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LIQUEFACTION EVALUATIONS AT DOE SITES

Agenda

- Background
- Purpose and Objective
- Liquefaction Methods
- Site Evaluations
- Aging
- Conclusions

Liquefaction at DOE Sites

Background

Background

- Liquefaction evaluations are required at all DOE sites
- Methods have evolved over the years, but there is currently only one consensus methodology;
  - Youd et al., 2001
- Two other methods have emerged in the last few years;
  - Cetin et al., 2004
  - Idriss & Boulanger, 2008

Background

- Youd et al., was the result of two workshops (NCEER/NSF) held in the late 1990s, culminating in a NCEER report and a ASCE publication in 2001. The method is widely used.
- Cetin et al., was the result of several doctoral dissertations and evaluations at University of California-Berkeley. It culminated in a ASCE publication in 2004.
- Idriss & Boulanger is the result of several MS & doctoral dissertations and evaluations at University of California-Davis. It culminated in an EERI Monograph in 2008.

Background

- There is currently ongoing discussion in the profession regarding the Cetin et al., and Idriss & Boulanger methods.
- There is no such discussion regarding Youd et al.
- This presentation will present results from each for comparison.
- We will also present results from the SRS site-specific methodology for comparison to Youd et al.

Liquefaction at DOE Sites

Purpose & Objectives

Purpose & Objectives

- The overall purpose is to present and show differences in each of the methodologies (Youd, Cetin, and Idriss & Boulanger) with respect to liquefaction factor of safety (FS)
- Comparisons will be shown of various parameters along with some discussion
- An added comparison will be made between the SRS site-specific and Youd methodologies to introduce a potential aging correction

Liquefaction at DOE Sites

Liquefaction Methods

Liquefaction Evaluation Methods

- Youd et al., 2001
  - Only consensus liquefaction method
  - NSF/NCEER Workshops in the 1990s
  - ASCE Geotechnical Journal October 2001
- Cetin et al., 2004
  - Re-evaluated some key case histories
  - ASCE Geotechnical Journal December 2004
- Idriss & Boulanger 2008
  - EERI Monograph 12 (MNO-12)
- SRS site-specific, 2008
  - Results from site-specific laboratory testing

BECHTEL

Liquefaction Methods

- For this comparative evaluation the Seed & Idriss simplified equation will be used to calculate the earthquake demand.
- Each of the four methods will utilize the specific recommendations of each method for the various parameters (e.g., r_d, MSF, C_N, and K_σ).
- The evaluation with the 3 methods will utilize results from the standard penetration test (SPT), using the method-specific triggering relationship.
- The added comparison between the SRS and Youd methods will utilize the triggering relationships developed for the Cone Penetration Test (CPT).

Liquefaction Methods

- Just a reminder, the Seed/Idriss simplified equation;

$$CSR = \frac{\tau_{ave}}{\sigma'_{vo}} = 0.65 \cdot \frac{\sigma_{vo}}{\sigma'_{vo}} \cdot \frac{a_{\max}}{g} \cdot r_d$$

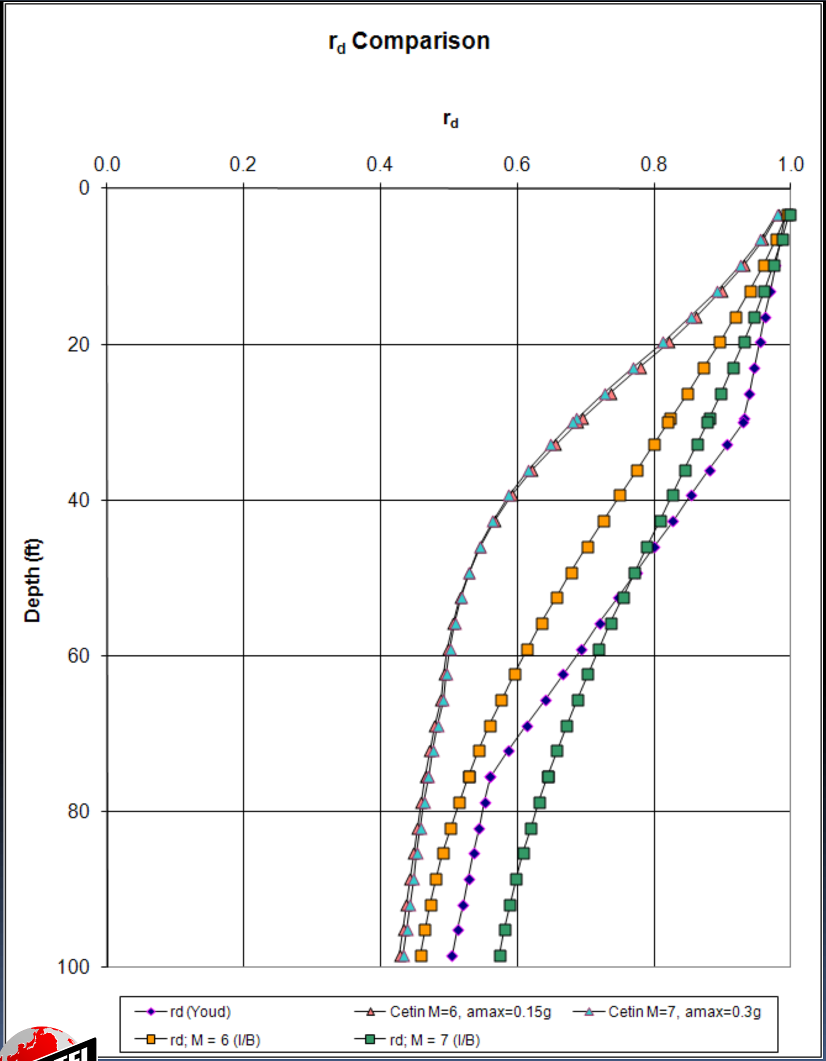
- The safety factor against liquefaction is defined as;

$$\mathrm{FS} = \frac{\mathrm{CRR}_{7.5}}{\mathrm{CSR}} \cdot \mathrm{MSF} \cdot \mathrm{K}_{\sigma} \cdot \mathrm{K}_{\alpha} \cdot \mathrm{K}_{\mathrm{age}}$$

Liquefaction Methods

- Where;
  - CSR is the earthquake demand
  - CRR is the soil's capacity (resistance or strength)
  - MSF the magnitude scaling factor
  - K_{α} a correction for static shear stress (set to 1 for this comparison)
  - K_{σ} a correction for overburden pressure
  - K_{age} a correction for age (set to 1 for the comparison of the 3 methods)
  - σ'_{vo} and σ_{vo} effective and total overburden pressures

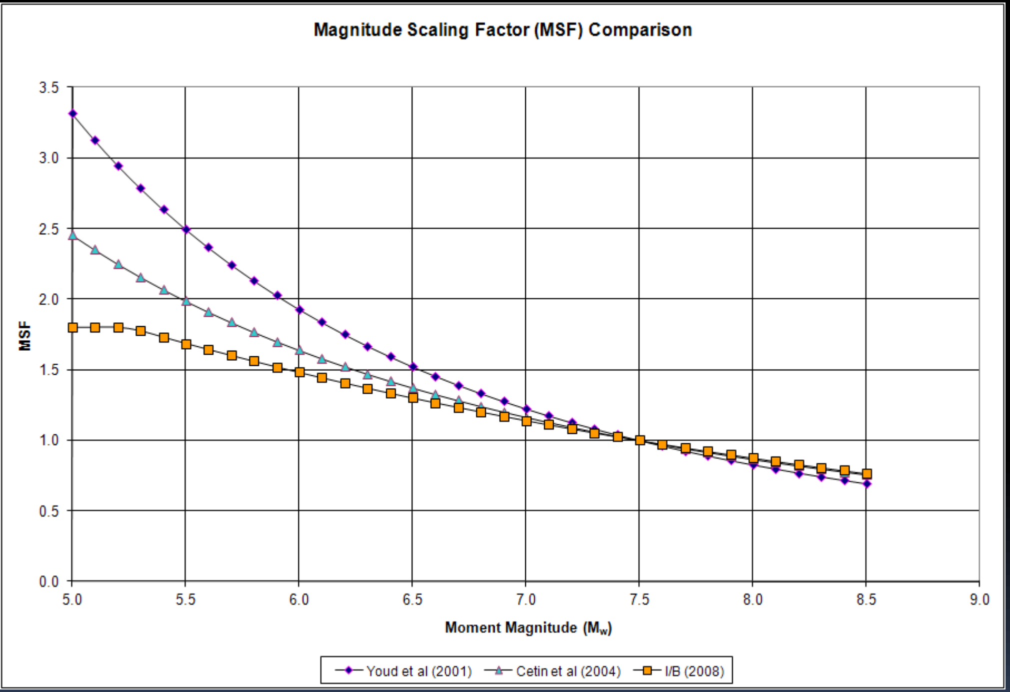
Liquefaction Methods



Stress Reduction Coeff. (r_d)

- Cetin et al., lower at all depths shown
- Youd et al., varies with depth
- Idriss & Boulanger changes with earthquake M and depth
- Cetin et al., changes with depth, M, a_{max} and V_s
- Site response analysis eliminates these differences

