UPDATE OF THE SPT- AND CPT-BASED LIQUEFACTION TRIGGERING PROCEDURES

presented by

I. M. Idriss
Professor Emeritus, University of California at Davis
Consulting Geotechnical Engineer, Santa Fe, NM
imidriss@aol.com

Presented at the

1st WORKSHOP ON GEOTECHNICAL EARTHQUAKE ENGINEERING

"Liquefaction Evaluation, Mapping, Simulation and Mitigation"

Organized by

Earthquake Engineering Research Institute (EERI) San Diego Chapter

San Diego
September 12, 2014

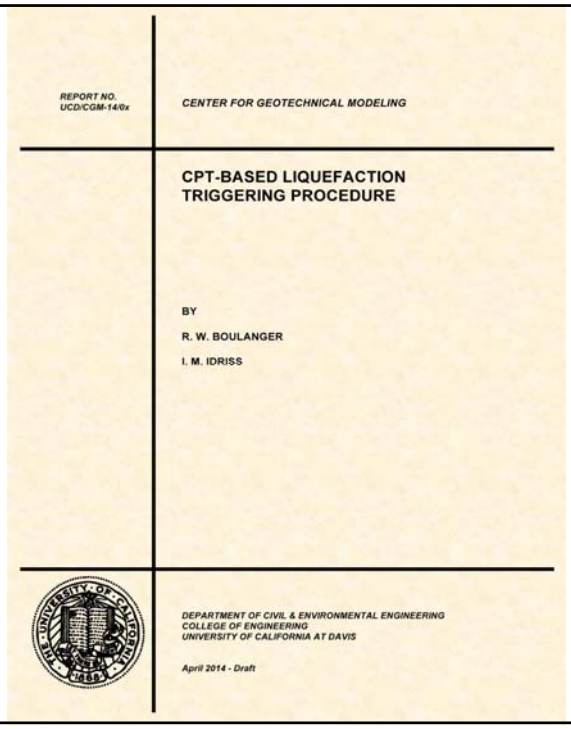
Reference material

The presentation today is based on material published in the following report:

Boulanger, R. W. and Idriss, I. M. (2014) "CPT and SPT Based Liquefaction Triggering Procedures", Report UCD/CGM- 14/01, Department of Civil and Environmental Engineering, University of California, Davis, CA, 138 pp.

This report can be downloaded from:

http://retrocee.engr.ucdavis.edu/faculty/boulanger/PDFs/2014/Boulanger_Idriss_CPT_and_SPT_Liq_triggering_CGM-14-01_2014.pdf



Outline of Presentation

1. Magnitude Scaling Factor (MSF)

- ***Modified MSF expression to be a function of magnitude, soil type, and denseness of the soil***

2. Update of SPT-based approach

- ***Added 24 Case Histories (14 from Turkey & 10 from Taiwan)***
- ***Incorporated new MSF expression***
- ***No change in CRR versus $(N_1)_{60cs}$***

Outline of Presentation

3. Update of CPT-based approach

- ***Changed Δq_{c1N} as a function of FC***
- ***Changed CRR versus q_{c1Ncs}***

4. Examination of the CPT-based case histories in terms of the soil behavior type (SBT) index, I_C

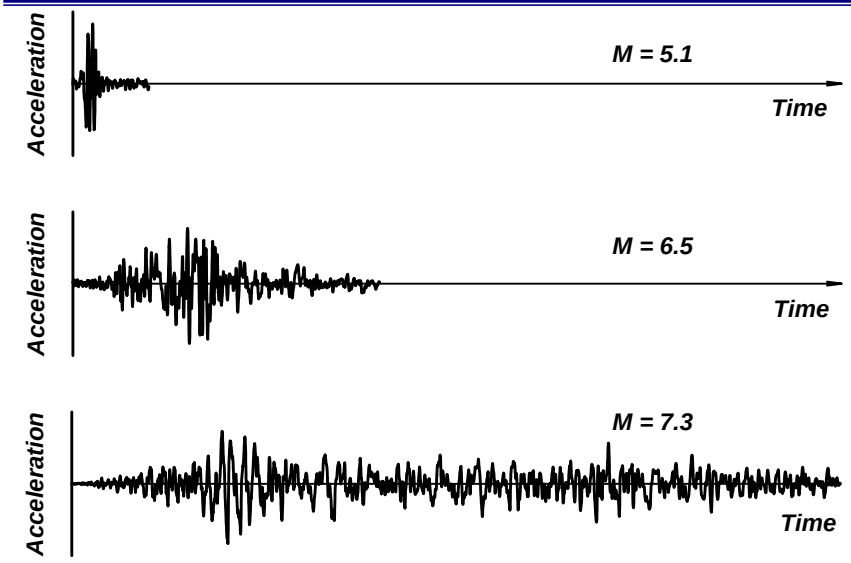
MAGNITUDE SCALING FACTOR (MSF)

DEMAND -- CSR

The value of CSR for each case history is calculated using the following expression:

$$(CSR)_{M=7.5;\sigma'_v=1\ atm} = 0.65\left(\frac{\sigma_{vo}a_{max}}{\sigma'_{vo}}\right)(r_d)\left(\frac{1}{MSF}\right)\left(\frac{1}{K_\sigma}\right)$$

