Application of Liquefaction Susceptibility Criteria within a Logic Tree Framework

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Pacific Earthquake
Engineering Research Center

Federal Highway
Administration

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Outline

- Aim of Next Generation Liquefaction (NGL) Project
- Existing Liquefaction Susceptibility Models
- Logic Tree Framework
- Illustrative Case History from 1999 Kocaeli Earthquake
- Application of Logic Tree Framework

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Aim of NGL Susceptibility Project

- Use laboratory test databases
- Distinguishing from case histories
- Probabilistic assessment
- Use inherent soil characteristics
  - Atterberg limits
  - I_c from CPT results

NGL NEXT GENERATION LIQUEFACTION

NGL Website

Brandenberg et al. (2020)

"Susceptibility: potential of soil to experience significant pore pressure generation and strength loss; evaluated as a fundamental material characteristic."

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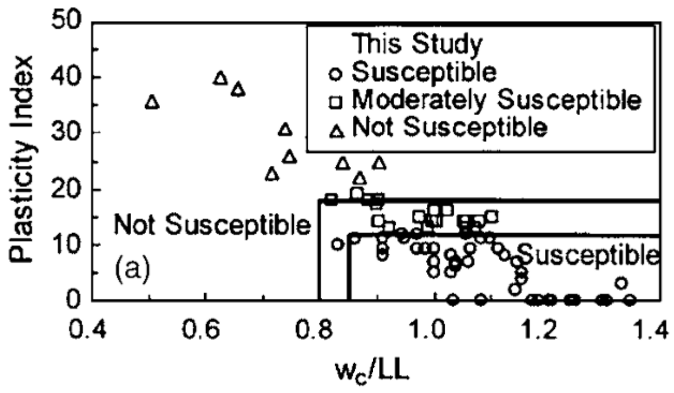
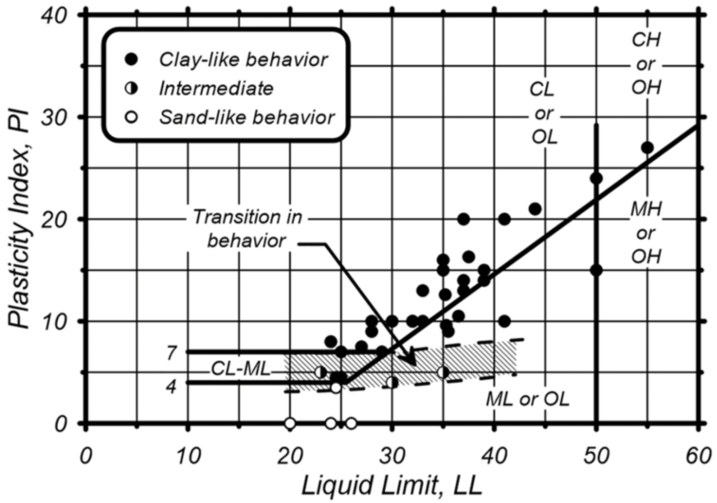
B&S06 and B&I06 Models

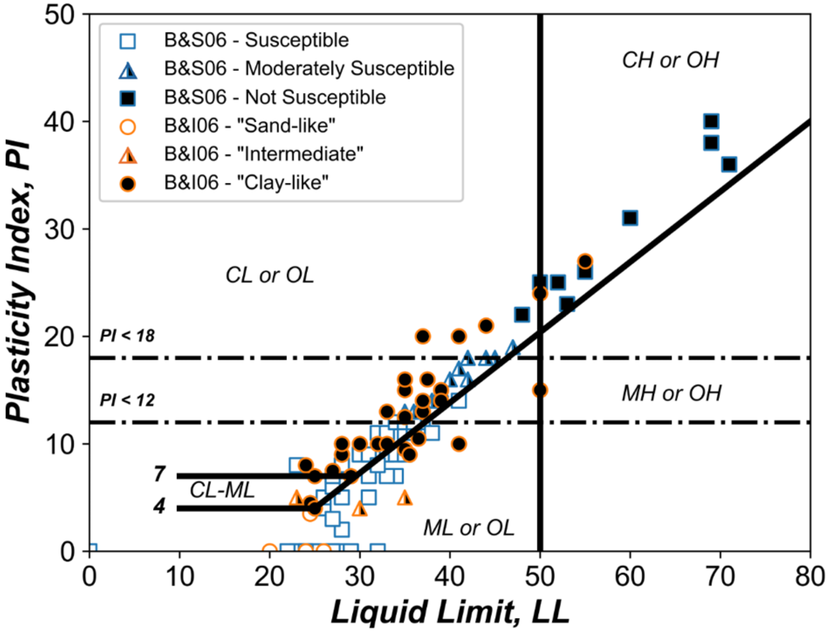


Bray and Sancio (2006)



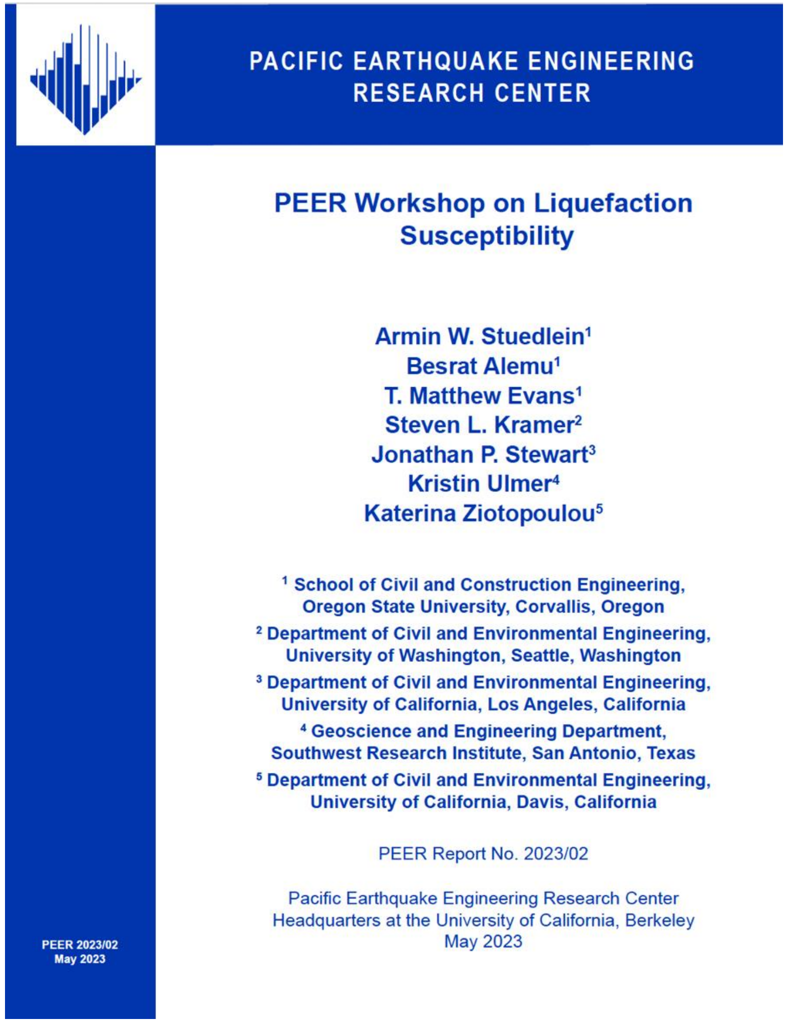
Boulanger and Idriss (2006)

