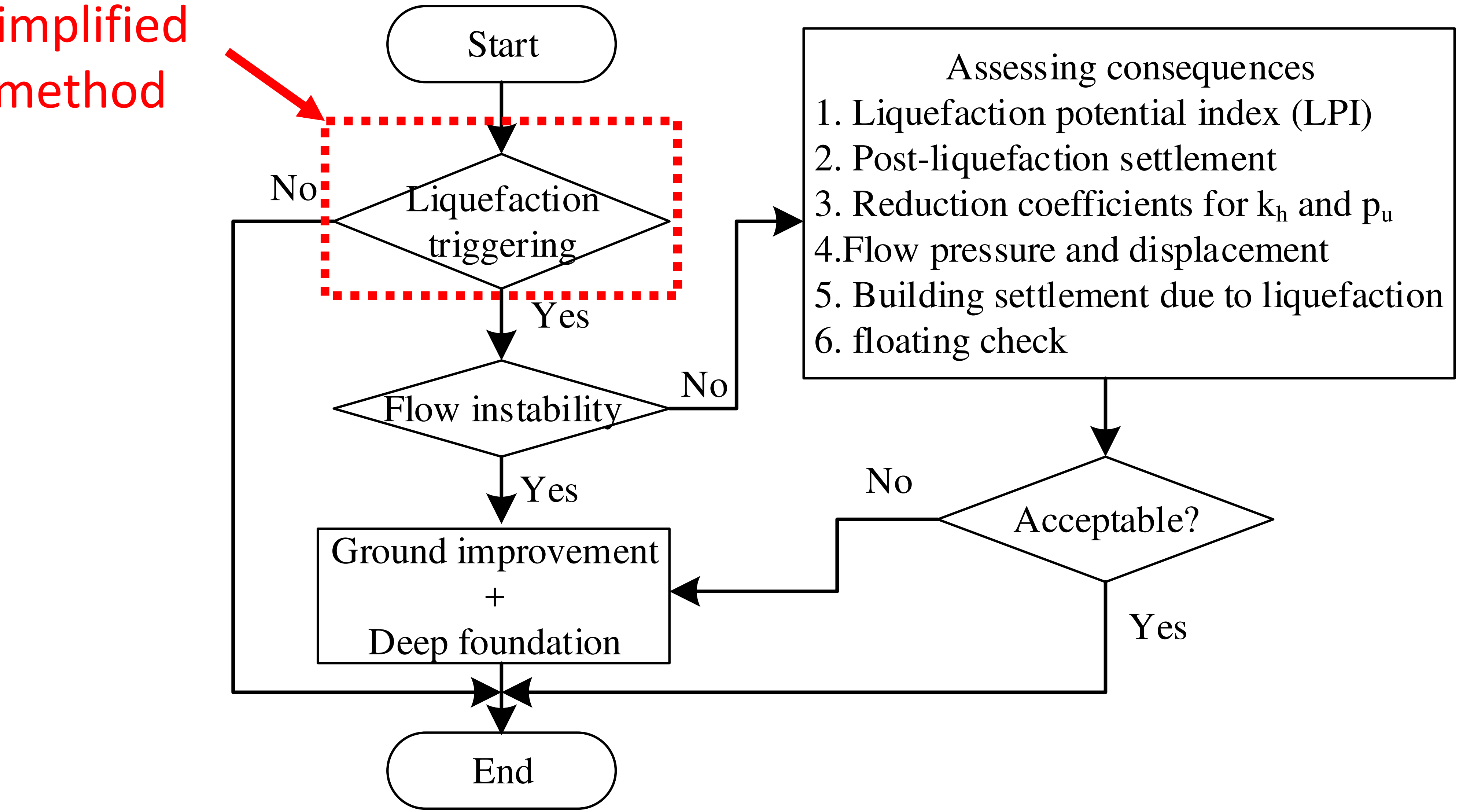
On the Simplified Methods for Assessing Liquefaction Potential of Soils : Twenty Years Development of HBF Method

Speaker: Jin Hung Hwang

Prof., Civil Engineering Department, National Central University, Taiwan
Geotechnical Division Head, NCREE

Flow Chart to Solve Liquefaction Problems



Outline

- Introduction to the simplified methods commonly used in the world
- Framework of NCREE-HBF method and its main features
- Comparison Studies of the simplified methods
- Conclusions and suggestion

Introduction

- The pioneer works on the simplified stress based method
  - Seed & Idriss (1971); Seed & Idriss (1979); Seed et al.(1985)
  - Other followers in USA:Youd et al.(2001); Cetin et al.(2004); Idriss and Boulanger (2004); Boulanger and Idriss(2014)
- The similar works in Japan
  - Iwasaki et al.(1982); JRA(1990,1996); Tokimatsu and Yoshimi(1983); AIJ(2001)
- A new simplified method called HBF was developed in Taiwan
  - Basing on Chi-Chi earthquake cases
  - A cyclic resistance ratio curve of HyperBolic Function(HBF) is used
  - Verification by local and worldwide liquefied and non-liquefied data

The Framework of the Simplified Method for Assessing Soil Liquefaction Potential

Black Box

$$= \frac{CRR}{CSR} = \frac{K_{FC} \cdot K_{\sigma} \cdot K_{\alpha} \cdot CRR_{M=7.5}}{0.65 \cdot \frac{\sigma_v}{\sigma'_v} \cdot A_{max} \cdot r_d \cdot \frac{1}{MSF}}$$