Effects of duration

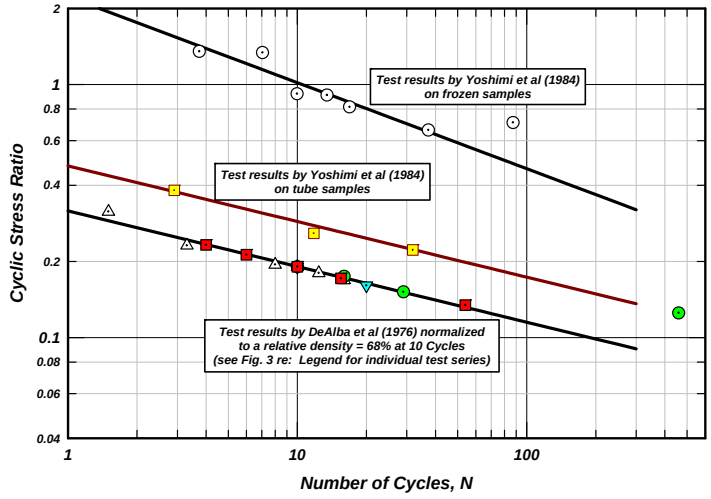


MSF used to account of effects of duration

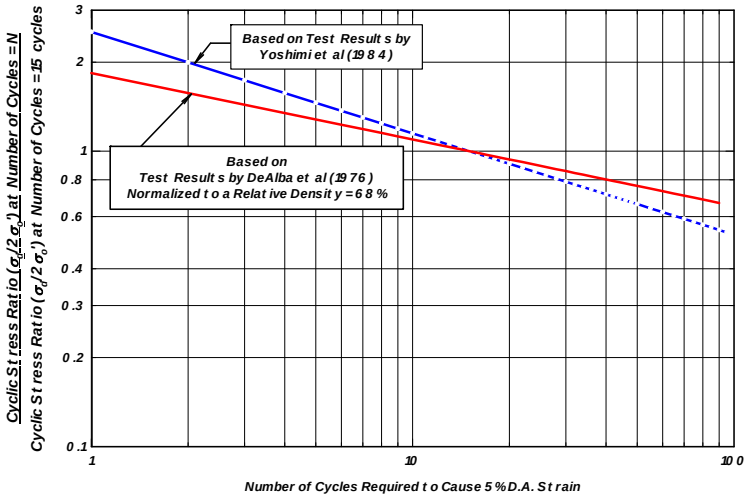
History of the development of MSF:

1. ***Seed et al. (1975): proposed a relationship between "Number of Equivalent Uniform Cycles, N_{eq}" & Magnitude, M, which led to the initial development of "MSF Values".***
2. ***Seed & Idriss (1982): Tabulated "MSF Values" as a function of M; used shaking table test results by DeAlba et al. (1976) relating CRR to "Number of Uniform Cycles".***
3. ***Idriss (1999): Used results of cyclic tests on frozen samples by Yoshimi et al. (1984) to derive a revised relationship between N_{eq} & M, which resulted in a revised MSF relationship.***
4. ***Boulanger & Idriss (2014): Modified MSF expression to be a function of magnitude, soil type, and denseness of the soil, as summarized in this presentation.***

$$CRR = aN^{-b}$$



Cyclic Stress Ratios Used in Re-Deriving Equivalent Uniform Cycles as a Function of Earthquake Magnitude



Normalized Cyclic Stress Ratios Used in Re-Deriving Equivalent Uniform Cycles as a Function of Earthquake Magnitude

Effects of duration

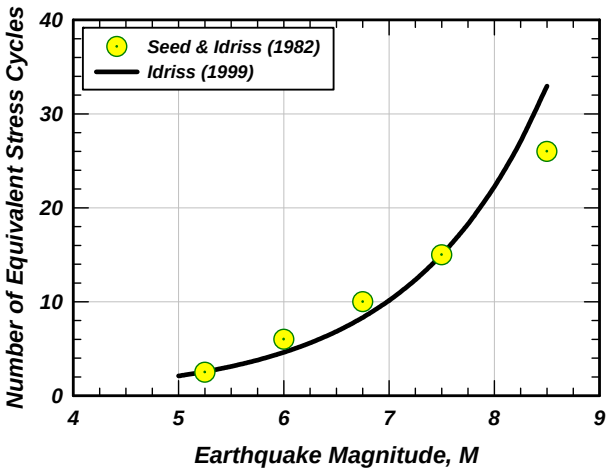


Figure 62 – Mean number of equivalent uniform cycles at 65% of the peak stress versus earthquake magnitude.

