Eidgenössische Technische Hochschule Zürich

Condition indicators for soil behavior under earthquake loading

Juliane Buchheister

Jan Laue

Institute for IGT Geotechnical Engineering

MERCI

Overview

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2. Identification of relevant soil indicators
3. Procedure for liquefaction susceptibility, example application
4. Experiments
5. Conclusions
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Introduction

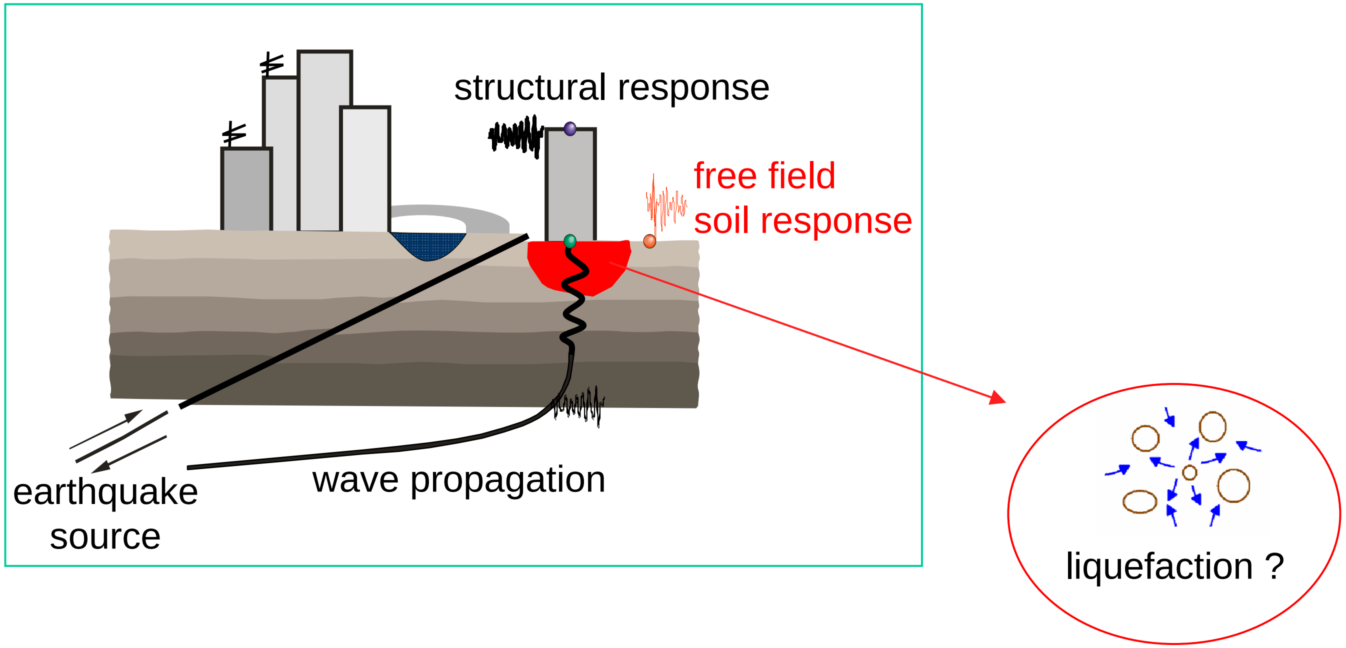


Fig 1: Schematic picture of the earthquake phenomenon with focus on the soil behavior

