Paris, January 27th 2015

Comité Français de Mécanique des Sols et de Géotechnique

PIERRE FORAY MEMORIAL

BEHAVIOR OF SOILS UNDER STATIC, CYCLIC AND DYNAMIC LOADINGS

ZELAZNY MOST - POLAND

TAILINGS STORAGE FACILITY GEOTECHNICAL CHARACTERIZATION OF COPPER TAILINGS

Michele Jamiolkowski – Emeritus Professor

Politecnico di Torino

2013 FACTS FILE

ZELAZNY MOST COPPER TAILINGS POND

Maximum dam height: 63 m

Total volume stored: 527×10^6 m^3

Storage rate: $\cong 17.5 \times 10^6$ m^3/annum

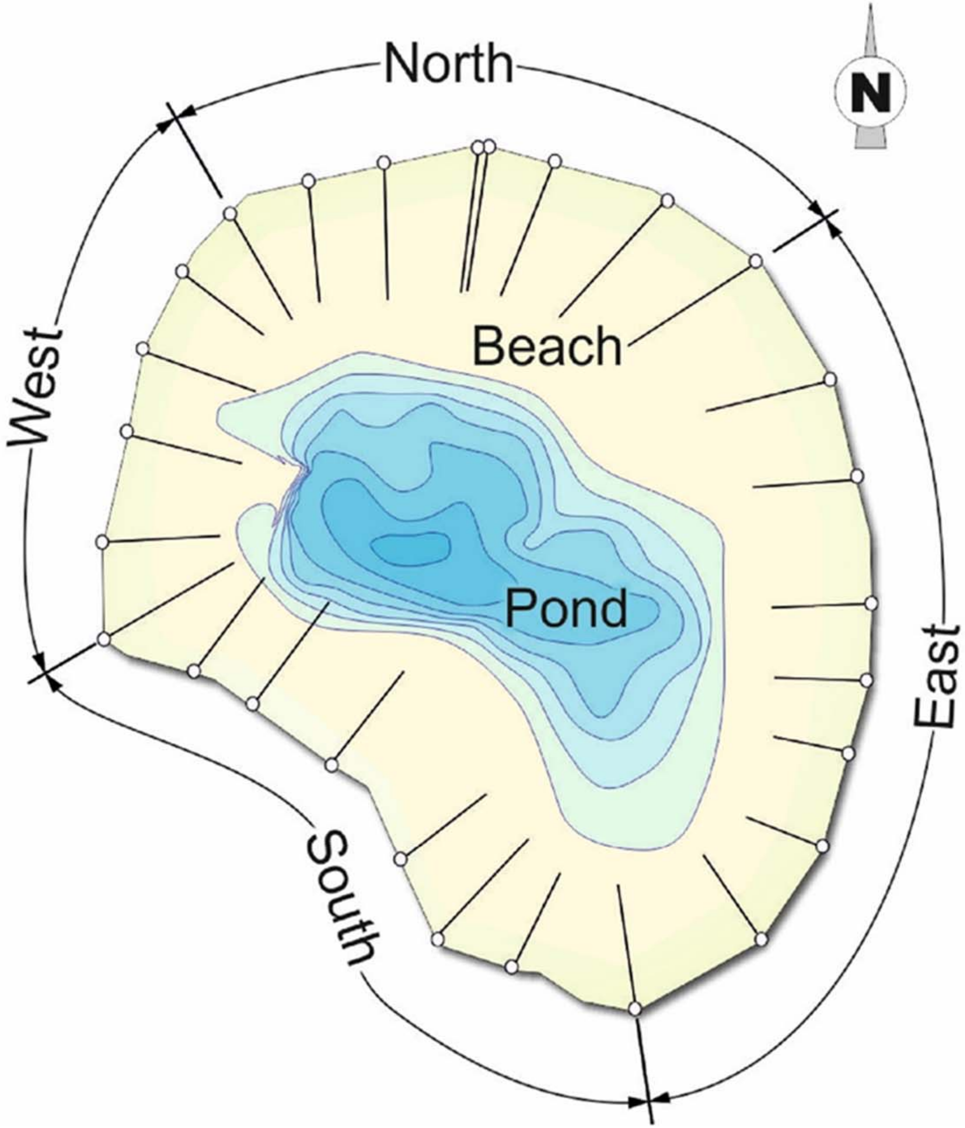
Area covered: 12.4 km^2

Total length of dam: 14.3 km

Operation period: 1977 to 2042

DAM HEIGHT AND CREST ELEVATION
Updated at December 2013

ZELAZNY MOST COPPER TAILINGS POND



Dams Height, m	
North:	39
West:	49
South:	34
East:	63

Crest Elev., m asl	
North:	177.5
West:	177.5
South:	177.0
East:	177.5

INTERNATIONAL BOARD OF EXPERTS: IBE

ZELAZNY MOST COPPER TAILINGS POND

CONSIDERING:

- DEPOSITORY OPERATION TIME: 1977→2042
- SCALE OF FACILITY AND LOCAL POPULATION
- RING DAM STABILITY: A GEOTECHNICAL CHALLENGE

IN 1992 POLISH GOVERNMENT AND MINE, ON WORLD BANK RECOMMENDATION, APPOINTED A FOUR-MEMBER IBE:

→ Dr. D. CARRIER, (USA)
→ Prof. K. HØEG (NORWAY)
→ Prof. R.D. CHANDLER (UK)
→ Prof. M. JAMIOLKOWSKI (ITALY)

TO OVERSEE, WITH POLISH EXPERT PROF. W. WOLSKI, THE SAFE TAILINGS DAMS CONSTRUCTION VIA OBSERVATIONAL METHOD [PECK (1969,1980)]

