Liquefaction Potential Analysis Based on CPT: Grain Size ad Relative Density (D_{50} and Dr)

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-Summary -

The liquefaction potential is an important aspect of earthquake engineering practice since its contribution to the safety of construction.

The physical properties of sand soil that include grain size and density had known give effects to the liquefaction.

Those physical properties of sand soil associated to liquefaction resistance have been studied in laboratory.

The potential of liquefaction is needed to be mapped for wide area, it is a big job. Then the data collection and the assessment must be affordable.

The method based on previous research is discussed here to assess the liquefaction potential.

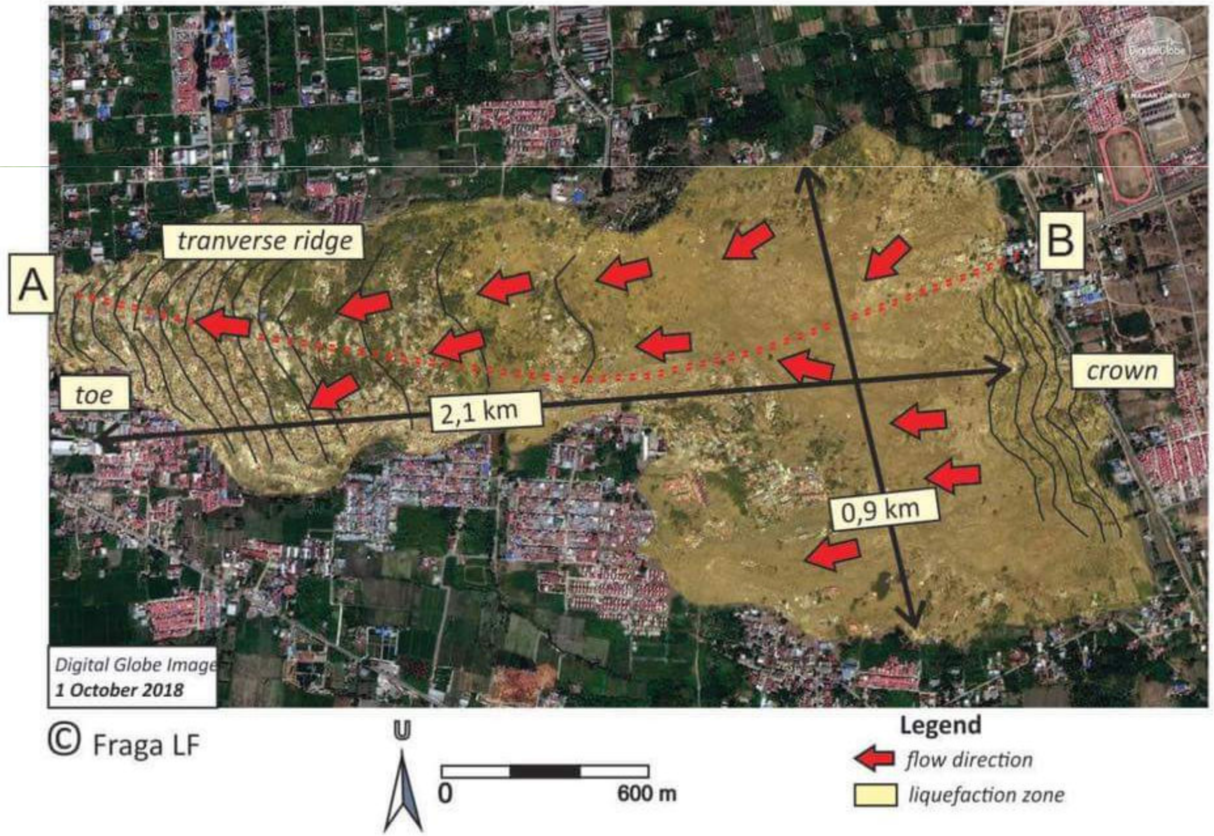
There are some faced problems that must be resolved immediately in the near future.

The example case is a real construction design of reclamation shore in order to develop a new port in Indonesia. The treatment to be accomplished is compaction efforts to reach a certain relative density in order to avoid the possibility of liquefaction on site.

Keywords: Liquefaction, CPT, Grain size, Relative density

Introduction: effects of liquefaction

The Skecth of Liquefaction in Petobo, south of Palu

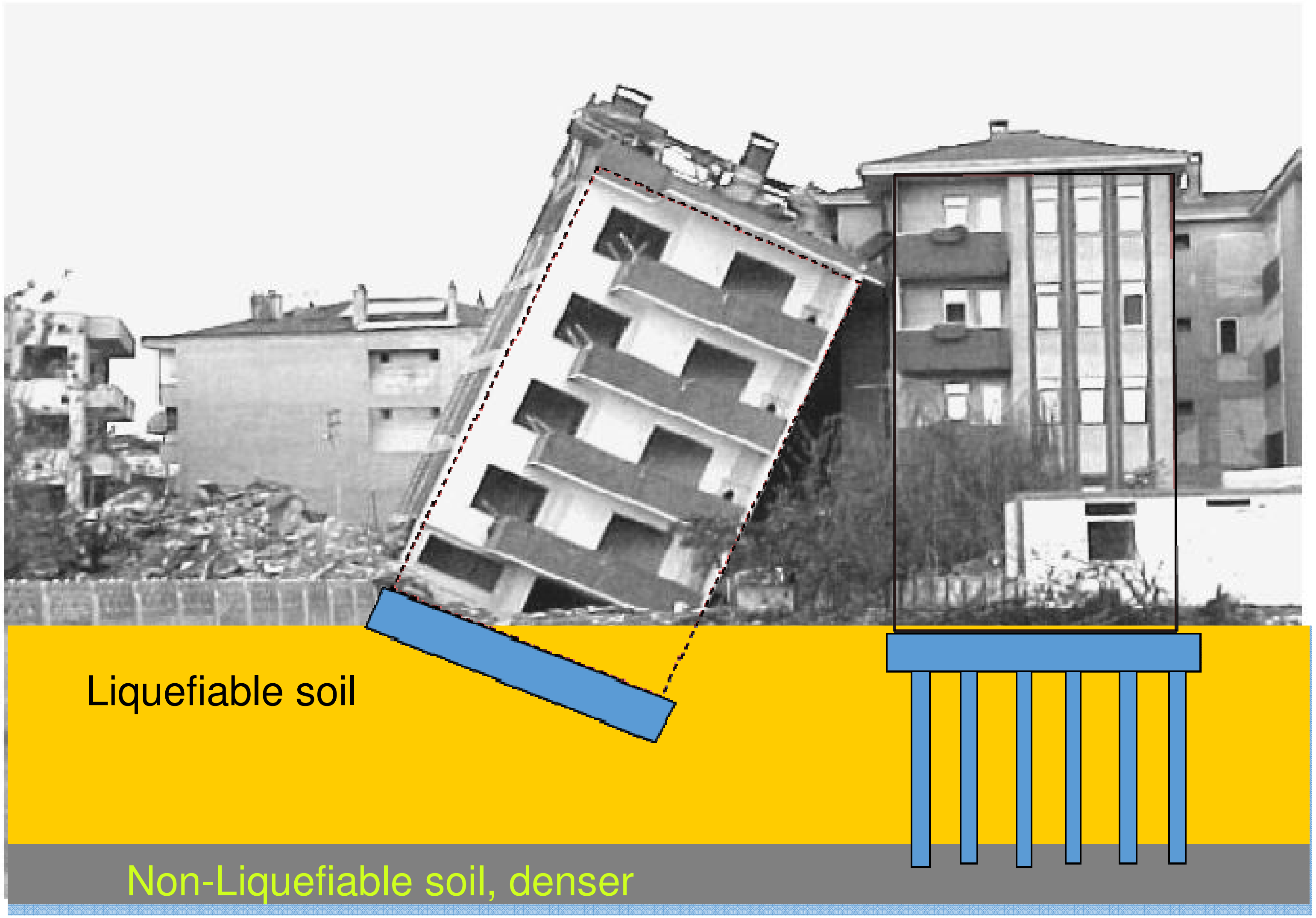


Introduction

Lost of bearing
on foundations

(Padang, 2009)

Lost of bearing on foundations



Building that collapsed during the 1999 Turkey (Kocaeli) earthquake due to liquefaction

- Earthquake Engineering Handbook (Chen, W.F., & Scawthorn, C., 2003)

Lateral Spreading

Contoh Kejadian G30'SPadang:

1. Jalan pinggir Pantai Purus
2. Wisma Indah Tabing
3. Gunung Tigo Pariaman
4. Jalan inspeksi Kuranji, Lapai

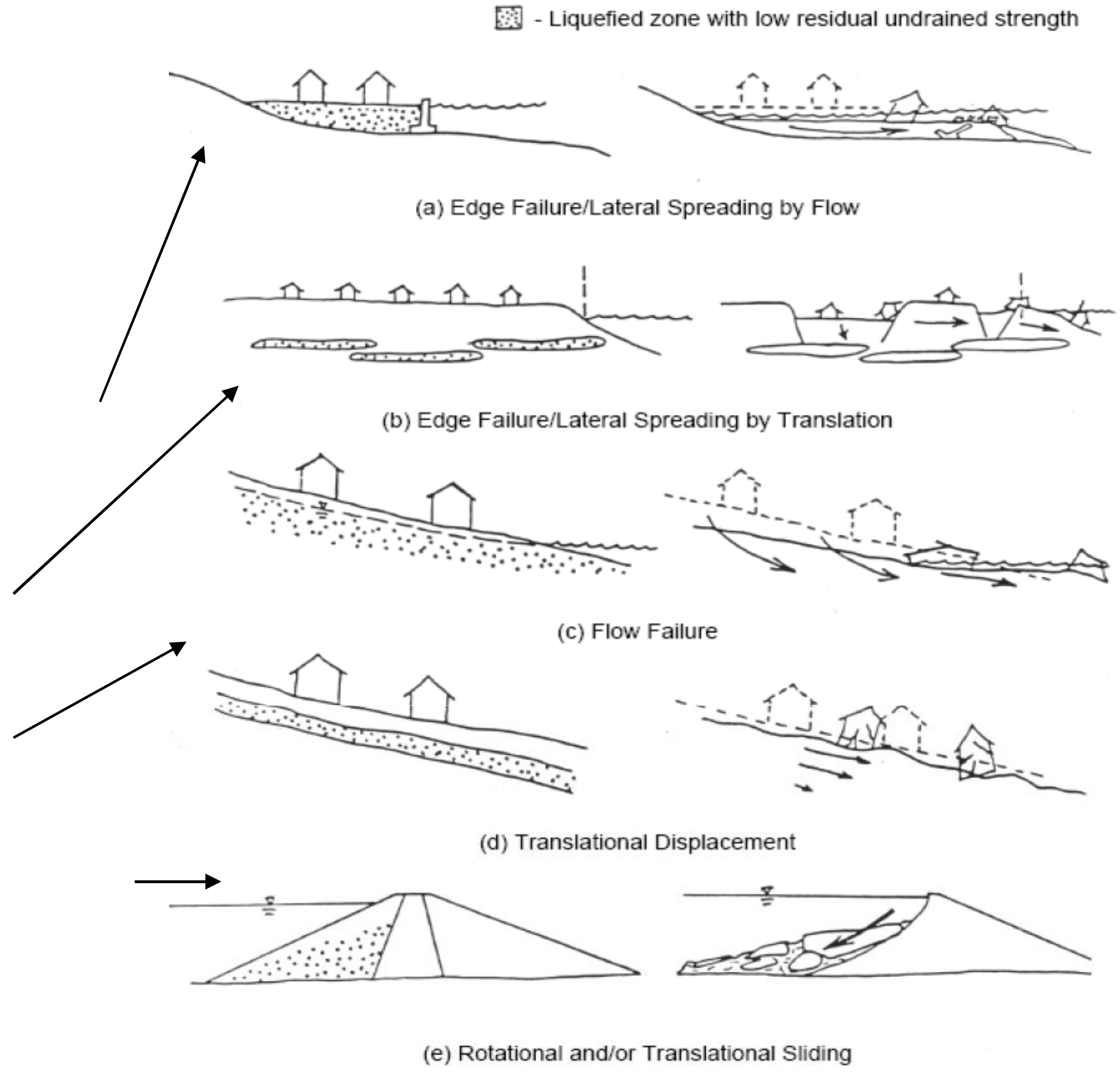


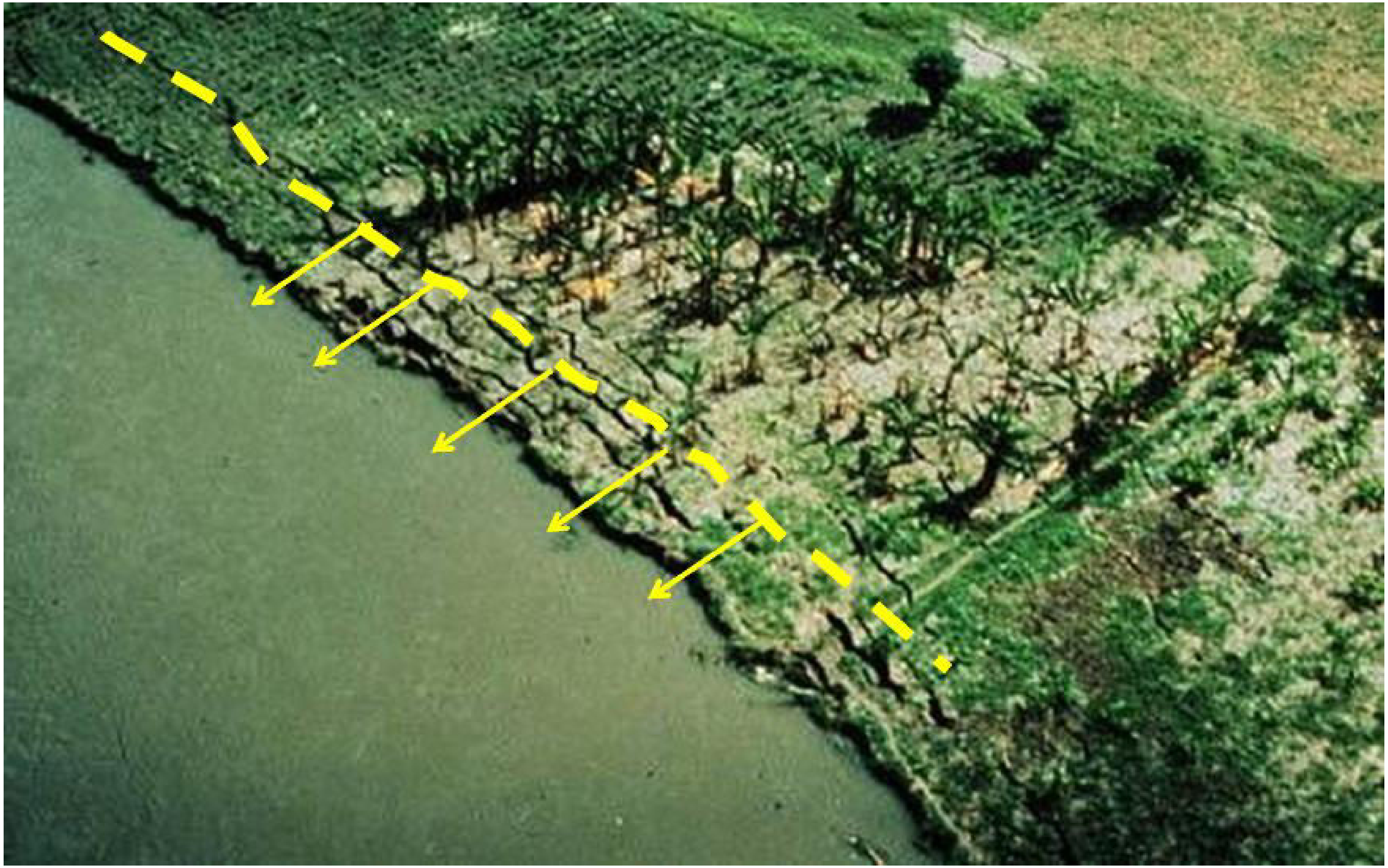
Fig. 44: Schematic Examples of Liquefaction-Induced Global Site Instability and/or "Large" Displacement Lateral Spreading

1.1 Examples of Lateral spreading due to Liquefaction.

[3] US DOD NAVFAC DM 7.4 "*Soil Dynamics and Special Design Aspects*"

The 1976 Guatemala earthquake caused lateral spreading along the Motagua river

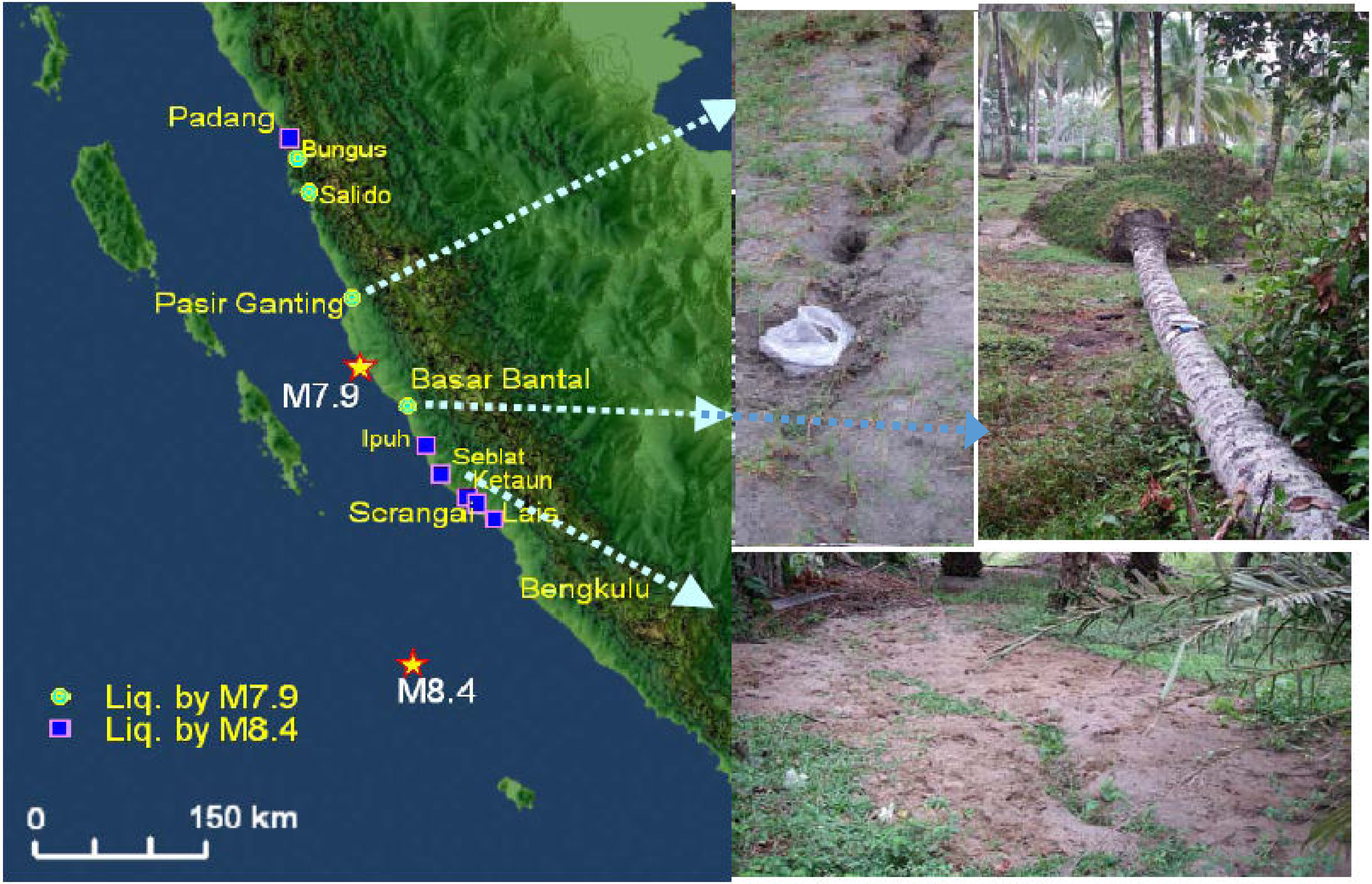
http://www.ce.washington.edu/~liquefaction/html/what/what2.html



Crack on the roads

Pidie, 2016

FIGURE 7.13 Subsidence and lateral spreading due to liquefaction lead to the collapse of buildings along the shoreline in the fishing village of Guzelyali during the 1999 Turkey (Kocaeli) earthquake. (J.C. Borrero photo, courtesy National Oceanic and Atmospheric Administration-National Geophysical Data Center)



(a) Locations of observed liquefaction (b) views of some ground liquefaction

Damaged bridge

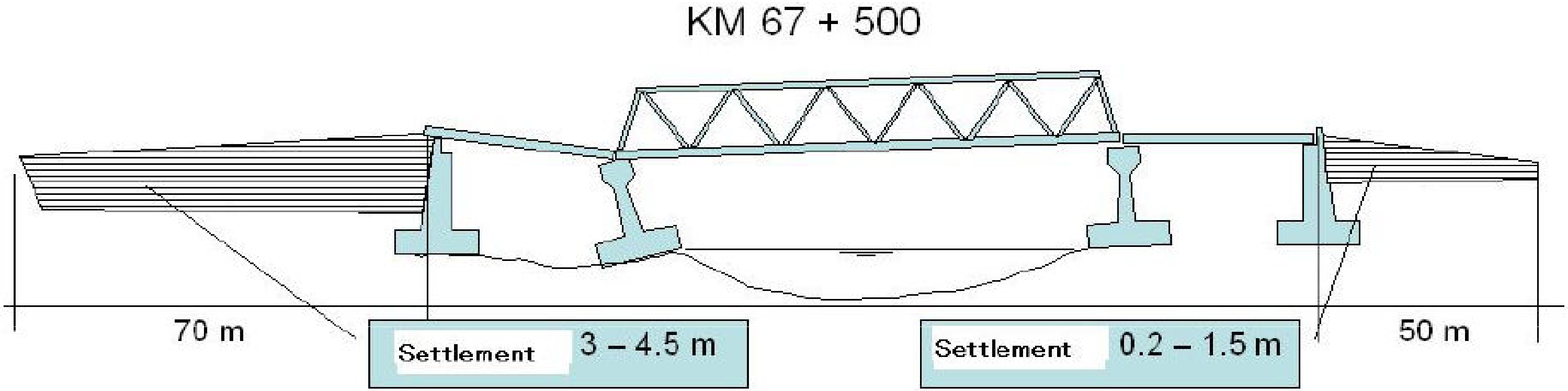


Fig.8.3 Liquefaction induced damage to Muzoi River bridge by 2005 Nias earthquake