Comparison of these models



They can provide significantly different results

Discussion at 2023 PEER Workshop



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

PEER Workshop on Liquefaction Susceptibility

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PEER Report No. 2023/02

Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley
May 2023

PEER 2023/02
May 2023

Participants of 2023 PEER Workshop wanted to:

- Form a database
  - Laboratory tests
  - Index properties
  - CPT results
- Develop a liquefaction susceptibility model
  - Material inherited characteristics
  - Probabilistic

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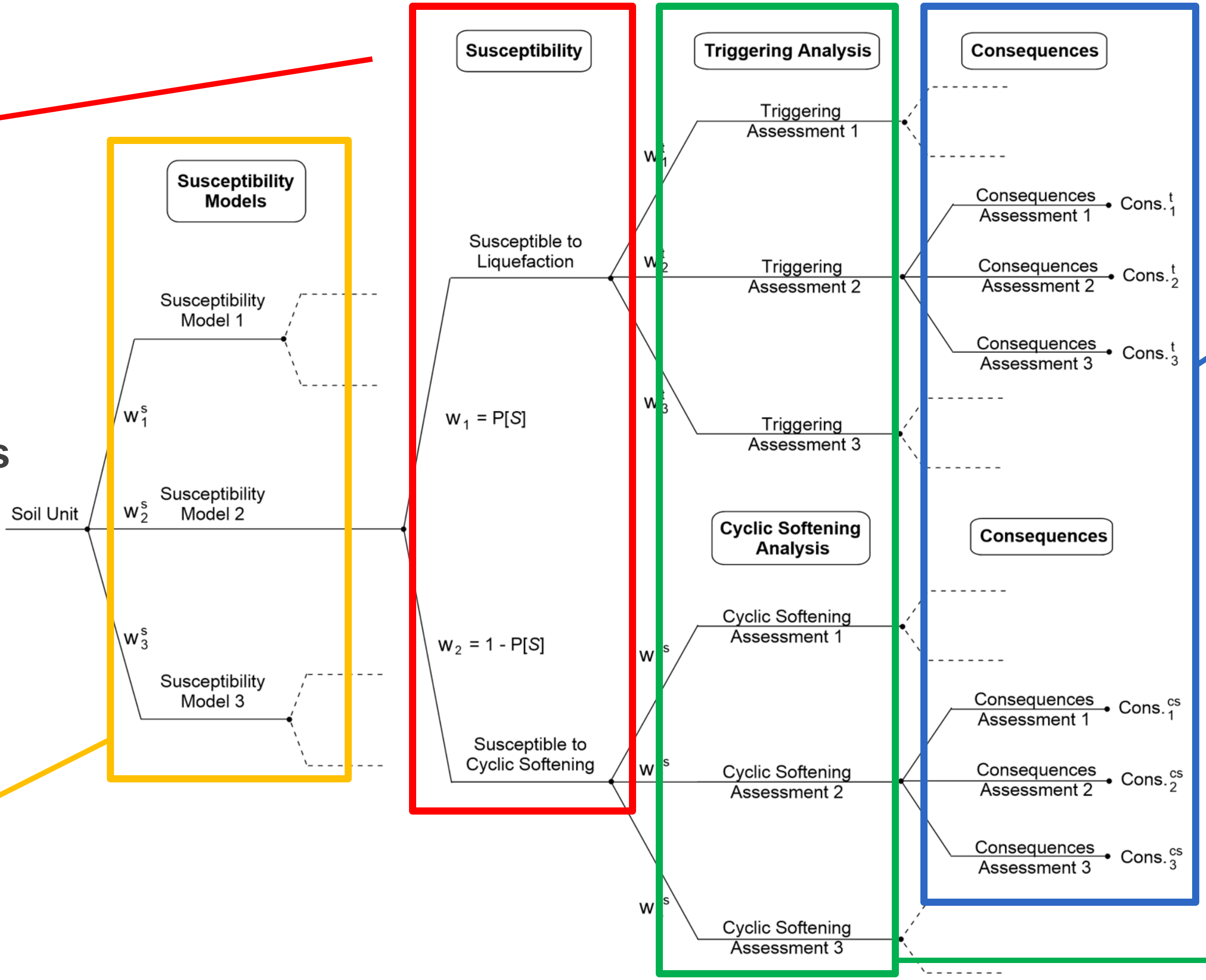
Logic Tree Framework

Phase 1: Susceptibility

All phases are connected by weights (i.e., probabilities)