GEOTECHNICAL CHARACTERIZATION OF TAILINGS

ZELAZNY MOST COPPER TAILINGS POND

Selected Topics

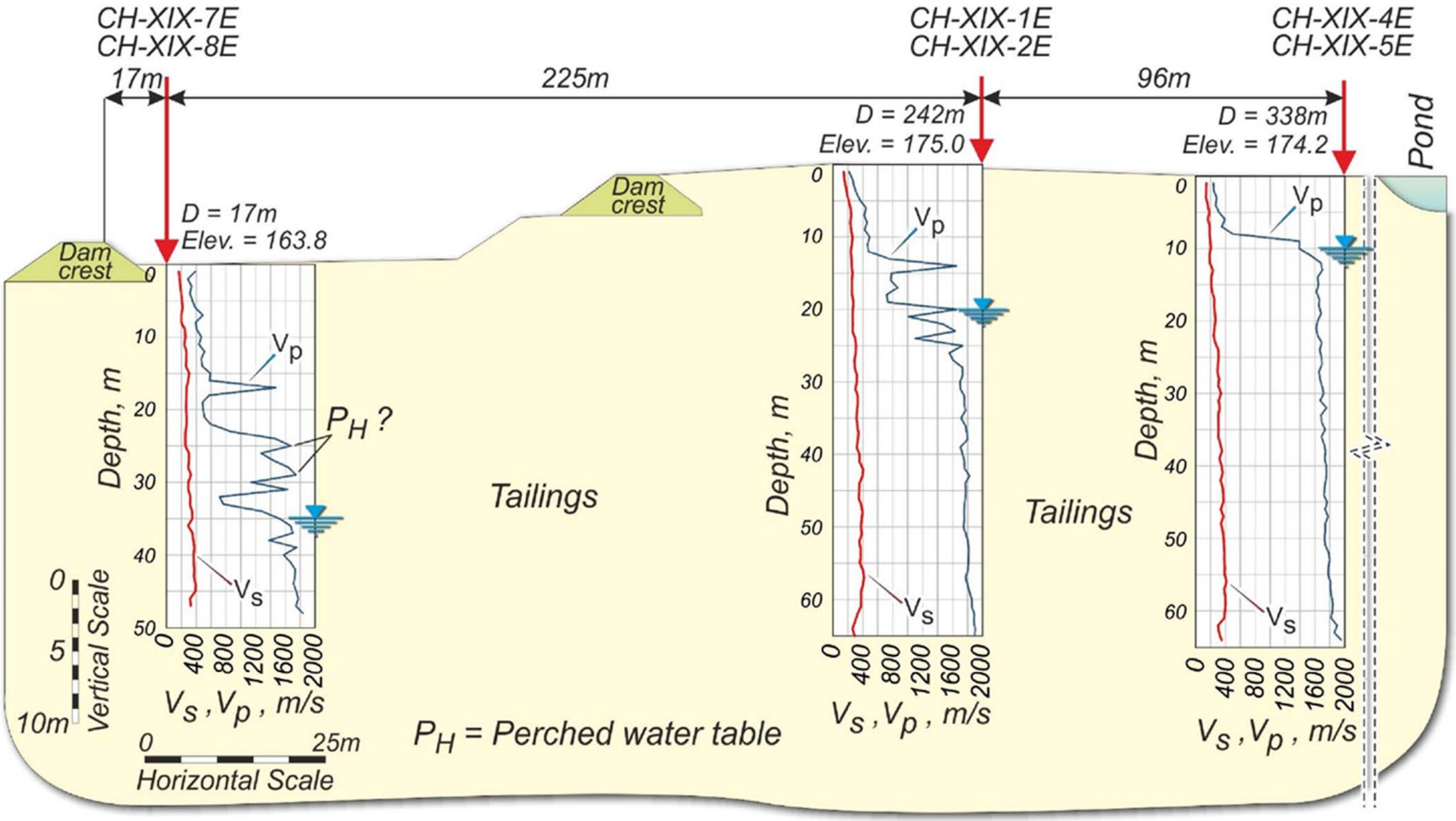
In situ tests

- Spatial variability → S-CPTU, S-DMT (V_s & V_{s1})
- Location of the saturation surface → CHT (V_p)
- Evaluation of in situ porosity → CHT (V_p & V_s)

