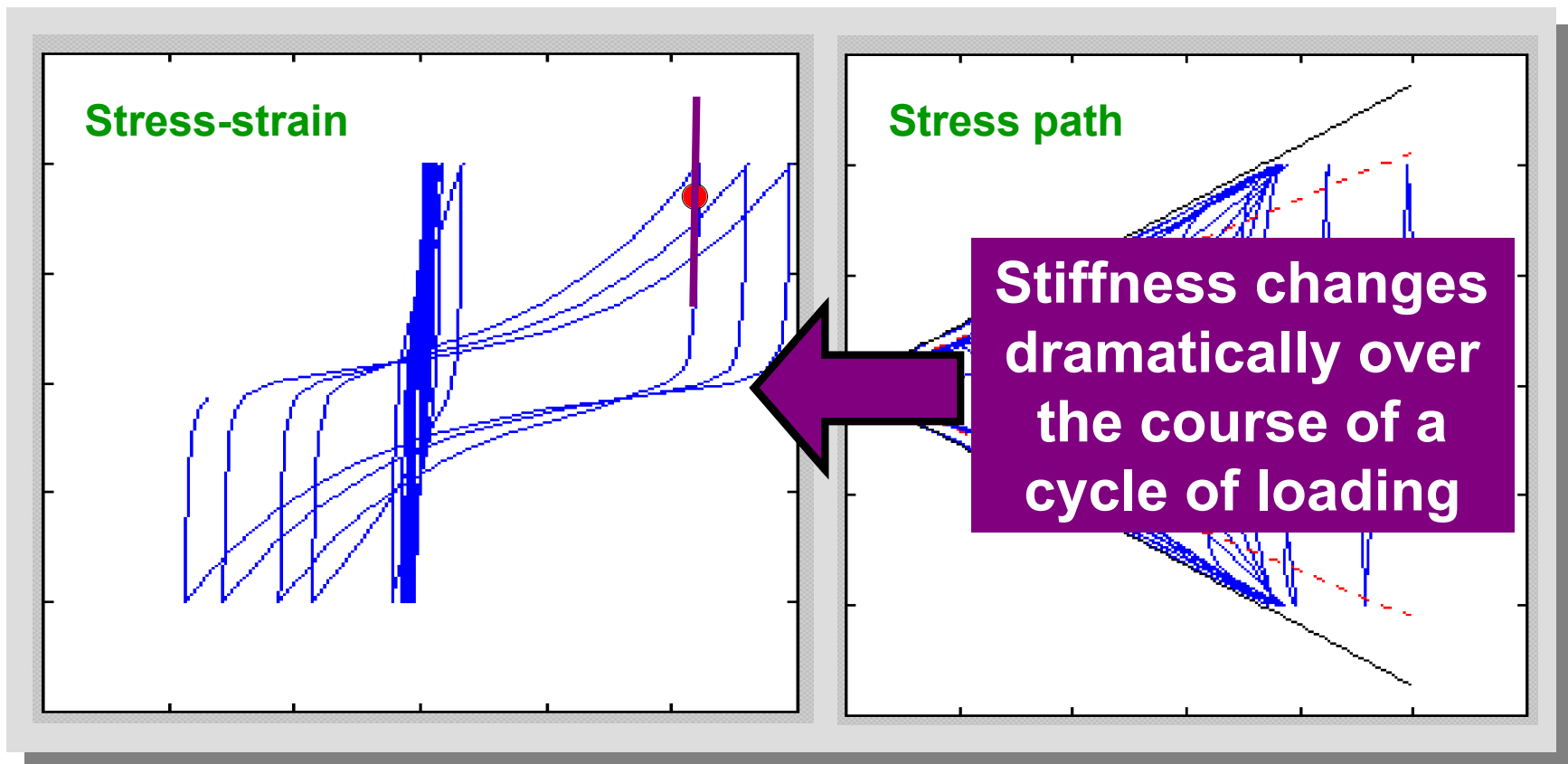


## Effects of Liquefaction

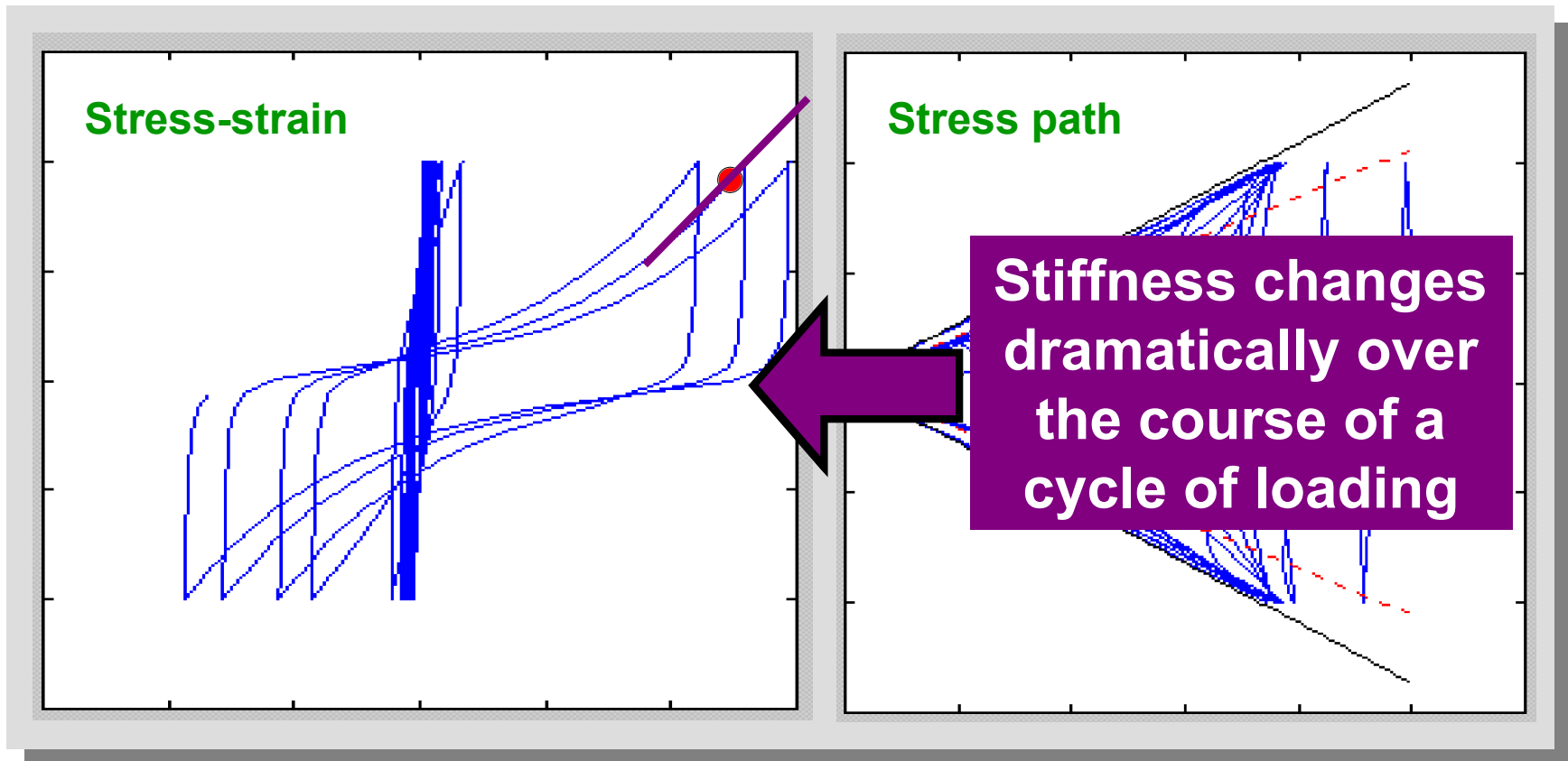




## Effects of Liquefaction



## Effects of Liquefaction