Identification of relevant soil indicators

First step: Study of codes - different site classification procedures

e.g. Comparison EC (a), NEHRP (b) and TC (c) in an area of Adapazari

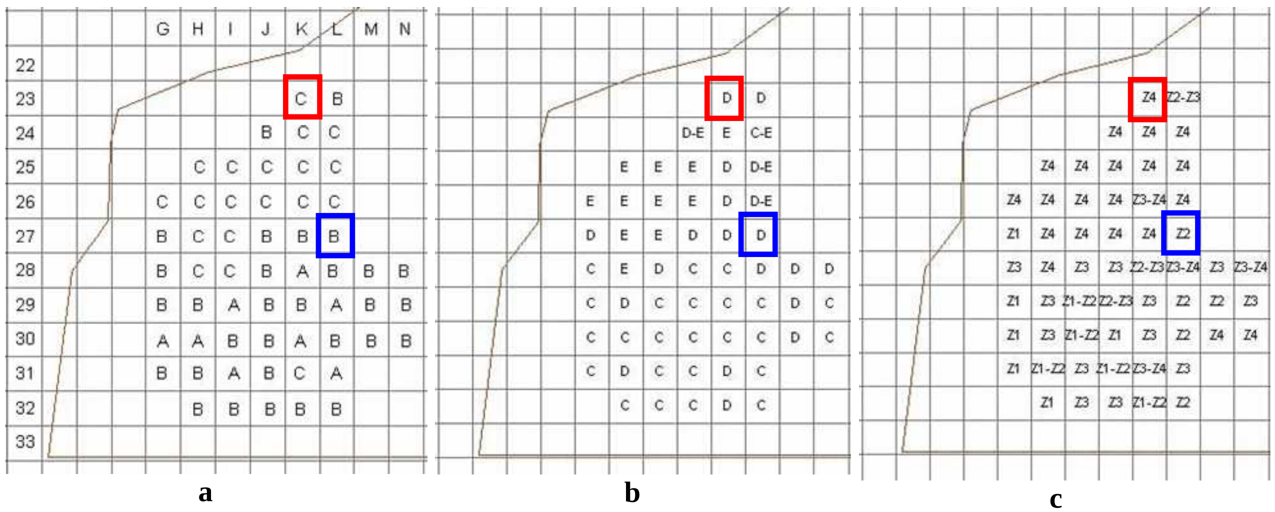


Fig 2: Comparison of the soil classification based on a cutout of the south area of Adapazari: (a) Eurocode Soil Classes (b) NEHRP Site Classes (c) Turkish Code Local Site Classes