Laboratory tests on undisturbed samples retrieved from hand-dug pits using gel-push piston sampler

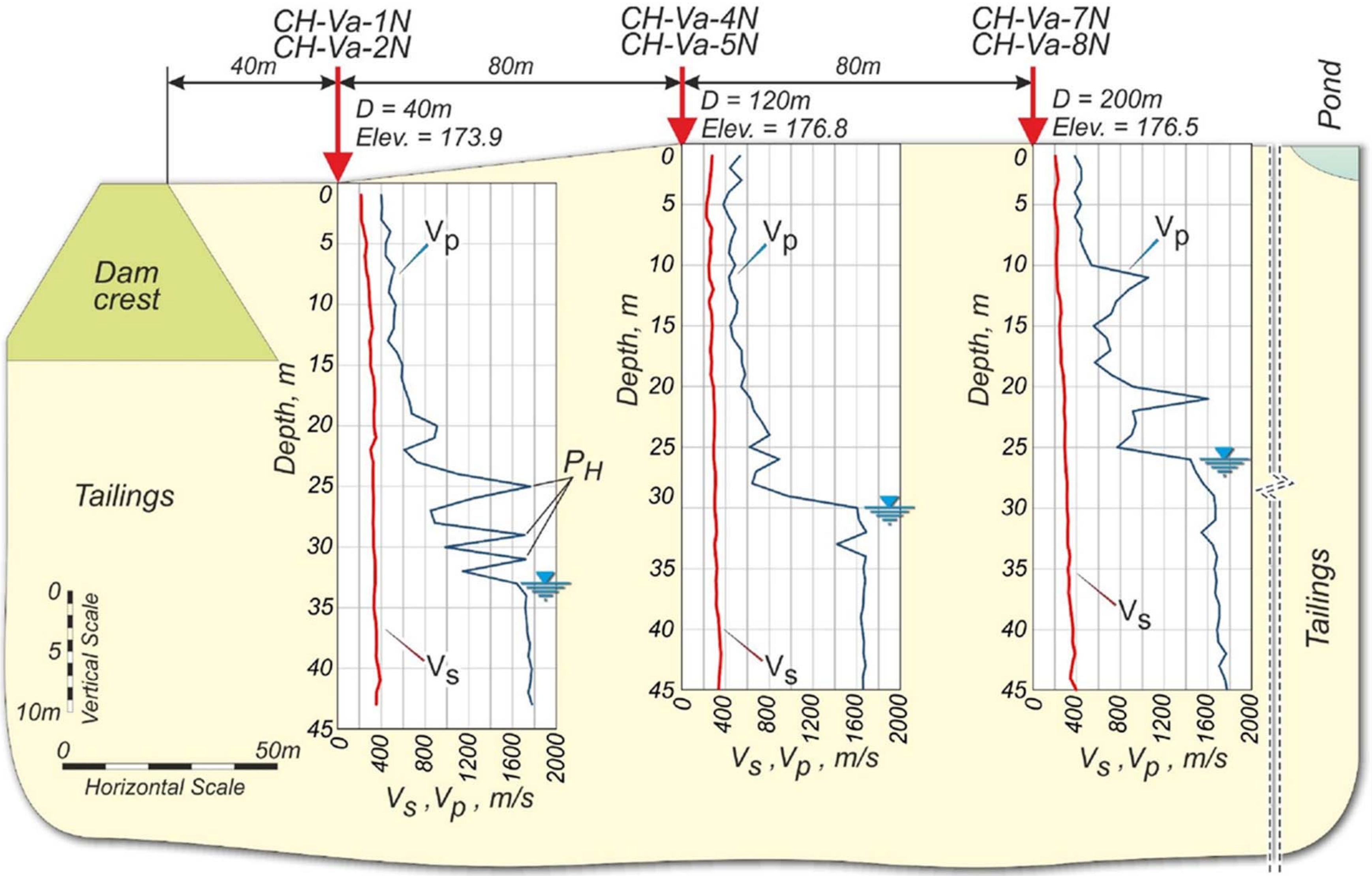
- Index properties and grading
- Monotonic undrained triaxial compression tests (TX-CIU & TX-CK_0U) → susceptibility to flow failure