→

Performance Check

Verification by liquefied and non-liquefied earthquake case

The key relation is $CRR_{M=7.5}$ vs. $(N_1)_{60}$ for clean sand

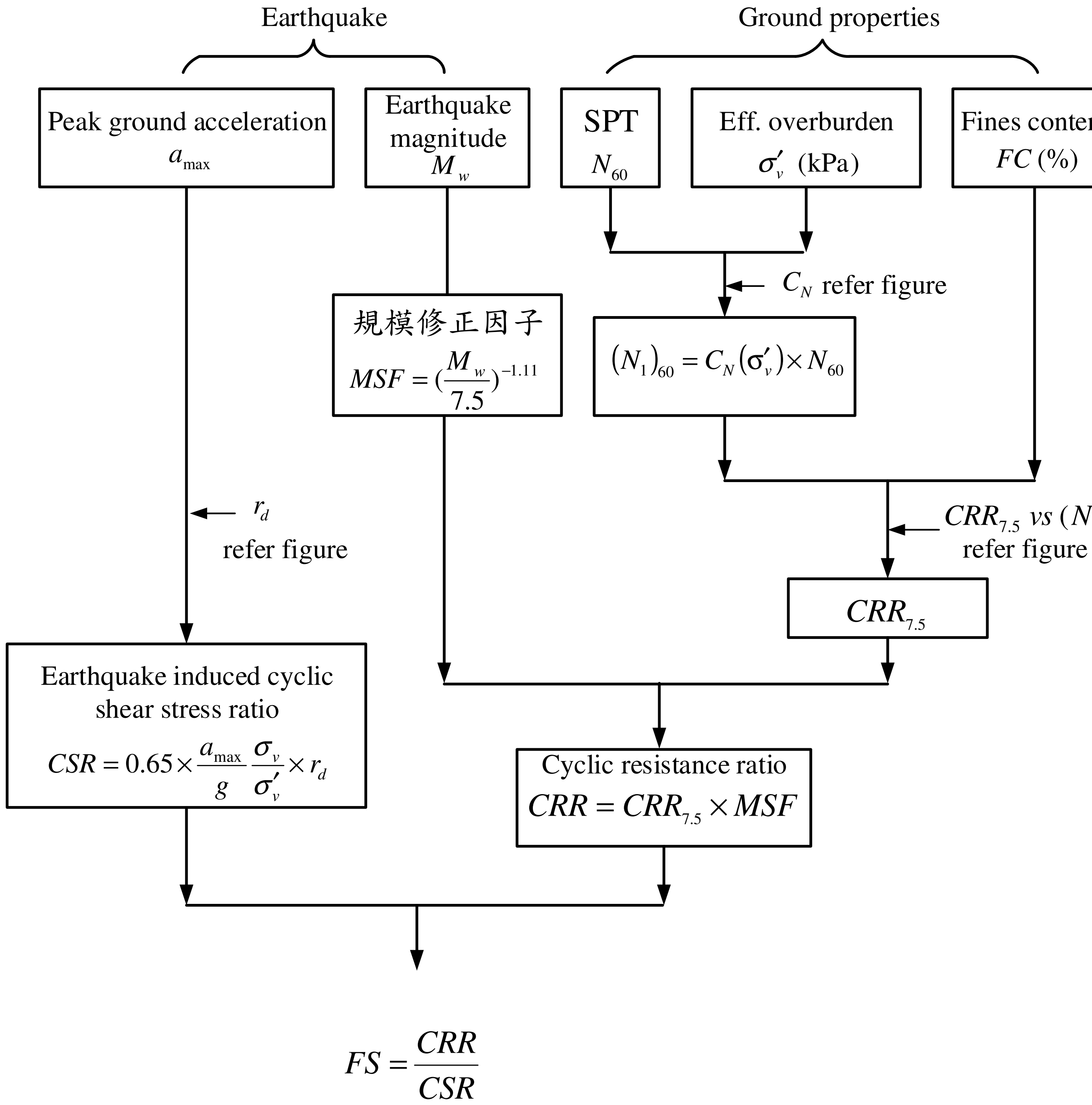
Parameters in the black box used in liquection triggering analysis

Description	Parameter	Notes
Cyclic resistance curve	$CRR_{7.5}$	$CRR_{7.5}$ vs $(N_1)_{60CS}$ for cleansand
SPT borehole correction factors		
Overburden stress	C_N	
Diving energy	C_E	
Rod length	C_R *	$(N_1)_{60} = C_N C_E C_R C_B C_s \cdot N$
Borehole size	C_B *	
Sampler	C_S *	
Fines correction	$FC(\%)$	$\Delta(N_1)_{60}$ vs $FC(\%)$ $(N_1)_{60CS} = (N_1)_{60} + \Delta(N_1)_{60}$
CRR stress adjustment	K_σ *	
CRR initial stress adjustment	K_α *	$CRR = K_\sigma \cdot K_\alpha \cdot CRR_{7.5}$
Magnitude scaling factor	MSF	Number of cycles
Shear stress reduction factor	r_d	Visco-elastic seismic response

