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# Historical Changes in the State of the Art of Seismic Engineering and Effects of those changes on the Seismic Response Studies of Large Embankment Dams

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# Seismic Safety Evaluation Process for Embankment Dams and Foundations

## Authority, Guidance & Procedures

## ER 1110 – 2 – 1155 (Sept 1997)

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Seismic safety evaluations of embankment dams is typically a complex, multistage process requiring progressively more detailed definition of certain project characteristics and analyses at each subsequent phase.

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- Seismic evaluations / re-evaluations are to be accurately identified and conducted with minimum expenditures of project funds.

- Embankment dams and foundations not requiring modifications are accurately identified and removed from study at the earliest possible point in the evaluation process

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**Seismic Evaluations of USACE dams are funded through operations and maintenance funds.**

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# Seismic Evaluation Procedures and Methods of Analysis

- Develop design earthquake, and resulting ground motion parameters, response spectra and earthquake time histories at the site.
- Perform field investigations.
- Determine the liquefaction resistance of the embankment and foundation.
- Determine post earthquake shear strength of soils.
- Prepare cross-sections of areas of the dam with highest potential for instability due to existence of liquefaction susceptible soils.
- Perform seismic response analyses of these sections to determine the expected dam performance.
  - Static Equilibrium Slope Stability
  - Deformation Response Analyses

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# Liquefaction Susceptibility of Embankment and Foundation Soils

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# Liquefaction Susceptibility

- Seed's SPT Based Empirical Approach
- Chinese Criteria

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# CHINESE CRITERIA
# for Liquefaction of Fine-Grained Soils

- Liquid Limit ( $L_L$ ) $\leq$ 35
- Natural Water Content ( $W_N$) $\geq$ 0.90 $L_L$
- % Passing 0.005mm $\leq$ 20

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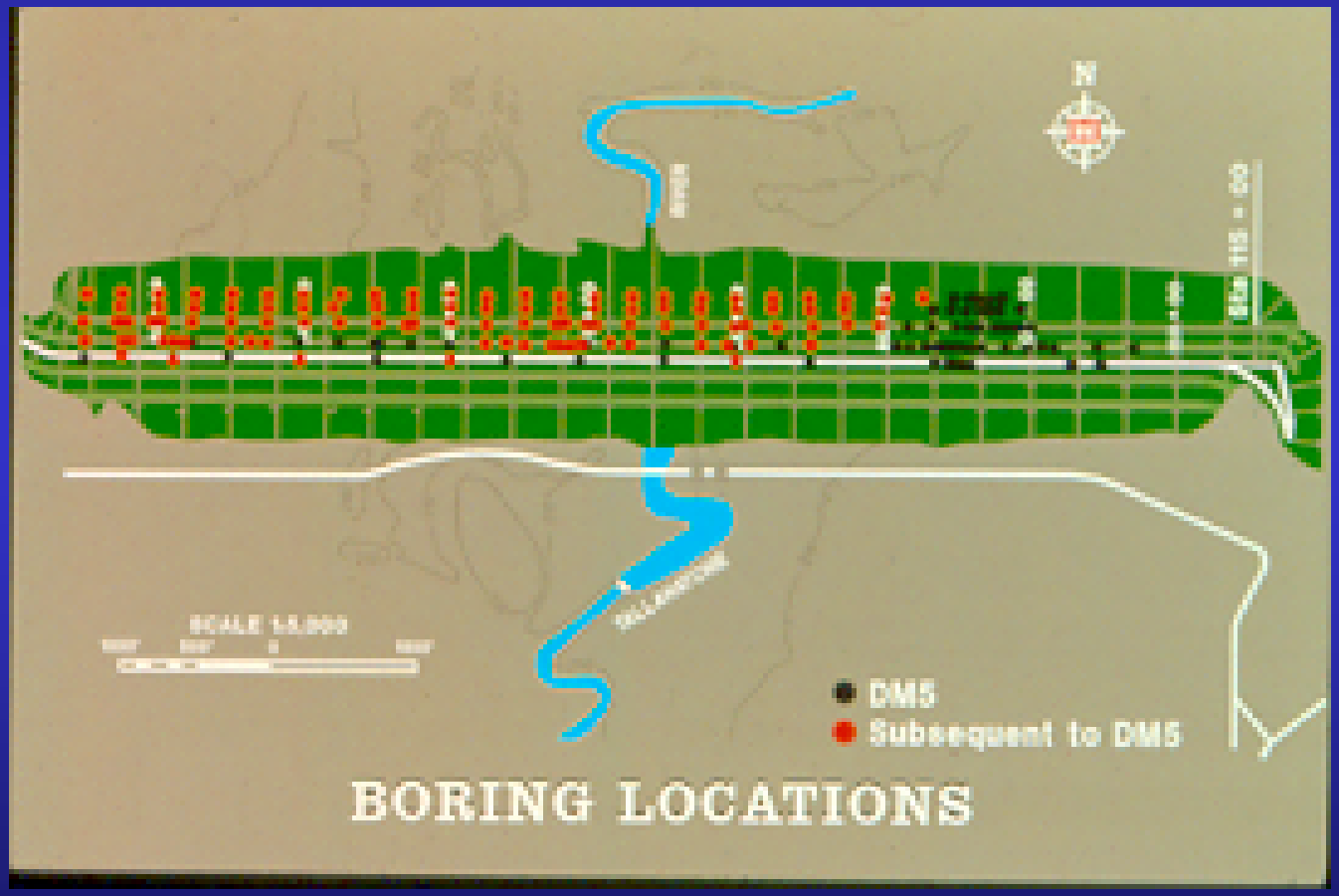