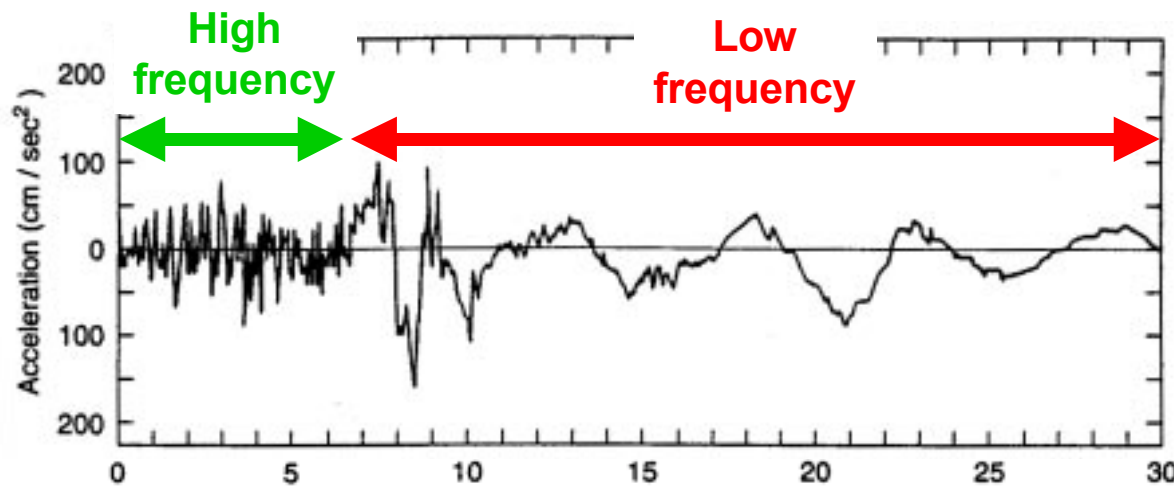


## Effects of Liquefaction

### Response

Stiffness generally decreases

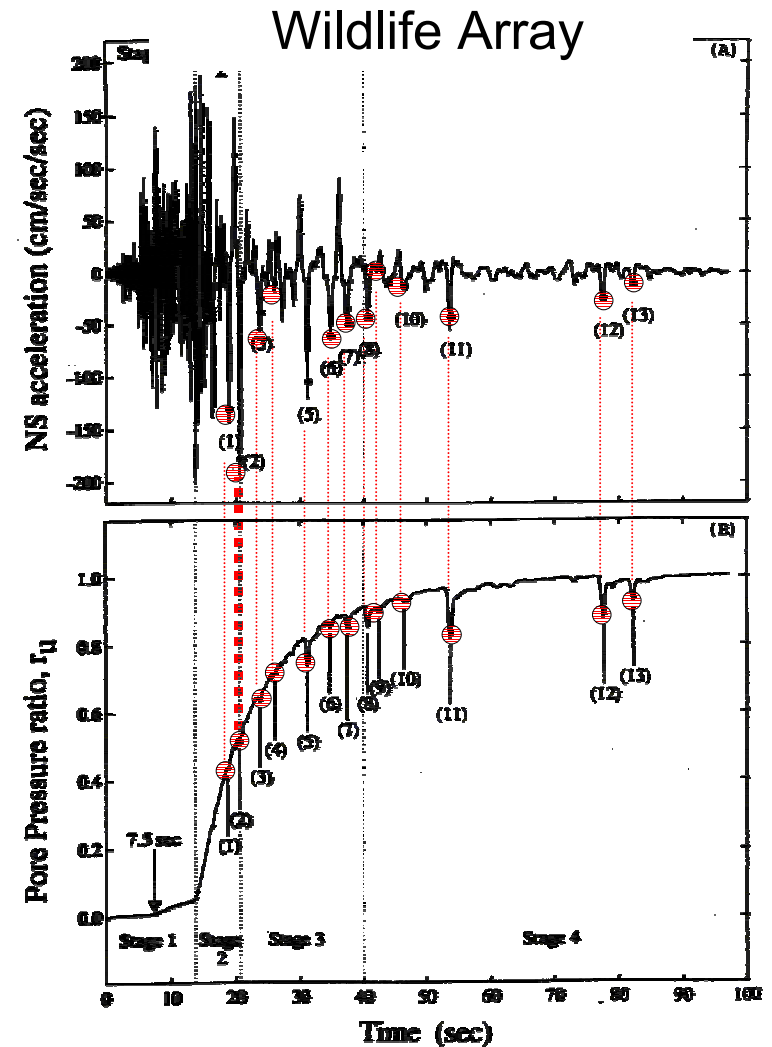
- Longer period motion
- Lower acceleration amplitudes
- Higher displacement amplitudes



## Effects of Liquefaction

Phase transformation

Increasing stiffness with strain  
“De-liquefaction shock waves”