* :Neglectable

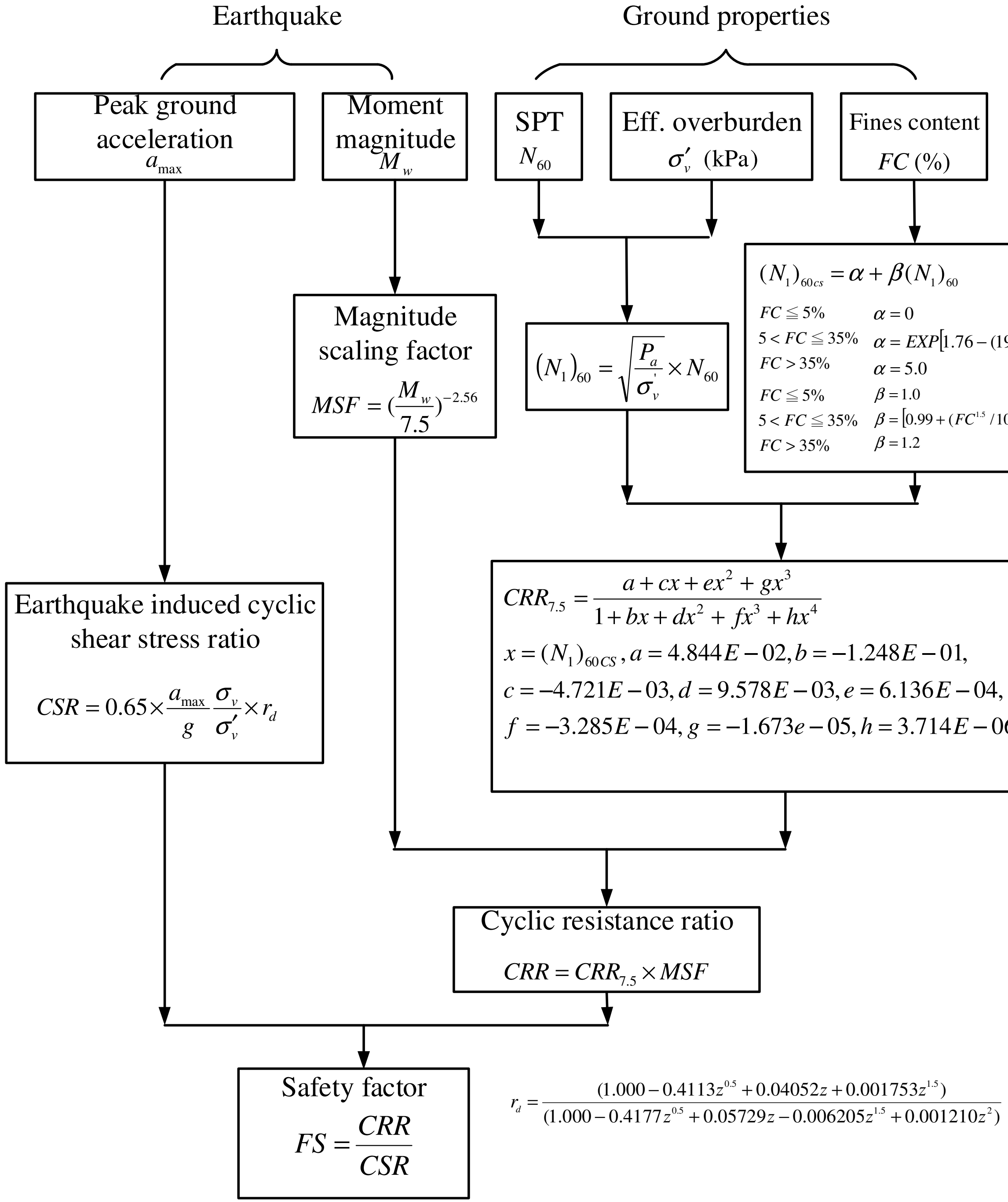
Seed et al. Method

- The pioneer and original works (1971, 1979, 1983, 1985)
- All the parameters need to refer figures
- Innovative and intrinsic framework to solve problems of soil mechanics
- It is still good enough now since it was established 48 years ago



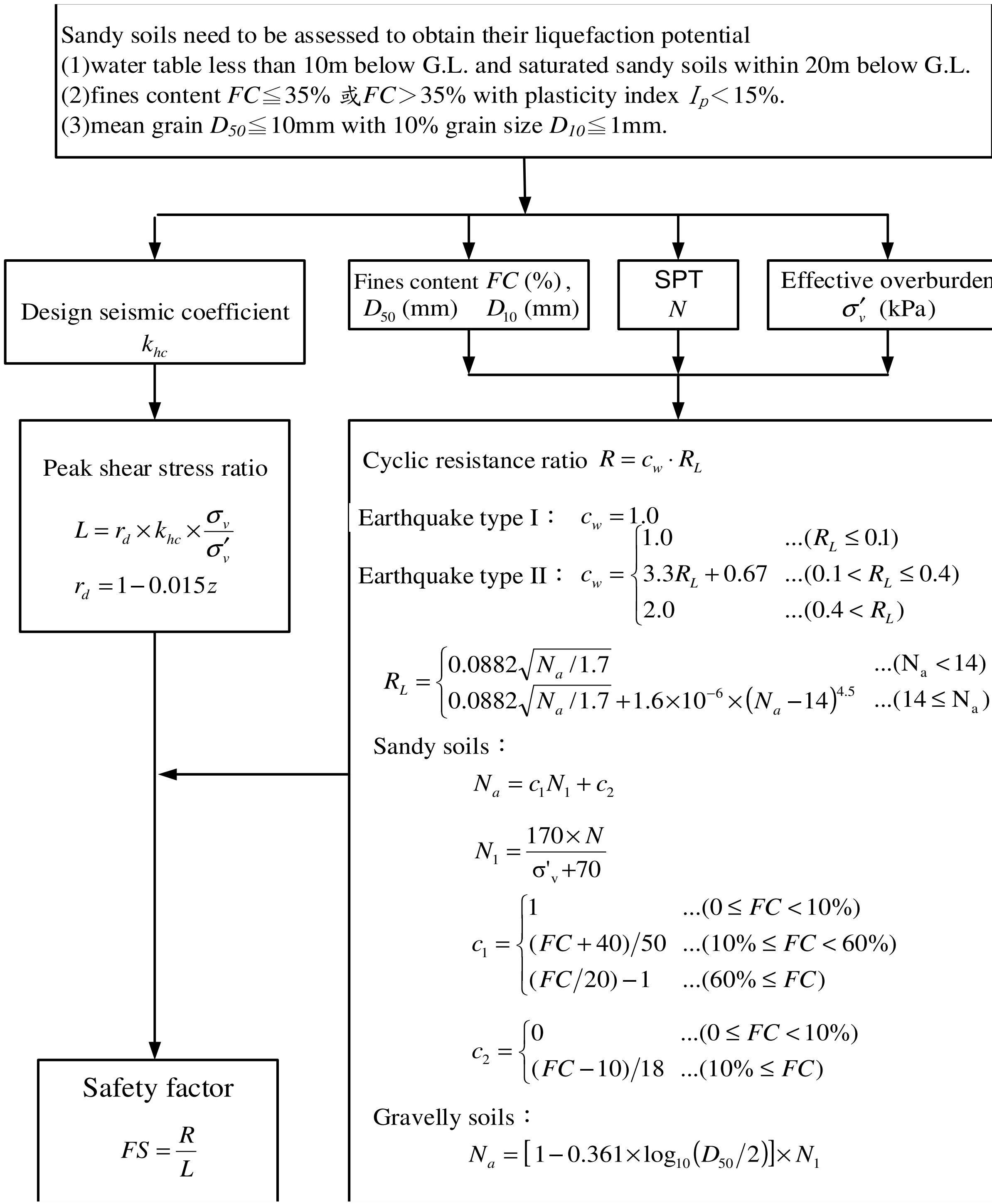
NCEER Method (2001)