Various Susceptibility Models



Phase 3: Consequences

Phase 2: Triggering or Cyclic Softening

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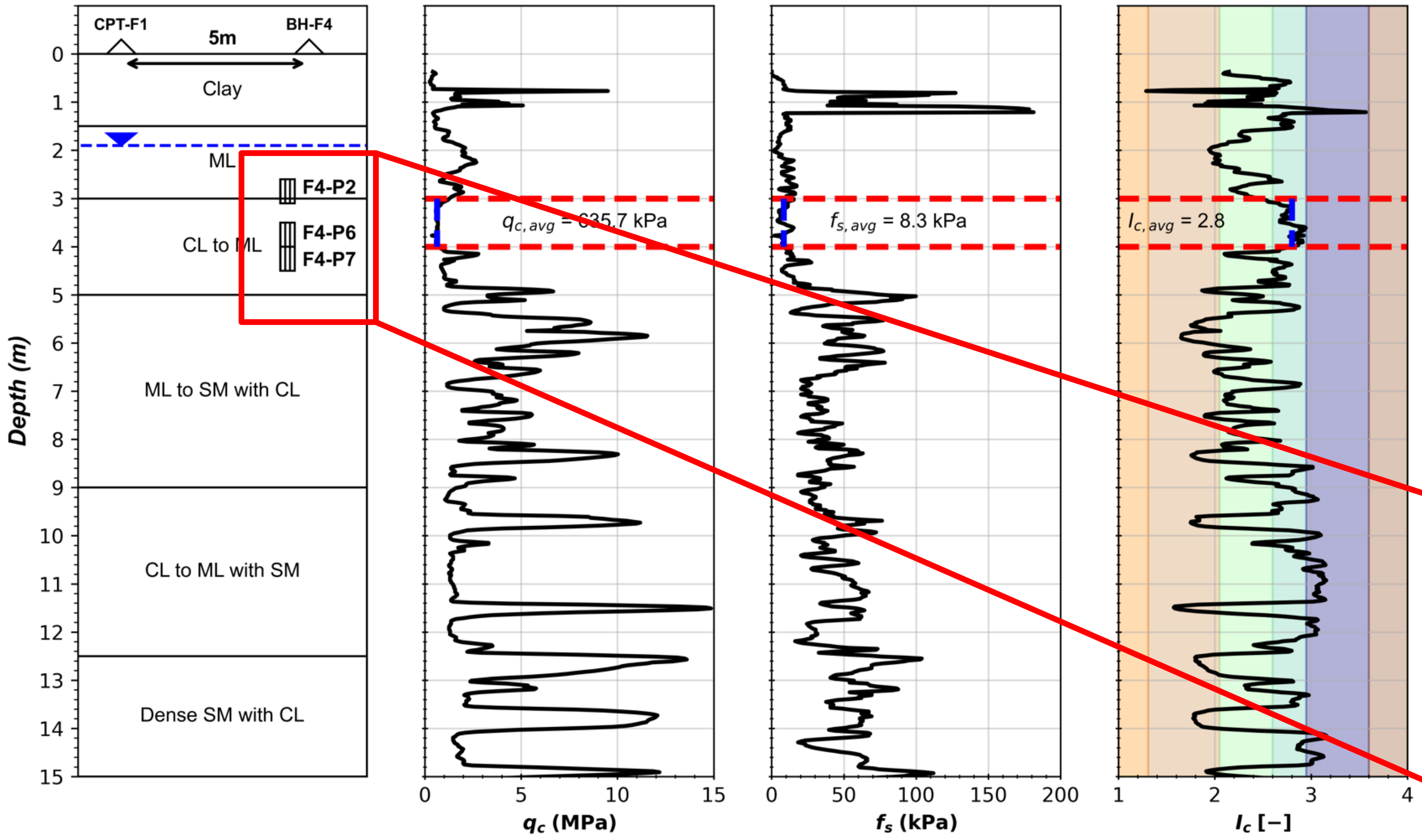
Case History – Adapazari Site F



Data source: *Sancio* (2003)

- Investigated layer: 3 – 4 m
- *PI* = 10, *LL* = 32, w_c/LL = 1.1 and *FC* = 80%

Specimen No.	Depth (m)	*FC* (%)	*PI*	w_c/LL
F4-P2B	2.90 – 3.10	61	NP - 7	1.10 – 1.45
F4-P6A	3.55 – 3.75	97	18	0.82
F4-P7A	4.00 – 4.20	93	7 - 10	1.00 – 1.06

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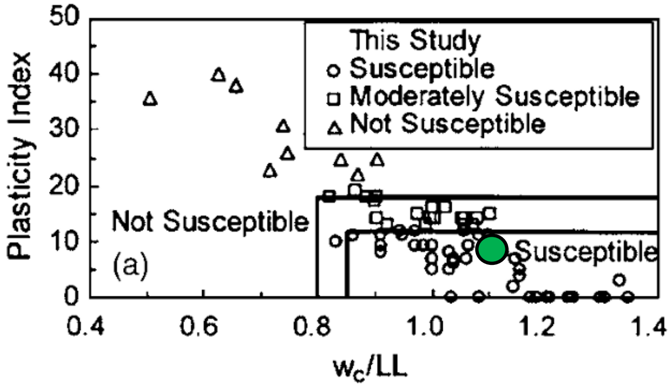
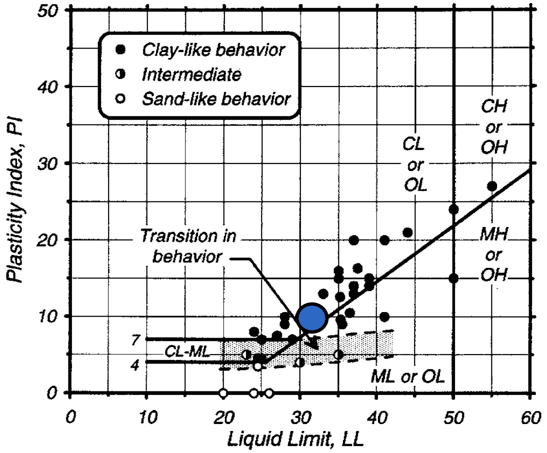
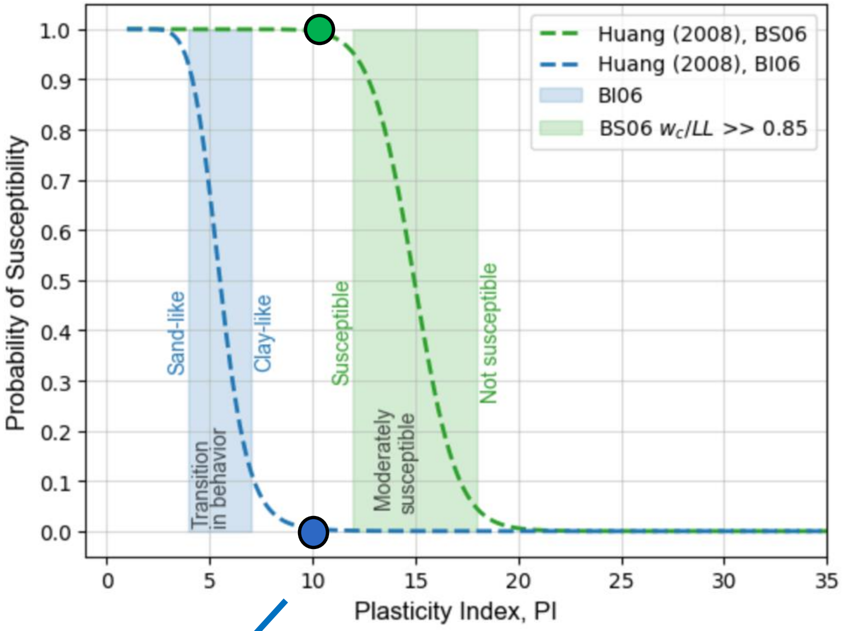
Phase 1: Susceptibility Assessment
PI – based models