Identification of relevant soil indicators

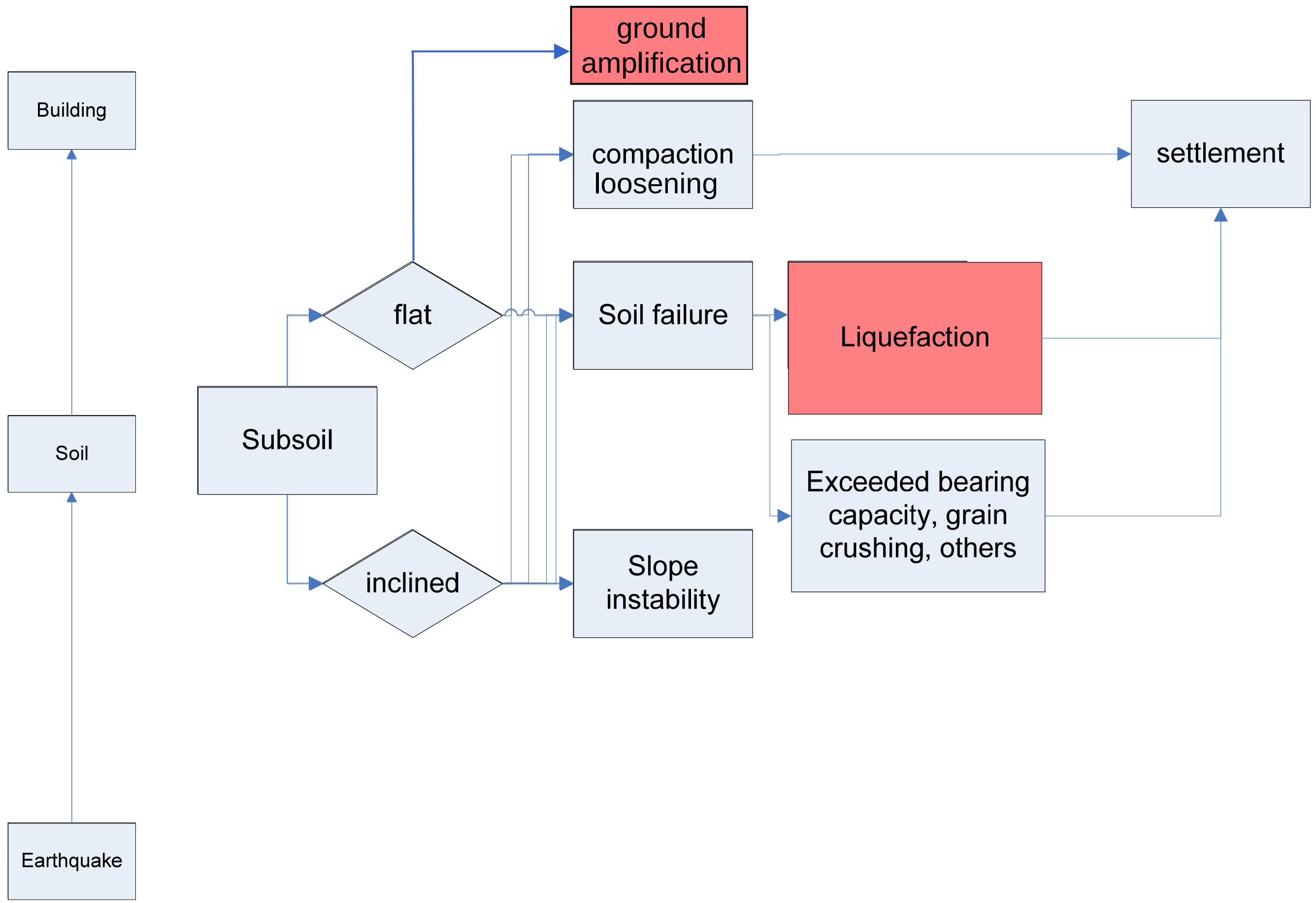


Fig 3: Flow chart of the fist ideas

Identification of relevant soil indicators

BPN soil part

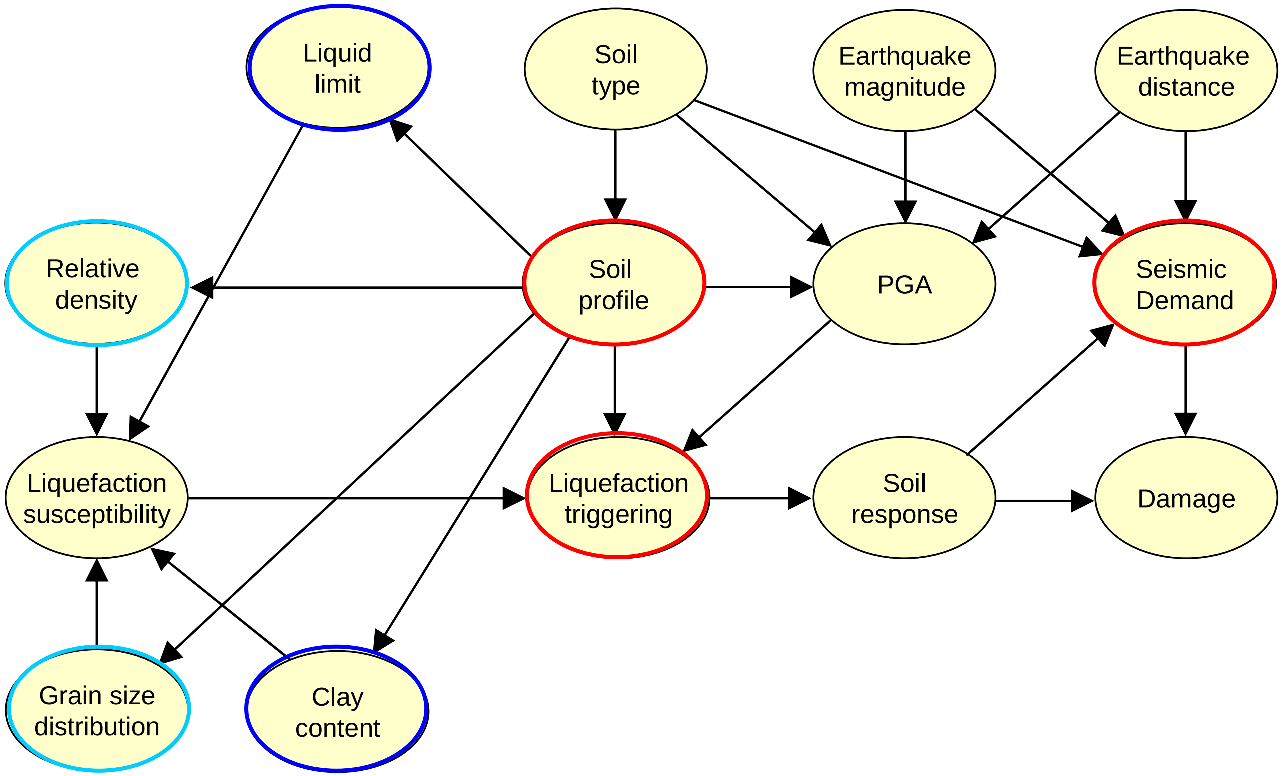


Fig 4: Bayesian network of the condition indicators in the soil (Buchheister et al., 2006)

Identification of relevant soil indicators: ground amplification

Determination by site response analysis

-> Use of shake type program (1D)

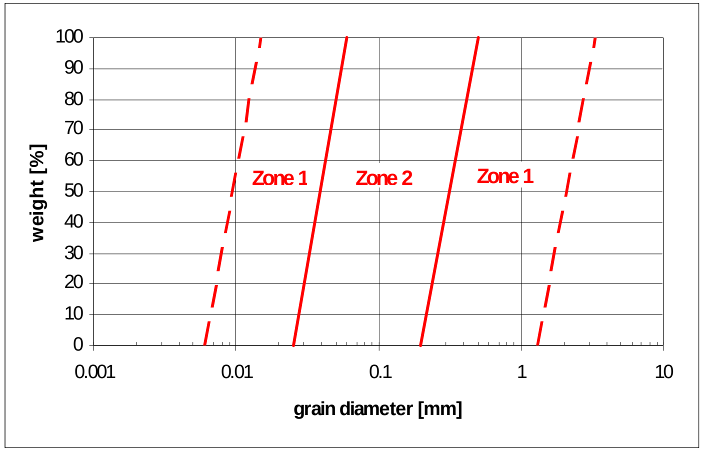
-> Indicators:

- Soil layer thickness,
- unit weight,
- maximum shear modulus or shear wave velocity,
- modulus reduction curve and damping ratio curve.

⇒ (de-) amplification of the earthquake loading due to the subsoil

Procedure for liquefaction susceptibility

lab criteria KTA (coarse grained soils) + MCC (fine grained soils)



	Liquid Limit, LL<32%	Liquid Limit, LL≥32%
Clay Content <10%	GW-GM, GP-GM GW-GC, GP-GC GM, GM-GC SW-SM, SP-SM SW-SC, SP-SC SM ,SC, SM-SC ML	
Clay Content ≥10%	GC SM-SC CL-ML CL	MH, CH ML CL-ML CL

field criterion: simplified procedure

Fig 5: Grain size distribution zones according to the German nuclear safety standard KTA

Tab 1: Liquefaction susceptibility for USCS classified soils based on typical classification parameters. Cycled soil types produce controversial results.