- Based on Seed method (1985) with complicated equations to fit original CRR curves, stress reduction factor and fines correction factor
- This method is nearly the same as Seed et al's method.
- The proposed method has been discussed by many experts in a NCEER workshop(1997)
- A representative of US method



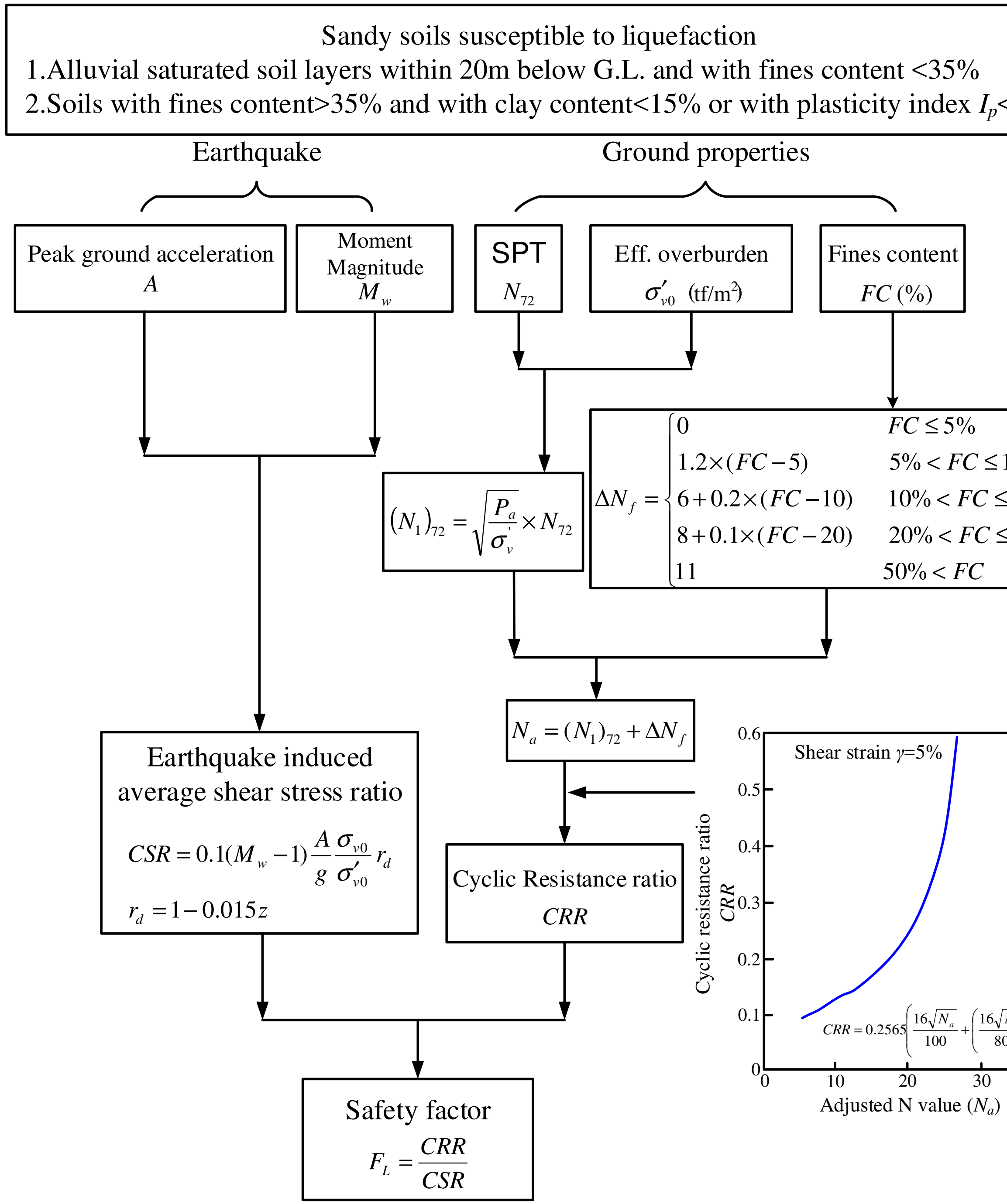
JRA Method (1996)

- ■Peak shear stress ratio
- ■Neglecting influence of earthquake magnitude
- ■Resistance depending on earthquake type
- ■Conservative for soils with high N value
- ■Non-conservative for soils with high fines content and little plasticity



AIJ Method (2002)

- ■Based on the method proposed by Tokimatsu and Yoshimi(1983)
- ■Equivalent shear stress ratio
- ■The function of cyclic resistance curve is also simple
- ■The framework is similar to that of USA
- ■Fines correction is non-conservative