Jembatan Pasir Ganting
– Pesisir Selatan –

Fig.5.9 Damage to the arch bridge at Pasir Ganting due to ground liquefaction

Fig.5.11 Damage to approach embankments of bridges

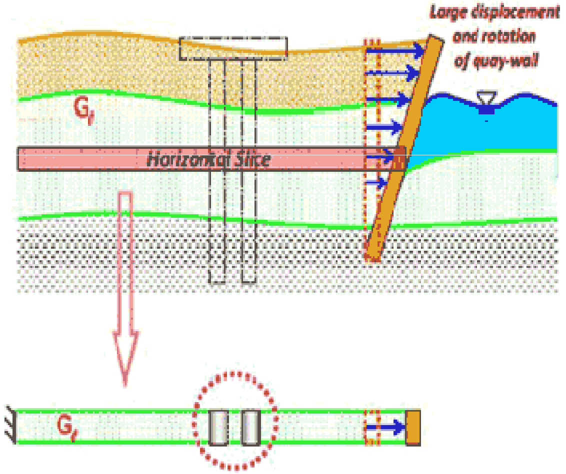
Liquifaction under the bridge

Lateral spreading caused the foundations of the Showa bridge to move laterally so much that the simply supported spans became unseated and collapsed

http://foundationconcretes.com/foundation-failure-due-to-earthquake-generated-liquefaction dan http://www.ce.washington.edu/~liquefaction/html/quakes/niigata/niigata.html

Seawall Collapse
– Kobe 1995 –

http://www.gf.uns.ac.rs/~wus/wus07/web4/liquefaction.html

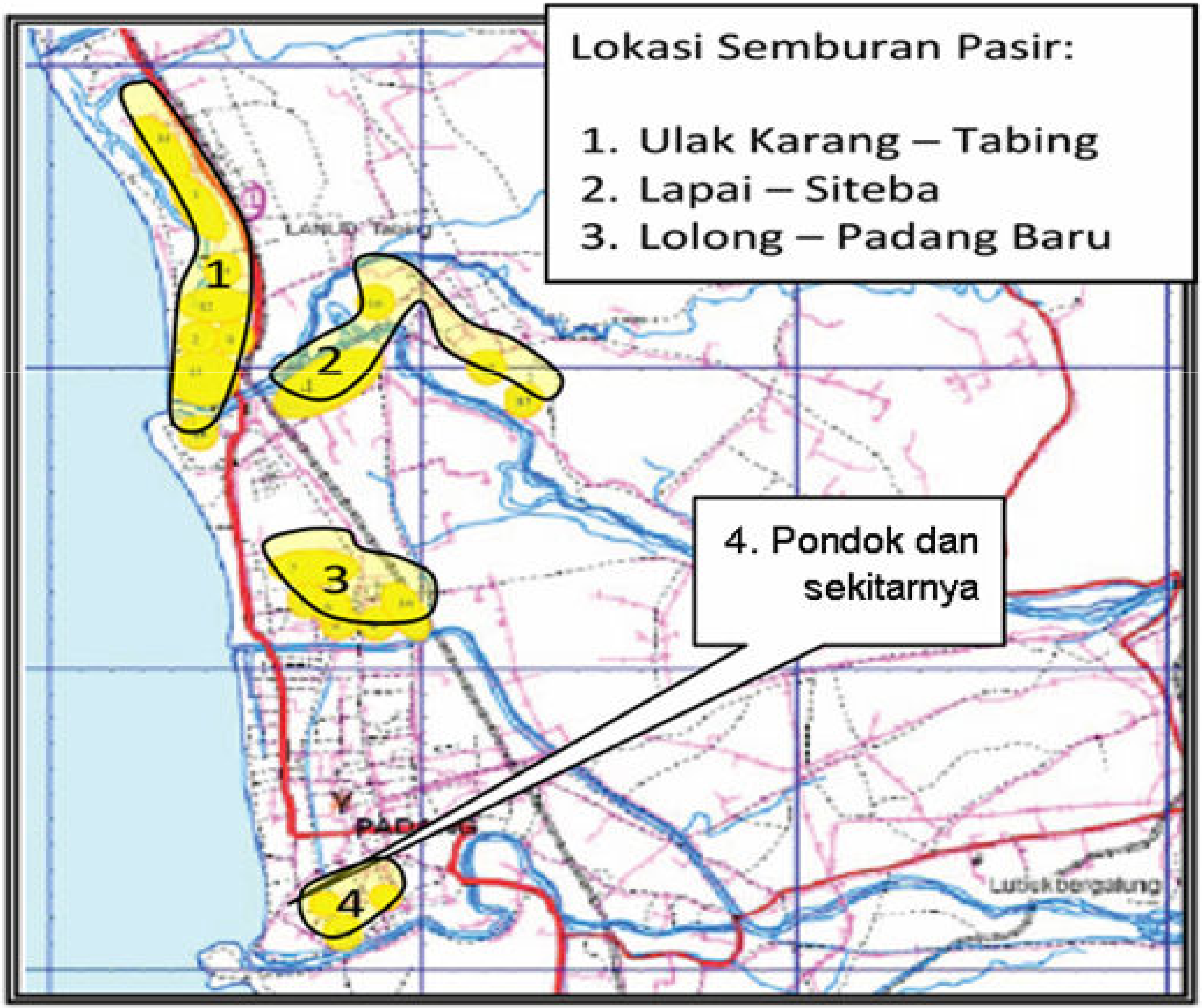


Cars …

http://www.gns.cri.nz/Home/Learning/Science-Topics/Earthquakes/Earthquake-Hazards

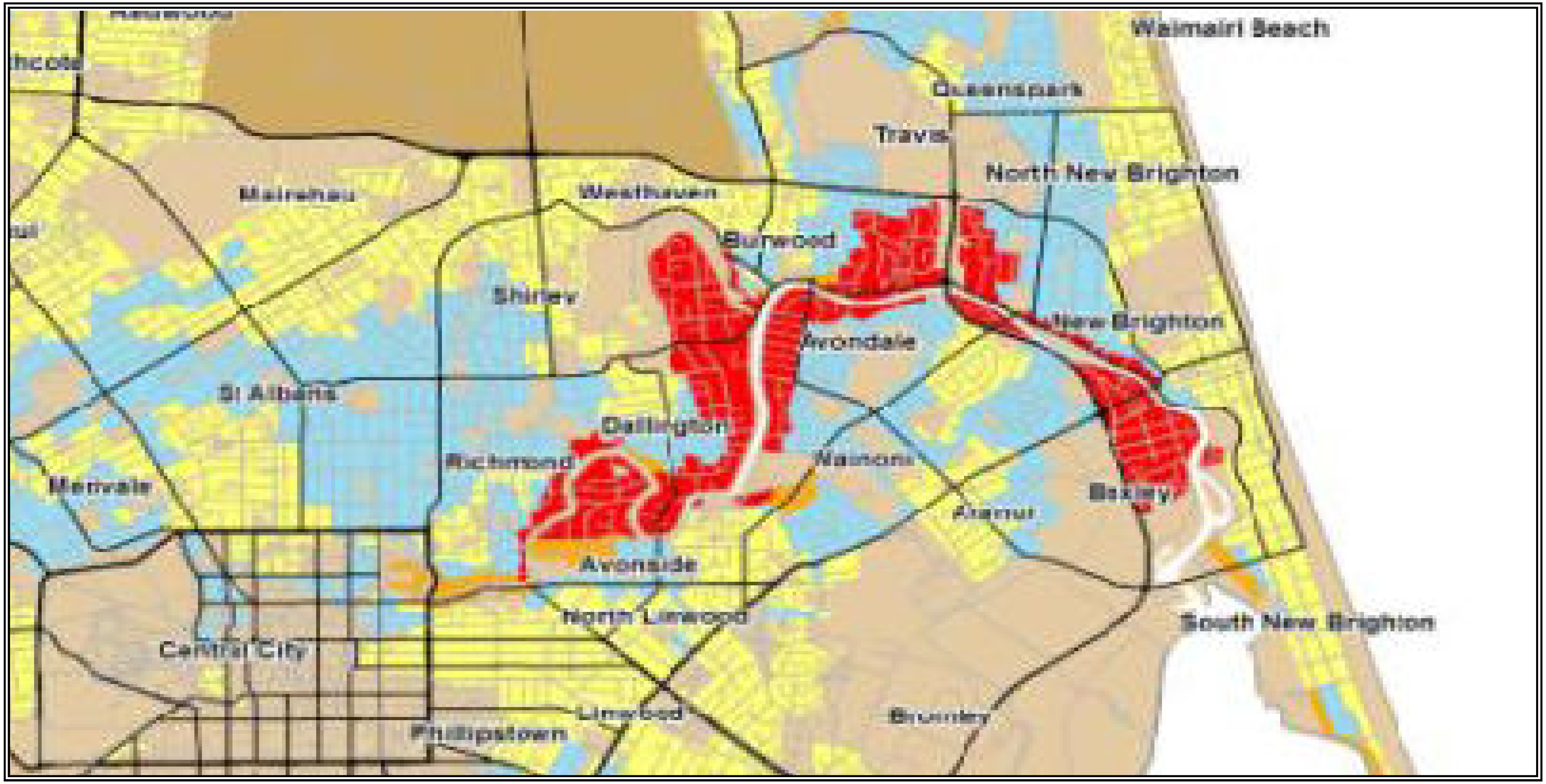
Liquefaction in Padang

(30S’2009)



Liquefaction in Christchurch, NZ 2011

(Sally Dellow, 2015)



Liquefaction definition:

In mathematical term, the liquefaction on the soil deposit is written as:

$$\sigma' = \sigma - u \leq 0.0 \qquad (1)$$

where σ and σ' are total and effective stresses in the soil respectively and u is the pore pressure in the liquefied soil element.

Lliquefaction potential of the soil depends on several factors:

- **Relative density, Dr**
- Initial stress of the soil, σ_i
- **Mean grain size of the soil, D50**
- Applied peak stress, σd or τmax
- Duration of the motion, t
- Over consolidation ratio, OCR
- Initial pore pressure, u_i

Liquefaction Assessment (N_{SPT} Base : **OLD**)

$$N_1 = N \cdot C_N$$

where C_N is taken (after Liao and Whitman, 1986)

$$C_N = \left(\frac{1}{\sigma'_v}\right)^{0.5}$$

$$N_{1,60} = N_1 \cdot C_R \cdot C_S \cdot C_B \cdot C_E$$

where C_R = correction for "short" rod length,
C_S = correction for non-standardized sampler configuration,
C_B = correction for borehole diameter, and
C_E = correction for hammer energy efficiency.

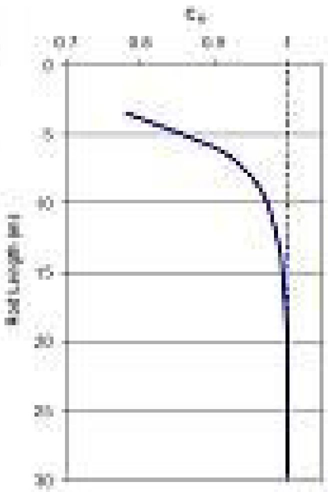


Fig. 9: Recommended C_R Values (rod length from point of hammer impact to tip of sampler).