Procedure for liquefaction susceptibility

Classification only based on the grain size distribution curve -> difficult for classification of silty sand

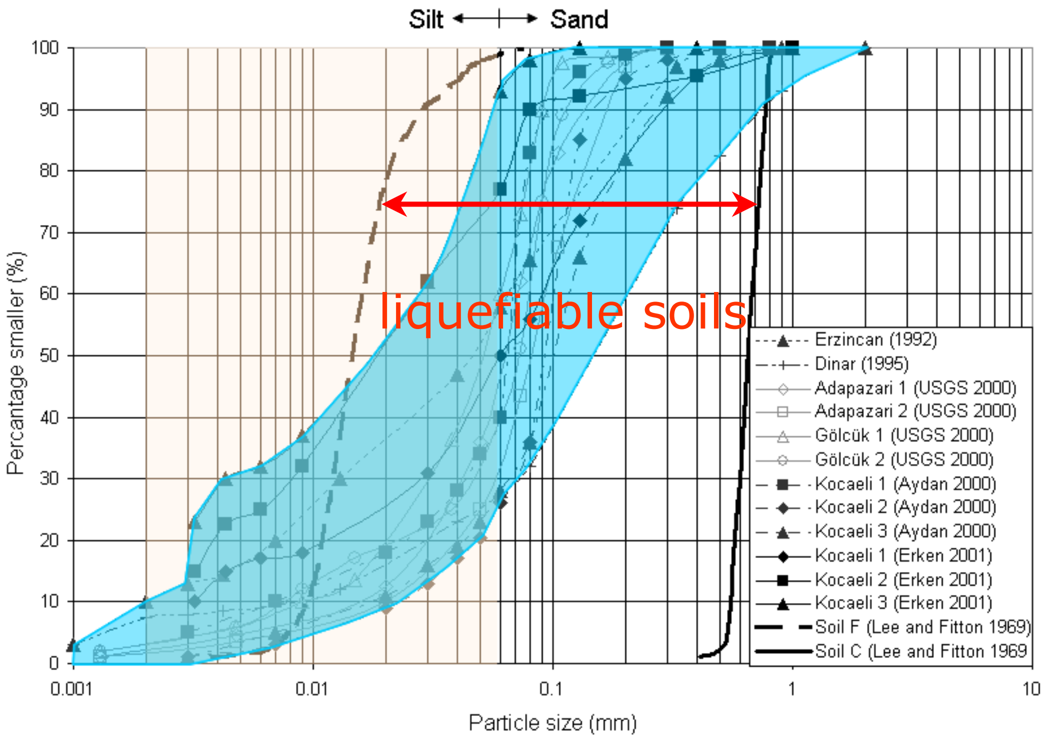
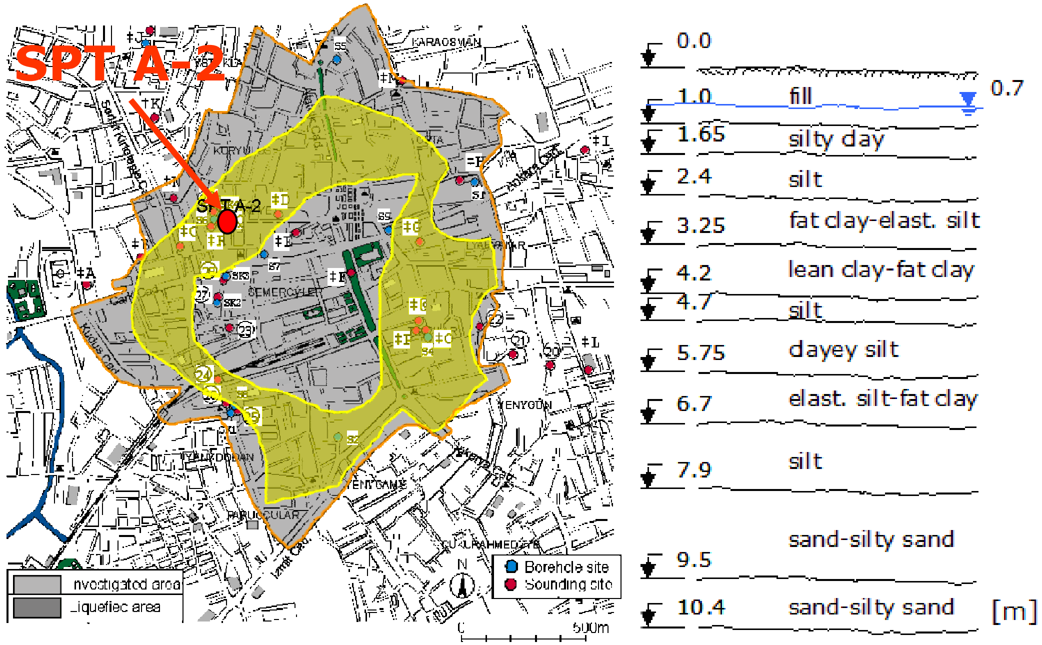