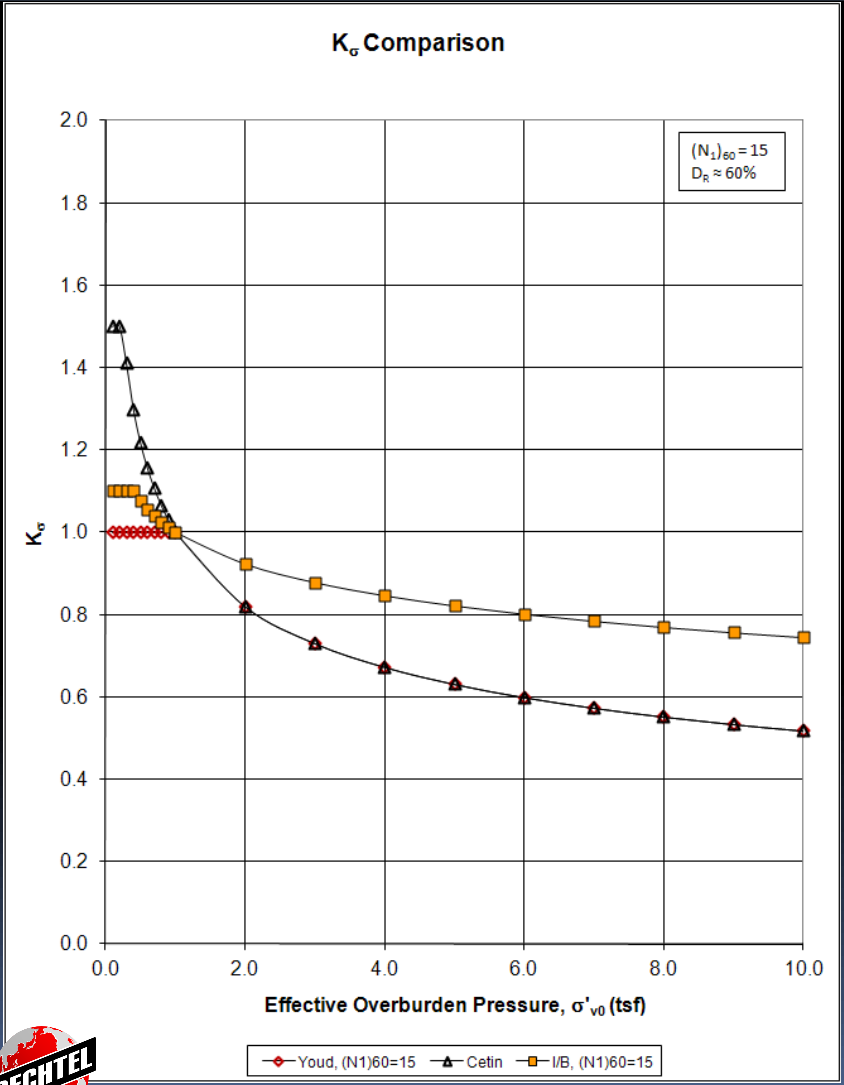
Liquefaction Methods



MSF Comparison

- All three show similar trends
- All three are equal at M_w = 7.5
- At M_w > 6.5, differences are minimal

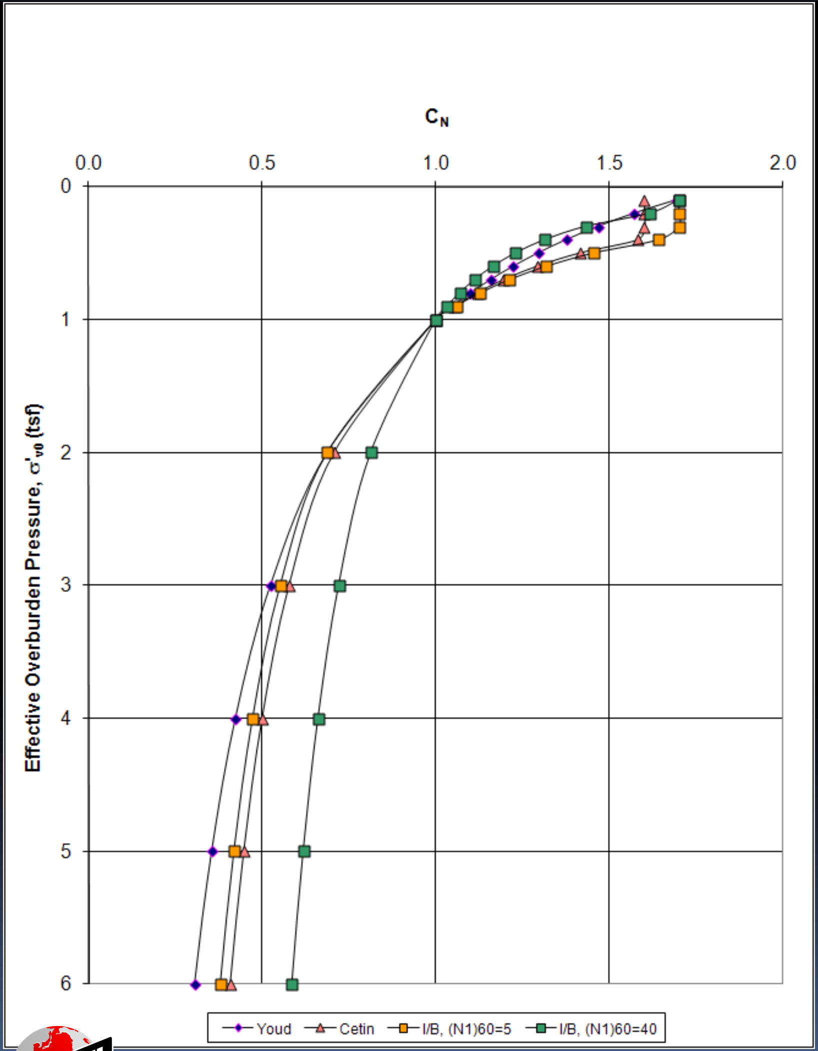
Liquefaction Methods



K_σ Correction

- Significant differences at shallow depths
- Values vary with overburden pressure and relative density (D_R)
- Most level-ground evaluations are at overburden pressures < 3.5 to 4 tsf

Liquefaction Methods



SPT C_N Correction

- All relationships converge at $\sigma'_o = 1$ tsf
- Relationships at $\sigma'_o < 4$ tsf are very similar
- At $\sigma'_o > 6$ tsf, differences can be important

SPT Triggering Relationships

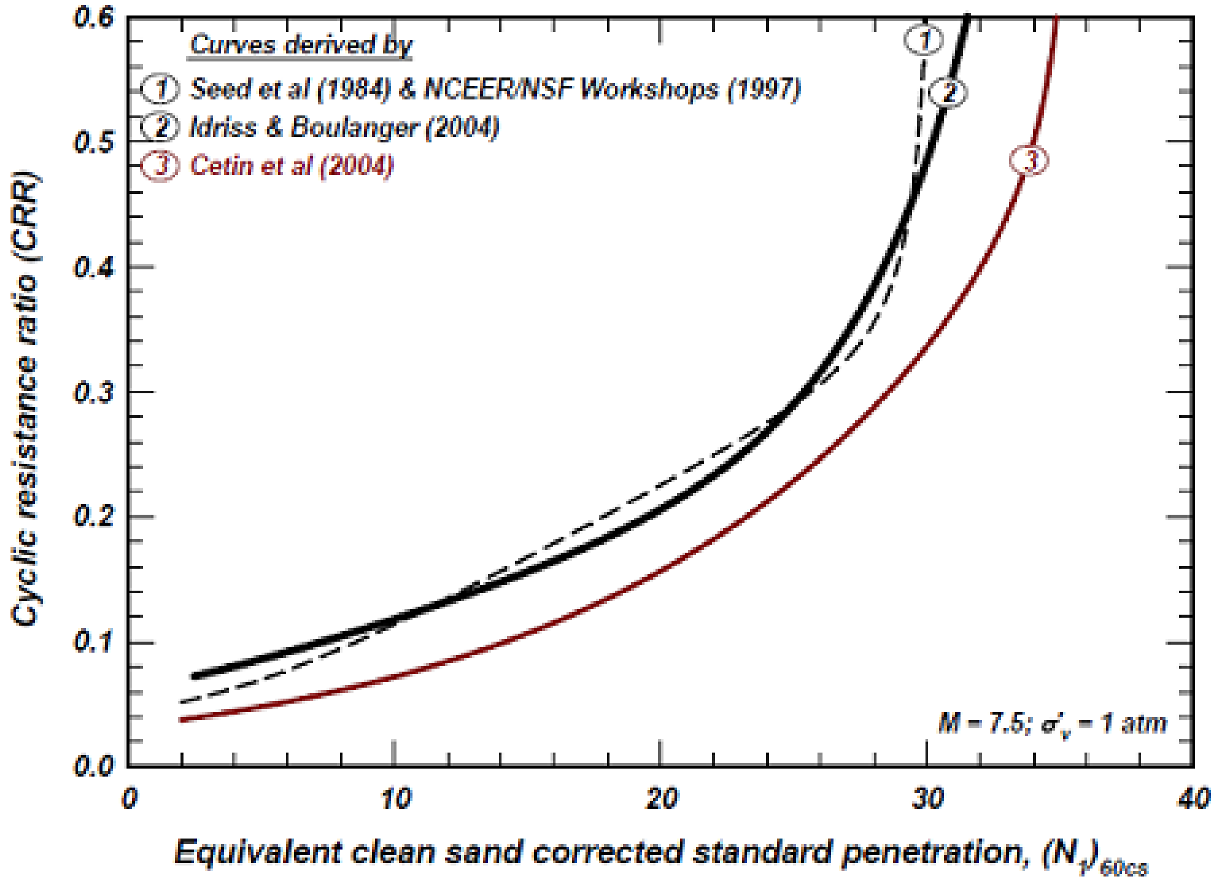


Figure 7.1. Liquefaction triggering correlations for M = 7.5 and σ'_v = 1 atm developed by: (1) Seed et al. (1984), as modified by the NCEER/NSF Workshops (1997) and published in Youd et al. (2001); (2) Idriss and Boulanger (2004, 2008); and (3) Cetin et al. (2004)