Effects of duration

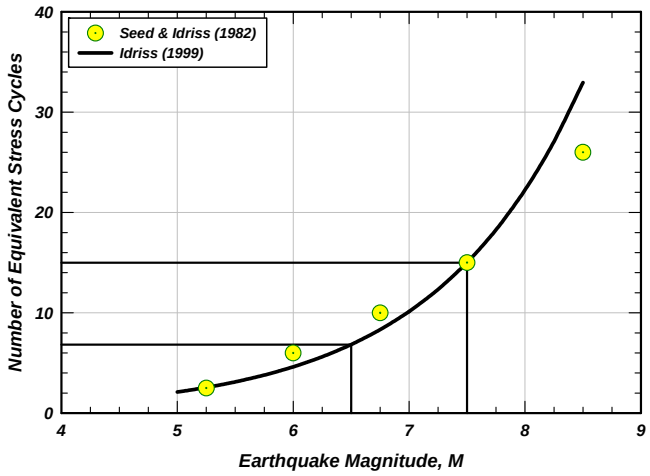


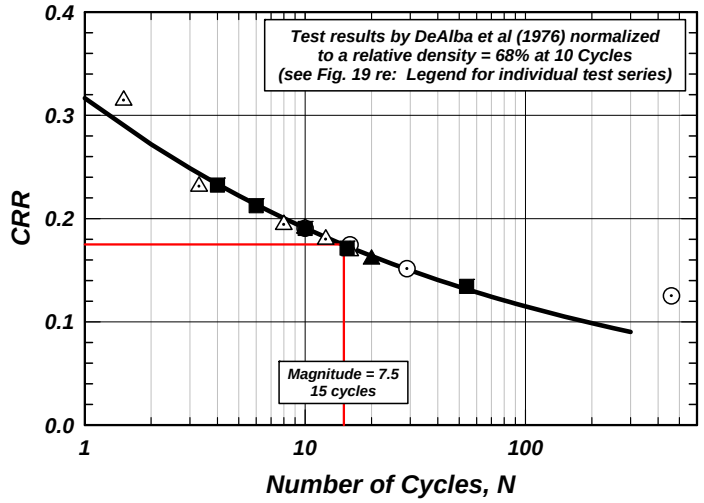
Figure 62 – Mean number of equivalent uniform cycles at 65% of the peak stress versus earthquake magnitude.

Effects of duration

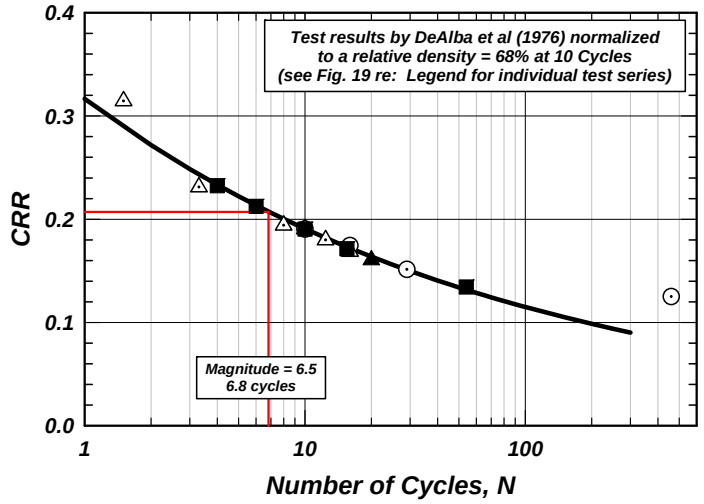
The number of cycles representing a given magnitude from the previous figure can be used in the lab-generated CSR versus N plot to obtain the level of CSR corresponding to that magnitude. This value of CSR divided by the CSR for a reference magnitude (usually M = 7½) is defined as a "magnitude scaling factor or MSF".

MSF is then used as a proxy for duration and is expressed as a function of earthquake magnitude.

Effects of duration



Effects of duration



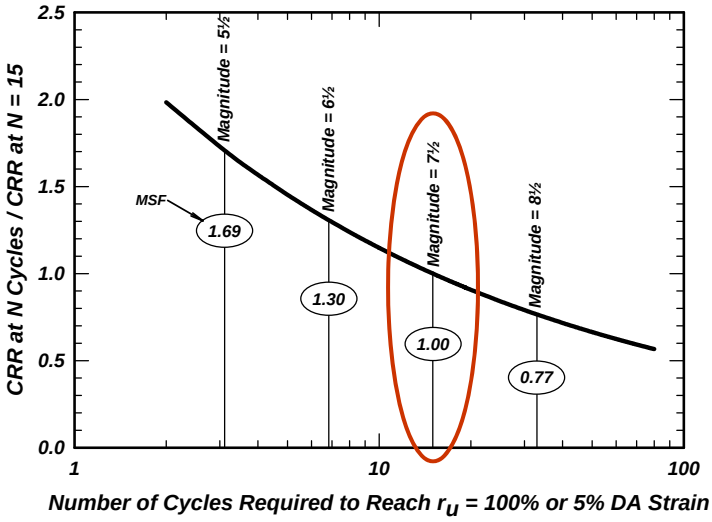
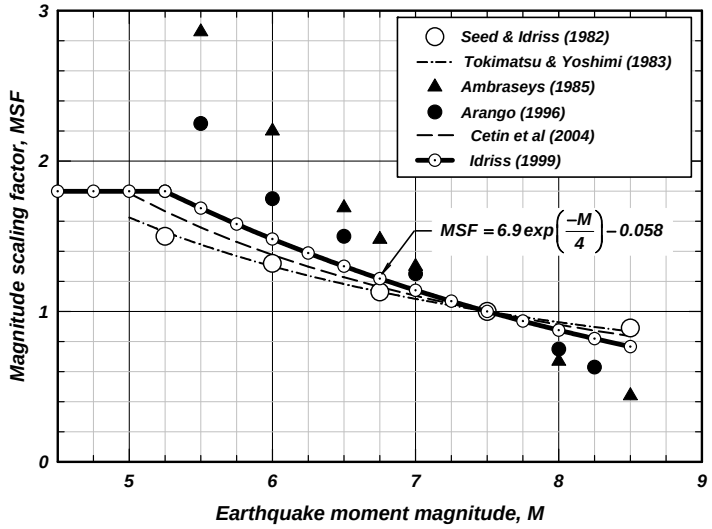
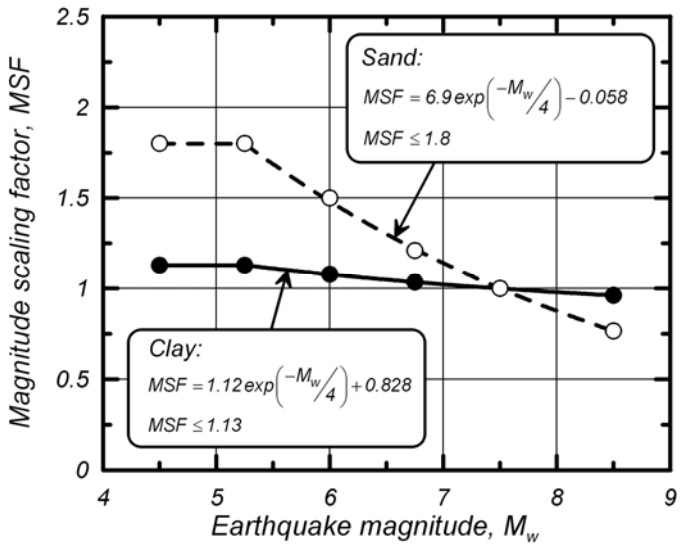