Fig 6: Baysian network of the condition indicators in the soil (Laue and Buchheister 2005)

Procedure for liquefaction susceptibility

Example: investigation at a known liquefied site in Adapazari



Location of site (Swedish Sounding)

Fig 7: Boring profile SPT A-2 [PEER 2000] in the liquefied area [investigated area after Yasuda in Ansal 2004] (Buchheister et al., 2006)

Procedure for liquefaction susceptibility

Comparison of a deterministic and probabilistic approach

layer	USCS soil type	MCC	criterion of KTA	F.S. of simplified procedure
1	Fill	-	-	-
2	ML/CL	x	-	1.09 liquefaction
3	ML	x	-	1.13 liquefaction
4	CH/MH	not susceptible	x	
5	CL/CH	x	-	0.71 liquefaction
6	ML	not susceptible	liquefaction possible	1.28 no liquefaction
7	CL	x	-	
8	MH/CH	not susceptible	no liquefaction to be expected	0.67 liquefaction
9	ML	not susceptible	liquefaction possible	0.85 liquefaction
10	SP-SM	-	liquefaction possible	
11	SP-SM	-	liquefaction possible	1.17 liquefaction

7.0	10	n.a.	11.19	2.417	n.a.	99.93	0.084	n.a.	99.95	0.113	n.liq.	9.009
	20	n.a.	0.210	0.078	n.a.	98.60	0.056	n.a.	99.88	0.093	n.liq.	0.077
	40	n.a.	0	0.017	n.a.	0.104	0.039	n.a.	0.123	0.035	n.liq.	0.043
	80	n.a.	0	0.011	n.a.	0.035	0.023	n.a.	0.031	0.028	n.liq.	0.028
7.5	10	n.a.	99.94	99.98	n.a.	99.95	99.93	n.a.	99.94	99.93	n.liq.	99.21
	20	n.a.	7.930	3.905	n.a.	99.93	0.095	n.a.	99.94	0.108	n.liq.	0.095
	40	n.a.	0	0.025	n.a.	5.35	0.046	n.a.	60.31	0.046	n.liq.	0.047
	80	n.a.	0	0.006	n.a.	0.083	0.019	n.a.	0.039	0.035	n.liq.	0.031

Tab 2: Summary of results of the deterministic approach (Buchheister et al., 2006)

Tab 3: Summary of results of the probablistic approach (Buchheister et al., 2006)

Open questions

not included in the selected procedure for liquefaction susceptibility:

- influence of the loading function
- influence of the stress state
- influence of the fines content, especially silt (complex subdivision between plastic and non plastic fines)

Idea for further research

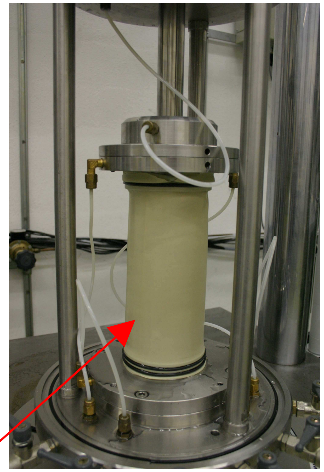
Liquefaction influencing parameters

f (relative density, grain size distribution, soil type, grain texture and structure, consolidation stresses, stress-strain history, intensity and duration of the earthquake)

=> detailed investigation into the stress state and loading function of silty sand with laboratory experiments