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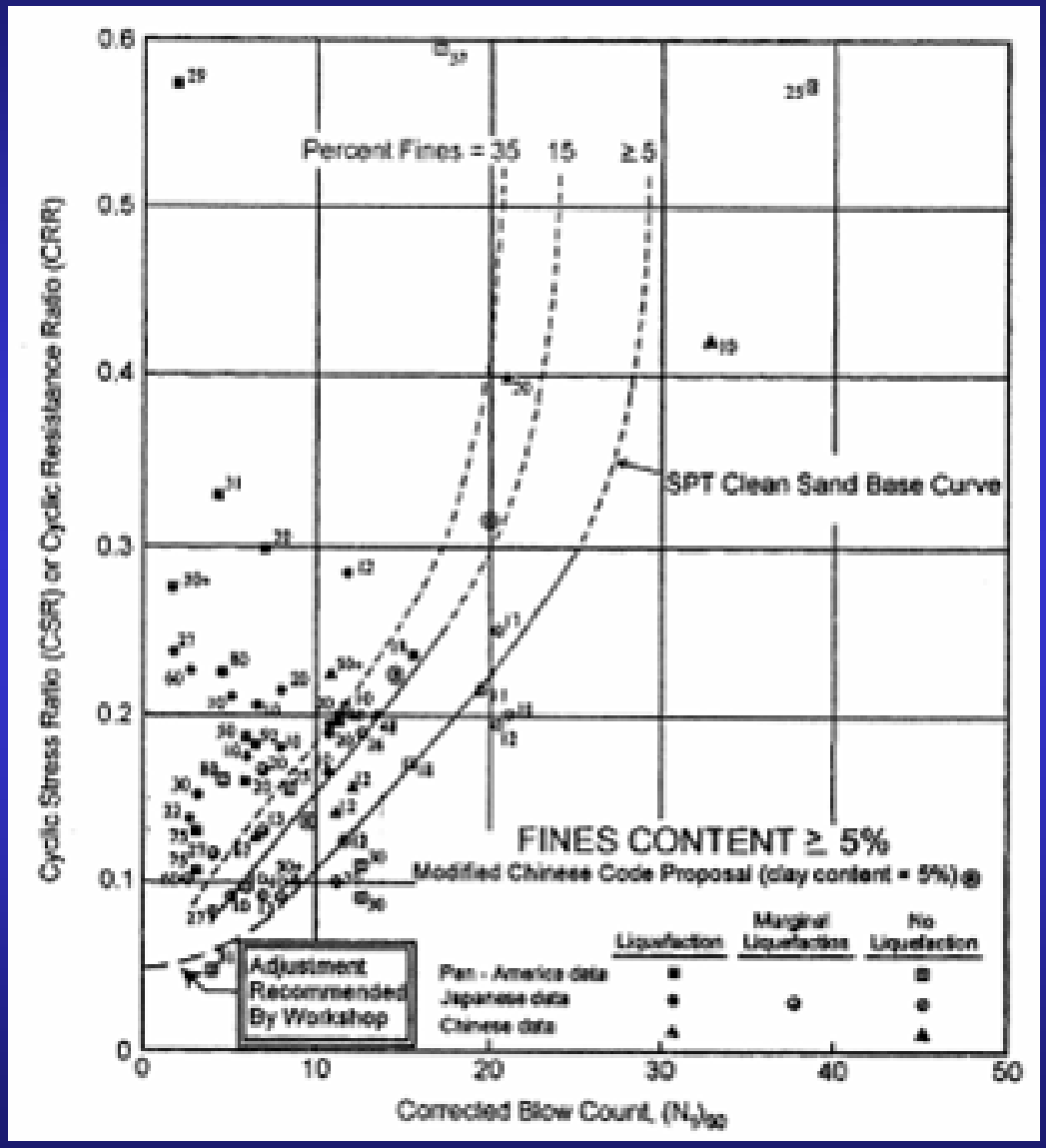