Table 1: Recommended Corrections for SPT Equipment Energy and Procedures

C_R	(See Fig. 9 for rod length correction factors)
C_S	$C_S = 1 + \frac{N_{1,60}}{100}$ (Eq. T-1)
C_B	Borehole diameter: 65 to 115 mm — 1.00; 150 mm — 1.05; 200 mm — 1.15
C_E	$C_E = \frac{ER}{60\%}$ (Eq. T-2)

$$CSR = 0.65\left(\frac{\sigma_v a_{max}}{\sigma'_{v}}\right) r_d$$

in which a_{max} is the maximum horizontal acceleration

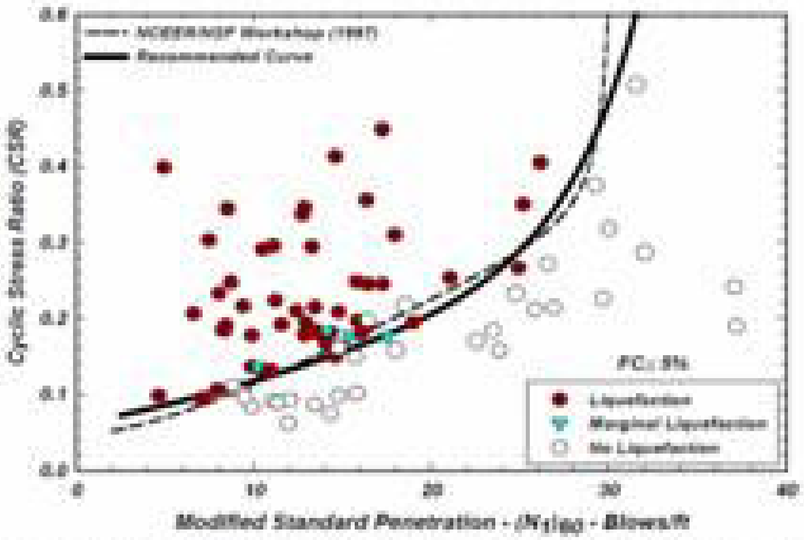


Fig. 14: SPT case histories of clean sands with the curve proposed by the NCEER Workshop (1997) and the recommended curve for $M = 7\frac{1}{2}$ and $\sigma'_v = 1$ atm (≈ 1 tsf).

$$r_d = 0.12\exp(0.22M) \quad (6d)$$

The uncertainty in r_d increases with increasing depth

$$\ln(r_d) = \alpha(z) + \beta(z)M$$

$$\alpha(z) = -1.012 - 1.126\sin\left(\frac{z}{11.73} + 5.133\right)$$

$$\beta(z) = 0.106 + 0.118\sin\left(\frac{z}{11.28} + 5.142\right)$$

Liquefaction Assessment : N_{SPT} from Seed et al. (**New**)

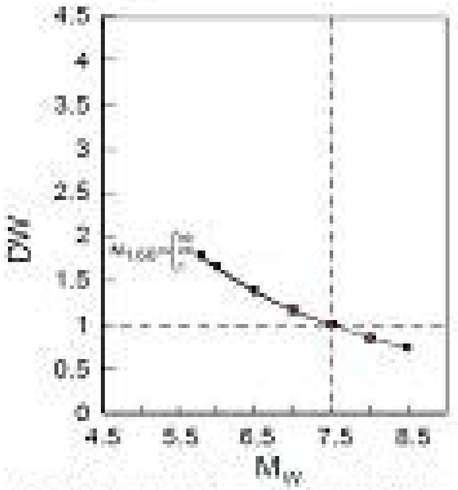
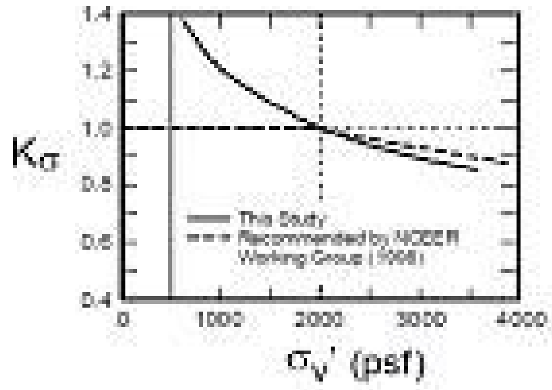


Fig. 15: Recommended Magnitude-Correlated Duration Weighting Factor as a Function of $N_{1,60}$



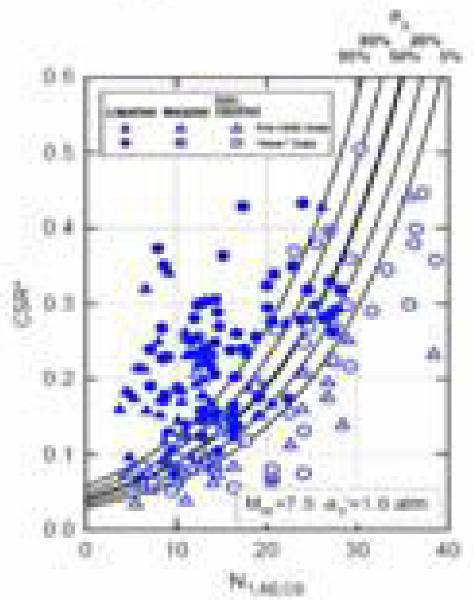


Fig. 16: Recommended "Probabilistic" SPT-Based Liquefaction Triggering Correlation (for M_w=7.5 and σ_v'=1.0 atm)

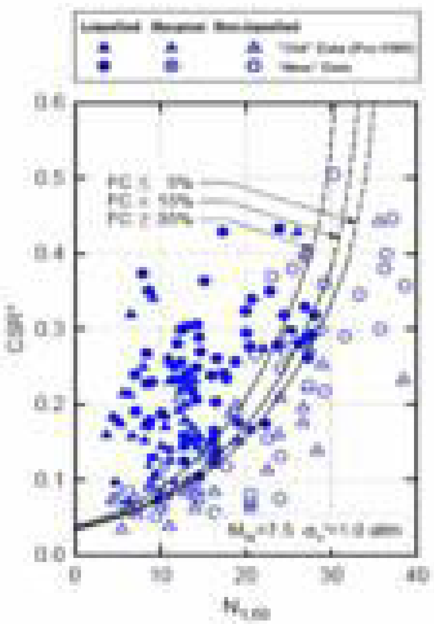
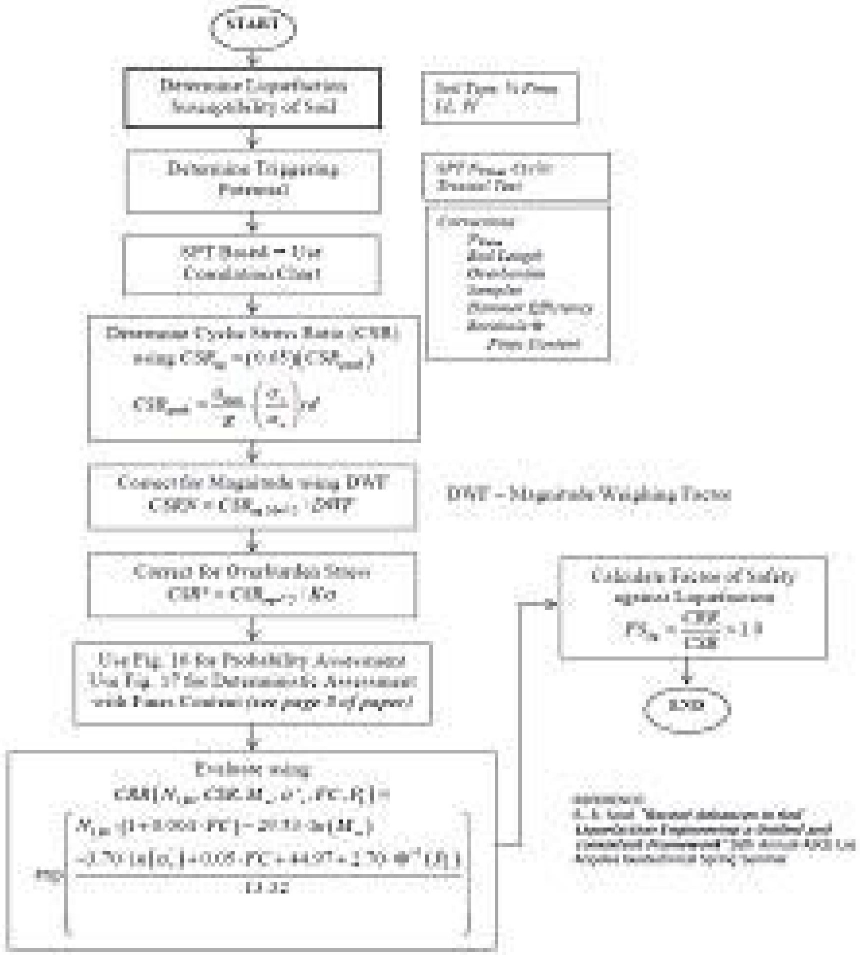


Fig. 17: Recommended "Deterministic" SPT-Based Liquefaction Triggering Correlation (for M_w=7.5 and σ_v'=1.0 atm) with Adjustments for Fines Content Shown



Appendix 1: Flow Chart for Liquefaction Susceptibility Assessment

The basic problems,

- The assessment method is complicated
- The introduced parameters is unfamiliar
- Year to year the method is revised and more complicated
- Need a new method that is “easy” and “cheap”
- For wide areas, the budget must be reasonable
- The young engineer must be able to assess

Simple Assessment Method

In mathematical term, the liquefaction on the soil deposit is written as:

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where σ and σ' are total and effective stresses in the soil respectively and u is the pore pressure in the liquefied soil element.

Liquefaction potential of the soil depends on several factors:

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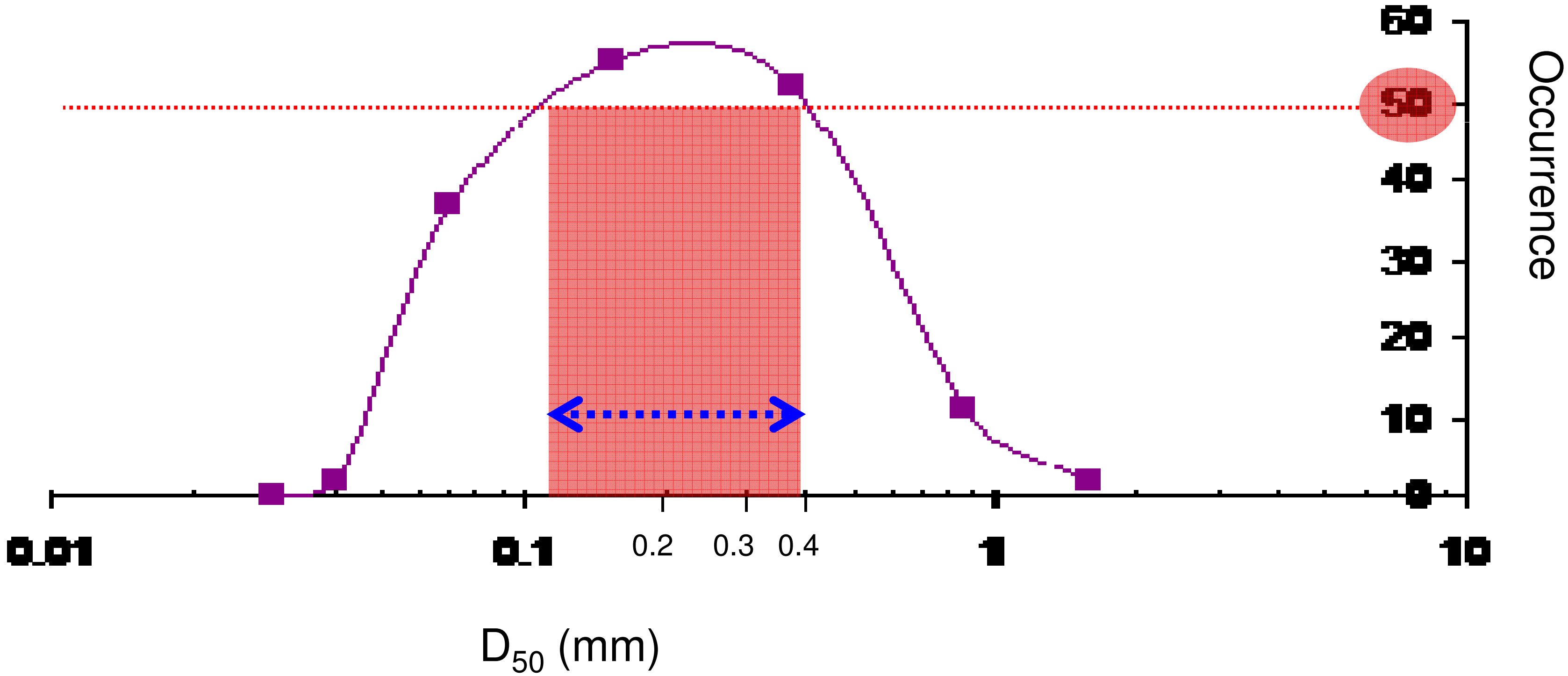
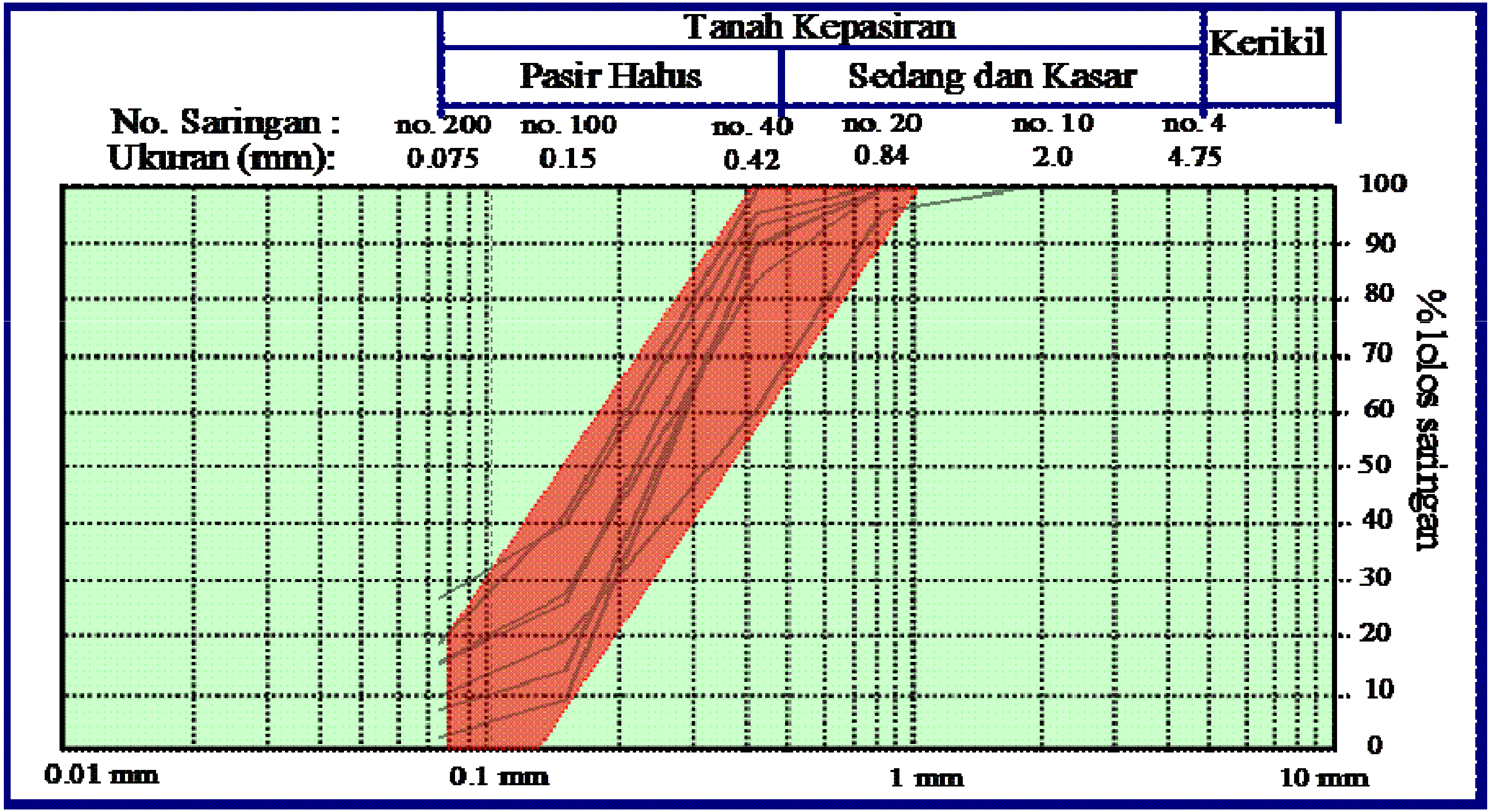
- **Mean grain size of the soil, D50**
- **Applied peak stress, σ_d or τ_{max}**
- Initial stress of the soil, σ_i
- Duration of the motion, t
- Over consolidation ratio, OCR
- Initial pore pressure, u_i

Data Record

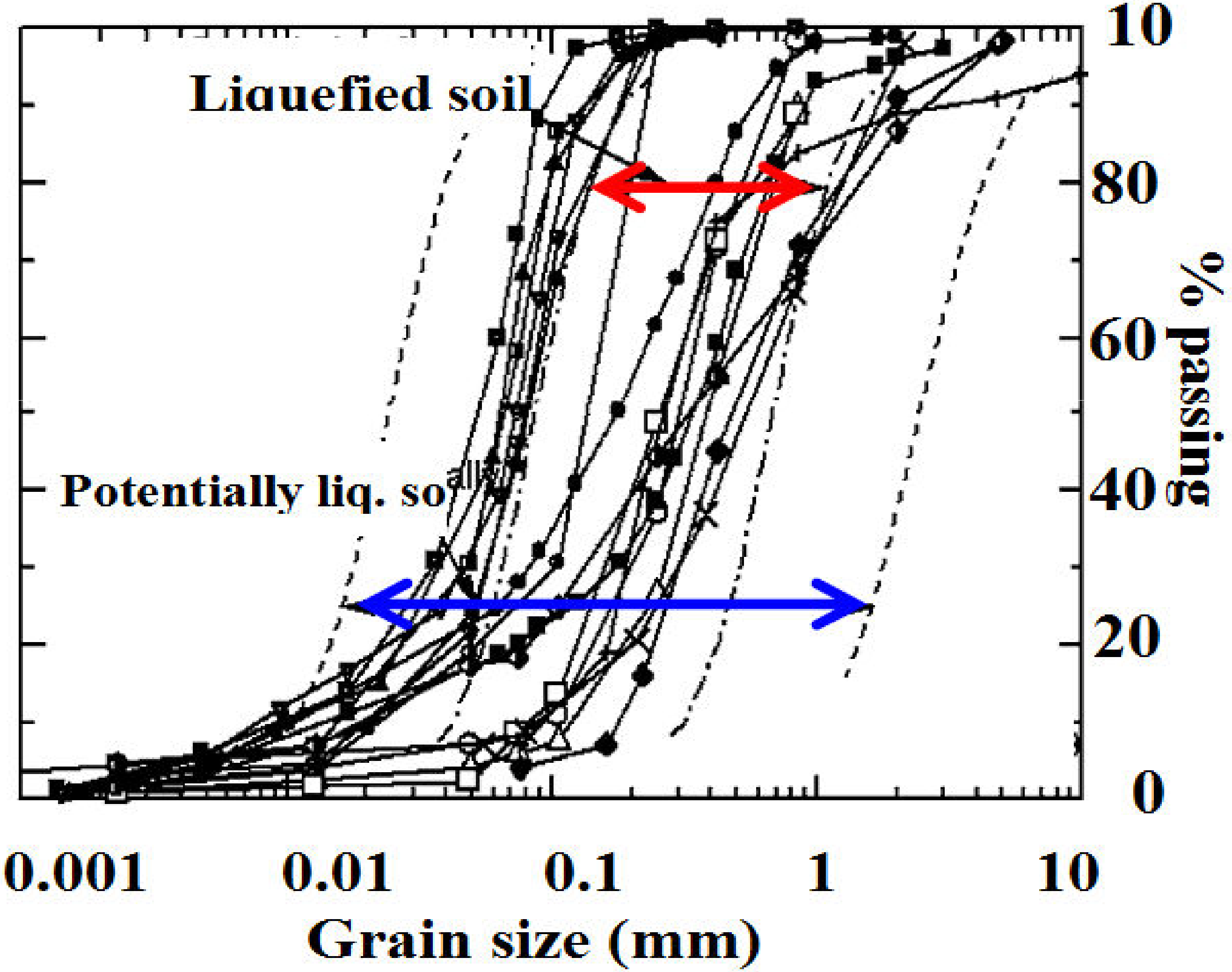
- D_{50} of Liquefied soil around the world
  (from 150 occurrences)



Padang City Liquefied Soil

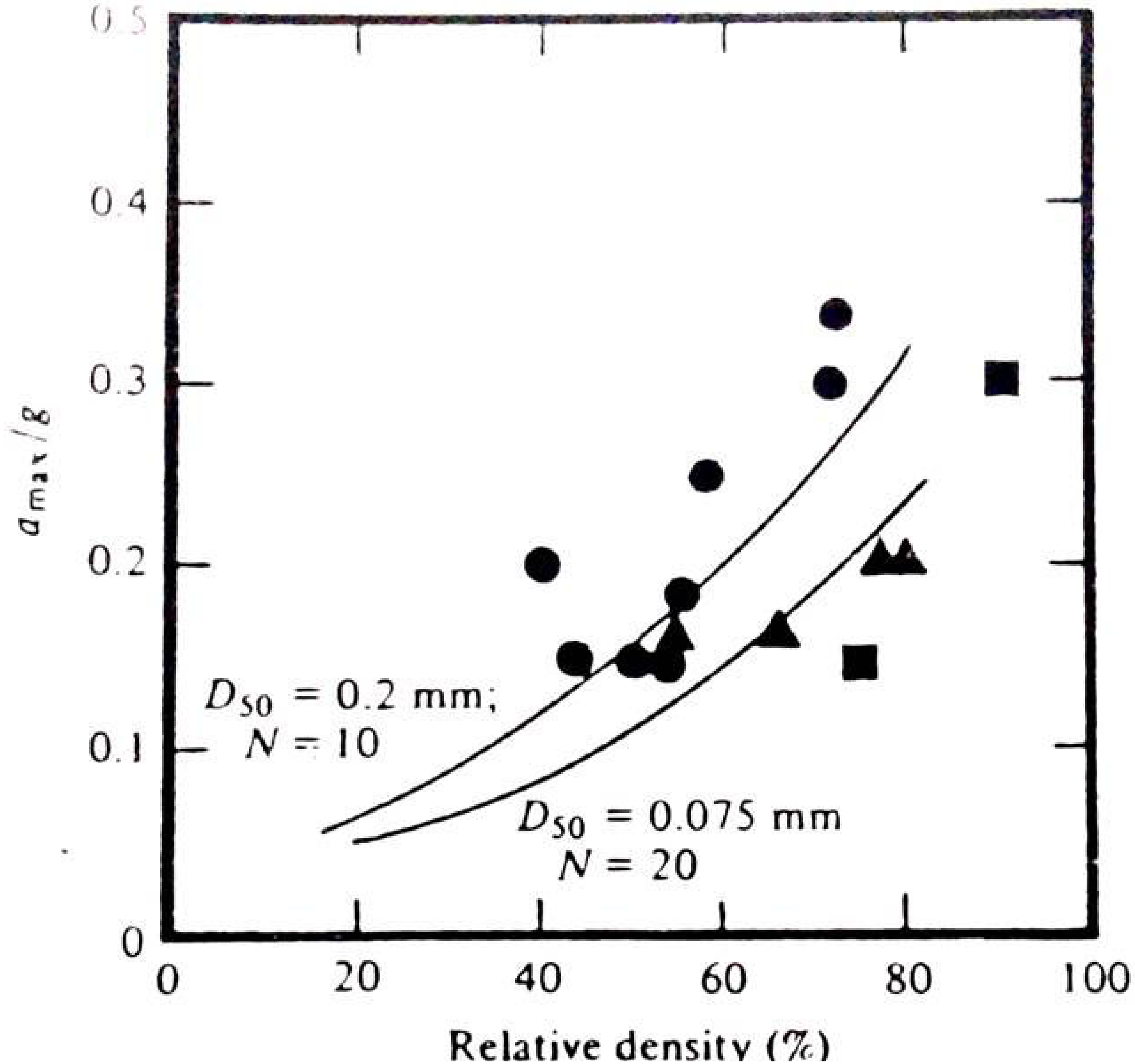


Omer's Note



Liquefied soil
Potentially liq. soils
10
80
60
40
20
0
% passing
0.001
0.01
0.1
1
10
Grain size (mm)

Seed and Idriss, 1971



Evaluation of liquefaction potential for sand, water table 10 ft (3.05 m) below ground surface: ● liquefaction, a_{max} estimated; ■ no liquefaction, a_{max} estimated; ▲ no liquefaction, a_{max} recorded. [Seed, H. B., and Idriss, I. M. (1971). "Simplified Procedure for Evaluating Soil Liquefaction Potential," *Journal of the Soil Mechanics and Foundations Division, ASCE*, 97 (SM9), Fig. 12, p. 1261.]