Idriss & Boulanger, 2010

SPT Triggering Relationships

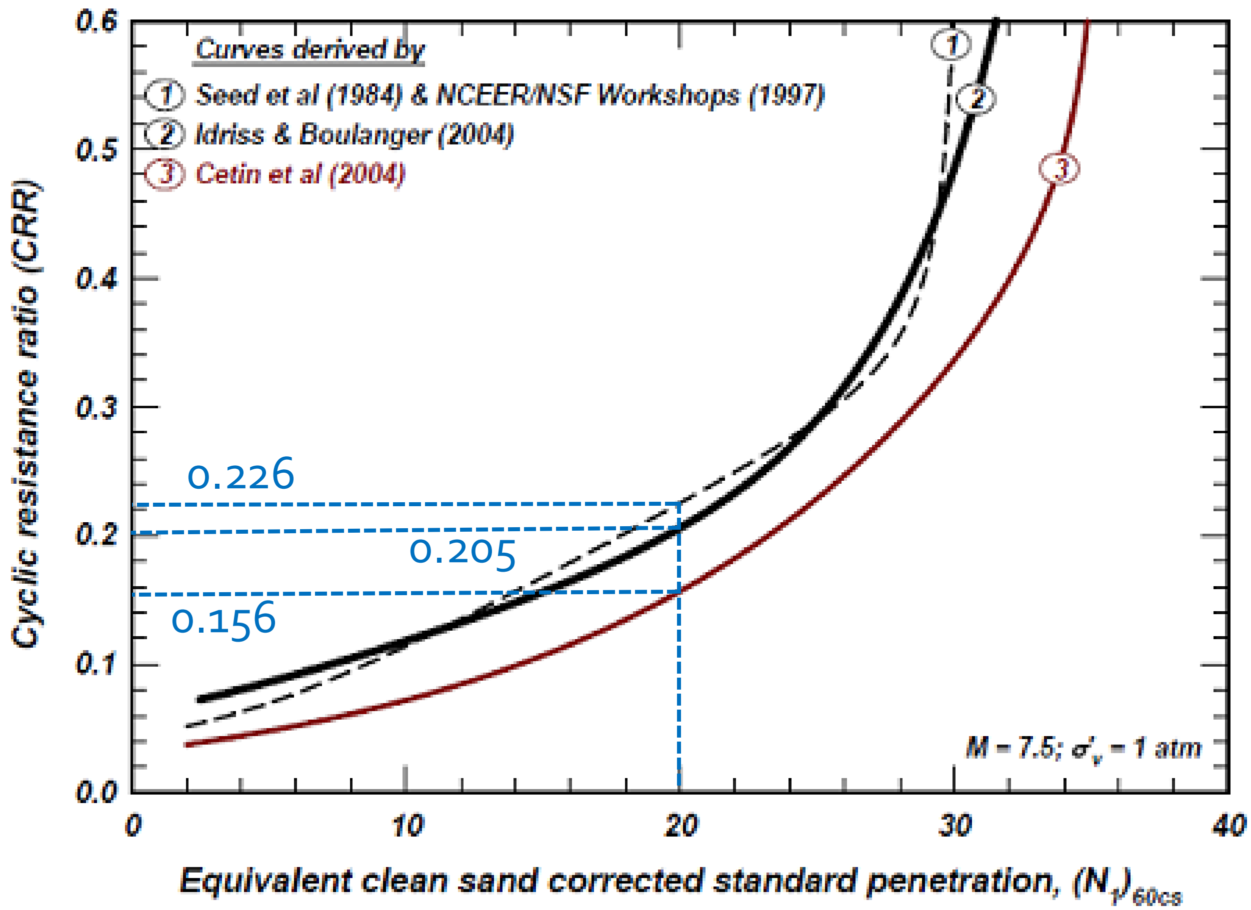


Figure 7.1. Liquefaction triggering correlations for M = 7.5 and σ'v = 1 atm developed by: (1) Seed et al. (1984), as modified by the NCEER/NSF Workshops (1997) and published in Youd et al. (2001); (2) Idriss and Boulanger (2004, 2008); and (3) Cetin et al. (2004)

Adapted from Idriss & Boulanger, 2010

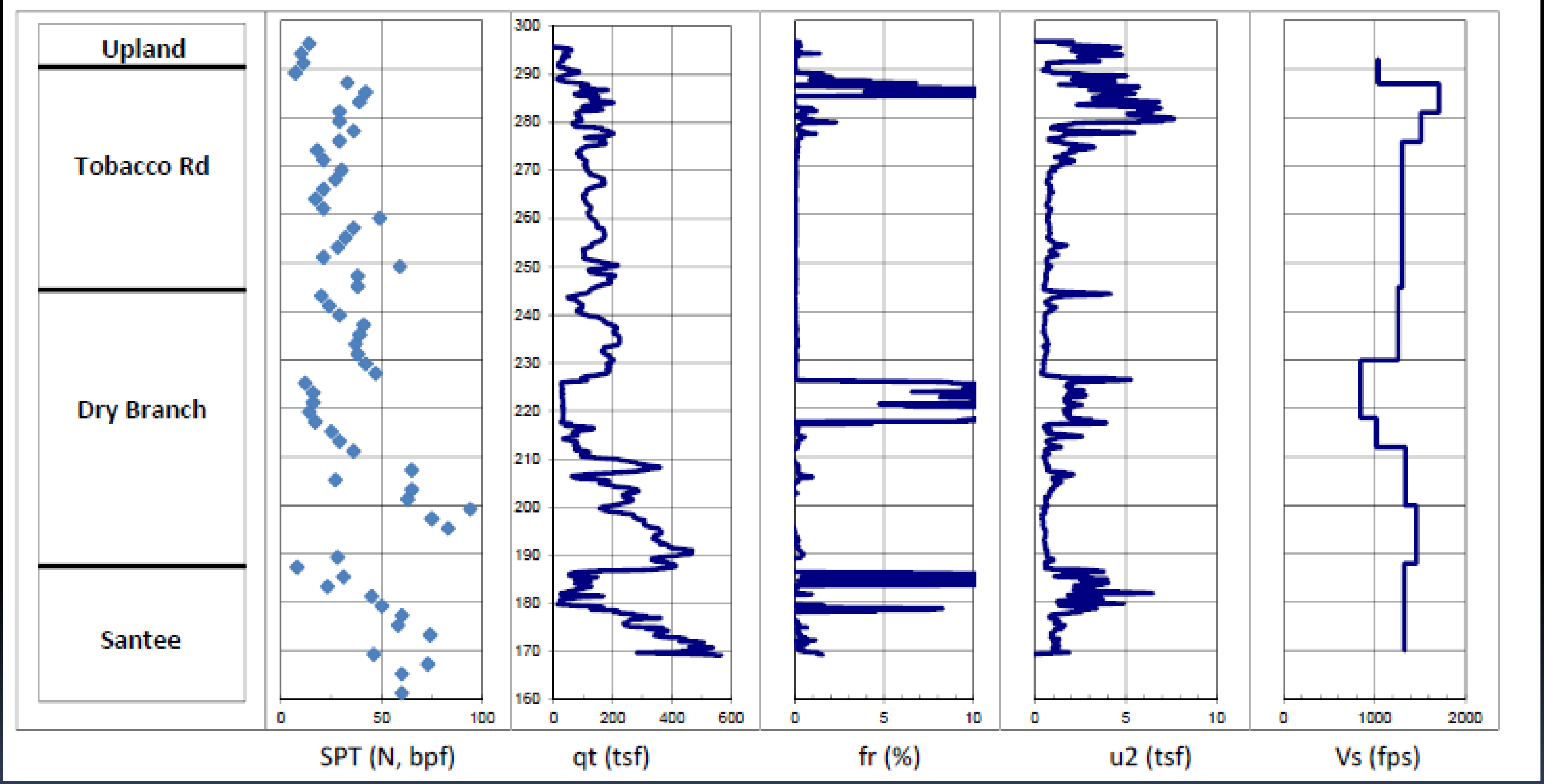
Triggering Relationships
(most important difference)

- CRR at $(N_1)_{60cs}$ = 5
  - I/B:Y = 0.087/0.068 = 1.28
  - C:Y = 0.048/0.068 = 0.71
- CRR at $(N_1)_{60cs}$ = 20
  - I/B:Y = 0.205/0.226 = 0.91
  - C:Y = 0.156/0.226 = 0.69
- CRR at $(N_1)_{60cs}$ = 10
  - I/B:Y = 0.118/0.115 = 1.03
  - C:Y = 0.072/0.115 = 0.63
- CRR at $(N_1)_{60cs}$ = 30
  - I/B:Y = 0.48/0.6 = 0.8
  - C:Y = 0.338/0.6 = 0.56

Site Evaluations

Savannah River Site; F, Z, and K areas

SRS Generalized Profile



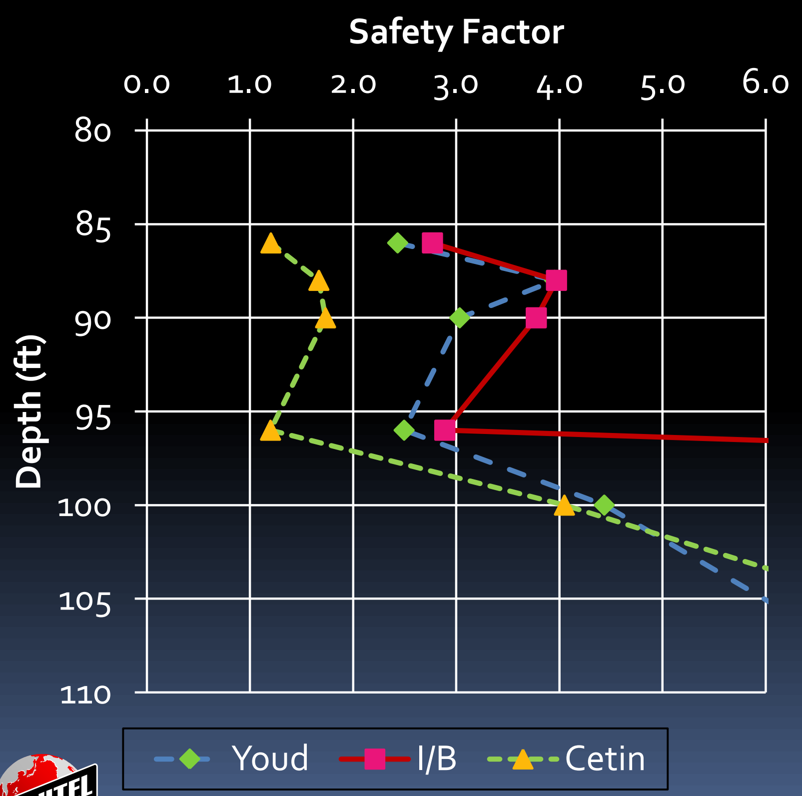
GWT varies by area;
K – 55 ft, F – 80 ft, Z – 55 ft