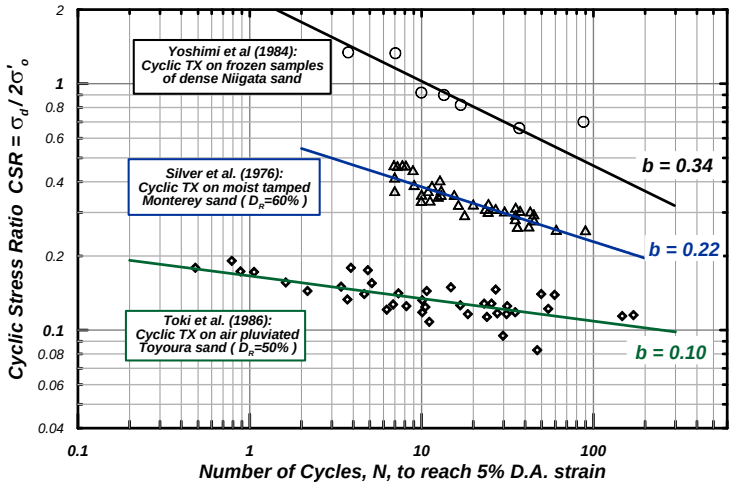
Illustration of the variation of MSF with number of cycles and magnitude.



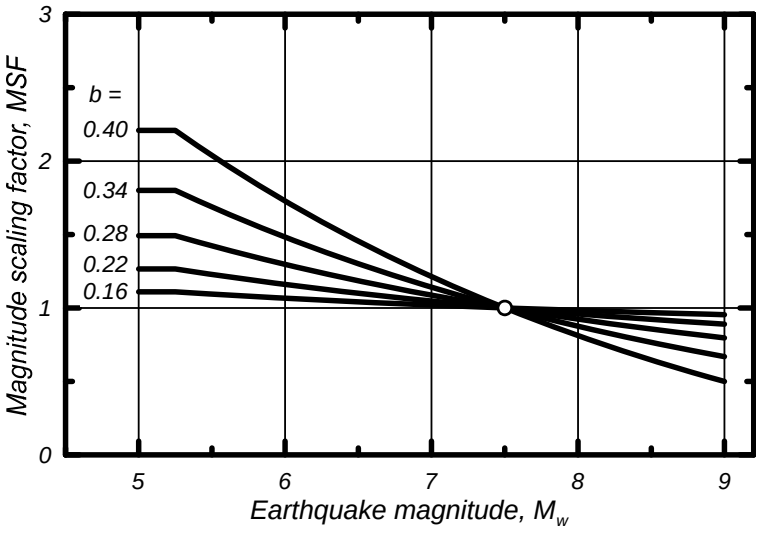
Magnitude scaling factor values proposed by various investigators



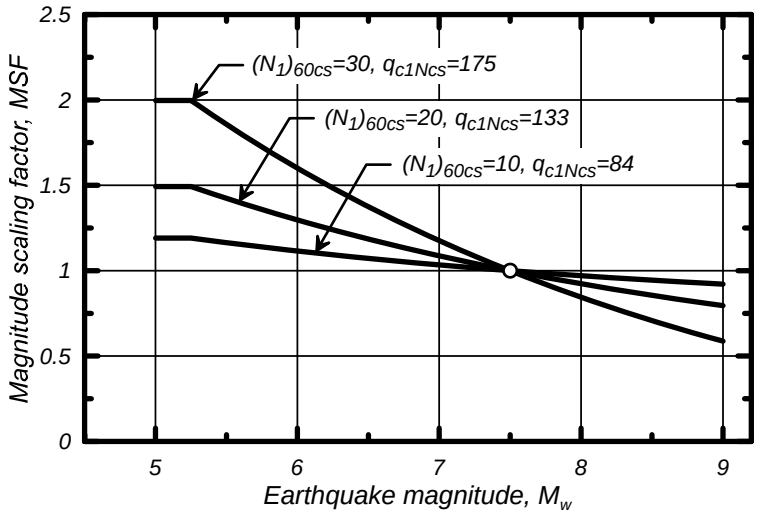
MSF relationship for clays and plastic silts (Boulanger and Idriss 2007)