Dr vs a_{max} for Liquefaction

TABLE 6-1
Approximate relationship between earthquake magnitude, relative density, and liquefaction potential for water table 1.5 m below ground surface*

Earthquake acceleration	High liquefaction probability	Potential for liquefaction depends on soil type and earthquake acceleration	Low liquefaction probability
0.10g	$D_r < 33\%$	$33 < D_r \leq 54$	$D_r > 54\%$
0.15g	< 48	$48 < D_r \leq 73$	> 73
0.20g	< 60	$60 < D_r \leq 85$	> 85
0.25g	< 70	$70 < D_r \leq 92$	> 92

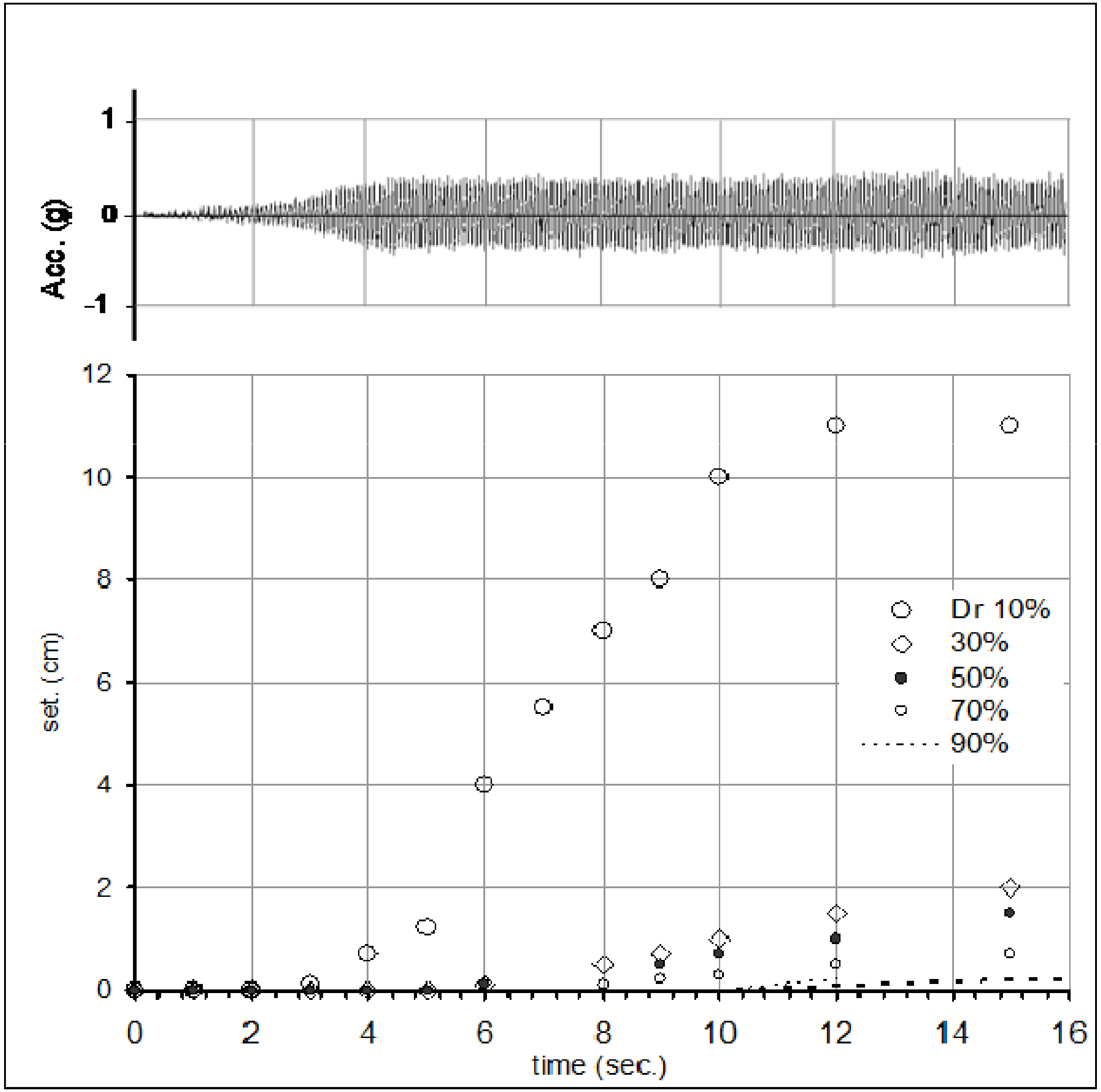
*From Seed and Idriss (1971).

Bowles J E, Foundation Analysis and Design, 1997

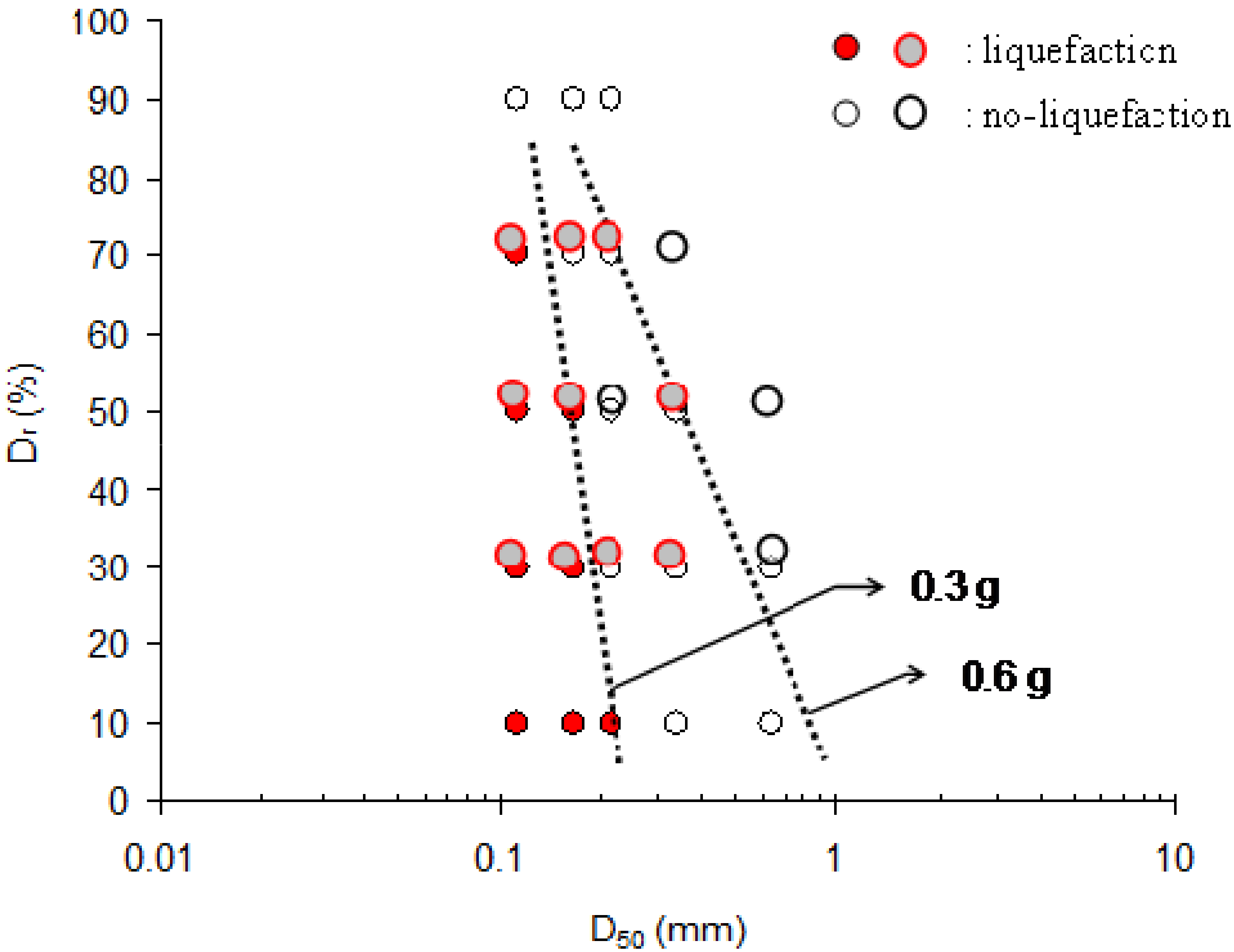
Laboratory Test

Liquefaction Test Results

$$D_r = \left(\frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}} \right) \left(\frac{(\gamma_d)_{max}}{\gamma_d} \right)$$



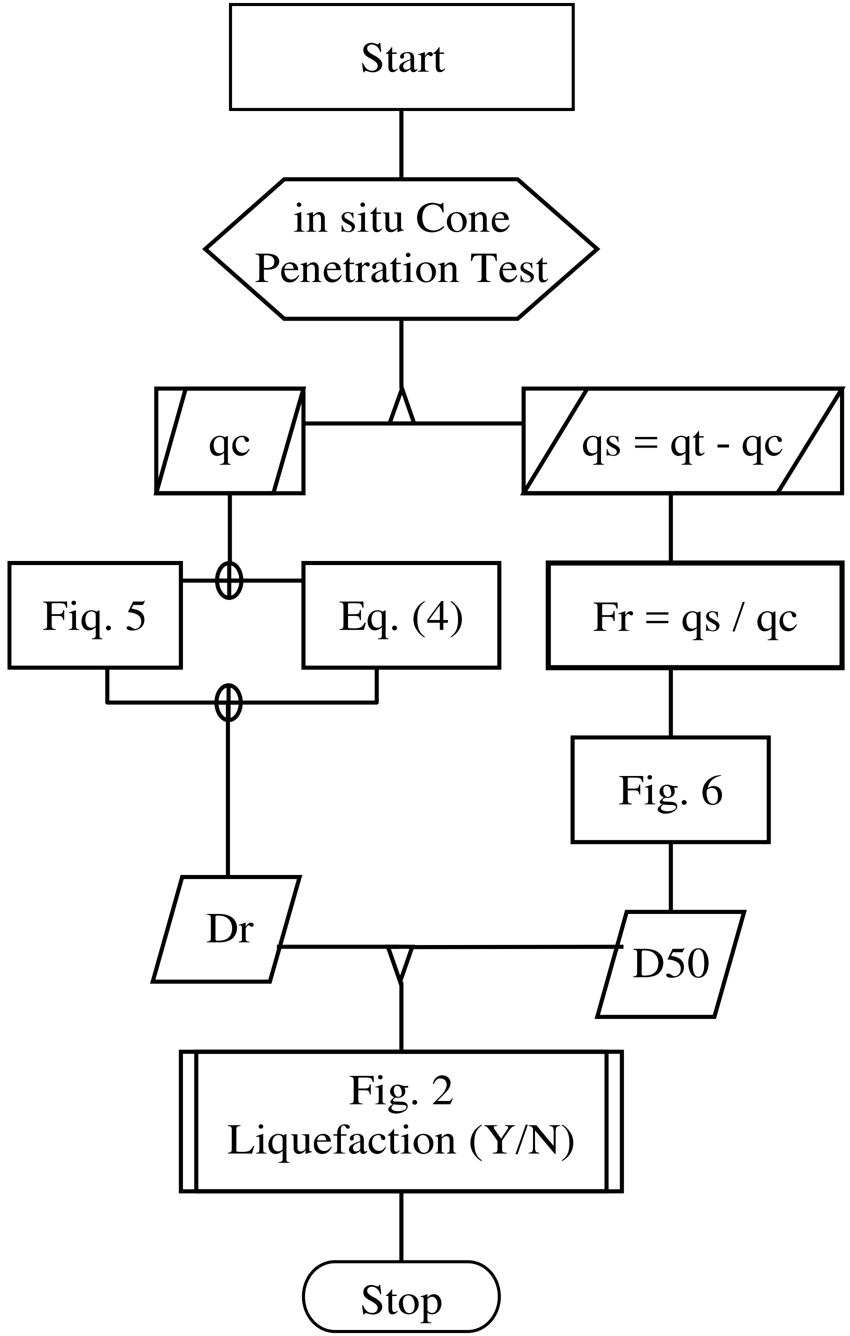
Liquefaction Dr and Size



Important points

- Relative density. (Dr)
- Grain size, (D_{50})
- Maximum acceleration, (a_g)
- The CPT test is the most popular
- CPT is cheap and easy
- Many researches had been done related to CPT