SRS Seismic Demand

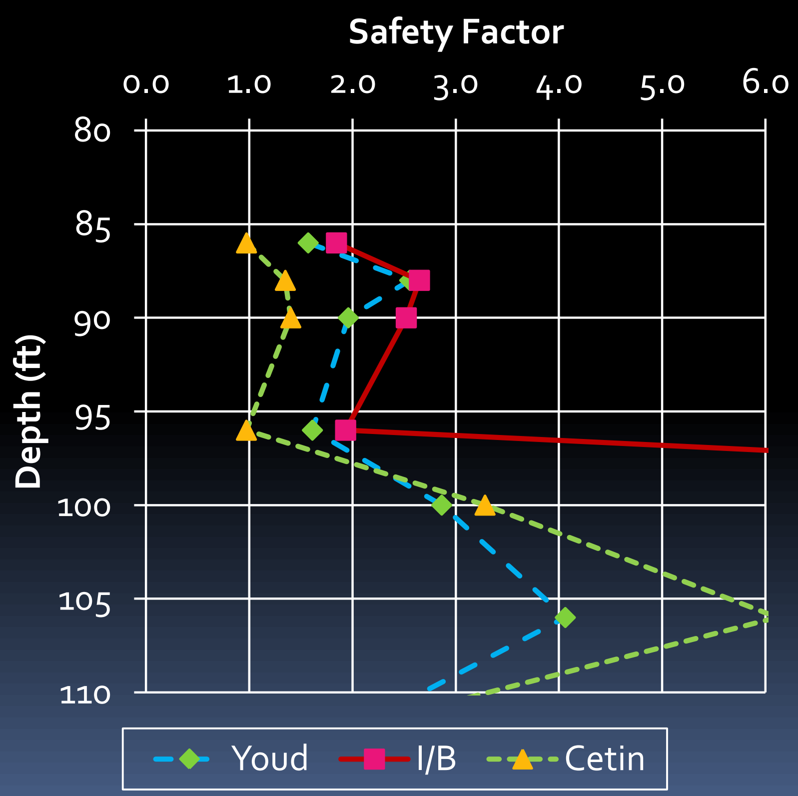
- Two earthquakes are utilized
  - Deterministic
    - M_w = 7.2, pga = 0.1g Charleston 50th (C50)
  - Probabilistic
    - M_w = 6.6, pga = 0.2g Design Basis Event (DBE)

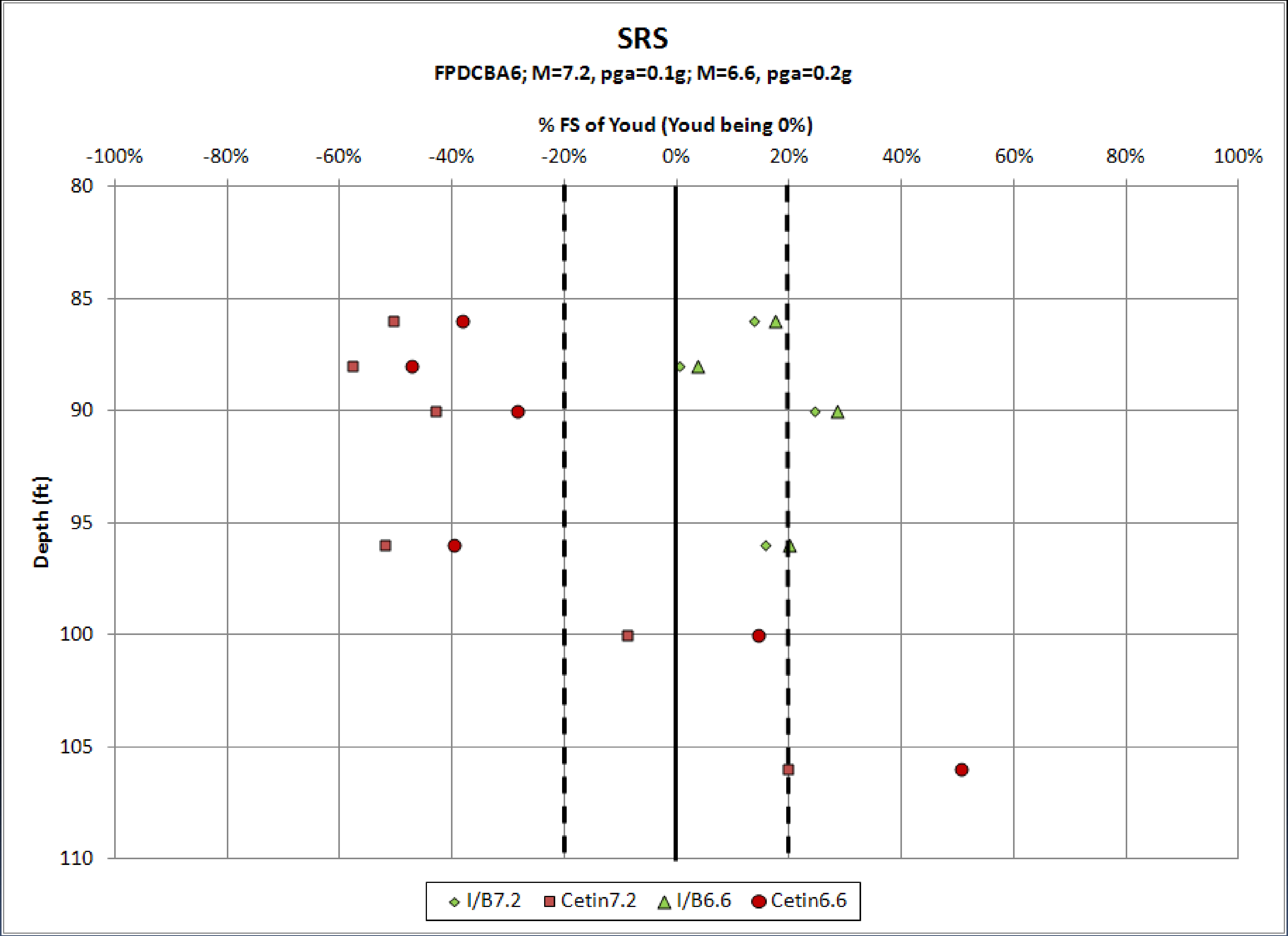
SRS F-Area

M_w=7.2, pga=0.1g

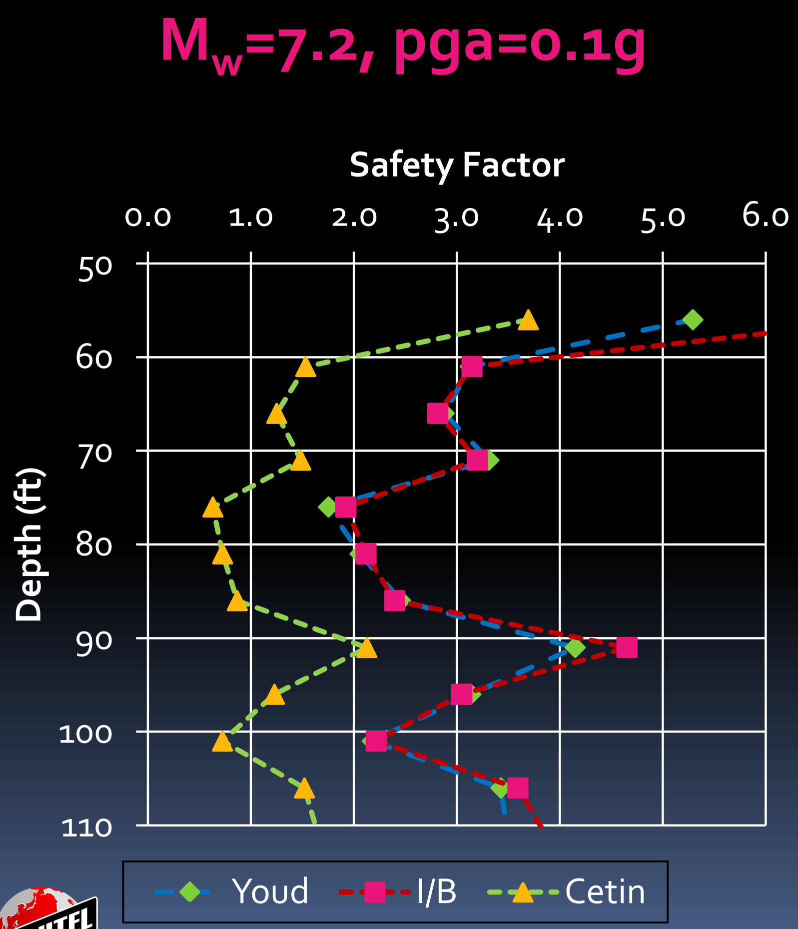


M_w=6.6, pga=0.2g

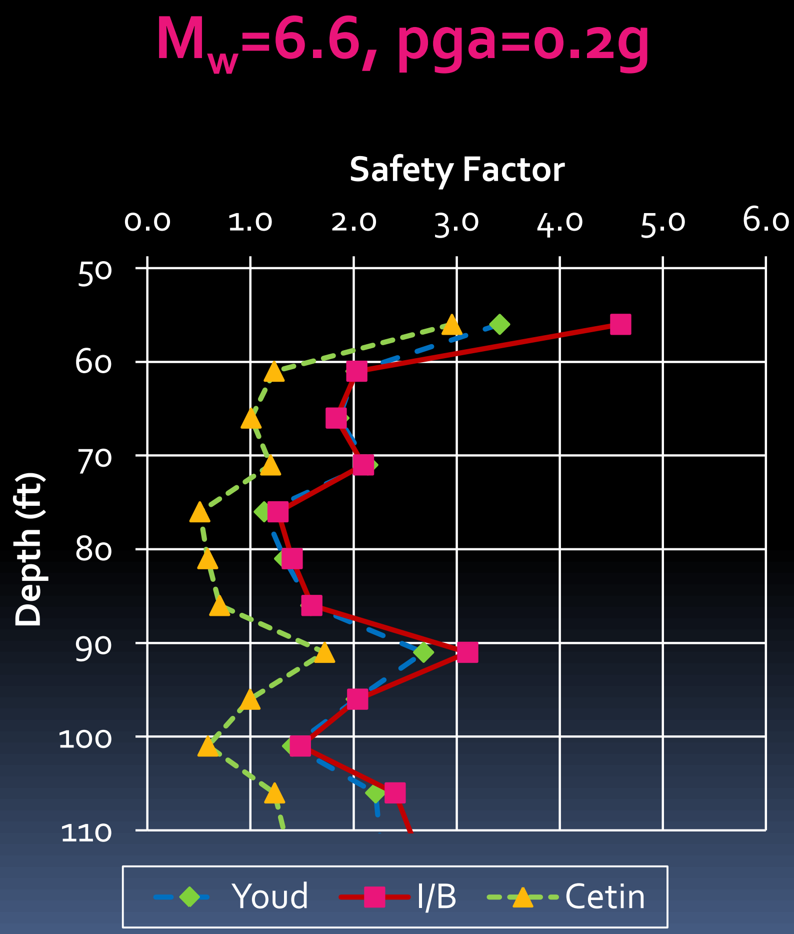



SRS
FPDCBA6; M=7.2, pga=0.1g; M=6.6, pga=0.2g
% FS of Youd (Youd being 0%)
-100%
-80%
-60%
-40%
-20%
0%
20%
40%
60%
80%
100%
Depth (ft)
80
85
90
95
100
105
110
I/B7.2
Cetin7.2
I/B6.6
Cetin6.6