Effects of denseness on slope b

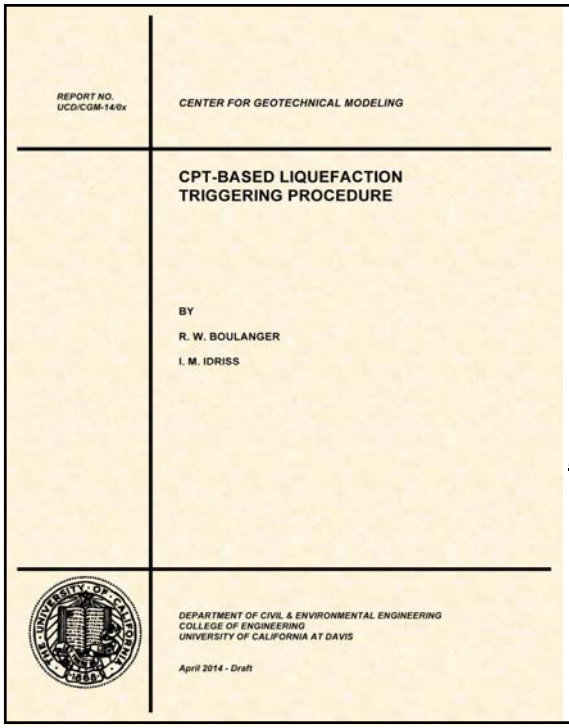


Variation in the MSF relationship with parameter b



Variation in the MSF relationship with $(N_1)_{60cs}$ & q_{c1Ncs}

UPDATE OF THE CPT-BASED APPROACH


REPORT NO.
UCD/CGM-14/0x

CENTER FOR GEOTECHNICAL MODELING

CPT-BASED LIQUEFACTION
TRIGGERING PROCEDURE

BY

R. W. BOULANGER

I. M. IDRISS

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
COLLEGE OF ENGINEERING
UNIVERSITY OF CALIFORNIA AT DAVIS

April 2014 - Draft

Total number of CPT-based case histories: 253
Y/N/M 180/71/2

US case histories:
Y/N/M 65/35/1

Japan case histories:
Y/N/M 24/13/1

New Zealand case histories:
Y/N 53/16

Other case histories:
Y/N 38/7

DEMAND – CSR

The value of CSR for each case history is calculated using the following expression:

$$(CSR)_{M=7.5;\sigma'_v=1\ atm} = 0.65\left(\frac{\sigma_{vo}a_{max}}{\sigma'_{vo}}\right)\frac{r_d}{MSF}\frac{1}{K_\sigma}$$

Key expressions – CPT-based procedure

$$q_{c1} = C_N q_c$$

$$q_{c1N} = q_{c1}/P_a$$

$$C_N = \left(\frac{P_a}{\sigma'_v}\right)^m \leq 1.7$$

$$m = 1.338 - 0.249\left(q_{c1N}\right)^{0.264}$$

P_a = atmospheric pressure having same units as q_c

Key expressions – CPT-based procedure

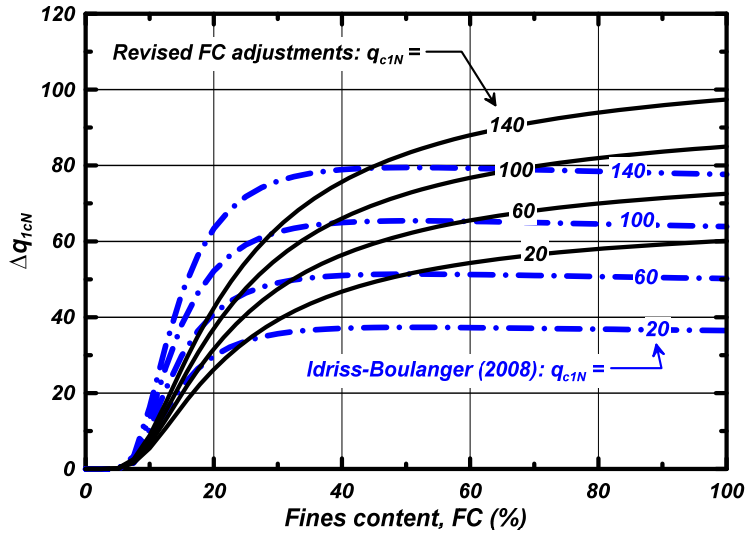
$$Q = \left(\frac{q_c - \sigma_v}{P_a}\right)\left(\frac{P_a}{\sigma_v'}\right)^n$$