2014 - Est Dam - Location of Saturation Line from V_p measurements



2014 - North Dam - Location of Saturation Line from V_p measurements

ZELAZNY MOST COPPER TAILINGS POND



DEPTH TO SATURATION LINE IN TAILINGS

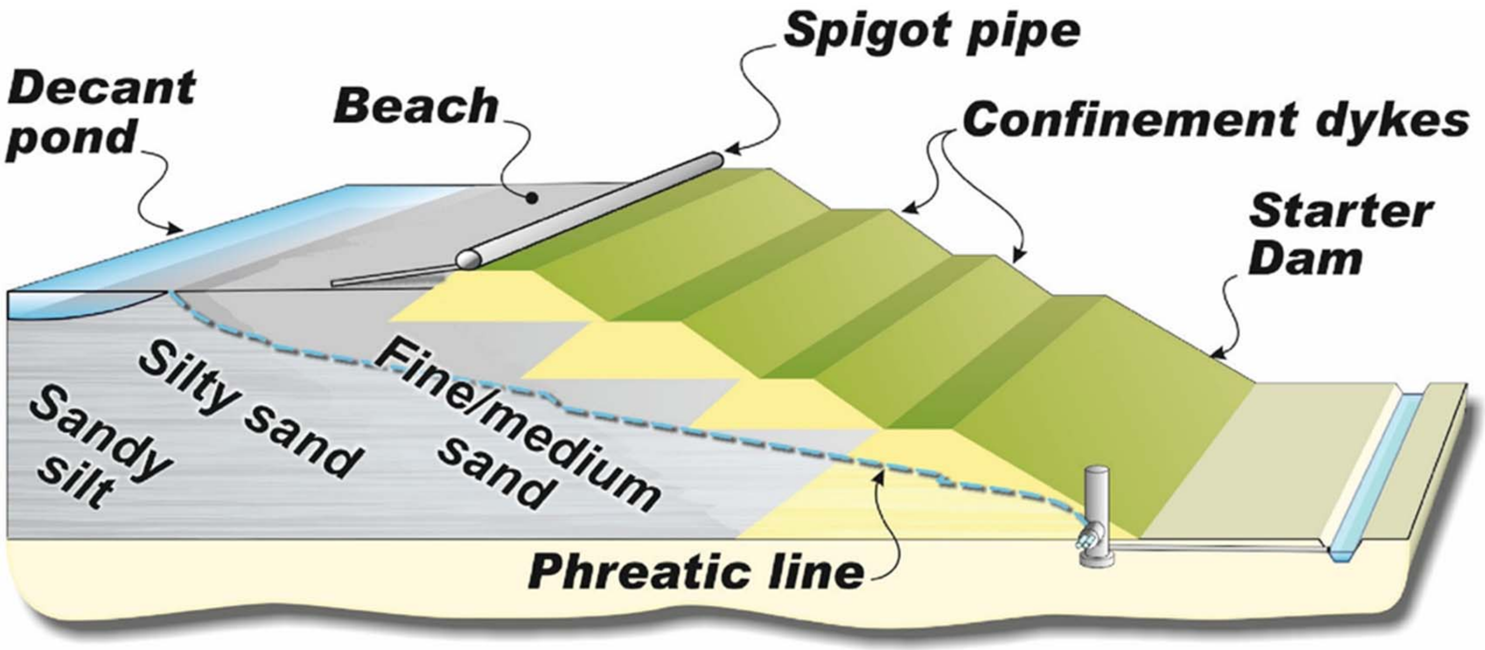
Cross-section	Lc (m)	Ds (m)	Elev. (m asl)	Lc (m)	Ds (m)	Elev. (m asl)
Year	2011			2014		
XIXE	17	37	165	17	36	165
	242	16	170	242	20	175
	338	8	170	338	11	175
VaN	40	31	171	40	32	174
	120	25	171	242	30	176
	200	21	170	338	24	176
VIIIW	41	29	171	41	33	174
	132	20	171	242	23	174
	217	9	170	338	17	174