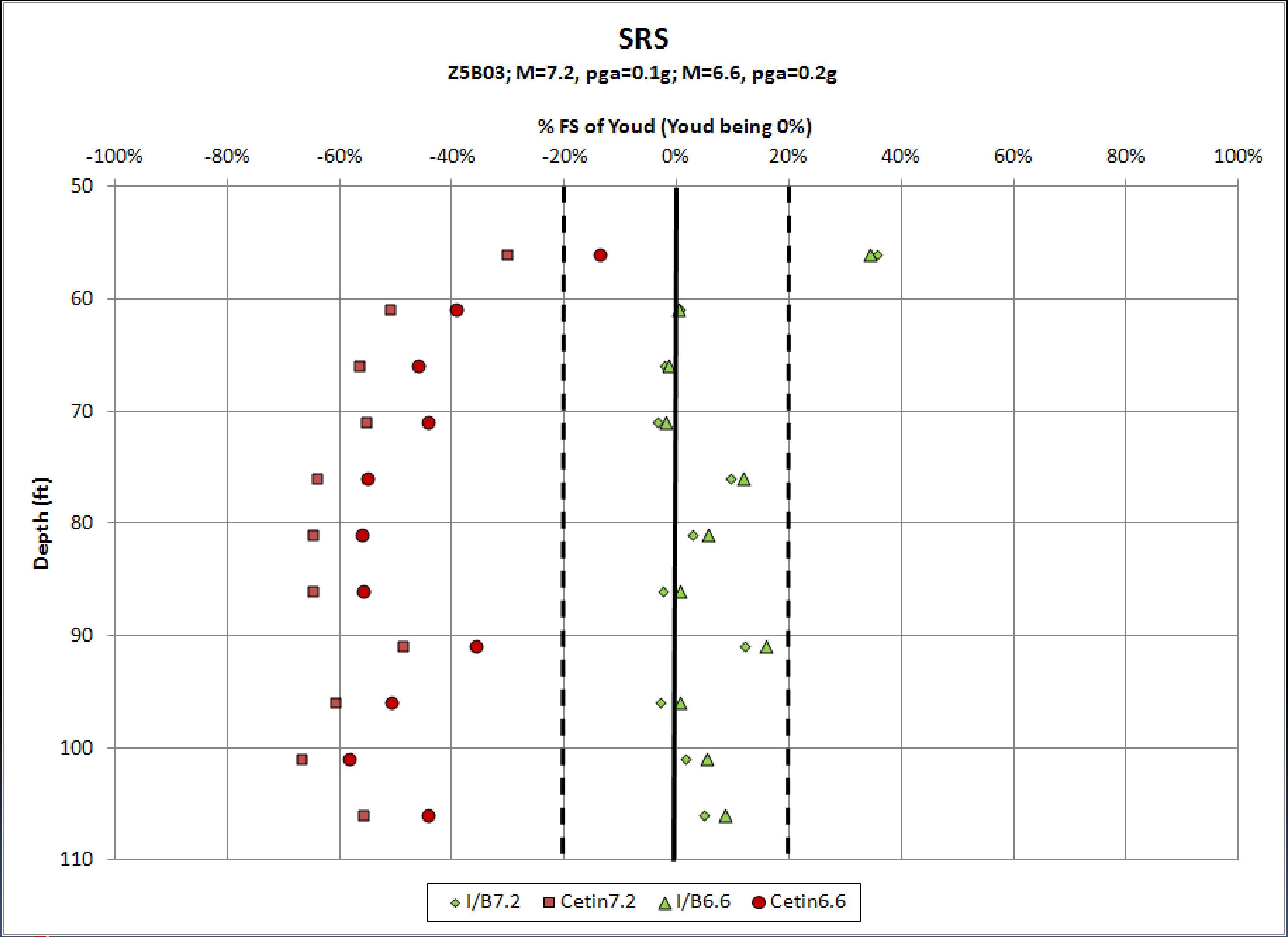
SRS Z-Area



Mw=7.2, pga=0.1g
Safety Factor
0.0
1.0
2.0
3.0
4.0
5.0
6.0
50
60
70
80
90
100
110
Depth (ft)
Youd
I/B
Cetin

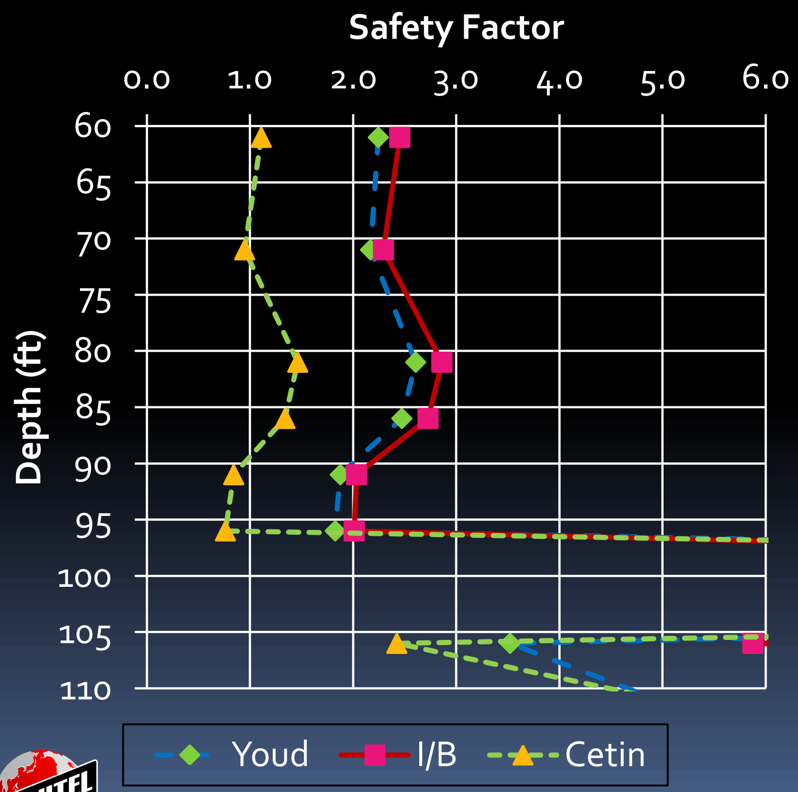


Mw=6.6, pga=0.2g
Safety Factor
0.0
1.0
2.0
3.0
4.0
5.0
6.0
50
60
70
80
90
100
110
Depth (ft)
Youd
I/B
Cetin

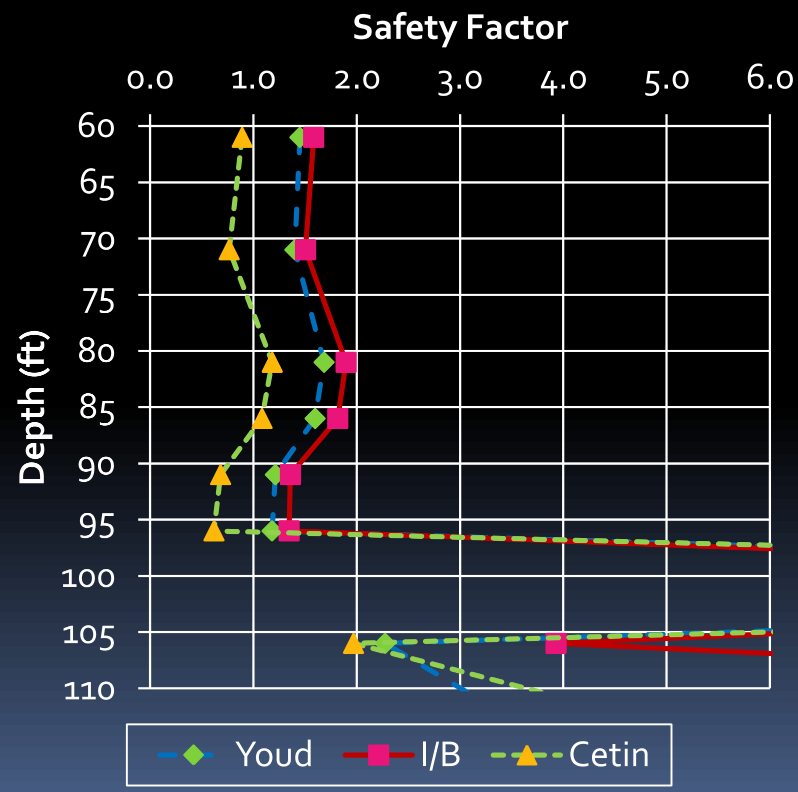

SRS
Z5B03; M=7.2, pga=0.1g; M=6.6, pga=0.2g
% FS of Youd (Youd being 0%)
-100%
-80%
-60%
-40%
-20%
0%
20%
40%
60%
80%
100%
50
60
70
80
90
100
110
Depth (ft)
I/B7.2
Cetin7.2
I/B6.6
Cetin6.6