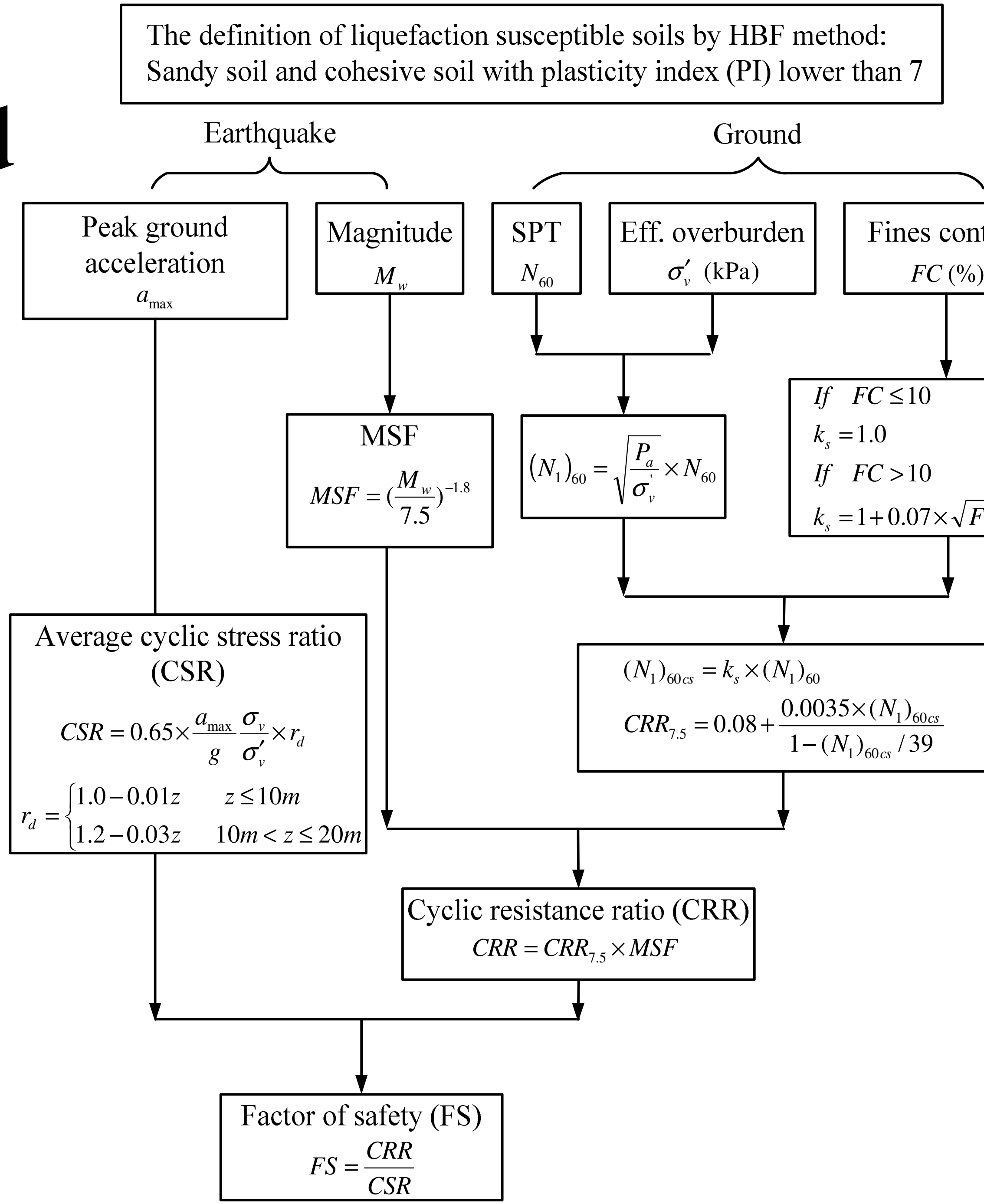


NCREE- HBF Method (2019)

- Based on the liquefied and non-liquefied cases of 1999 Chi-Chi earthquake
- Use of HyperBolic Fuction (HBF) to fit cyclic resistance ratio curve
- The equations used are as elegant and simple as possible
- Soils with Ip>7 are regarded as clay-like soils and unsusceptible to liquefaction

ramework of HBF Method nd Its Main Features

Feature 1: All the formula used to calculate cyclic resistance ratio (CRR), stress reduction factor (rd), correction factor of fines content (Ks), magnitude scaling factor (MSF), and overburden stress correction factor (C_N) are as simple and elegant as possible so that engineers can prevent calculation errors or coding mistakes that commonly encountered in practices.