Liquefaction analysis based on CPT: Dr and D_{50}

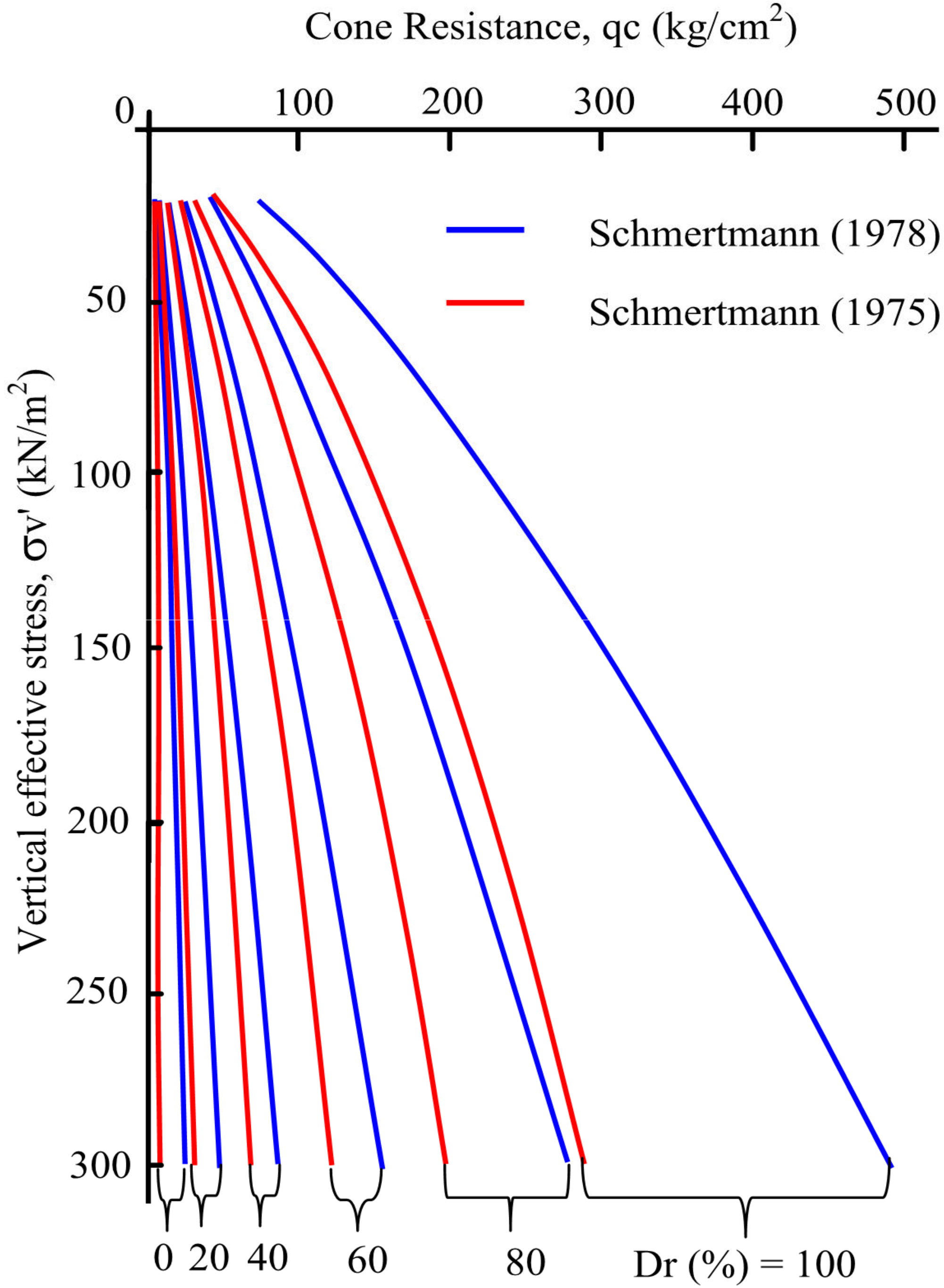


Dr from CPT

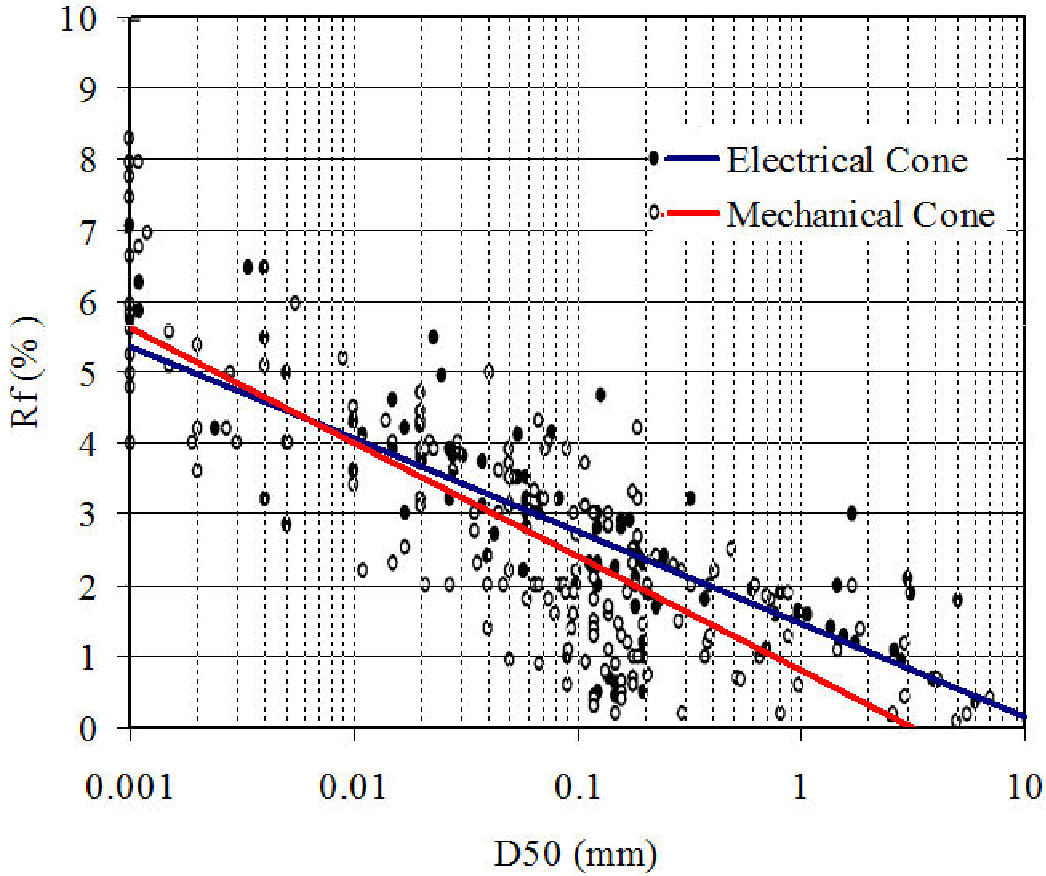
Dr = C2(-1) ln Q/C0

***C0*=15.7, *C2*=2.41 and**
***Q*=(*qc/pa*)/(σv'/*pa*)-0.5.**

Douglas, B. J. and Olsen, R. S. (1981),Soil classification using electric cone penetrometer Cone Penetration Testing and Experience, Proc. of the ASCE National Convention, St. Louis,209-27, American Society of Civil Engineers (ASCE)



D_{50} from CPT



D_{50}= 3.043 e -1.7712 Rf

for mechanical cone

Examples:

Proyek	: SD 02 Malalak Selatan	Tanggal Uji	: 4 April 2010
Lokasi	: Agam	Diuji Oleh	: Dody L
Nomor Titik	:S2	Diperiksa	: A H