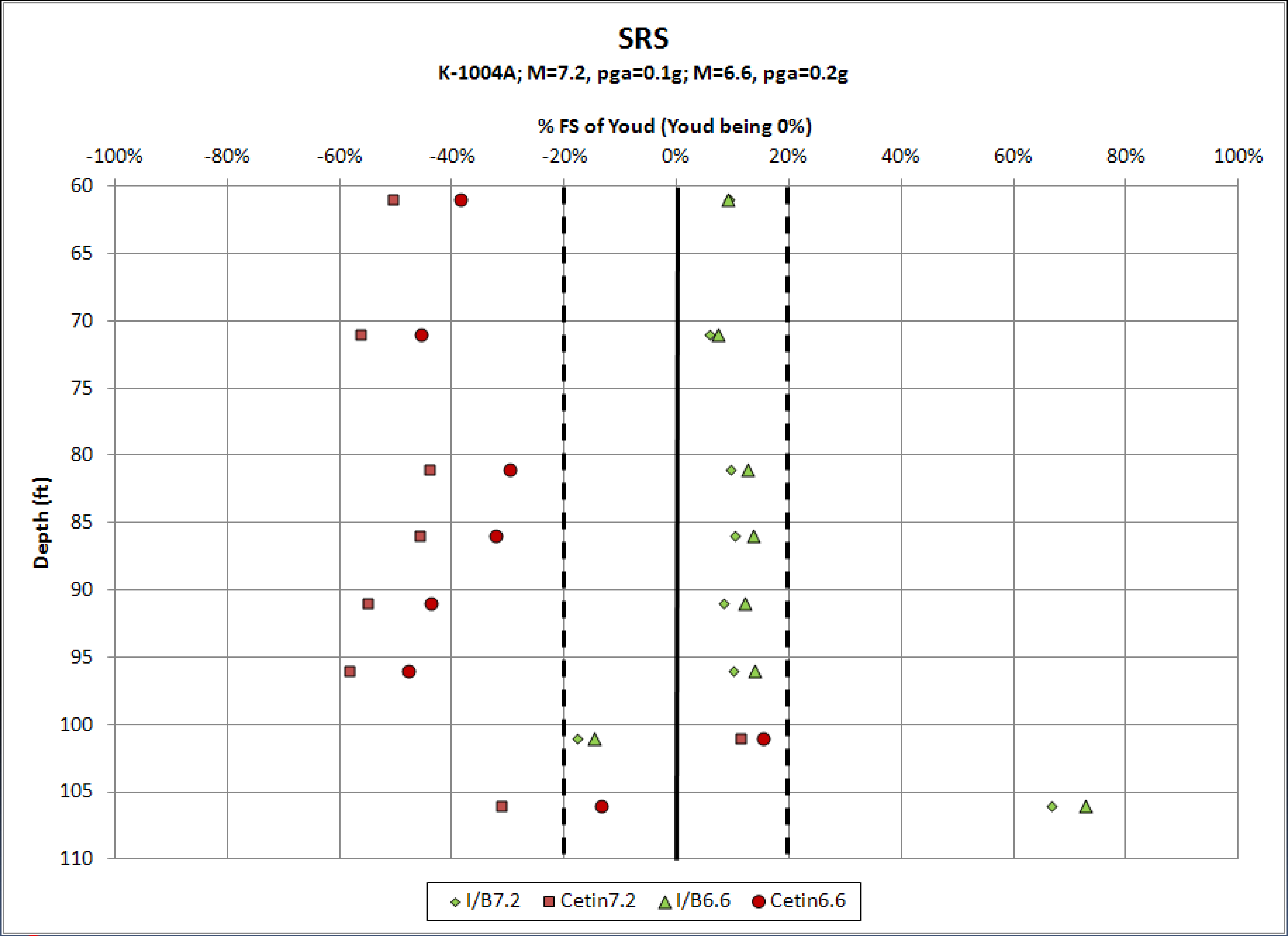
SRS K-Area

M_w=7.2, pga=0.1g



M_w=6.6, pga=0.2g




SRS
K-1004A; M=7.2, pga=0.1g; M=6.6, pga=0.2g
% FS of Youd (Youd being 0%)
-100%
-80%
-60%
-40%
-20%
0%
20%
40%
60%
80%
100%
Depth (ft)
60
65
70
75
80
85
90
95
100
105
110
I/B7.2
Cetin7.2
I/B6.6
Cetin6.6

SRS Results

- In general;
  - Cetin results in lower FS
  - Youd and Idriss/Boulanger are comparable

- Neglecting very high FS;
  - I/B is about 9% of Youd with a σ ~ 20% for the C50 (M_w = 7.2)
  - I/B is about 12% of Youd with a σ ~ 21% for the DBE (M_w = 6.6)

  - Cetin is about -44% of Youd with a σ ~ 24% for the C50 (M_w = 7.2)
  - Cetin is about -30% of Youd with a σ ~ 27% for the DBE (M_w = 6.6)

Site Evaluations

Paducah (PDGP)

Paducah Seismic Demand

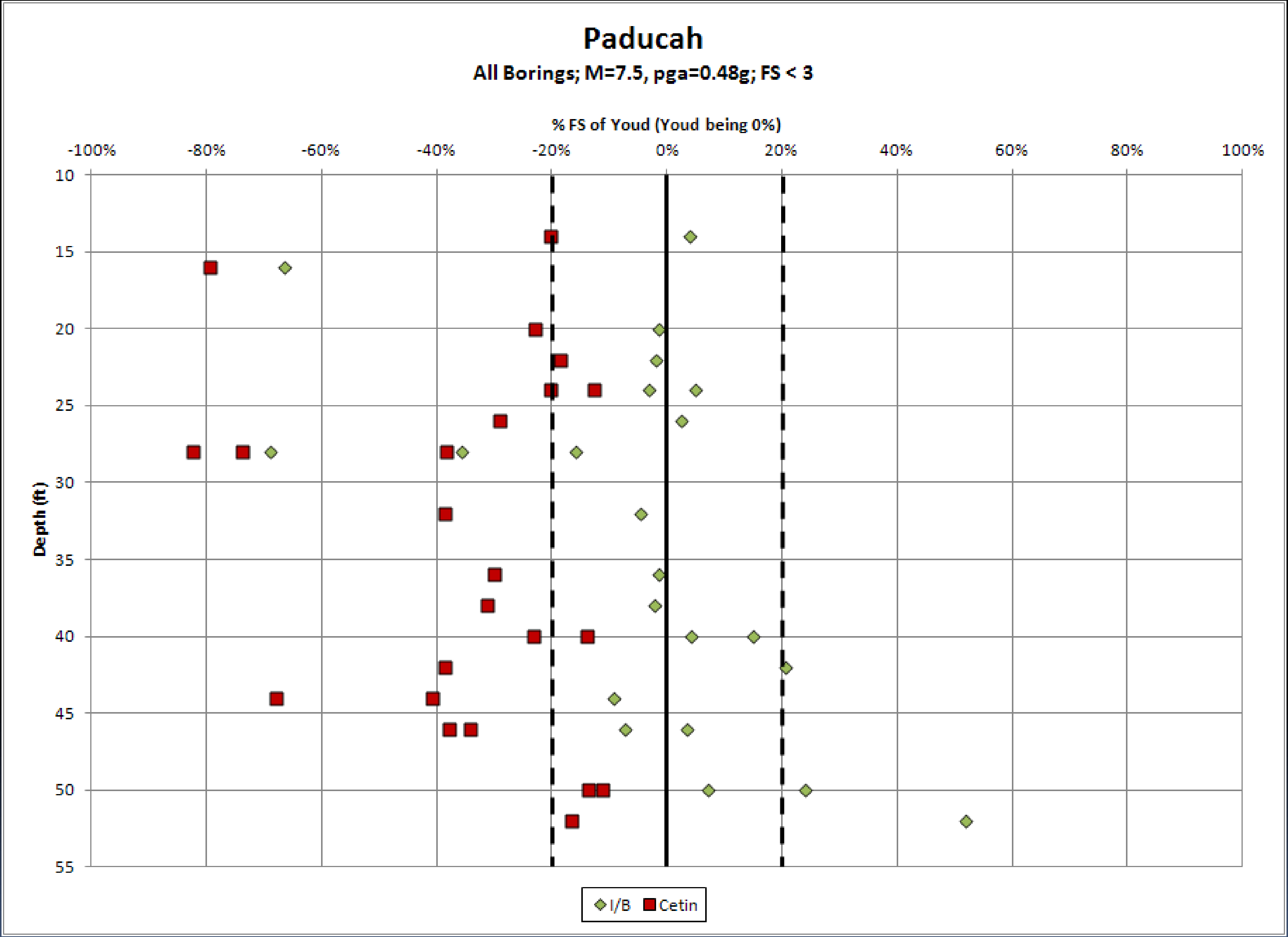
- $M_w = 7.5$, pga = 0.48g

Paducah Generalized Profile

Elevation (ft, msl)	Layer	Description	N value (bpf)
400 385	Zone 1	Soft to Firm, Low to Medium Plastic Loess	
375	Zone 2	Medium Plastic Silt and Clay	
365	Zone 3	Poorly Graded Sand to a Well Graded Sand and Gravel	5 to 35+
355	Zone 4	Firm Interbedded Silts and Low Plasticity Clays	
345	Zone 5	Fine to Med Poorly Graded Sand with Some Gravel	5 to 35+
310	Zone 6	Low Plastic Silt and Clay with Laminations	

GWT assumed at 10 ft

PDGP; SB-01, 02, 03, 05, 06



Paducah
All Borings; M=7.5, pga=0.48g; FS < 3
% FS of Youd (Youd being 0%)
-100%
-80%
-60%
-40%
-20%
0%
20%
40%
60%
80%
100%
10
15
20
25
30
35
40
45
50
55
Depth (ft)
I/B
Cetin

PGDP Results

- In general, the results for each of the three methods are much closer, however;
  - Cetin results in lower FS
  - Youd and Idriss/Boulanger are comparable
- Overall;
  - Idriss/Boulanger is about -4% of Youd with a σ ~ 26% (16 of 22 [73%] analyses within ±20% of Youd)
  - Cetin is about -35% of Youd with a σ ~ 22% results (6 of 23 [26%] analyses within ±20% of Youd)