$$F = \left(\frac{f_s}{q_c - \sigma_v}\right).100$$

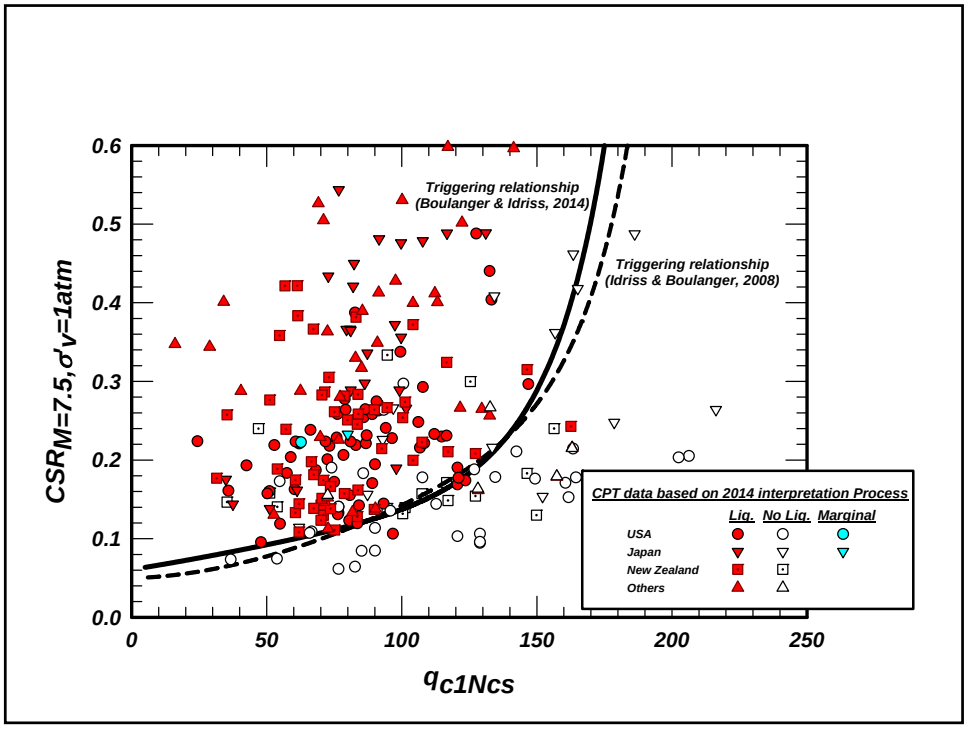
$$I_C = \sqrt{\left[3.47 - Log_{10}(Q)\right]^2 + \left[1.22 + Log_{10}(F)\right]^2}$$

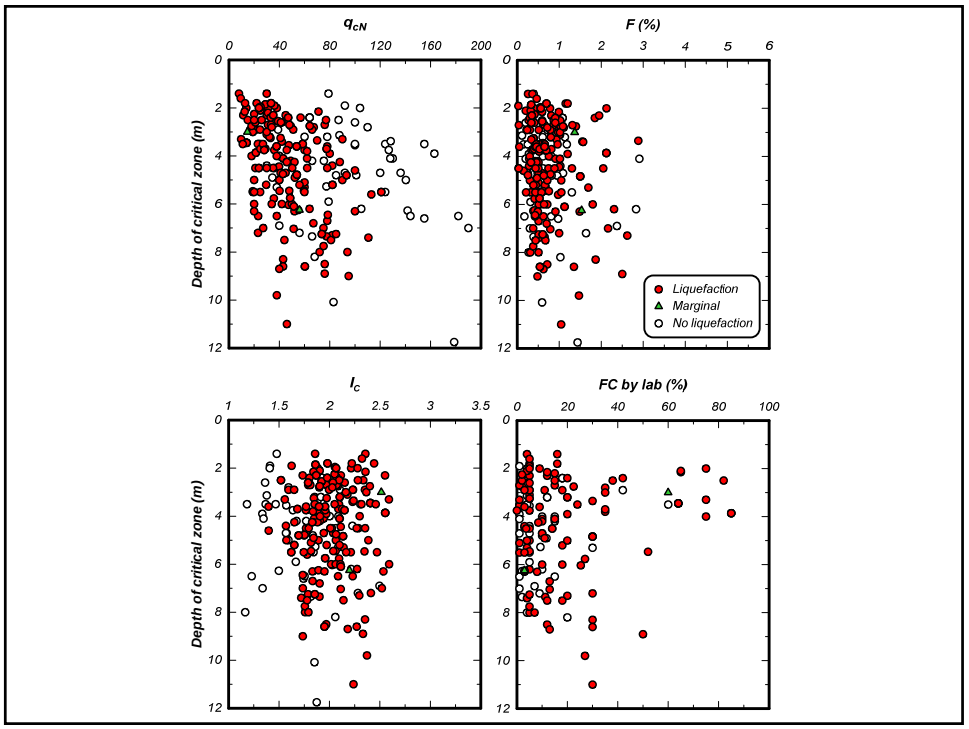
$$FC = 80\left(I_C + C_{FC}\right) - 137$$