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# Liquefaction Susceptibility Criteria
# Sardis Dam Earthquake Study

Sands $N_{1(60)} \leq 10$

Fine Grained Soils: $N_{1(60)} \leq 4$

$4 \leq N_{1(60)} \leq 10$

and

Chinese Criteria

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# Post Earthquake Residual Strength of Liquefiable Fine Grained Soils

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# Assumption

**Liquefiable fine grained soils perform like remolded soils such that their post earthquake strength is the residual strength of the soil**

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# Laboratory Testing

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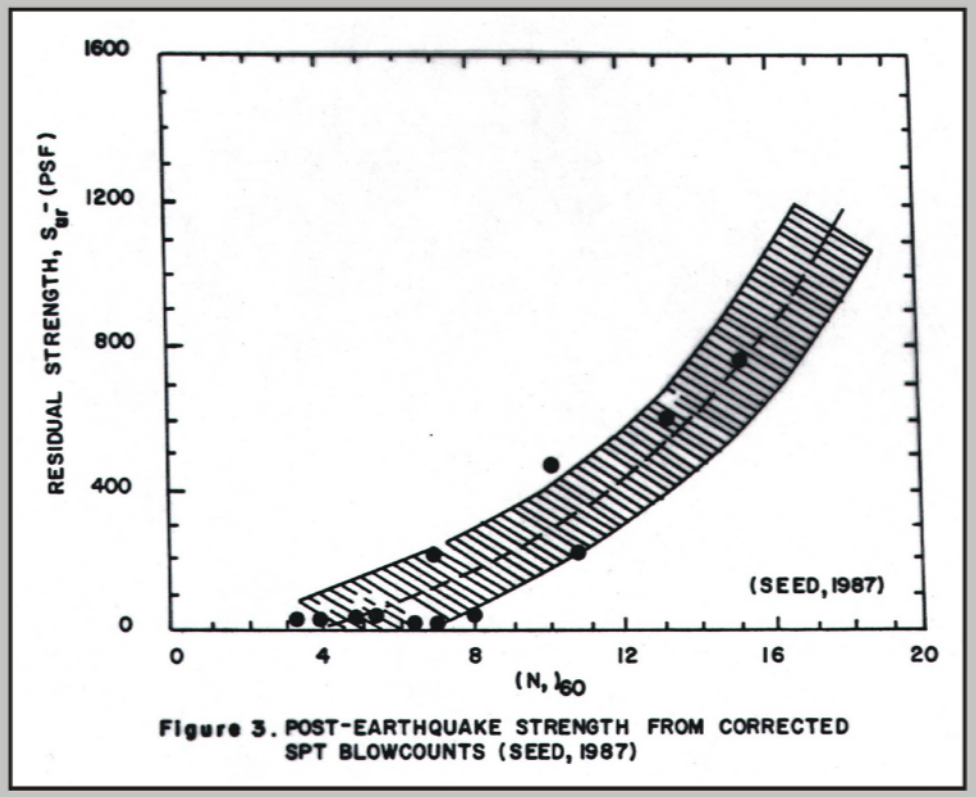


Figure 3. POST-EARTHQUAKE STRENGTH FROM CORRECTED SPT BLOWCOUNTS (SEED, 1987)