Bray and Sancio (2006)



Boulanger and Idriss (2006)



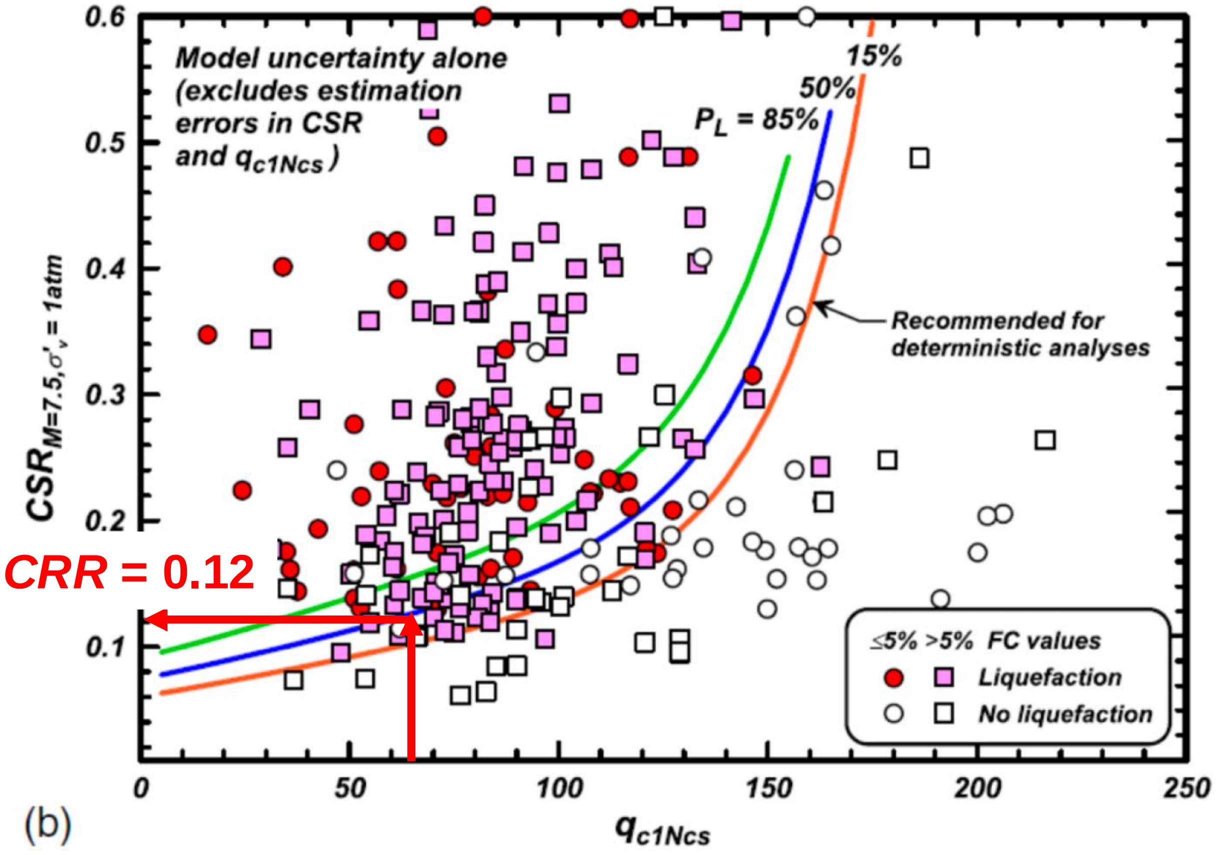
Bray and Sancio (2006)

Susceptible to Liquefaction → $P[S] \approx 100\%$

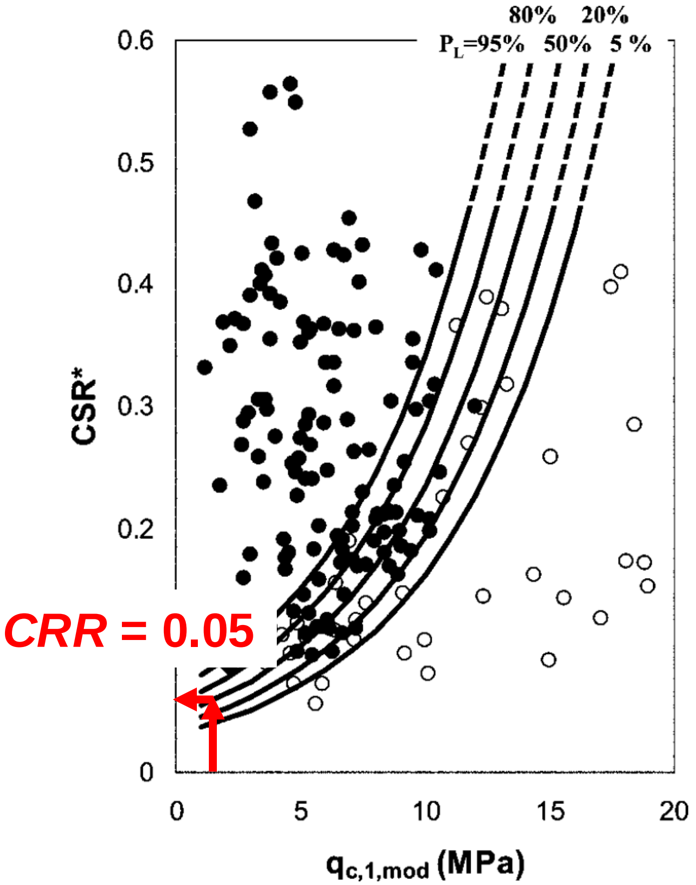
Boulanger and Idriss (2006)