## Effects of Liquefaction

Ground failure - permanent deformations

Horizontal

Lateral spreading

Flow slides

Vertical

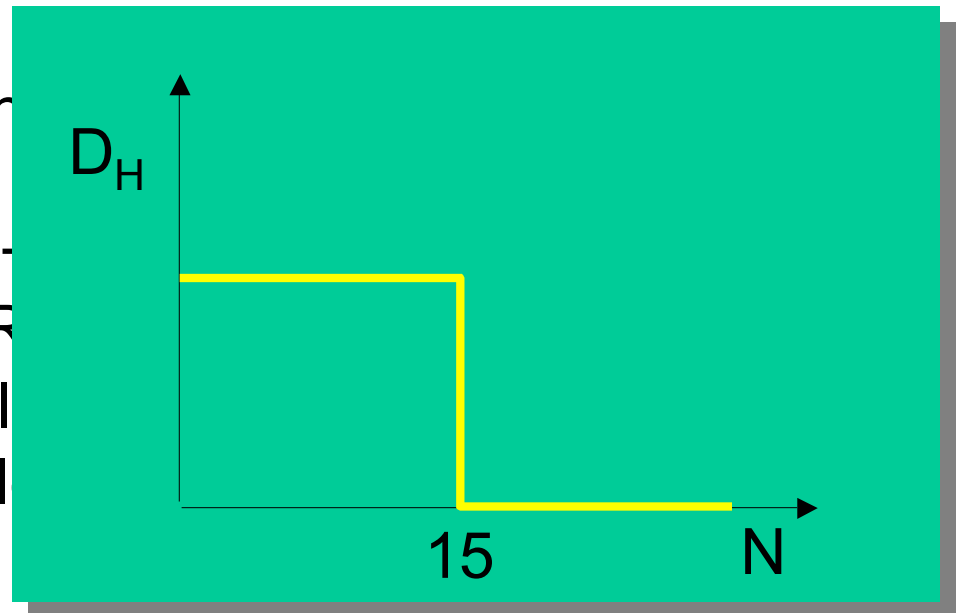
Settlement

## Effects of Liquefaction

Lateral spreading

Estimation of permanent

$$\log D_H = -17.614 - 0.011 F + 3.976 I - 0.923 I$$

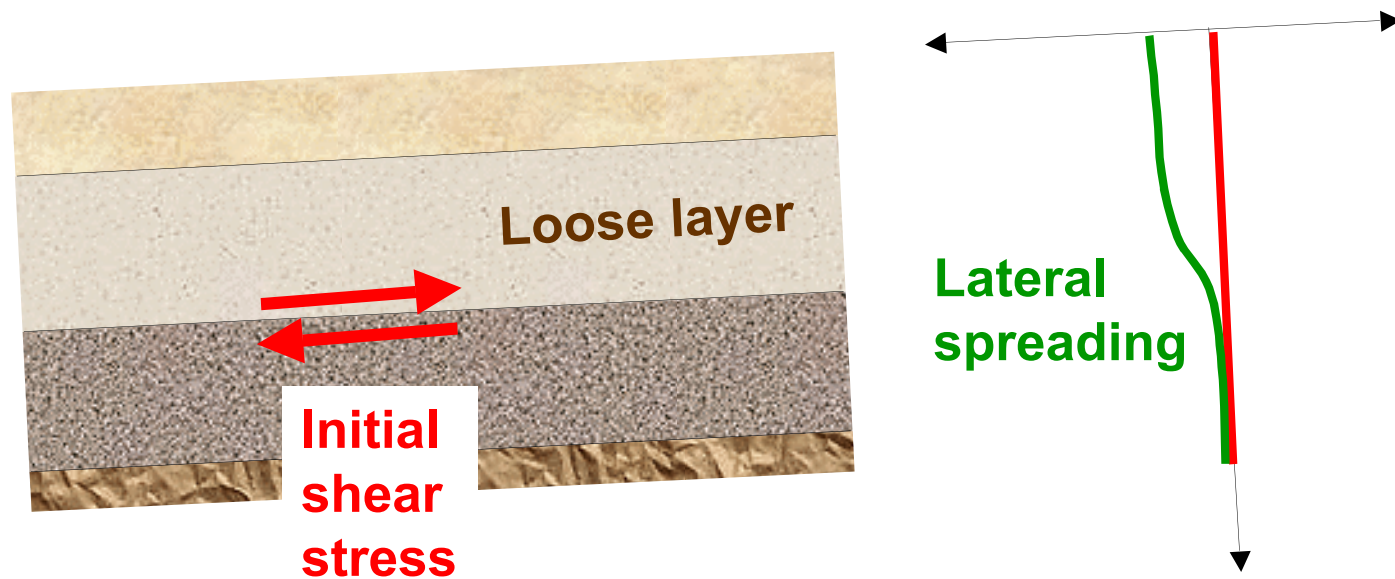


Based solely on regression

Provides only ground surface displacement

# Effects of Liquefaction

Lateral spreading



What controls displacements?

## Effects of Liquefaction

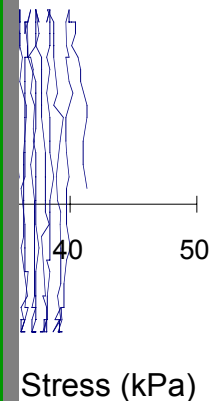
### Conclusions:

We must be able to model phase transformation behavior to predict the performance of structures located on or near sites where lateral spreading can occur.

We need more experimental data on phase transformation behavior and the factors that affect it.