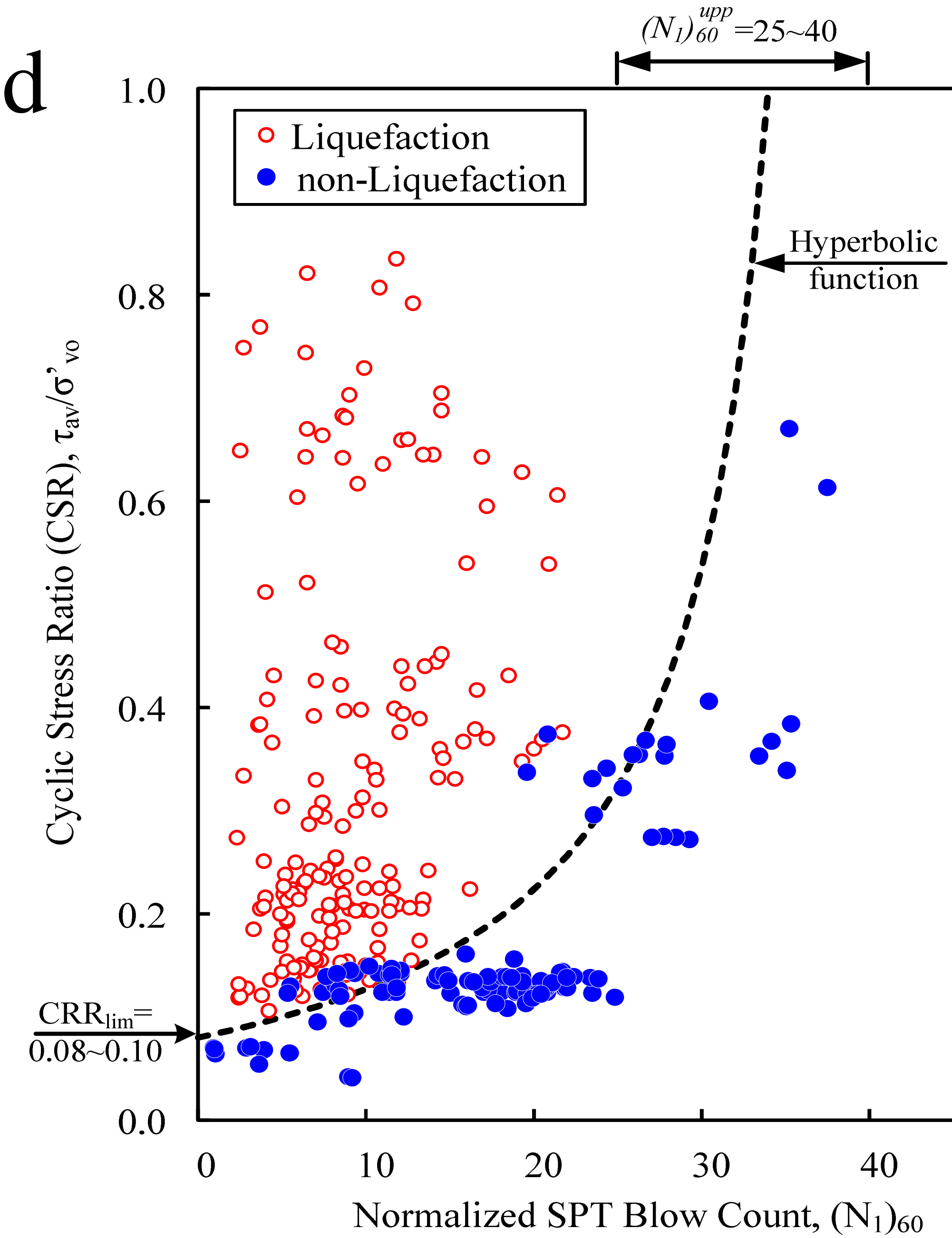


he Main Features of HBF Method

eature 2: The method fits the CRR (Mw=7.5) curve of clean sand by using a hyperbolic function

$$CRR = A + \frac{B \times (N_1)_{60cs}}{1-(N_1)_{60cs}/C} = 0.08 + \frac{0.0035(N_1)_{60cs}}{1-(N_1)_{60cs}/39}$$

Where, the constant A is corresponding to the CRR_{lim} with a value of 0.08, the constant B is corresponding to the rate of increase in CRR with respect to $(N_1)_{60cs}$ with a value of 0.0035, and the constant C is corresponding to the $(N_1)_{60}^{upp}$ with a value of 39. Thus, all the parameters in the hyperbolic function have their physical meanings.

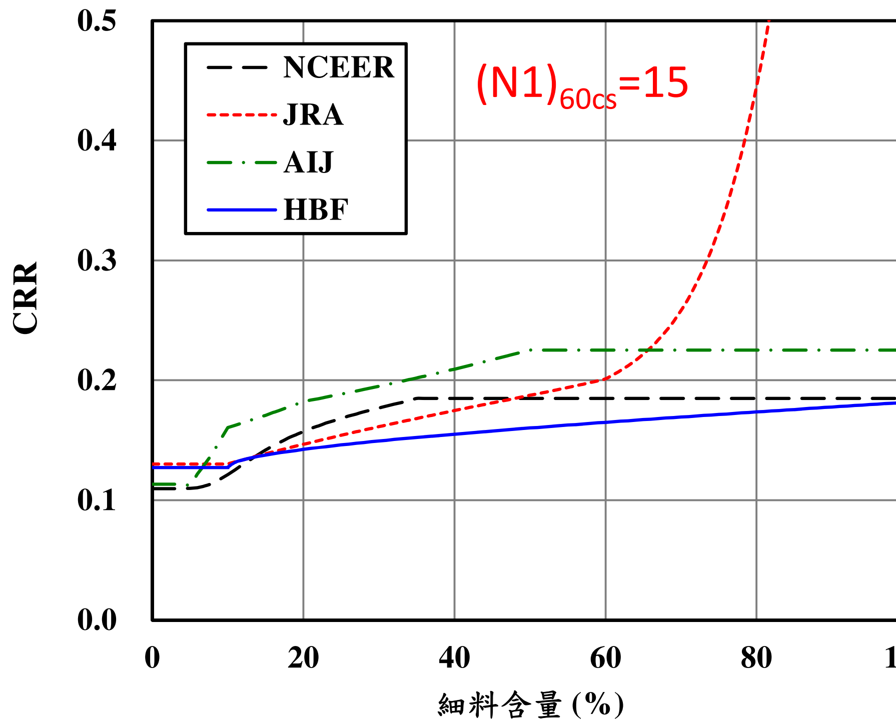


The Main Features of HBF Method

Feature 3: The HBF method believes the cohesive soils with plasticity index PI>7 are clay-like materials which will not liquefy and only exhibit cyclic softening behavior under seismic shaking. This criteria is in consistent with the suggestion by Boulanger and Idriss (2006) as well as the definition of clay soil in the plasticity chart proposed by Casagrande (1948), and the study on the cyclic resistance of Taipei cohesive soils (Hwang et al., 2000).