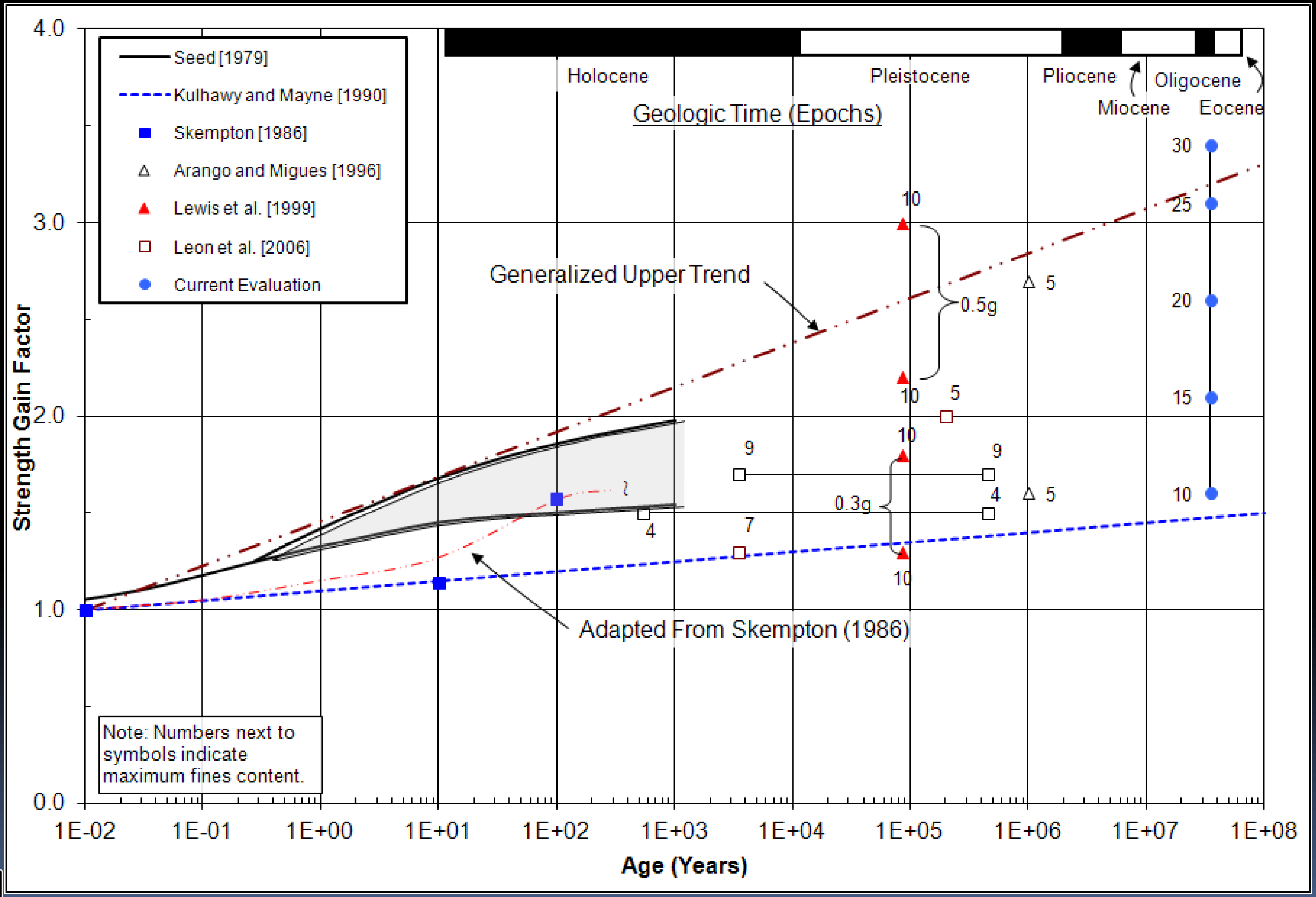
Aging

Savannah River Site

Aging (SRS)

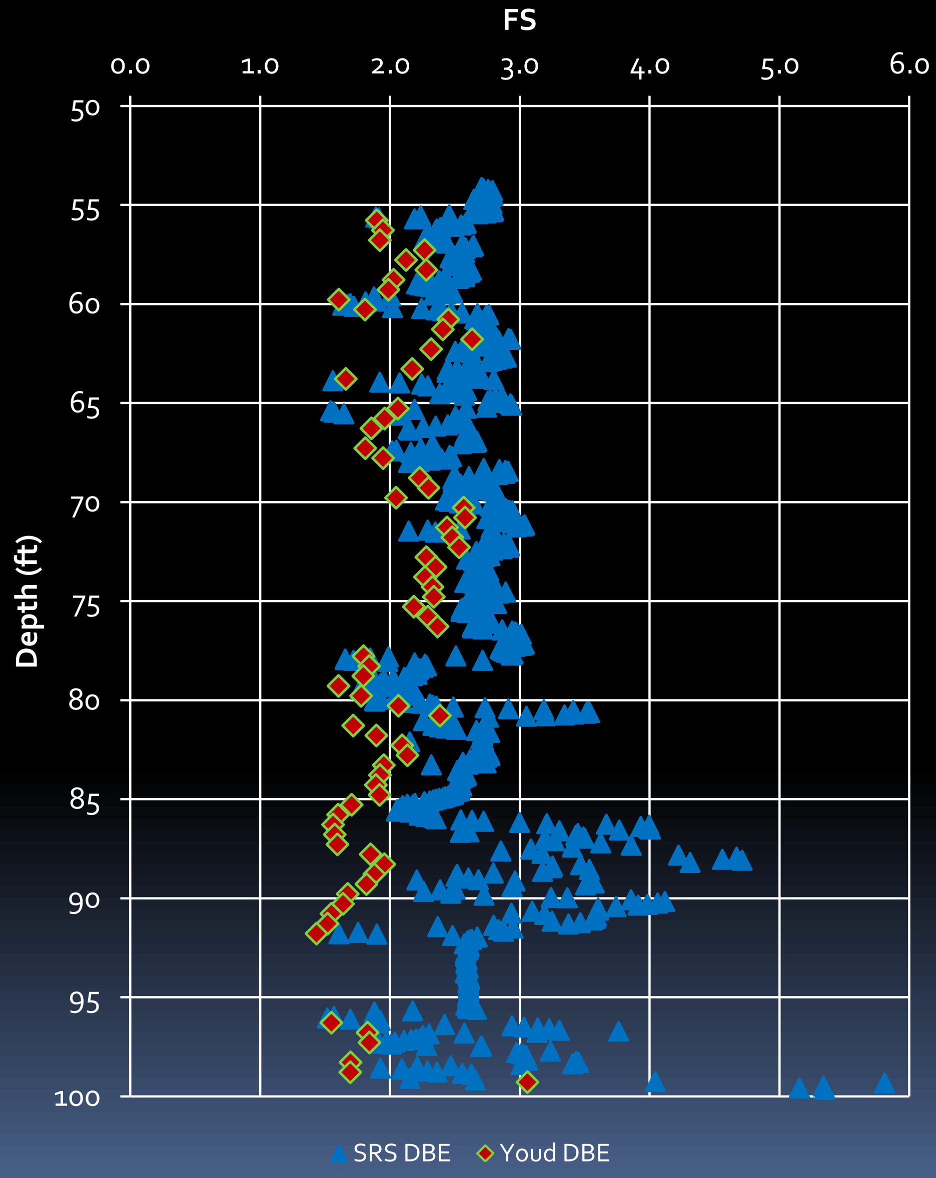
- Compare Youd et al., (2001) to the SRS methodology
- SRS methodology based on site-specific testing (CRR and K_σ); no attempt was made to correct for disturbance
- Most other parameters (C_N, MSF, r_d) follow recommendations of Youd
- Difference in computed FS can be attributed to aging
- Compare results for CPT in K-Area