We need more high-quality field data on lateral spreading case histories

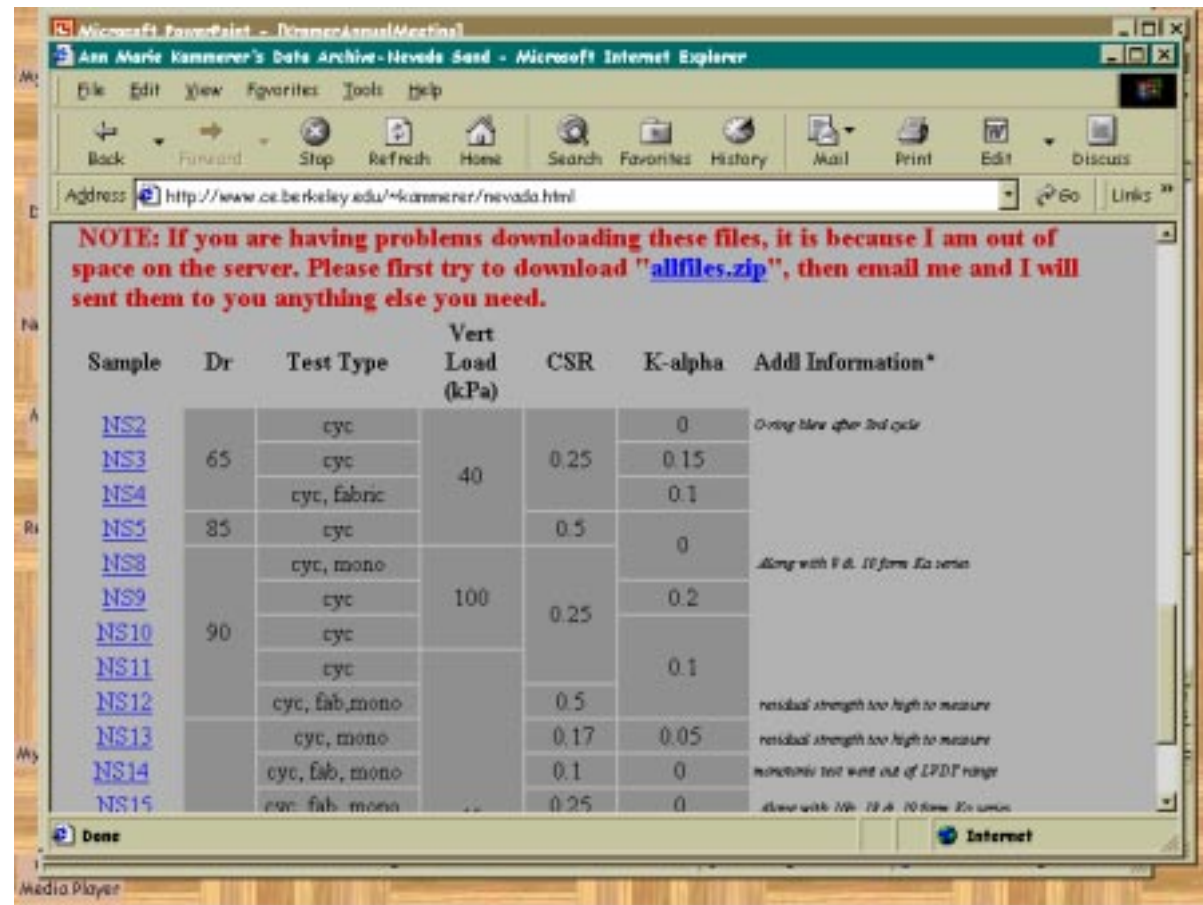
-10





# What are we doing about these issues?

Evaluation of Post-Liquefaction Residual Strength and Stress-Strain Behavior  
Seed, Pestana, Kammerer

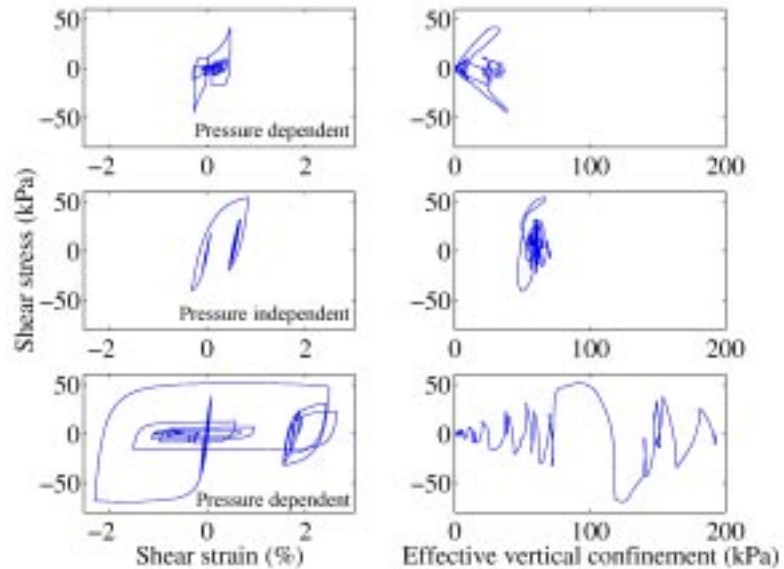


<http://www.ce.berkeley.edu/~kammerer/nevada.html>

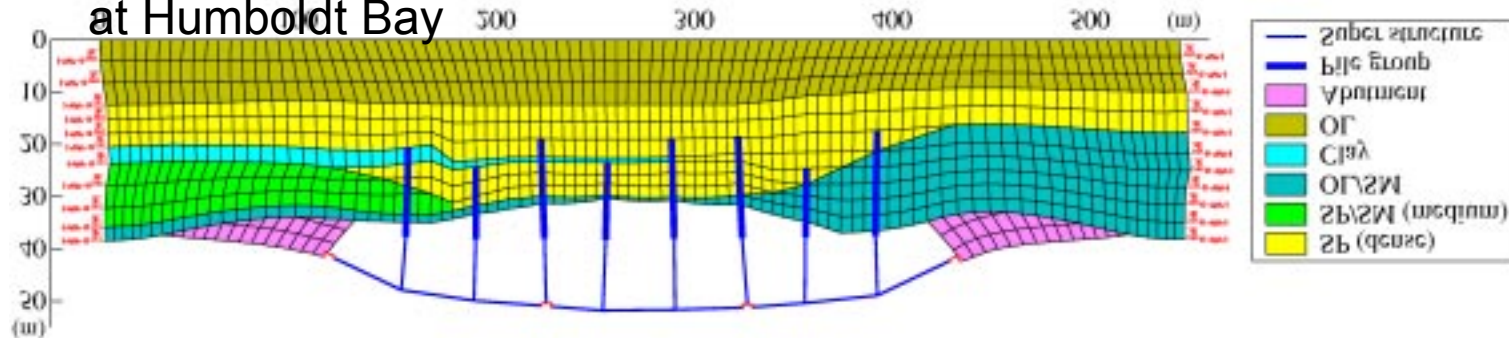


# What are we doing about these issues?

Modeling of Lateral Spreading and Effects on Foundations and Super-structure  
 Elgamal, Yang