Clay-like behavior → $P[S] \approx 0\%$

Phase 2: Triggering Assessment



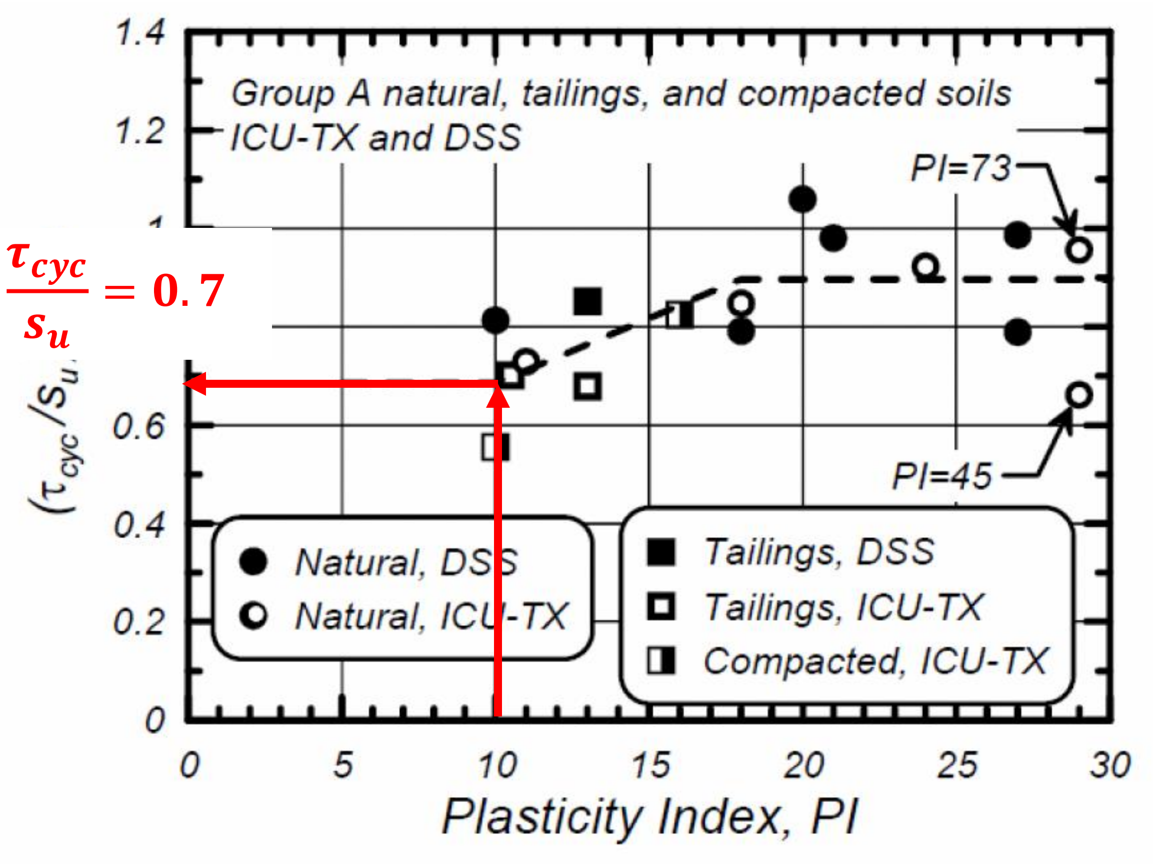
Boulanger and Idriss (2016)



Moss et al. (2006)

- $q_c = 635.7\ kPa$
- $q_{c1N} = 10$
- $FC = 80\%$
- $\Delta q_{c1N} = 55$
- $q_{c1Ncs} = 65$
- $q_{c1,mod} = 1$ MPa

Phase 2: Cyclic Softening Assessment
Dahl et al. (2018)



Boulanger and Idriss (2024)