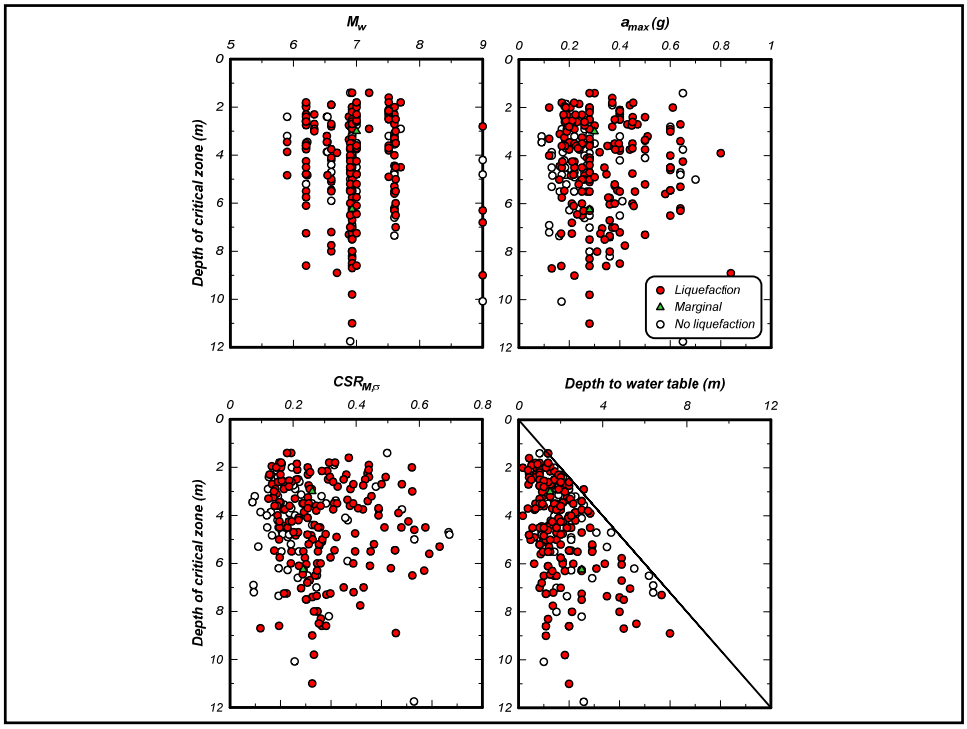
$$C_{FC} = 0,\ -0.29,\ 0.29$$

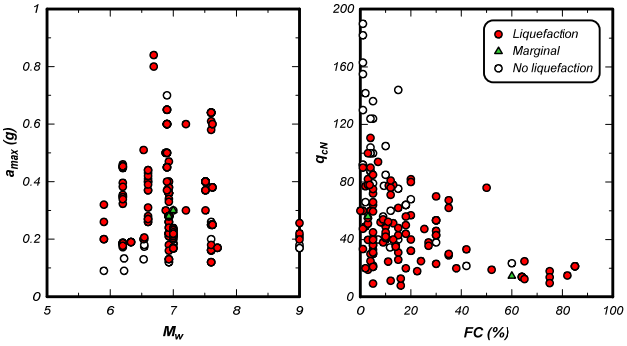


$$q_{c1N,cs} = q_{c1N} + \Delta q_{c1N}$$


Triggering relationship
(Boulanger & Idriss, 2014)
Triggering relationship
(Idriss & Boulanger, 2008)
CPT data based on 2014 interpretation Process
Liq.
No Liq.
Marginal
USA
Japan
New Zealand
Others
CSRM=7.5,σ'v=1atm
qc1Ncs
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200
250

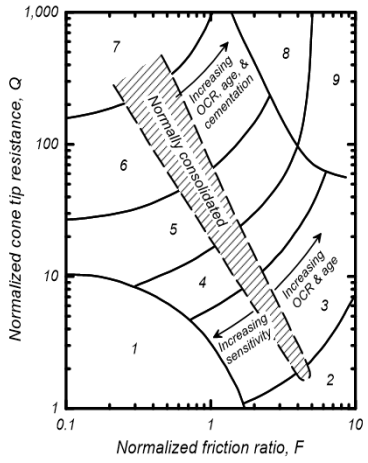

qcN
F (%)
Depth of critical zone (m)
Liquefaction
Marginal
No liquefaction
Ic
FC by lab (%)


M_w
a_{max} (g)
Depth of critical zone (m)
Liquefaction
Marginal
No liquefaction
$CSR_{M,\sigma'}$
Depth to water table (m)