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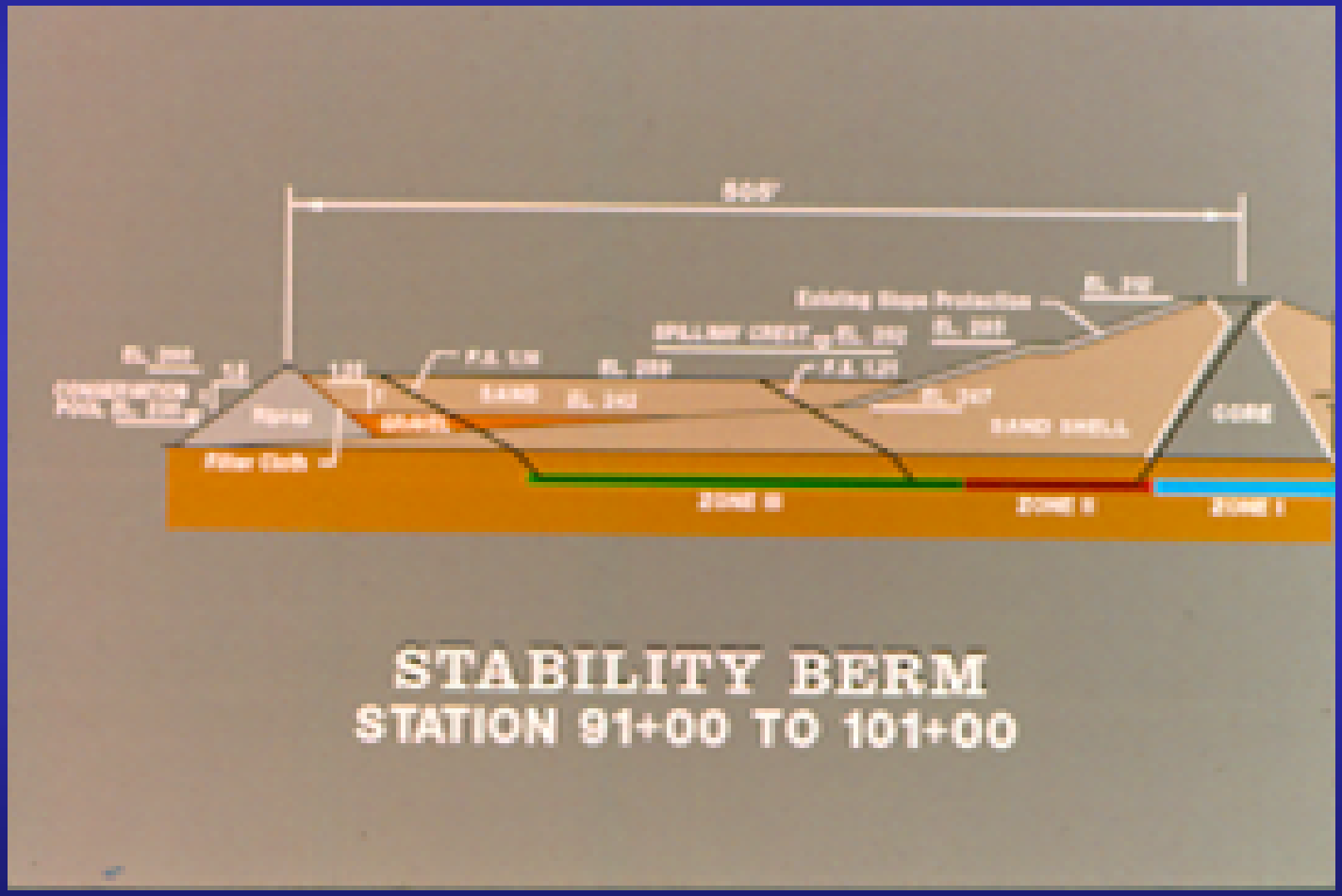

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# Modification to the Index Properties due to differences in Testing Methods between China and the U. S. and human error between laboratories.

- Chinese – Fall Cone Device
- U. S. A. – Casagrande Device

Joe Koester ( 1988)

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# 1st Recommendation

+ 15 percent to the measured % passing .005 mm

+ 5 percent to the $L_L$

+ 3 percent to the $W_N$

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# 2nd Recommendation

**USACE – Vicksburg & Woodward Clyde Consultants**

**+ 5 percent to the measured % passing .005 mm**

**+ 2 percent to the $L_L$**

**+ 1 percent to the $W_N$**

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# Post Earthquake Residual Strength of Liquefiable Fine Grained Soils

## Cone Penetration Testing Correlated to the Results of Field Vane Shear Test (FVST)

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$$Su = \frac{Qc - P'}{N_K}$$

$$N_K = \frac{Qc - P'}{Su\ (FVST)}$$

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# Sardis Dam E. Q. S.