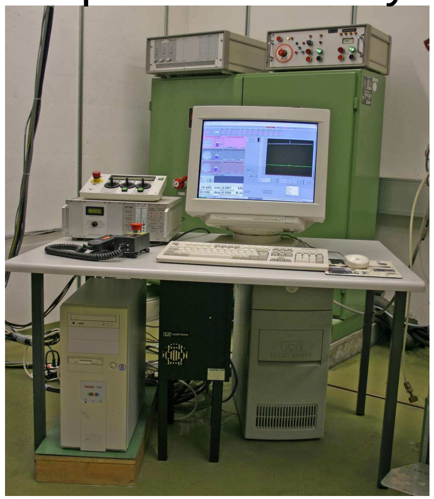
Hollow Cylinder Apparatus (HCA)

hydraulic load frame



soil specimen
100 x 50 x 200 mm

computer control system



pressure control unit

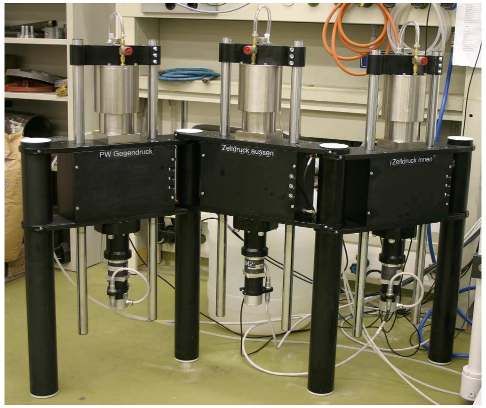


Fig 8: Hollow Cylinder Apparatus of the Institute for Geotechnical Engineering

HCA Experiments on fine sand

- Fine sand, sub-rounded to rounded grains, medium dense, fully saturated, anisotropic stress state
- Cyclic loading:
  - sine wave, deformation controlled
  - torsional f=1 Hz und A=1°
  - axial f=0.7 Hz and A=1mm
- Three experiments:
  - cyclic axial test
  - cyclic torsional test
  - cyclic axial and torsional test