The Main Features of HBF Method

eature 4: A lot of liquefied cases of non-lastic ML soils in central Taiwan were bserved during Chi-Chi earthquake (Ueng t al., 2004) and then resulted in several xperimental researches on these non-plastic oils (Huang et al., 2007; Chen et al, 2014). he conclusion is the correction of Fines ontent on CRR is suggested to be a little onservative, especially for non-plastic ML oils.



A Comparison of Cyclic Strength Curve

Method	**Cyclic strength curve ($CRR_{7.5}$)**
NCEER(2001)	$CRR_{7.5} = \frac{1}{34-(N_1)_{60cs}} + \frac{(N_1)_{60cs}}{135} + \frac{50}{(10(N_1)_{60cs}+45)^2} - \frac{1}{200}$
Cetin et al.(2004)	$CRR_{7.5} = \exp\left(\frac{(N_1)_{60}(1+0.004FC)-29.53\ln(M_w)-3.7\ln\left(\frac{\sigma_v}{P_a}\right)+0.05FC+16.85+2.7\Phi^{-1}(0.15,0,1)}{13.32}\right)$
HBF(2012)	$CRR_{7.5} = 0.08 + \frac{0.0035(N_1)_{60cs}}{1-(N_1)_{60cs}/39}$
Boulanger and Idriss (2014)	$CRR_{7.5} = \exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right)$

A Comparison of Stress Reduction Factor

Method	**Stress reduction factor (r_d)**
NCEER(2001)	$r_d = \frac{1.0 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5}}{1.0 - 0.4177z^{0.5} + 0.5729z - 0.006205z^{1.5} + 0.00121z^{2}}$
Cetin et al.(2004)	$z < 20m, \quad r_d = \frac{1 + \frac{-23.013 - 2.949a_{max} + 0.999M_w + 0.0525V^{*}_{S12m}}{16.258 + 0.201e^{0.341(-z + 0.0785V^{*}_{s12m} + 7.586)}}}{1 + \frac{-23.013 - 2.949a_{max} + 0.999M_w + 0.0525V^{*}_{S12m}}{16.258 + 0.201e^{0.341(0.0785V^{*}_{s12m} + 7.586)}}}$
HBF(2012)	$r_d = 1 - 0.01z \quad \text{from } z(m) \leq 10$ $r_d = 1.2 - 0.03z \quad \text{from } 10 < z(m) \leq 10$
Boulanger and Idriss (2014)	$r_d = \exp[\alpha(z) + \beta(z)M]$ $\alpha(z) = -1.012 - 1.126\sin\left(\frac{z}{11.73} + 5.133\right)$ $\beta(z) = 0.106 + 0.118\sin\left(\frac{z}{11.28} + 5.142\right)$

A Comparison of Fines Content Correction

Method	Fines content correction (C_N)
NCEER(2001)	$(N_1)_{60cs} = \alpha + \beta(N_1)_{60}$ $\alpha = 0;\ \beta = 0$ for $FC \leq 5$ $\alpha = \exp[1.76 - (190/FC^2)];\ \beta = 0.99 + \frac{FC^{1.5}}{1000}$ for $5 < FC \leq 35$ $\alpha = 5;\ \beta = 1.2$ for $FC > 35$
Cetin et al.(2004)	$C_{FINES} = 1 + 0.004FC + 0.05\left(\frac{FC}{(N_1)_{60}}\right)$ Lim:5%≤FC≤35%
HBF(2012)	$(N_1)_{60cs} = K_s(N_1)_{60}$ $K_s = 1$ for $FC \leq 10$ $K_s = 1 + 0.07\sqrt{FC - 10}$ for $FC > 10$
Boulanger and Idriss (2014)	$(N_1)_{60cs} = (N_1)_{60} + \Delta(N_1)_{60}$ $\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC+0.01} - \left(\frac{15.7}{FC+0.01}\right)^2\right)$

COMPARISON STUDIES OF THE HBF METHOD

- A total of 669 sets of SPT-based cases were collected
  - 302 sets of Chi-Chi earthquake data collected by Hwang and Yang (2001)
  - 367 sets of data collected by Youd et al. (1997)
- Summary of comparison using success rate of prediction

Success rate		Seed (1985)	NCEER (2001)	AIJ (1983)	JRA (1996)	JRA (1990)	HBF (200
quefied	FC≤10	96%(143/149)	97%(145/149)	99%(147/149)	99%(147/149)	87%(130/149)	95%(142/1
	10<FC≤30	88%(136/155)	92%(142/155)	90%(140/155)	97%(150/155)	81%(126/155)	98%(152/1
	FC>30	91%(63/69)	97%(67/69)	94%(65/69)	97%(67/69)	81%(56/69)	99%(68/6
Non-quefied	FC≤10	59%(62/105)	57%(60/105)	50%(53/105)	43%(45/105)	61%(64/105)	64%(67/10
	10<FC≤30	88%(130/147)	86%(126/147)	77%(113/147)	67%(99/147)	79%(116/147)	80%(117/1
	FC>30	91%(40/44)	82%(36/44)	75%(33/44)	75%(33/44)	64%(28/44)	75%(33/4
Liquefied		92%(342/373)	95%(354/373)	94%(352/373)	98%(364/373)	84%(312/373)	97%(362/3
Non-liquefied		78%(232/296)	75%(222/296)	67%(199/296)	60%(177/296)	70%(208/296)	73%(217/2
Total		86%(574/669)	86%(576/669)	82%(551/669)	81%(541/669)	78%(520/669)	87%(579/6