$N_K = 15$

$S = 4$

# Arkabutla Dam E. Q. S.

$N_K = 18$

$S = 4.5$

# Enid Dam E. Q. S.

$N_K = 20$

$S = 3.5$

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# Liquefaction Susceptibility
# Cone Penetration Test Criteria

## Sardis Dam E. Q. S

## $Qc \leq 20$ tsf

## $R_F \leq 2.0$

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# Post Earthquake Residual Strength Ratio (Sr/p′)

## (Sr/p′) ranges from .07 to .28

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# Post Earthquake Residual Strength as a Function of Overburden Stress

## Residual Strength Ratio (Sr/p′)

Sardis Sr/p′ = .075

Arkabutla Sr/p′ = .13 at toe and in the free field

Sr/p′ = .10 beneath embankment

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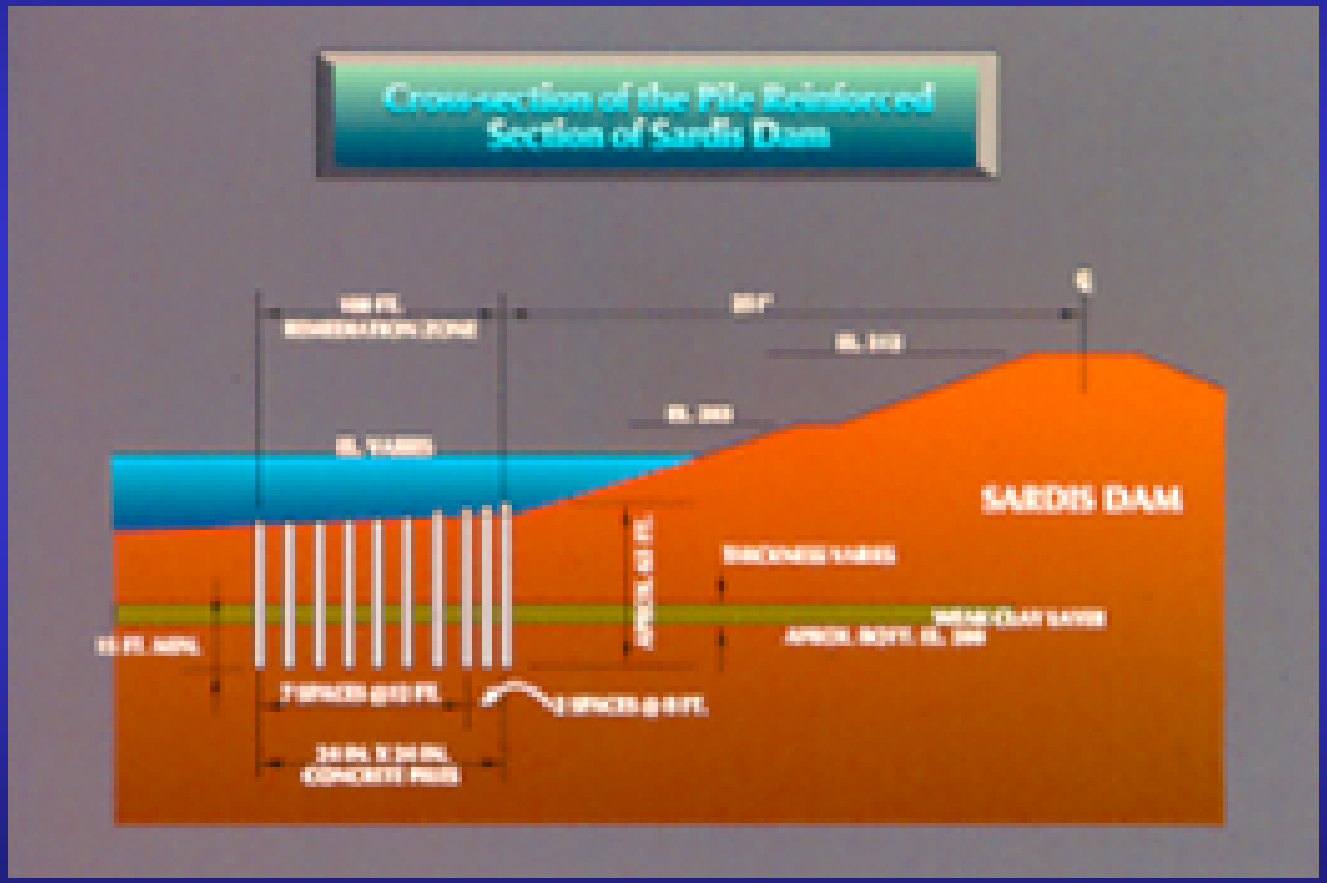