a_{max} (g)
M_w
q_{cN}
FC (%)
Liquefaction
Marginal
No liquefaction

Soil Behavior Type (SBT) Index, I_C

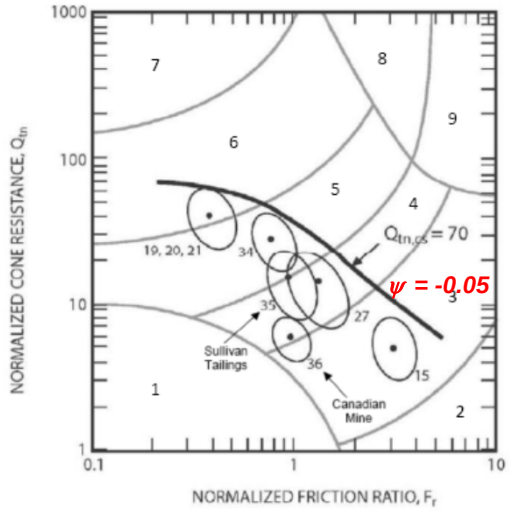
State Parameter, ψ



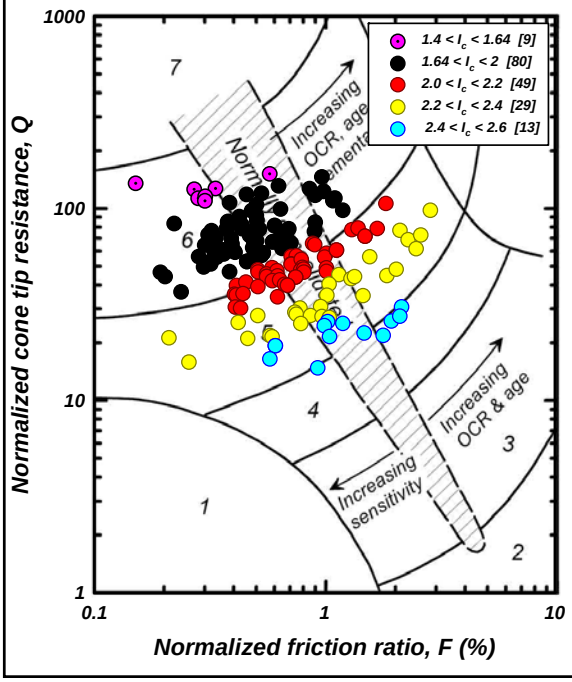
1. Sensitive, fine grained
2. Organic soils - peats
3. Clays - silty clay to clay
4. Silt mixtures - clayey silt to silty clay
5. Sand mixtures - silty sand to sandy silt
6. Sands - clean sand to silty sand
7. Gravelly sand to dense sand
8. Very stiff sand to clayey sand *
9. Very stiff, fine grained *

* Heavily overconsidated or cemented

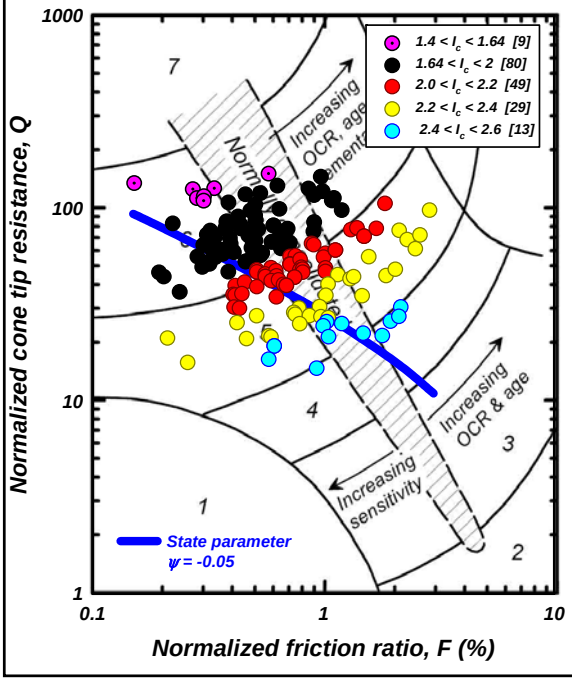
CPT-based soil behavior type classification chart by Robertson (1990)



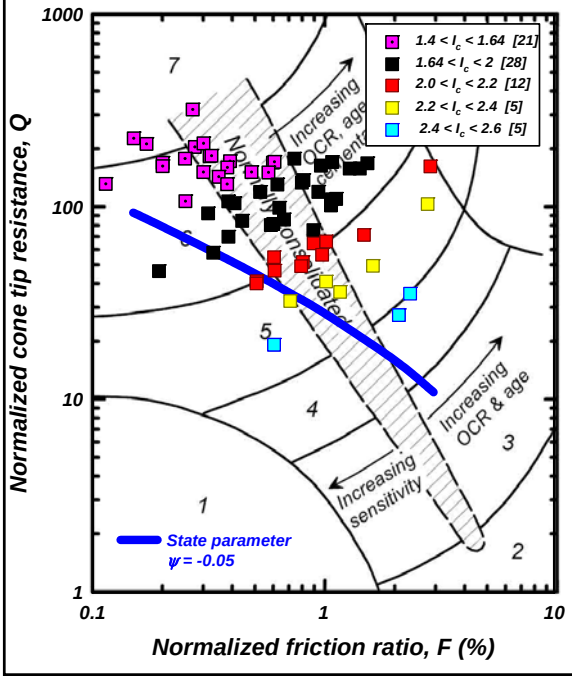
Liquefaction failure case histories (from Robertson 2010)
State parameter, ψ = -0.05



CPT Liquefaction Case Histories



CPT Liquefaction Case Histories



CPT No Liquefaction Case Histories

Concluding remarks

The Cone Penetration Test (CPT) has proven to be a very valuable tool for characterizing subsurface conditions and assessing various soil properties, including estimating the potential for liquefaction.

The main advantages of using the CPT are that it provides a continuous record of the penetration resistance and is less vulnerable to operator error than is the SPT test.

Its main disadvantages are the difficulty in penetrating through layers with larger particles (e.g., gravels) or very high penetration resistances (e.g., strongly cemented soils) and the need to perform companion borings or soundings to obtain soil samples.

Concluding remarks

- ***Development of the CRR versus $(N_1)_{60cs}$ or q_{c1Ncs} relations are based on using the equation:***

$$(CRR)_{M=7.5} = 0.65\left(\frac{\sigma_{vo}a_{max}}{\sigma'_{vo}}\right)\frac{r_d}{MSF}\frac{1}{K_\sigma}$$

Therefore, "forward" calculations should also be based on using this equation.

Calculation of shear stresses by convolving an inadequate number of input rock motions can lead to serious over or under estimation. The minimum number of input rock motions appears to be 7, but this issue is still under investigation.

Concluding remarks

Elements that affect site response in order of importance:

Input Motion

Soil Profile

Soil Properties

Method of Analysis

THANK YOU