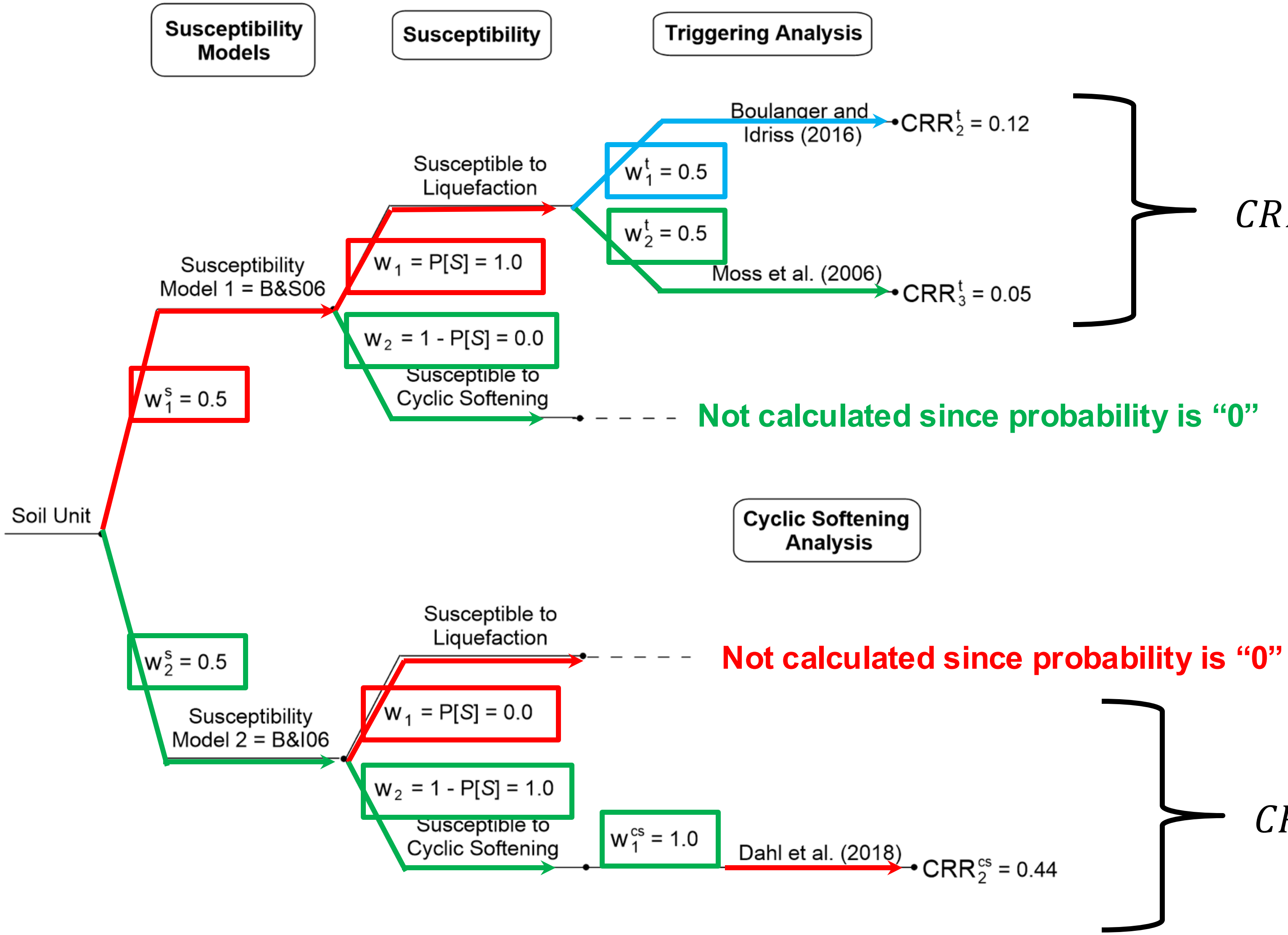
$$s_u = \sigma'_{vc} \cdot S \cdot OCR^m = 47 \cdot 0.25 \cdot 4^{0.8} = 36 \text{ kPa}$$

$$CRR_{DE,10} = \frac{\tau_{cyc}}{s_u} \cdot \frac{s_u}{\sigma'_{v0}} = 0.7 \cdot \frac{36}{47} = 0.54$$

$$CRR_{DE} = CRR_{DE,10} \cdot 0.9 \cdot \left(\frac{15}{10}\right)^{-0.2} = 0.44$$

Bi – directional and number of cycle corrections

Application of the Logic Tree – Case 1



$CRR = 0.09$

They provided significantly different results

$CRR = 0.44$

Application of the Logic Tree

$$CRR = \sum_{i=1}^{n^s} w_i^s \cdot \left(w_1 \cdot \sum_{j=1}^{n^t} \left(w_j^t \cdot CRR_j^t \right) + w_2 \cdot \sum_{k=1}^{n^{cs}} \left(w_k^{cs} \cdot CRR_k^{cs} \right) \right)$$

Susceptibility Models — $\sum_{i=1}^{n^s} w_i^s$

Susceptible to Liquefaction — w_1

Triggering Models — $w_j^t \cdot CRR_j^t$

Susceptible to Cyclic Softening — w_2

Cyclic Softening Models — $w_k^{cs} \cdot CRR_k^{cs}$

Case 1

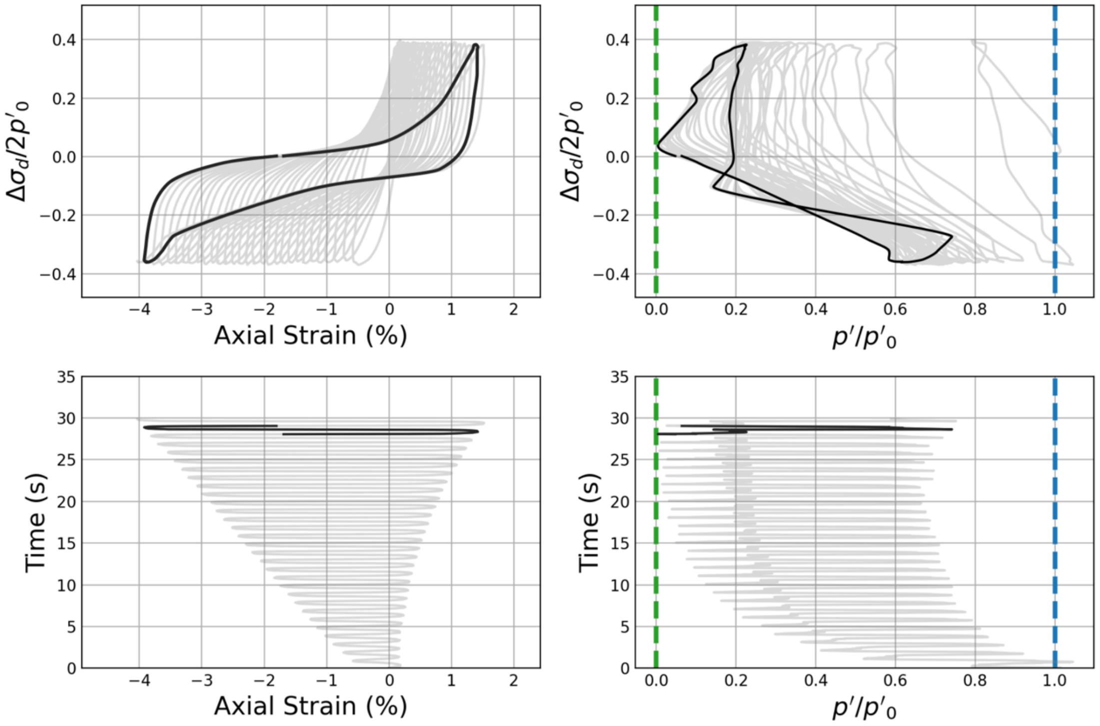
- ***Bray and Sancio (2006) Model*** → $CRR = 0.09$
- ***Boulanger and Idriss (2006) Model*** → $CRR = 0.44$

→ $CRR = 0.26$

The calculated overall CRR is intended to be used only for the determination of cyclic resistance. For consequences phase individual CRR’s should be used for the factor of safety determination!