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# Liquefaction Susceptibility
# Cone Penetration Test Criteria

## Arkabutla Dam E. Q. S

**Beneath Embankment**

$Qc \leq 20$ tsf

$R_F \leq 2.0$

**Toe and Free Field of Dam**

$Qc \leq 15$ tsf

$R_F \leq 2.0$

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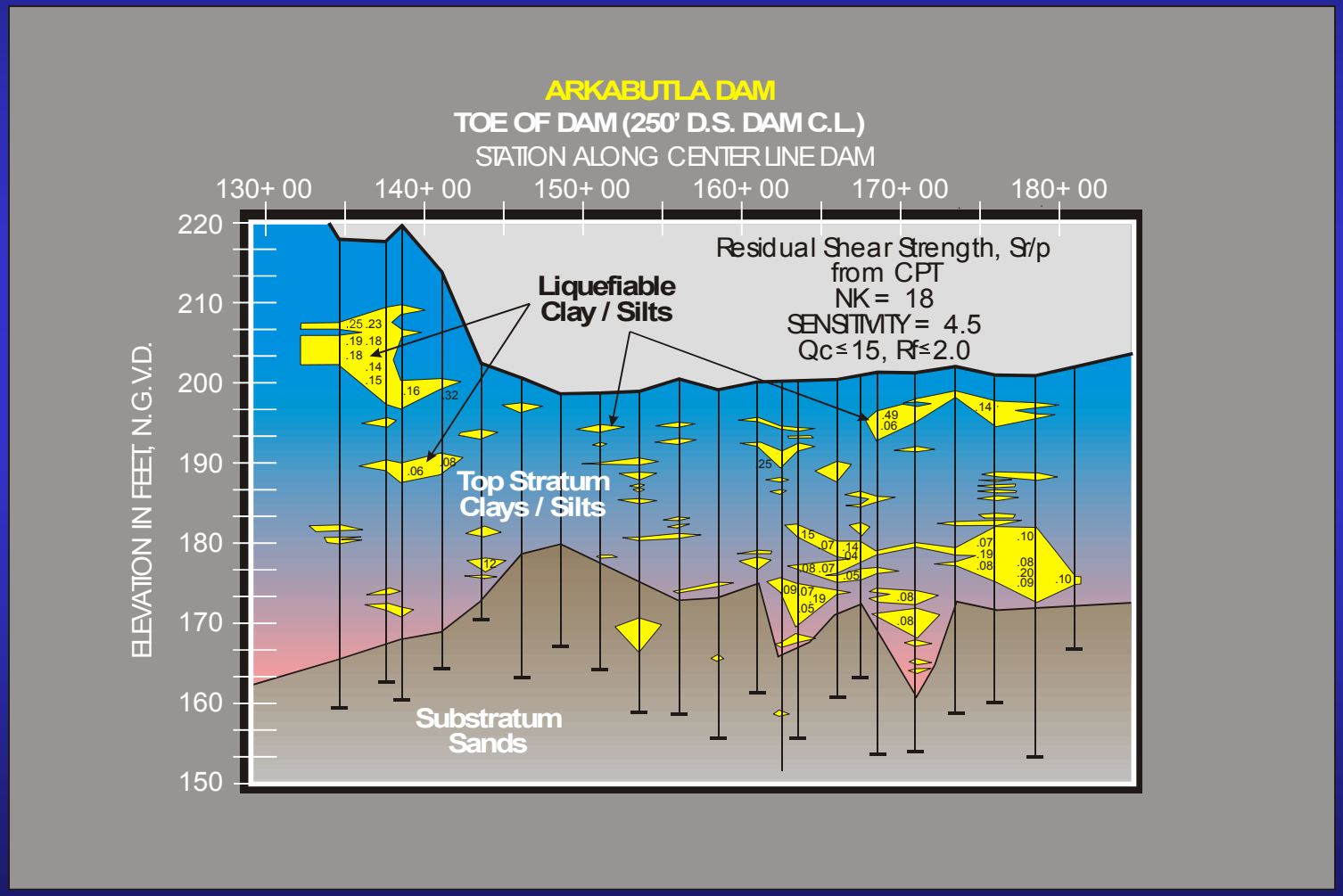