Lihat Grafik Samping — Lihat Grafik Samping

Depth (m)	q_c (kg/cm²)	q_t (kg/cm²)	q_s (kg/cm²)	(20/10) q_s (kg/cm²)	Cumulative q_s (kg/cm)	R_f (%)	Water table	γ = 15 kN/m³ $\sigma' = \gamma' \times z$	Dr (%)	D50 (mm)	Jenis (Soil type)	Dr,min 0.3 g	Dr,min 0.6 g	Fi (1 or 0)	Wi	LPI 6.22
0.00	0	0	0	0	0	0.0		0	60	3.078	cS			0	1.5086	0
0.20	10	10	0	0	0	0.0		3.00	60	3.078	cS			0		
0.40	15	15	0	0	0	0.0		6.00	60	3.078	cS			0		
0.60	20	22	2	4	4	0.0		9.00	60	3.078	cS			0		
0.80	20	26	6	12	16	3.0		12.00	60	0.042	fS			0		
1.00	20	26	6	12	28	3.0	m.a.t	15.00	60	0.042	fS			1	1.4306	1.14448
1.20	20	26	6	12	40	3.0		16.40	60	0.042	fS			1		
1.40	23	30	7	14	54	3.0		17.80	60	0.039	fS			1		
1.60	23	30	7	14	68	3.0		19.20	60	0.039	fS			1		
1.80	35	50	15	30	98	4.3		20.60	60	0.007	M			0		
2.00	50	70	20	40	138	4.0		22.00	80	0.010	fS			1	1.3562	1.3562
2.20	70	100	30	60	198	4.3		23.40	90	0.007	M			1		
2.40	75	105	30	60	258	4.0		24.80	100	0.010	fS			1		
2.60	75	100	25	50	308	3.3		26.20	100	0.026	fS			1		
2.80	75	98	23	46	354	3.1		27.60	100	0.038	fS			1		
3.00	70	100	30	60	414	4.3		29.00	100	0.007	M			1	1.2818	1.02544
3.20	70	95	25	50	464	3.6		30.40	100	0.018	fS			1		
3.40	50	75	25	50	514	5.0		31.80	80	0.002	M			0		
3.60	50	70	20	40	554	4.0		33.20	80	0.010	fS			1		
3.80	55	75	20	40	594	3.6		34.60	80	0.017	fS			1		
4.00	55	75	20	40	634	3.6		36.00	80	0.017	fS			1	1.2074	0.96592
4.20	55	73	18	36	670	3.3		37.40	80	0.028	fS			1		
4.40	55	75	20	40	710	3.6		38.80	80	0.017	fS			1		
4.60	60	75	15	30	740	2.5		40.20	80	0.086	fS			1		
4.80	40	60	20	40	780	5.0		41.60	70	0.002	M			0		
5.00	35	40	5	10	790	1.4		43.00	60	0.398	fS			0	1.133	0.6798
5.20	45	60	15	30	820	3.3		44.40	70	0.026	fS			1		
5.40	80	100	20	40	860	2.5		45.80	90	0.086	fS			1		
5.60	85	120	35	70	930	4.1		47.20	90	0.008	fS			1		
5.80	80	96	16	32	962	2.0		48.60	90	0.175	fS			0		
6.00	80	90	10	20	982	1.3		50.00	90	0.513	mS			0	1.0586	0.84688
6.20	65	80	15	30	1012	2.3		51.40	80	0.113	fS			1		
6.40	60	75	15	30	1042	2.5		52.80	70	0.086	fS			1		
6.60	65	85	20	40	1082	3.1		54.20	80	0.037	fS			1		
6.80	80	100	20	40	1122	2.5		55.60	80	0.086	fS			1		
7.00	85	105	20	40	1162	2.4		57.00	80	0.106	fS			1	0.9842	0.19684
7.20																
7.40																
7.60																
7.80																
8.00															0.9098	0
8.20																
8.40																
8.60																
8.80																
9.00															0.8354	0
9.20																
9.40																
9.60																
9.80																
10.00															0.761	0
10.20																
10.40																
10.60																
10.80																
11.00															0.6866	0
11.20																
11.40																
11.60																
11.80																
12.00															0.6122	0
12.20																
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13.00															0.5378	0
13.20																
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13.60																
13.80																
14.00															0.4634	0
14.20																
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14.80																
15.00															0.389	0
15.20																
15.40																
15.60																
15.80																
16.00															0.3146	0
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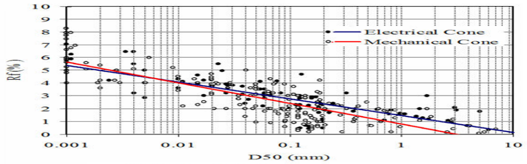
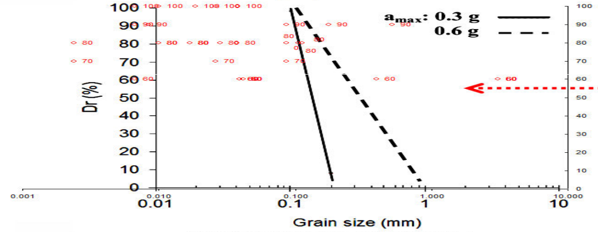
16.80																
17.00															0.2402	0
17.20																
17.40																
17.60																
17.80																
18.00															0.1658	0
18.20																
18.40																
18.60																
18.80																
19.00															0.0914	0
19.20																
19.40																
19.60																
19.80																
20.00															0.017	0
20.20																
20.40																
20.60																
20.80																
21.00															0.017	0

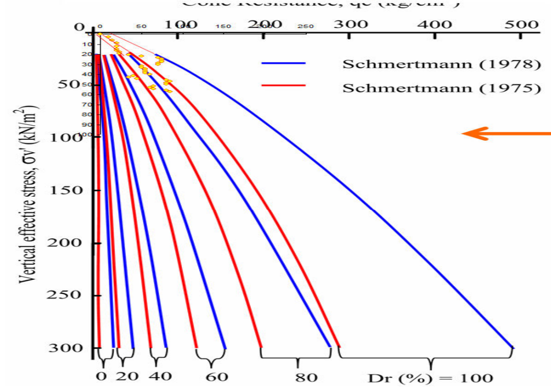
KESIMPULAN:

Potensi BESAR terlikuifaksi

LPI	Iwasaki [2]	Luna-Forest [6]	Chung et al [7]
0	VeryLow	Little to None	None
0-5	Low	Minor	Little to None
5-15	High	Moderate	Moderate
. 16	VeryHigh	Major	Severe

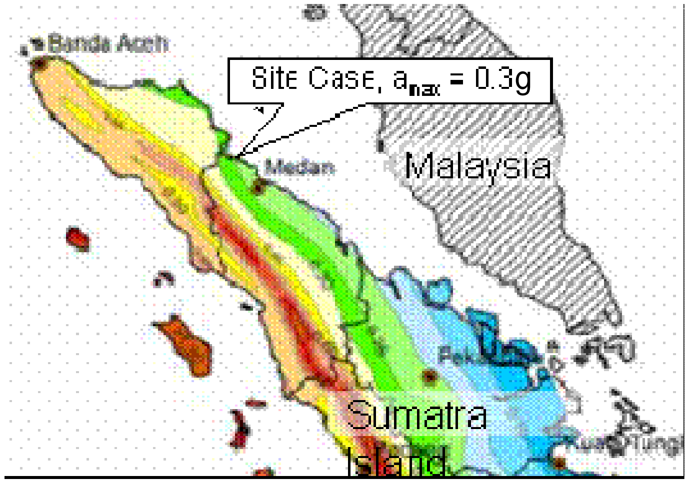


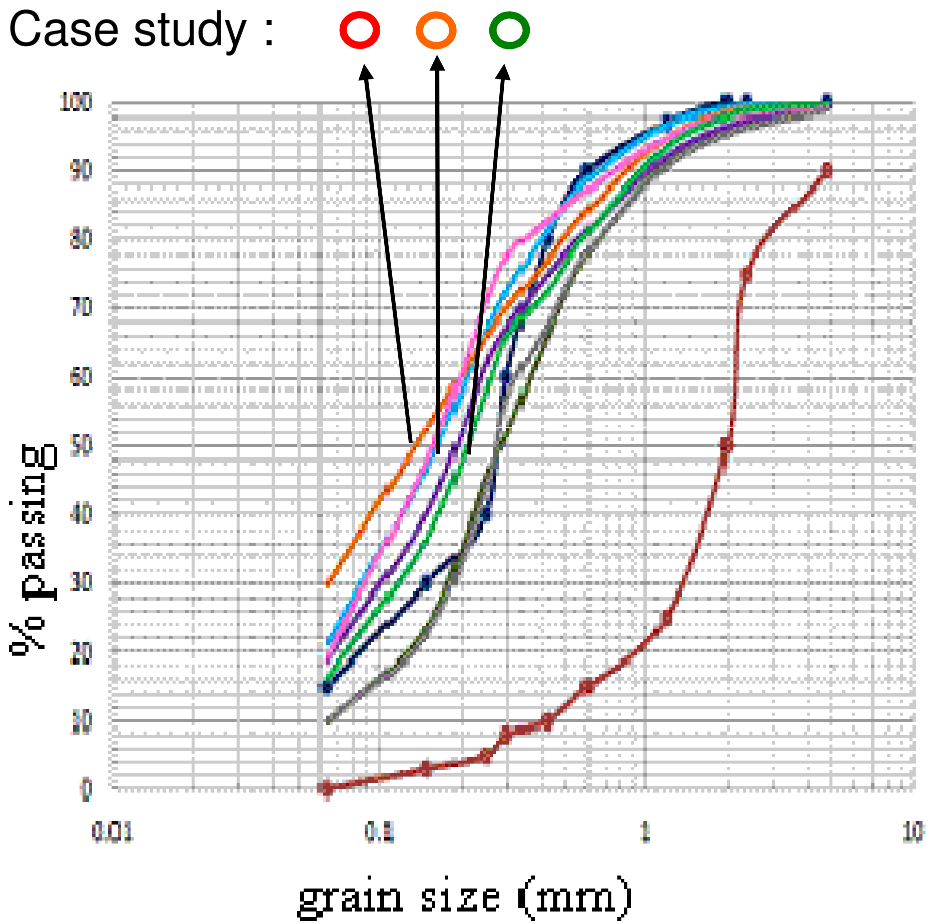




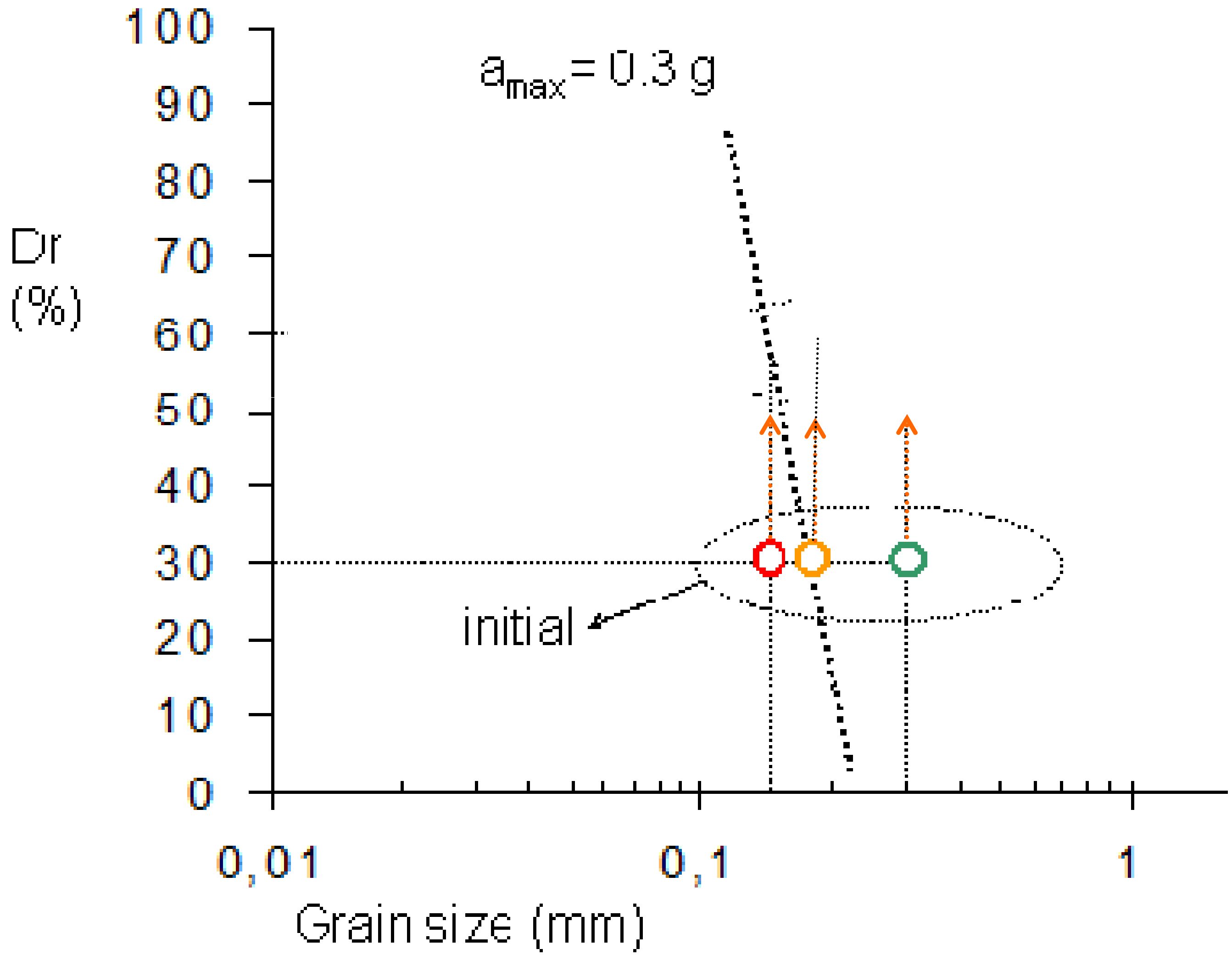
Application of the method

- **Particle distribution of Reclamation sand**





Assessment Results



Conclusions

- Liquefaction hazard must be assessed and plotted in a map. The assessment method is not difficult and expensive to be employed.
- The liquefaction potential assessment based on the relative density and the mean particle size must will practically cheap.
- The analysis of the case studies show that the analysis liquefaction performs good.
- The problem is to get correct good soil investigation data which were tested properly.

Thanks