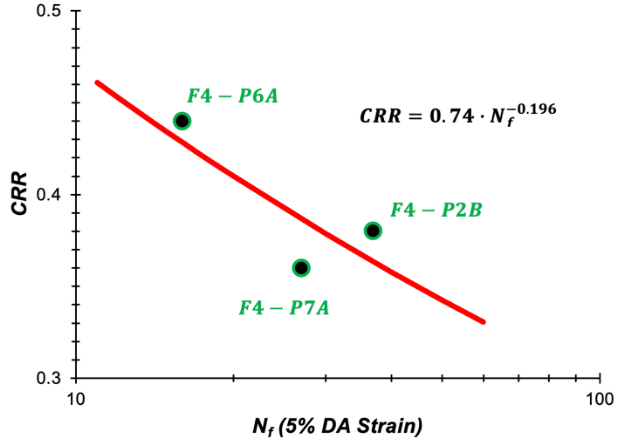
Case History – Cyclic Laboratory Test Results

Lab Viewer



$Data\ source: Sancio\ (2003)$

Specimen No.	Depth (m)	σ'_v (kPa)	*FC* (%)	*PI*	w_c/LL	N_f	K_σ	*CRR*
F4-P2B	2.90 – 3.10	43 ± 1.5	61	NP - 7	1.10 – 1.45	37	1.00	0.40
F4-P6A	3.55 – 3.75	48.5 ± 1.5	97	18	0.82	16	1.04	0.44
F4-P7A	4.00 – 4.20	52 ± 1.5	93	7 - 10	1.00 – 1.06	27	1.04	0.36