Lc = distance from the dam crest; Ds = depth to saturation line

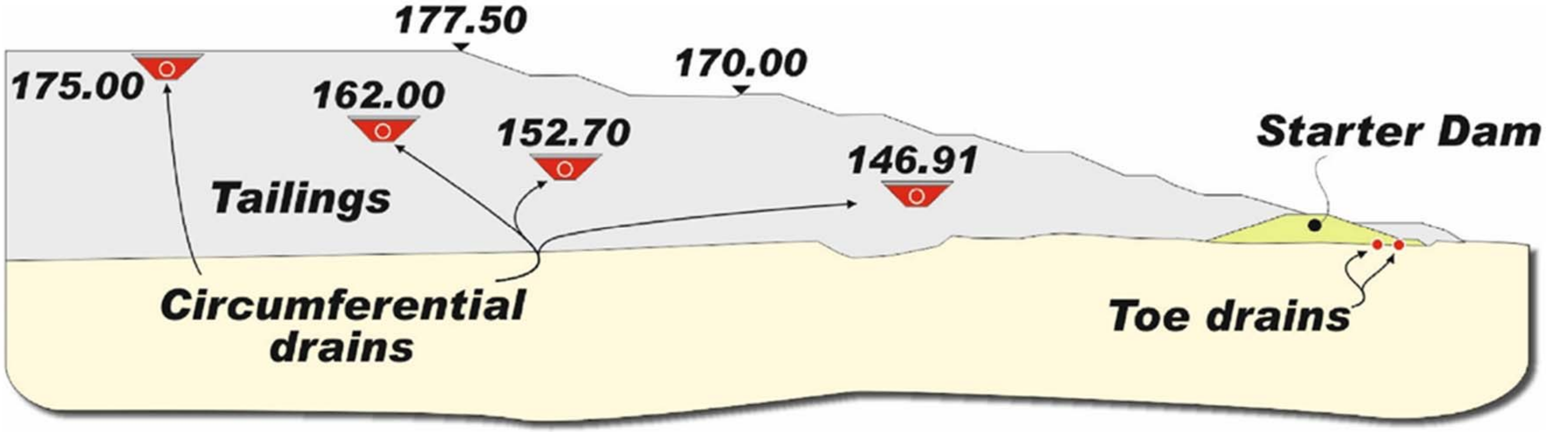
RING DAM - SCHEMATIC CROSS-SECTIONS

ZELAZNY MOST COPPER TAILINGS POND

UPSTREAM METHOD