Strength Gain vs Age



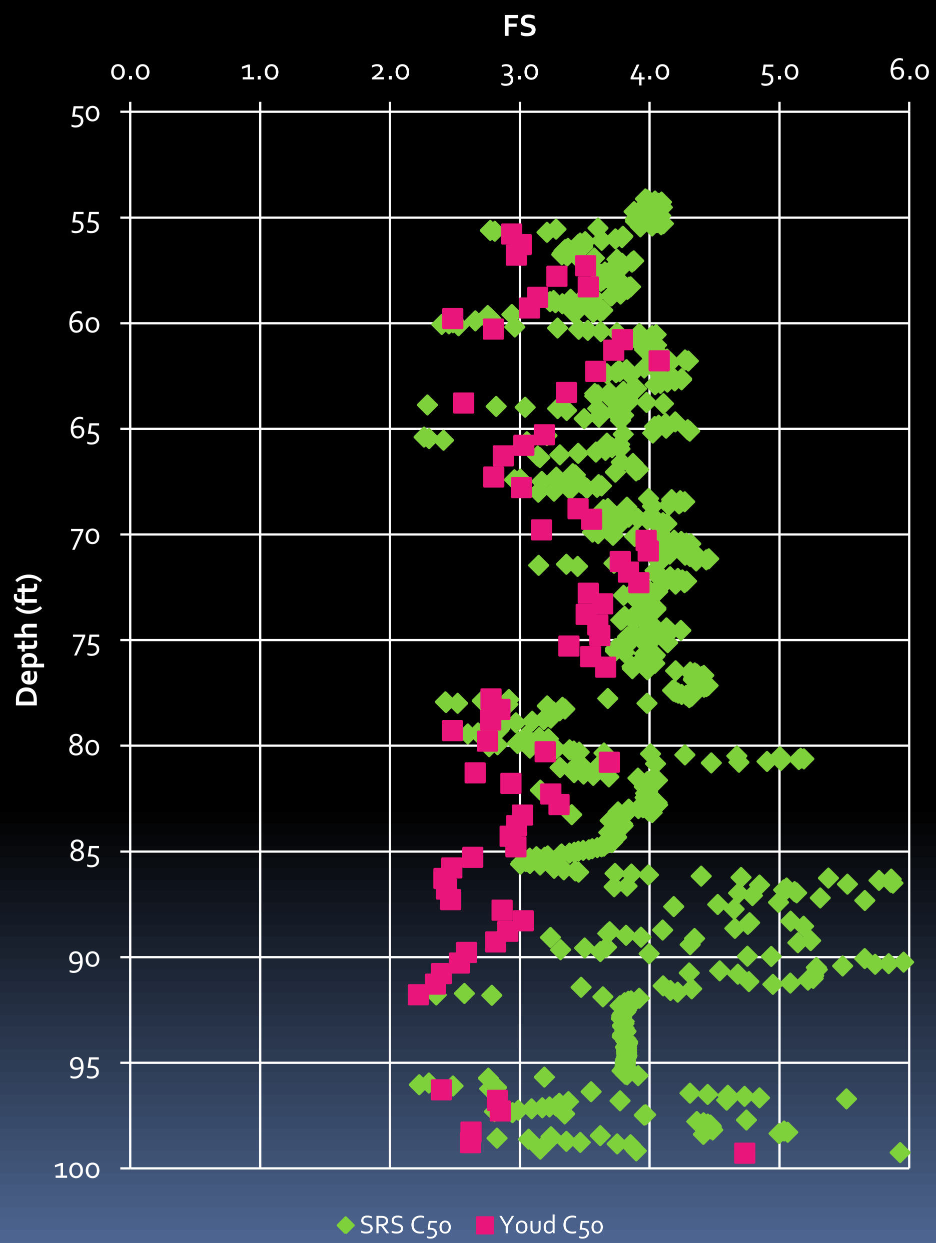
Lewis et al., 2008

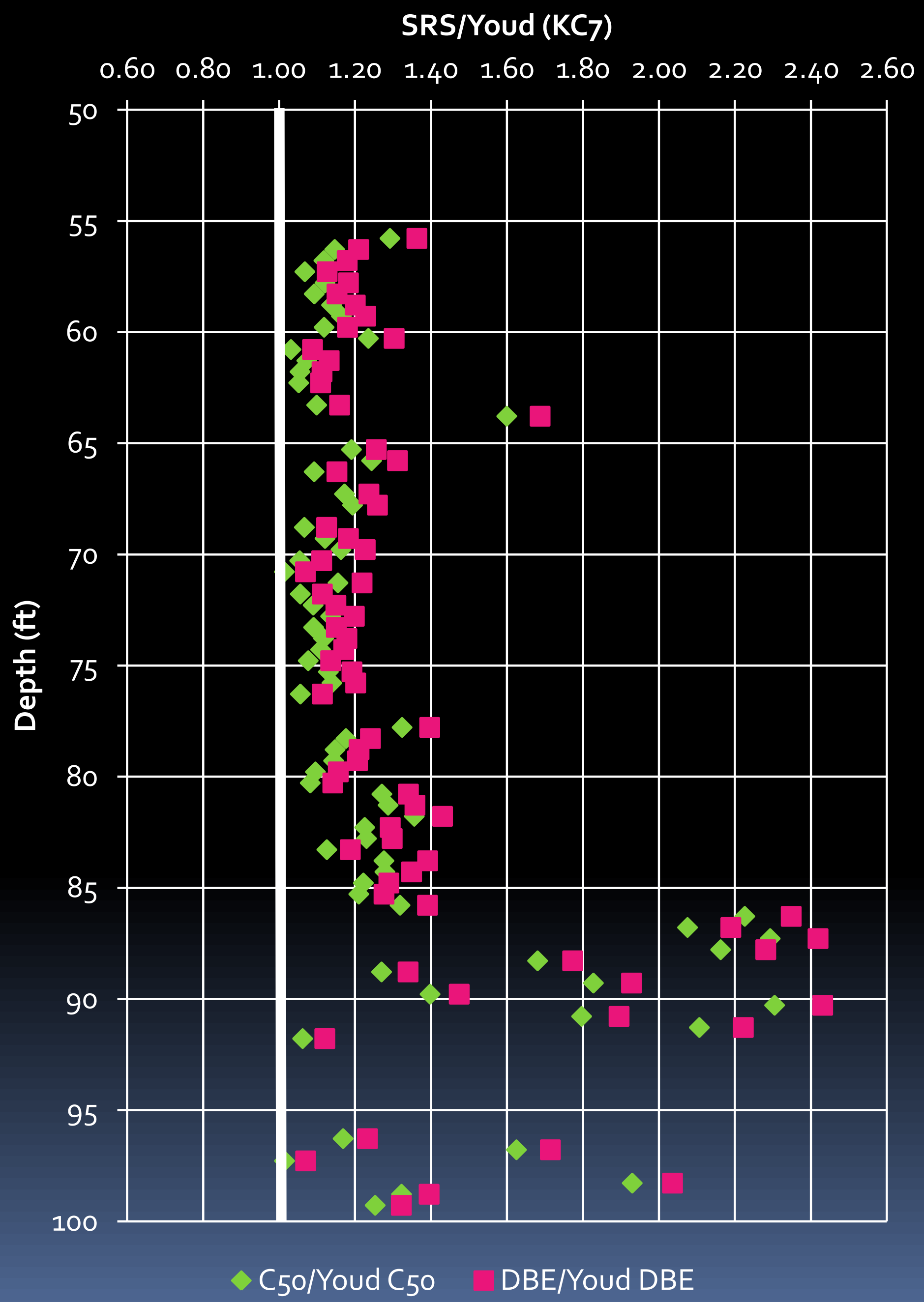
KC7



FS
0.0
1.0
2.0
3.0
4.0
5.0
6.0
50
55
60
65
70
75
80
85
90
95
100
Depth (ft)
SRS DBE
Youd DBE

KC7

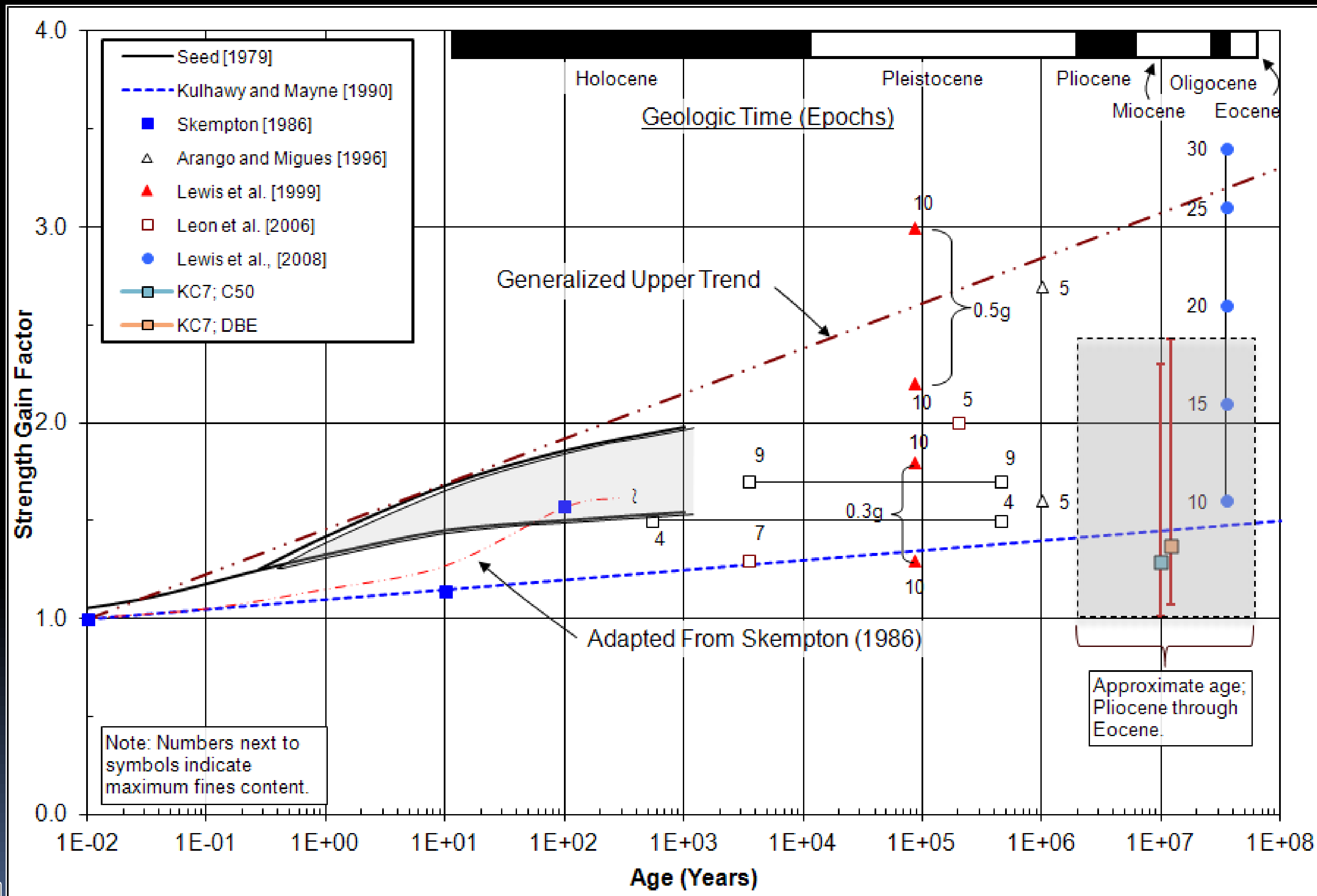

FS
0.0
1.0
2.0
3.0
4.0
5.0
6.0
50
55
60
65
70
75
80
85
90
95
100
Depth (ft)
SRS C50
Youd C50


SRS/Youd (KC7)
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
Depth (ft)
50
55
60
65
70
75
80
85
90
95
100
C50/Youd C50
DBE/Youd DBE

Aging (SRS)

- The results for CPT KC7 would indicate the following;
  - For the DBE (M_w = 6.6, pga = 0.2g);
    - Ratio of SRS/Youd ranges from about 1.1 to 2.4, with a mean ~ 1.4 (say ~ 1.1 to 1.2 from 55 to 80 ft)
  - For the C50 (M_w = 7.2, pga = 0.1g);
    - Ratio of SRS/Youd ranges from about 1 to 2.3, with a mean ~ 1.3 (say ~ 1.1 to 1.2 from 55 to 85 ft)

Strength Gain vs Age; SRS



Adapted from Lewis et al., 2008

Conclusions

- For the evaluations shown;
  - Youd et al., is the only consensus liquefaction evaluation method and is still recommended for use
  - Site-specific correlations (SRS) can be extremely valuable (expensive and time consuming)
  - More than one tool (e.g., SPT, CPT) is recommended for liquefaction evaluations
  - Youd et al., and Idriss/Boulanger are comparable
  - In general, Cetin et al., results in significantly lower FS than either Youd et al., and Idriss/Boulanger
  - For SRS soils, an aging correction factor appears appropriate when using the Youd et al., relationship (which is for Holocene soils)
  - Upcoming workshops specifically targeting resolution between Idriss/Boulanger and Cetin et al., methods would be very helpful in resolving differences