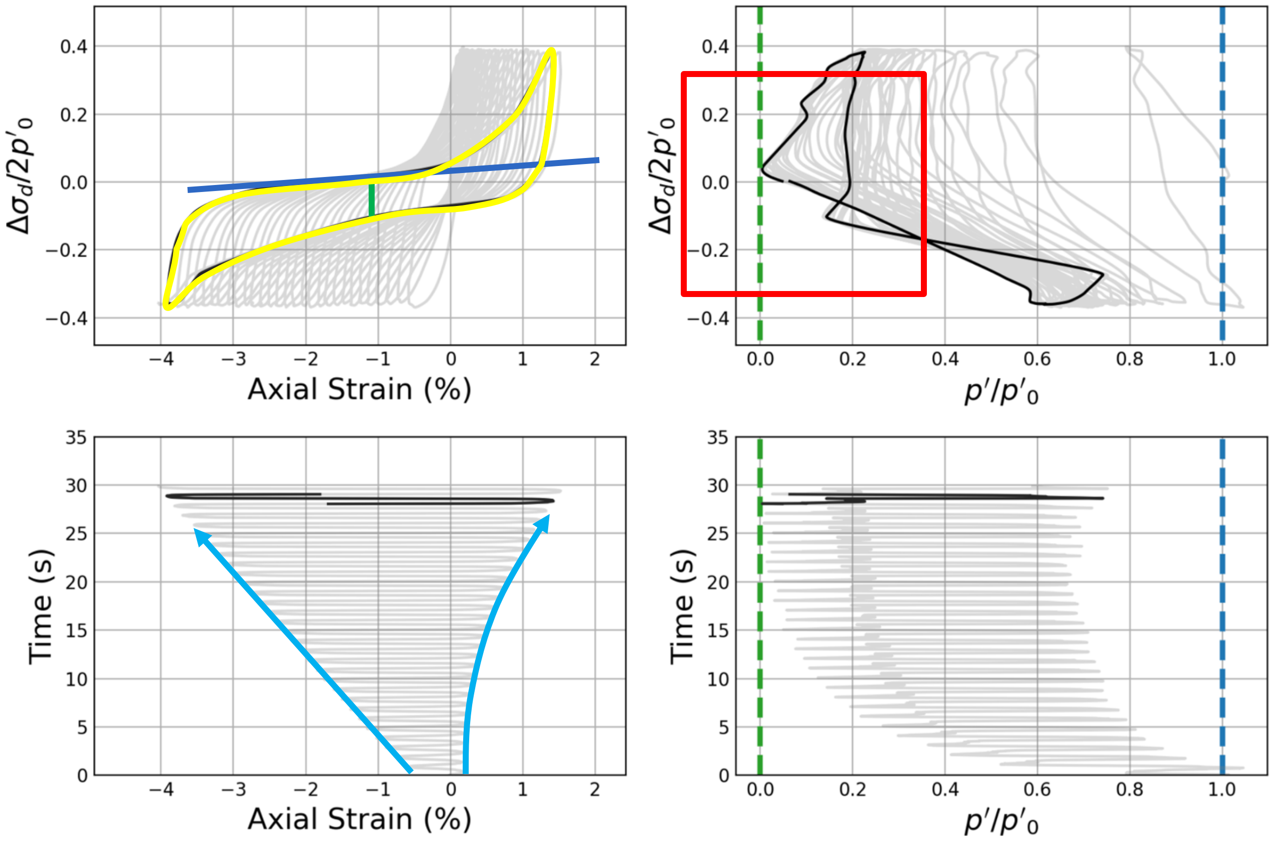


$$CRR_{CTX} = 0.74 \cdot N_f^{-0.196} = 0.74 \cdot 15^{-0.196} = 0.44$$

$$CRR_{field} = 0.44 \cdot 0.89 \cdot 0.90 = 0.35$$

$$\boldsymbol{K_0\ and\ bi-directional\ corrections}$$

Phase 1: Susceptibility Assessment
Lab Assessment

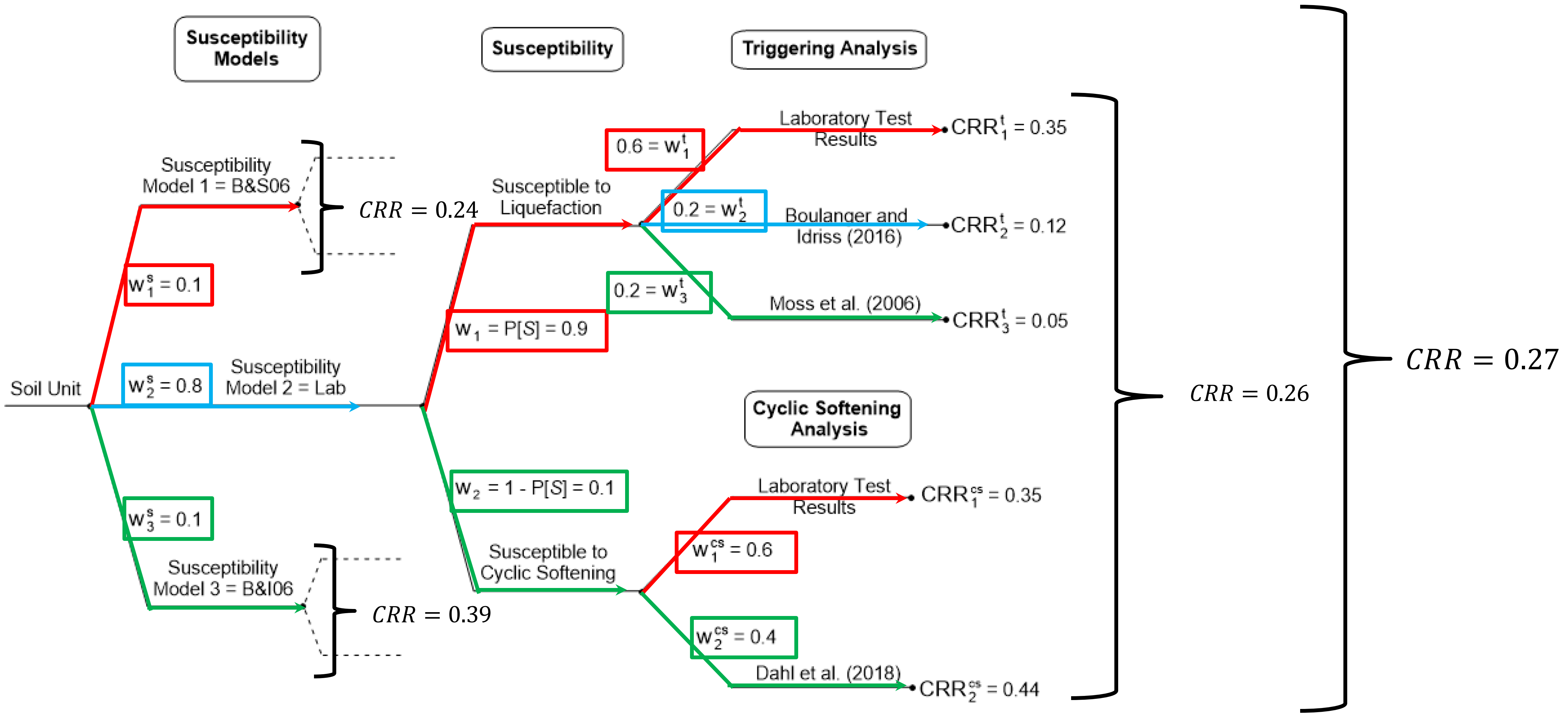


$Data\ source: Sancio\ (2003)$

Mostly *Sand-like* (i.e., *Susceptible to Liquefaction*) behavior is observed.

$P[S] = 90\%$

Application of the Logic Tree – Case 2



Conclusion

- Logic tree framework allows us to represent the effects of preceding phases to the following phases
- Case 2 (i.e., lab test is available) provides a more reliable estimation than Case 1 (i.e., no lab test is available)
- To have more information regarding the cyclic behavior of a soil body, cyclic test is suggested to be performed for more reliable estimations
- NGL database consists of over 350 CDSS and 145 CTX with co-located CPTs which are publicly accesible

Lab Viewer

Thank you for your attention!

References

Boulanger, R. W., & Idriss, I. M. (2006). Liquefaction susceptibility criteria for silts and clays. Journal of Geotechnical and Geoenvironmental Engineering, 132(11), 1413–1426. https://doi.org/10.1061/(asce)1090-0241(2006)132:11(1413)

Boulanger, R. W., & Idriss, I. M. (2024). Cyclic Strength Evaluation Criteria for Sand-Like, Clay-Like, and Intermediate Soils. GeoCongress2024. https://doi.org/10.1061/9780784485309.047

Brandenberg, S.J., Zimmaro, P., Stewart, J.P., Kwak, D.Y., Franke, K.W., Moss, R.E.S., Cetin, K.O., Can, G., Ilgac, M., Stamatakos, J., Weaver, T., and Kramer, S.L., (2020), “Next-generation Liquefaction Database,” Earthquake Spectra, Vol. 36, No. 2, pp.939-959.

Bray, J. D., & Sancio, R. B. (2006). Assessment of the liquefaction susceptibility of Fine-Grained soils. Journal of Geotechnical and Geoenvironmental Engineering, 132(9), 1165–1177. https://doi.org/10.1061/(asce)1090-0241(2006)132:9(1165)

Huang, Y., (2008), Performance-based design and evaluation for liquefaction-related seismic hazard, PhD Thesis, University of Washington, Seattle, WA.

Moss, R. A., Seed, R. B., Kayen, R. E., Stewart, J., Kiureghian, A. D., & Cetin, K. (2006). CPT-Based Probabilistic and Deterministic Assessment of In Situ Seismic Soil Liquefaction Potential. Journal of Geotechnical and Geoenvironmental Engineering, 132(8), 1032–1051. https://doi.org/10.1061/(asce)1090-0241(2006)132:8(1032)

Sancio, R. B. 2003. “Ground failure and building performance in Adapazari, Turkey.” Ph.D. Dissertation, Univ. of California at Berkeley, Berkeley, Calif.

Studlein, A., Alemu, B., Evans, T. M., Kramer, S., Stewart, J., Ulmer, K., & Ziotopoulou, K. (2023a). PEER Workshop on Liquefaction Susceptibility. In PEER. https://doi.org/10.55461/bpsk6314