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# Enid Dam Earthquake Study

- New evaluation of the Design Earthquake, and resulting ground motions, response spectra, and time histories.

- Modified Chinese criteria for liquefaction Susceptibility.

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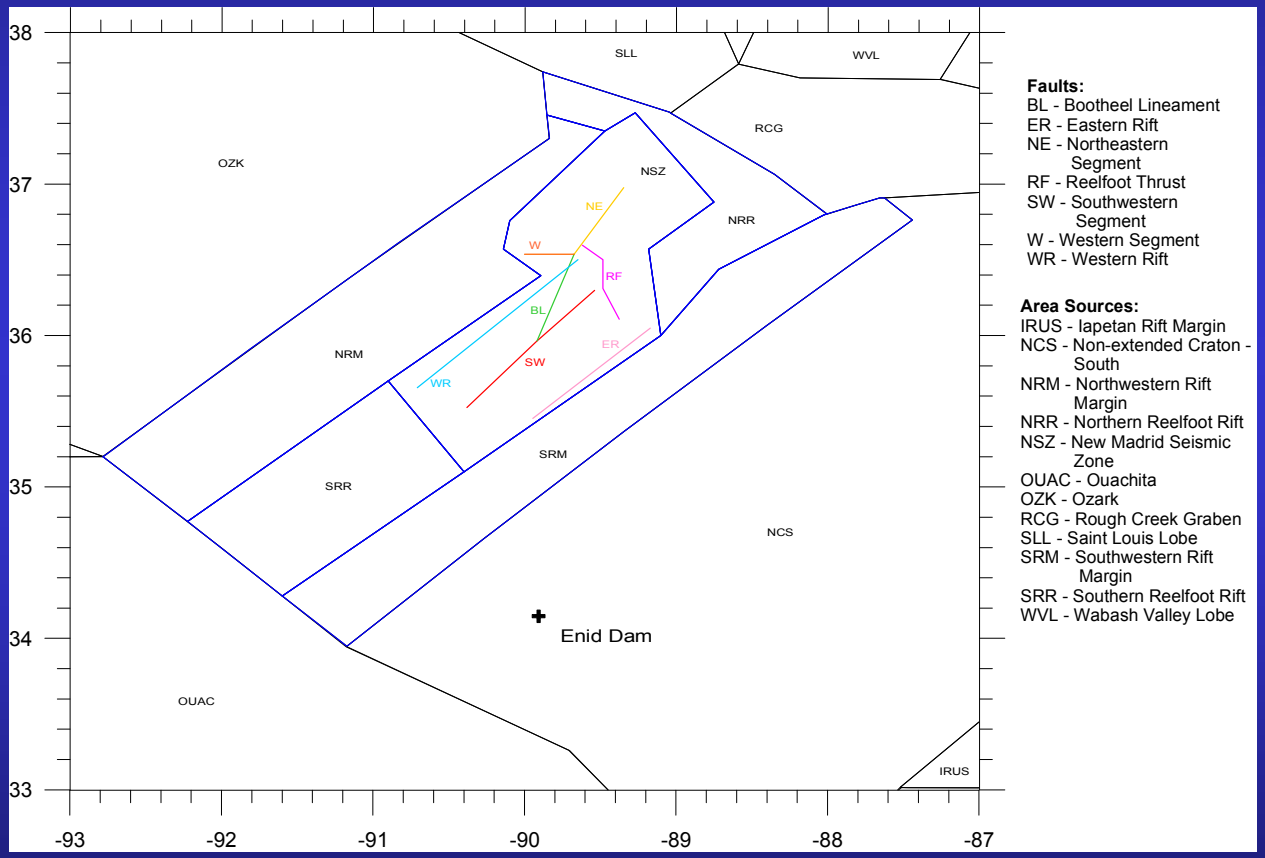