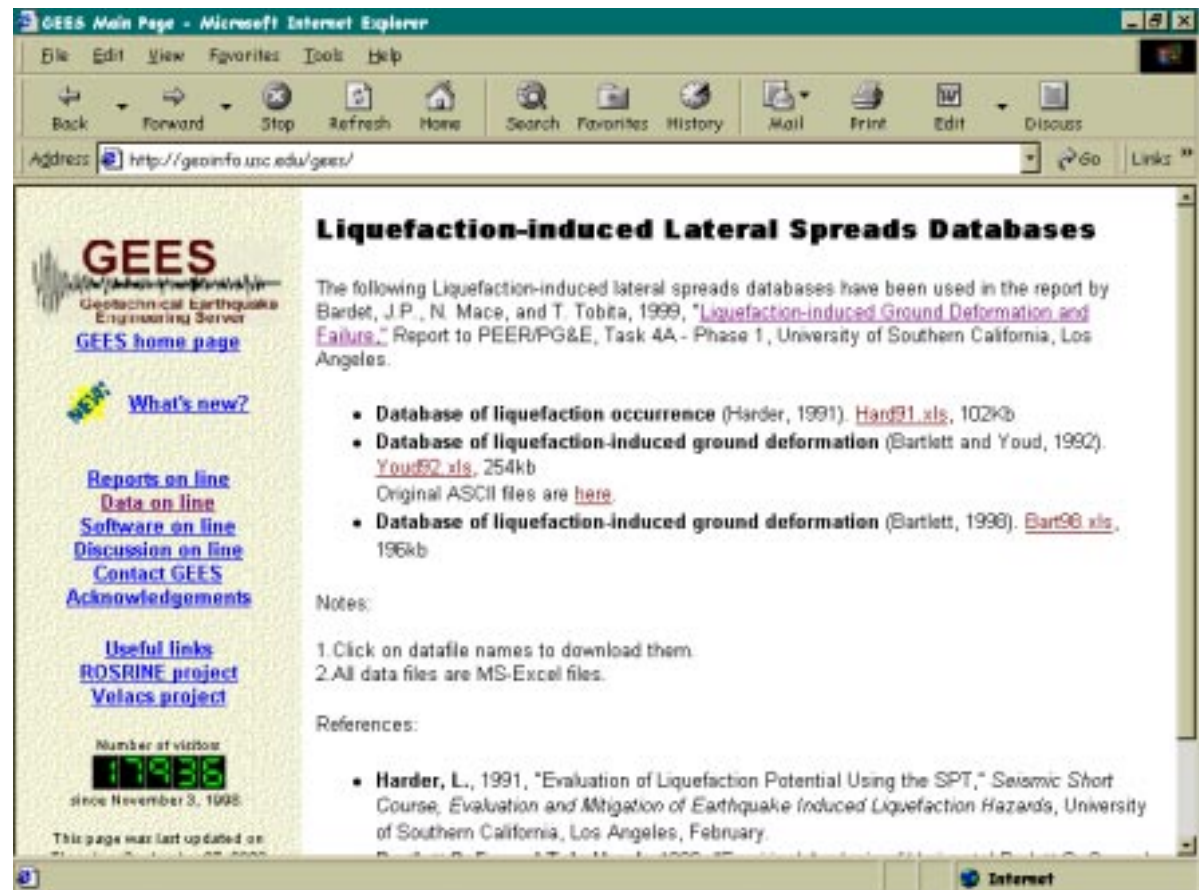


Middle Channel bridge at Humboldt Bay



# What are we doing about these issues?

Liquefaction-  
Induced Ground  
Deformation and  
Failure  
Bardet



<http://geoinfo.usc.edu/gees/>



## Effects of Liquefaction

Lateral spreading can cause damage to pile foundations



The diagram on the left shows a vertical pile foundation with a yellow outline. A dashed line indicates lateral displacement of the pile. A green arrow points from the text box to the pile. To the right, a photograph shows a building structure with significant lateral displacement and damage, with a green arrow pointing from the text box to the structure.

**Conclusions:**

We need to be able to predict the distribution of lateral spreading deformations with depth.

# What are we doing about these issues?

Centrifuge Modeling of  
Cyclic Mobility and  
Lateral Spreading  
Kutter, Dafalias