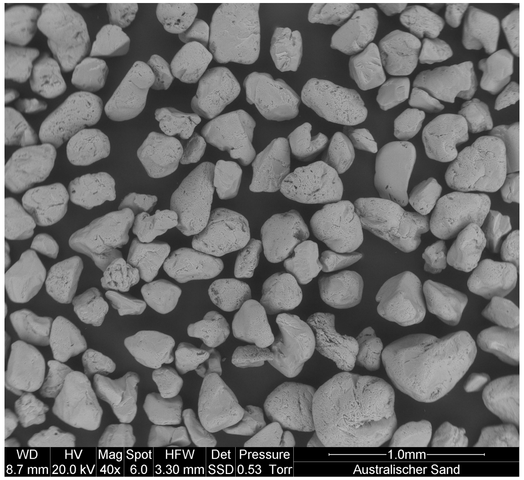
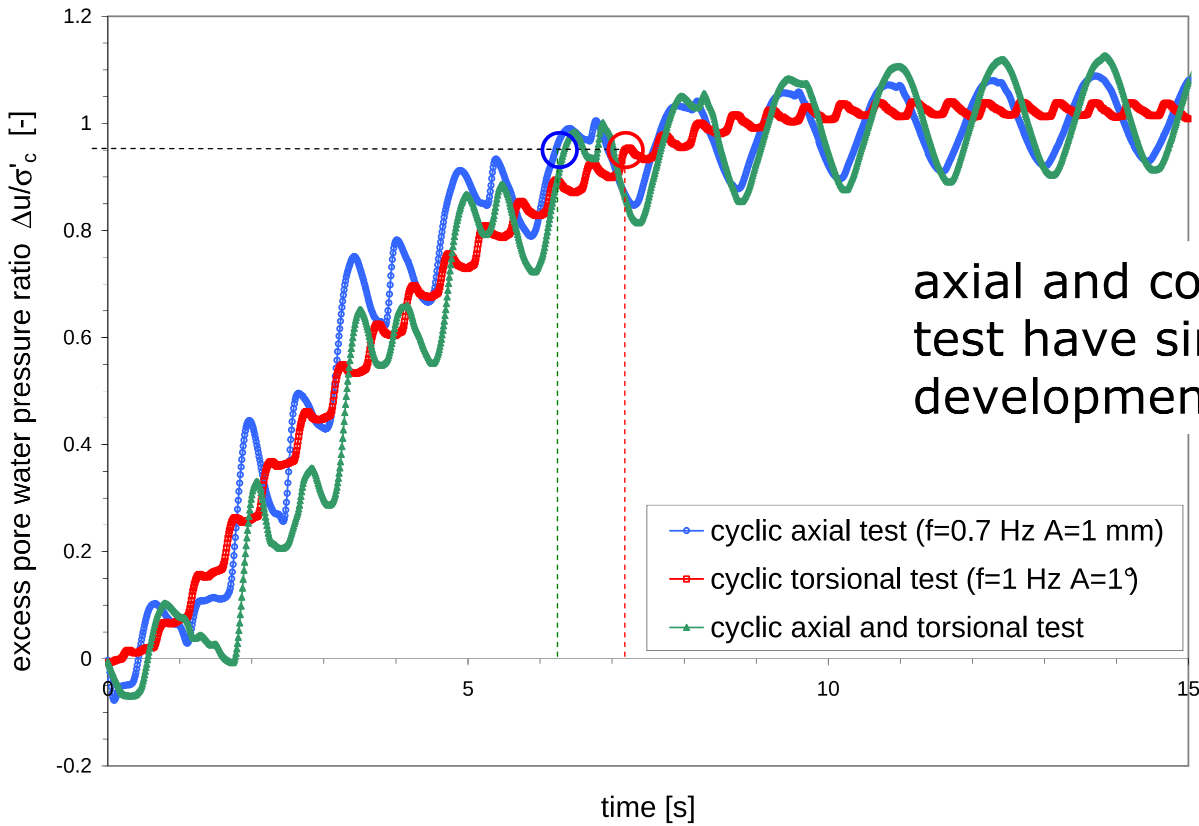


Fig 9: 40x magnification of grain size

HCA Results of first test series: Pore water pressure development



axial and combined test have similar Δu development

Fig 10: Pore water pressure development of all three tests (Buchheister and Laue, 2006)

Conclusions

- Relevant condition indicators for the soil part have been identified, focus is on liquefaction and ground amplification,
- Procedure for the liquefaction susceptibility is set up and implemented in the Bayesian network,
- Hollow cylinder test results show a promising way to investigate the mechanical behavior of silty and sandy soil due to earthquake loading.

Outlook

Secondary effects (non linear behavior) are not included in the state of the art

- Increase of pore water pressure reduces stiffness of the soil
- Deformation changes the soil density
  i.e. loose soil can densify -> v_s increases, whereas dense soil can dilate -> v_s decreases,
- Topographic influences,
- Anisotropic conditions.

Outlook

- investigation of ground motion characteristics,
- HCA experiments research stress state, silty soil,
- comparison to field data,
- find new condition indicator, based on mechanical properties, permeability and pulse period.

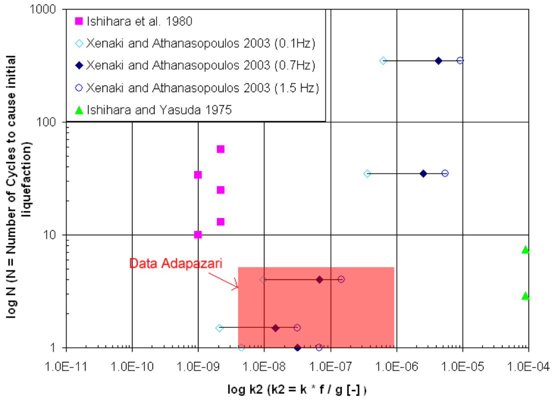


Fig 11: Number of cycles vs. the new factor "k2" (Laue and Buchheister, 2004)