**Faults:**
BL - Bootheel Lineament
ER - Eastern Rift
NE - Northeastern Segment
RF - Reelfoot Thrust
SW - Southwestern Segment
W - Western Segment
WR - Western Rift

**Area Sources:**
IRUS - Iapetan Rift Margin
NCS - Non-extended Craton - South
NRM - Northwestern Rift Margin
NRR - Northern Reelfoot Rift
NSZ - New Madrid Seismic Zone
OUAC - Ouachita
OZK - Ozark
RCG - Rough Creek Graben
SLL - Saint Louis Lobe
SRM - Southwestern Rift Margin
SRR - Southern Reelfoot Rift
WVL - Wabash Valley Lobe

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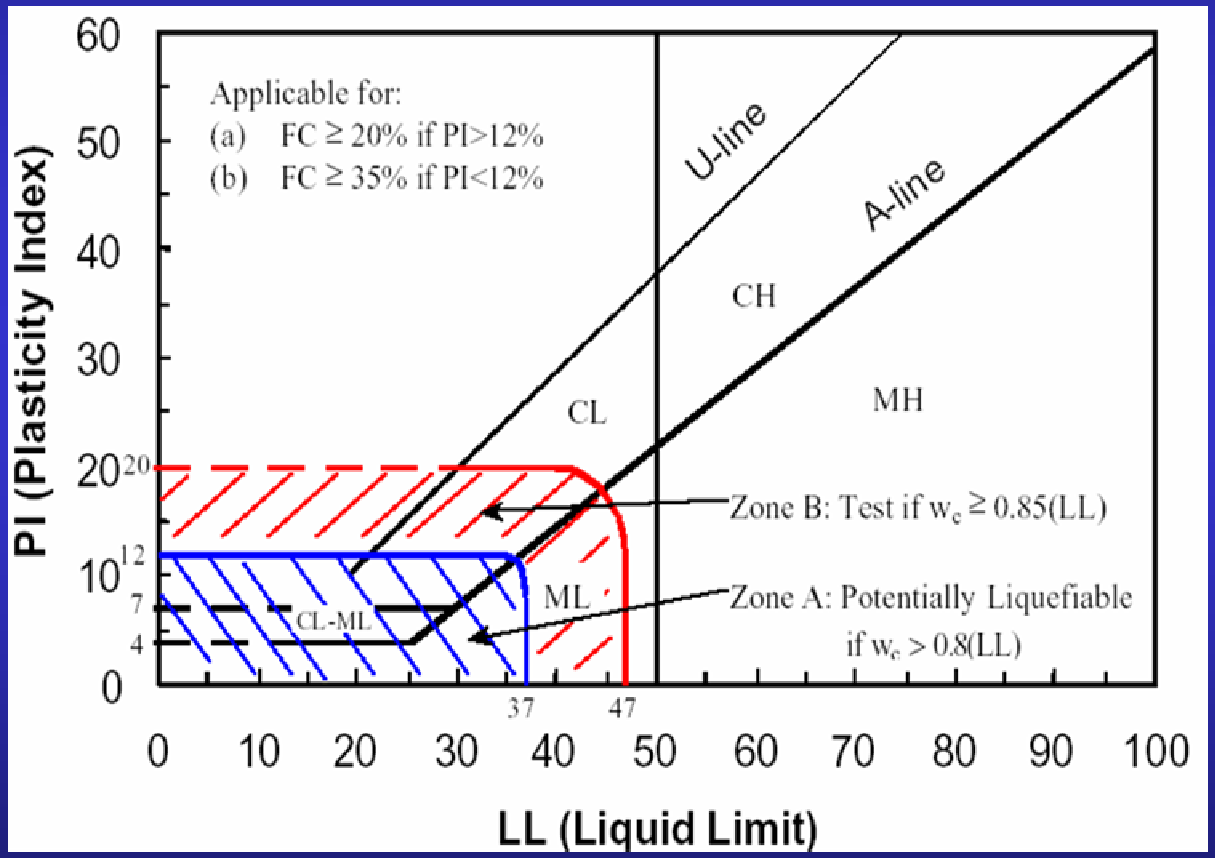

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# Lower of the level of uncertainty and conservatism

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# SAM STACY
# 601-631-5635
# USACE – Vicksburg

**sam.t.stacy@mvk02.usace.army.mil**