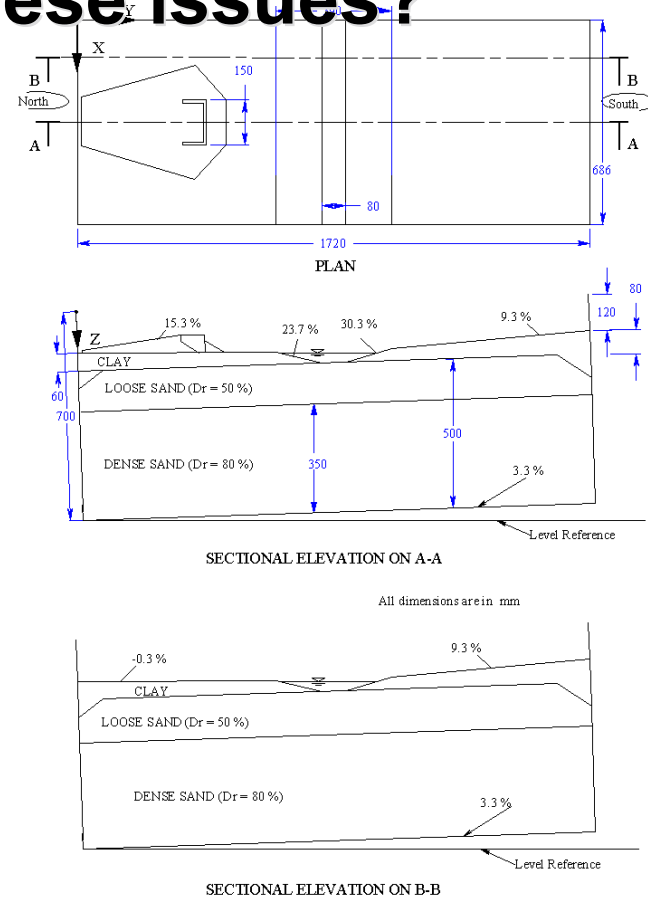
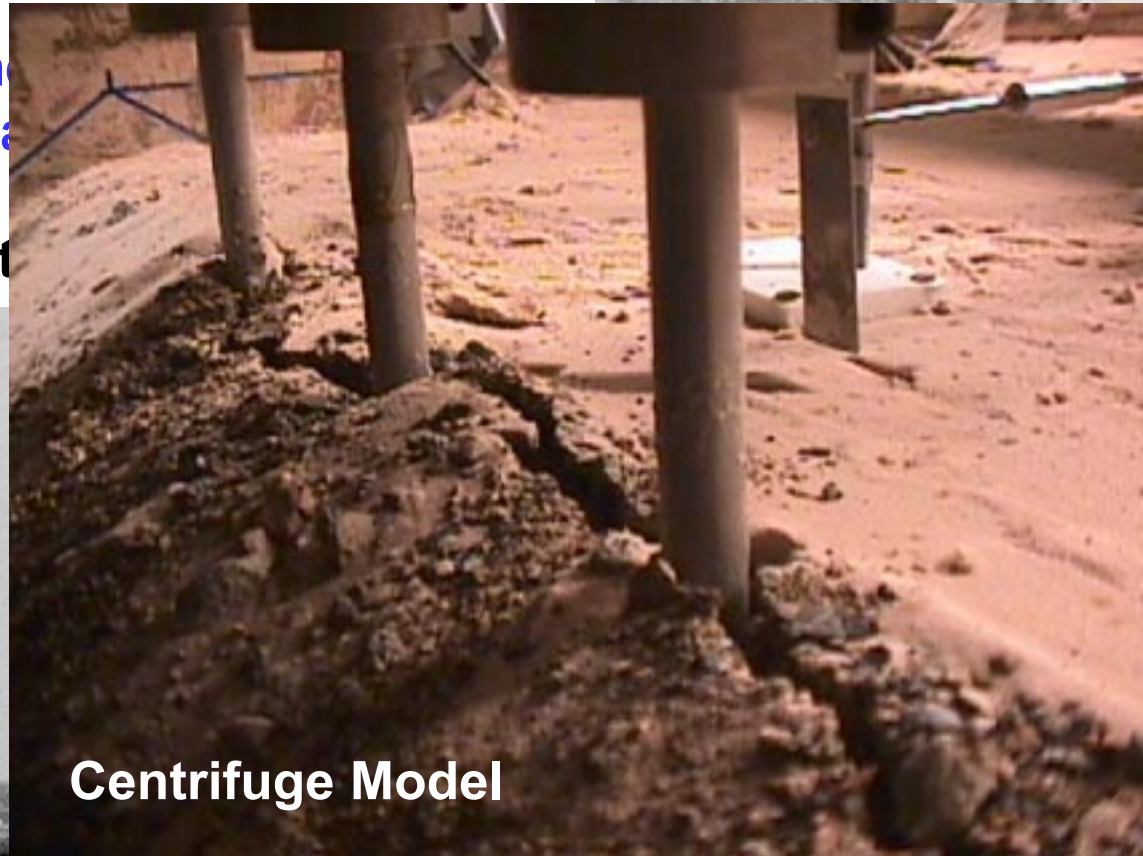


Figure 1: Model configuration for KKM01.

## What are we doing about these issues?

Seismic Performance  
Pile-Supported Wharves  
Structures

Dickenson, Kuttuva  
McCullough,  
Schlechter



## Effects of Liquefaction

### Flow slides

Occur relatively rarely  
Involve very large volumes of material  
Tremendously damaging