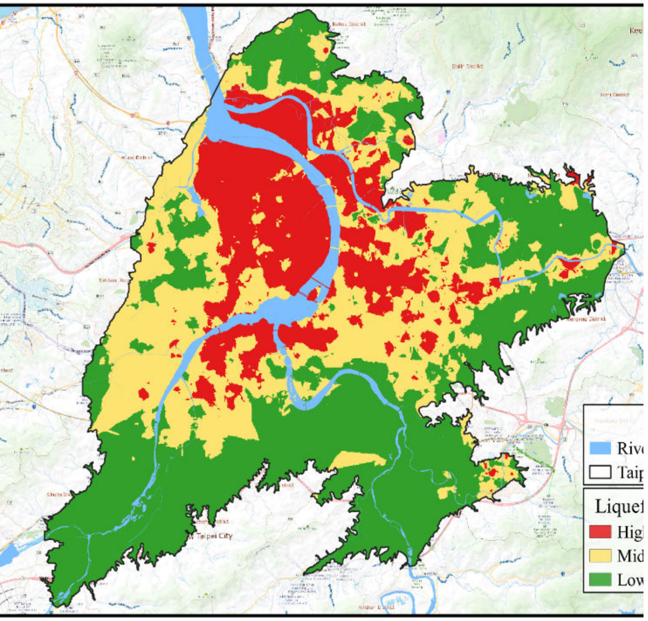
A comparison of Micro-zonation Map of Soil Liquefaction Potential in Taipei basin

- Using liquefaction potential index(P_L) by Iwasaki et al. (1978)
- The area of different liquefaction potentials in Taipei basin by different methods

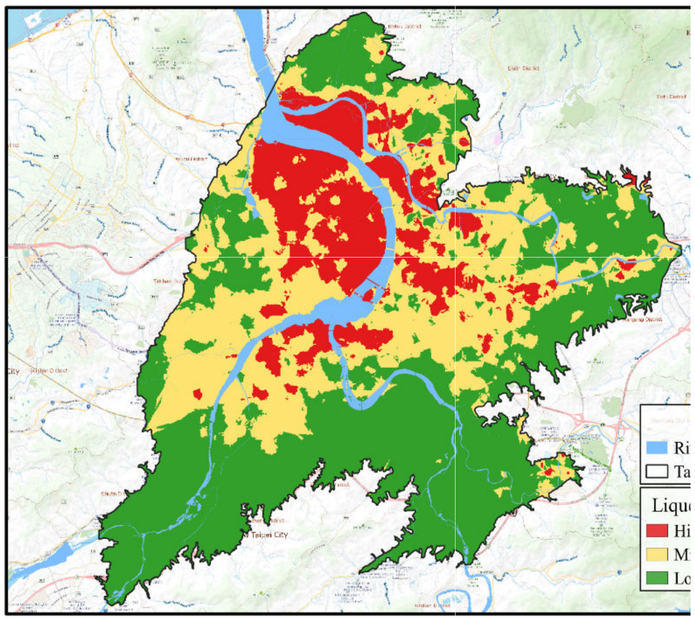
Liquefaction potential index	Degree of liquefaction sever
$P_L \leq 5$	slight
$5 < P_L \leq 15$	medium
$P_L > 15$	severe

Method	Liquefaction potential			Total
	Low	Middle	High	
	Area(km^2)/Percentage			
HBF (2005)	101.3/39%	95.0/36%	65.6/25%	261.9/100%
NCEER (2001)	111.7/43%	98.0/37%	52.1/20%	261.9/100%
JRA (1996)	76.3/29%	104.6/40%	80.9/31%	261.9/100%

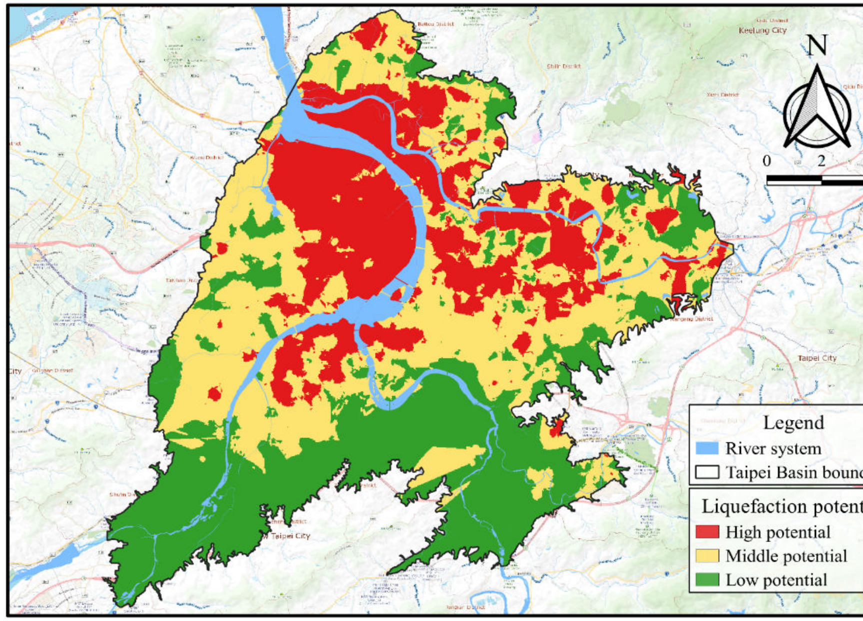
A comparison of Micro-zonation Map of Soil Liquefaction Potential in Taipei basin



HBF(2005)



NCEER(2001)



JRA(1996)

Conclusions and suggestions

- All the methods are acceptable in engineering practice.
- Each method is an integrated system. You can not replace one of the elements in A method with that in B method.
- The prediction accuracy of new methods are not necessarily better than the old methods.
- The prediction accuracy of more complicated methods are not necessarily better than simple methods.
- The main features and the merits of HBF method are illustrated
- The HBF method has more simple and elegant formula
- The performance of HBF method is as good as NCEER method
- It is suggested that the HBF method can be an acceptable alternative for assessing liquefaction potential in practice beside USA and Japan


Thank you very much
for
your attentions