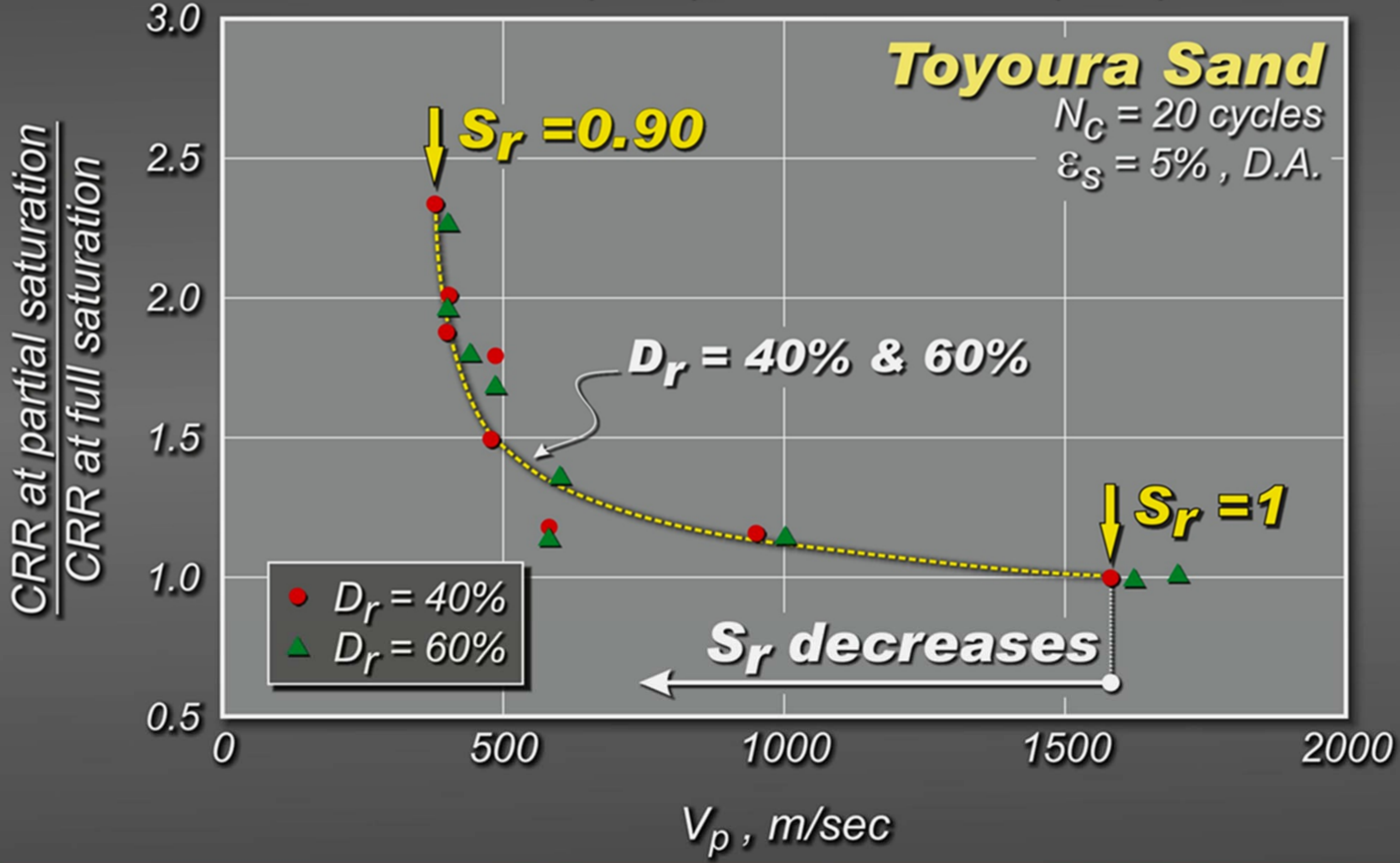


INTERNAL DRAINAGE SYSTEM



NORMALIZED CRR IN NEARLY SATURATED SAND vs. COMPRESSION WAVE VELOCITY

Ishihara et al (1998), Tsukamoto et al (2001)