**Fort Peck Dam**  
**>1200 ft displ**



**San Fernando Dam**  
**>200 ft**

## Effects of Liquefaction

Flow slides

Evaluation of flow

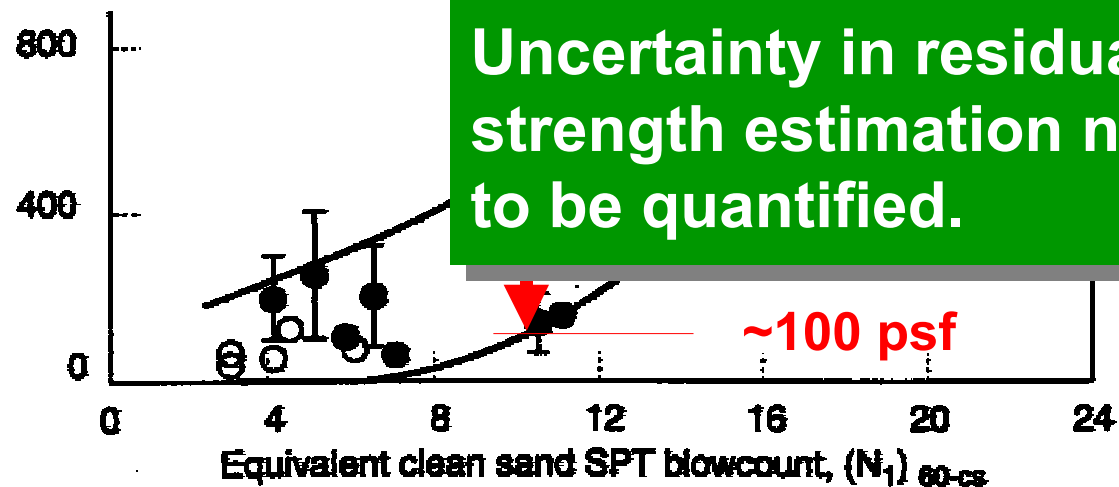
Static, limit equ

Requires resid

### Conclusion:

Residual strength, and the factors that affect it, needs to be better understood.

Uncertainty in residual strength estimation needs to be quantified.



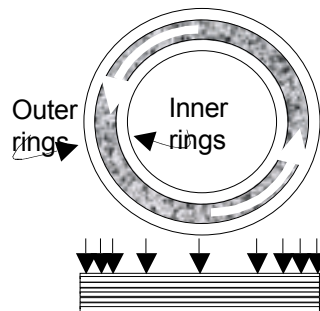


# What are we doing about these issues?

Uncertainty in  
residual strength  
evaluation  
Kramer



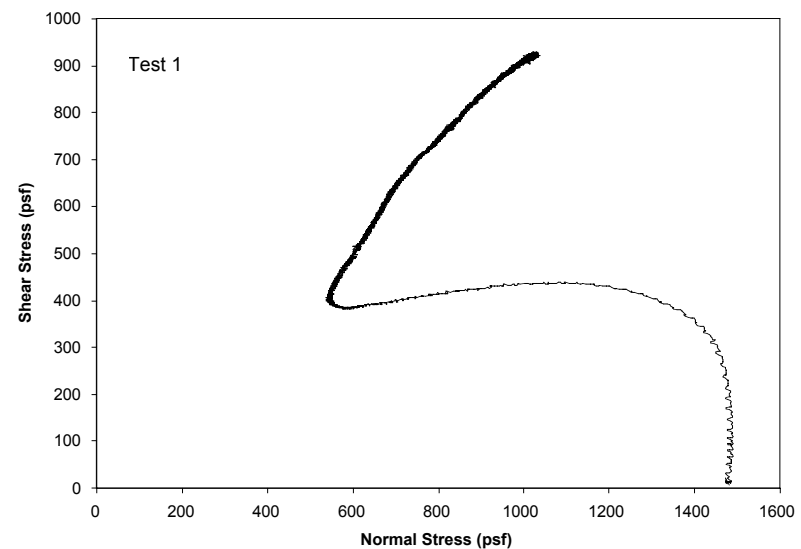
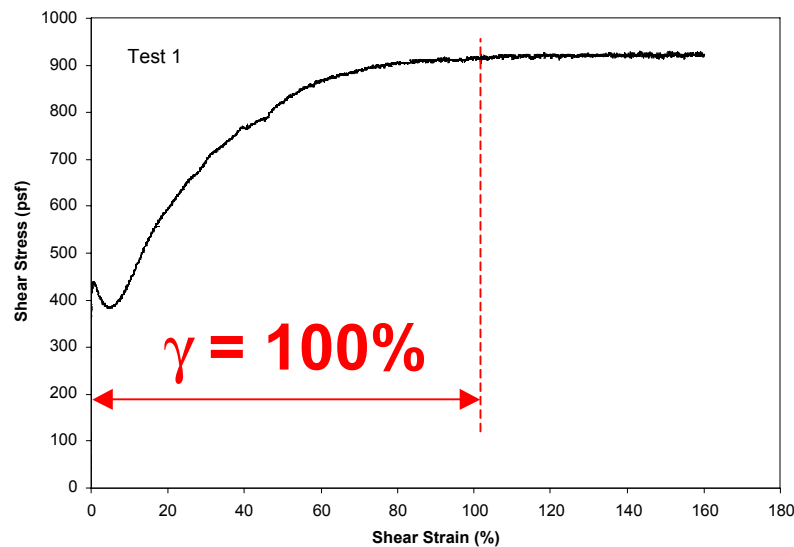
Ring Simple Shear  
Device (RSSD)



# What are we doing about these issues?

Uncertainty in  
residual strength  
evaluation

Kramer



## The Next Question:

What do we do about liquefaction?

- Abandon the site
- Improve the site

### Conclusion:

**Performance-based design  
procedures for soil improvement  
are needed**

## What are we doing about these issues?

Performance of  
Improved Ground  
Sitar, Hausler



<http://www.ce.berkeley.edu/~hausler/home.html>



## Summary

Consideration of liquefaction-related phenomena in PBEE will require:

- Additional laboratory testing of liquefiable soils – focusing on behavior after initial liquefaction
- Model testing of soil-structure systems
- Acquisition of high-quality field performance data
- Development of improved numerical modeling capabilities