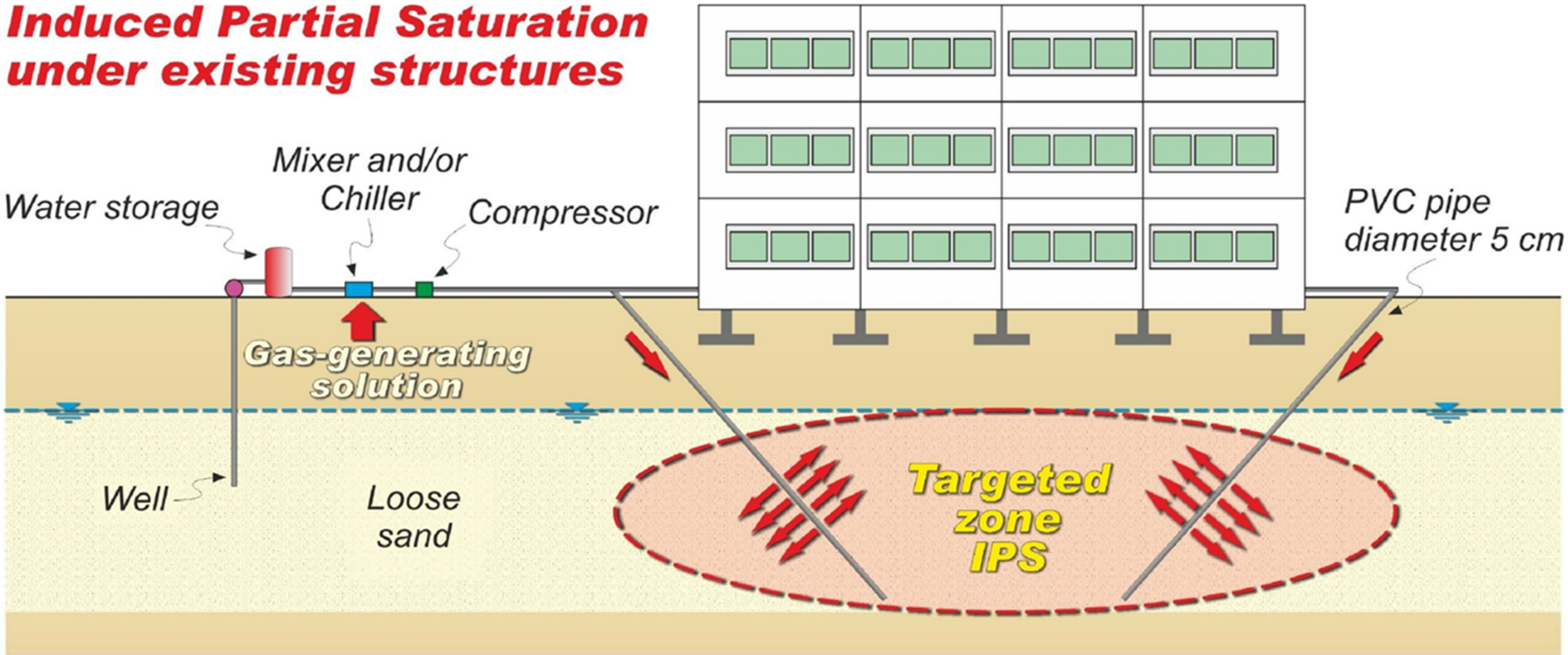
Alleviating Soil Liquefaction by Induced Partial Saturation

Jay Landers, ASCE Civil Engineering, N°S, 212, Research Project sponsored by U.S. NSF & NEES

Principal Researchers:

North-Eastern University, Prof. M. Yegian & Prof. A. Alsha W. Abebkeh
State University of NY at Buffalo, Prof. S. Thevanayagam
University of Texas at Austin, Prof. K.H. Stokoe
Boise State University, Prof. A. Farid

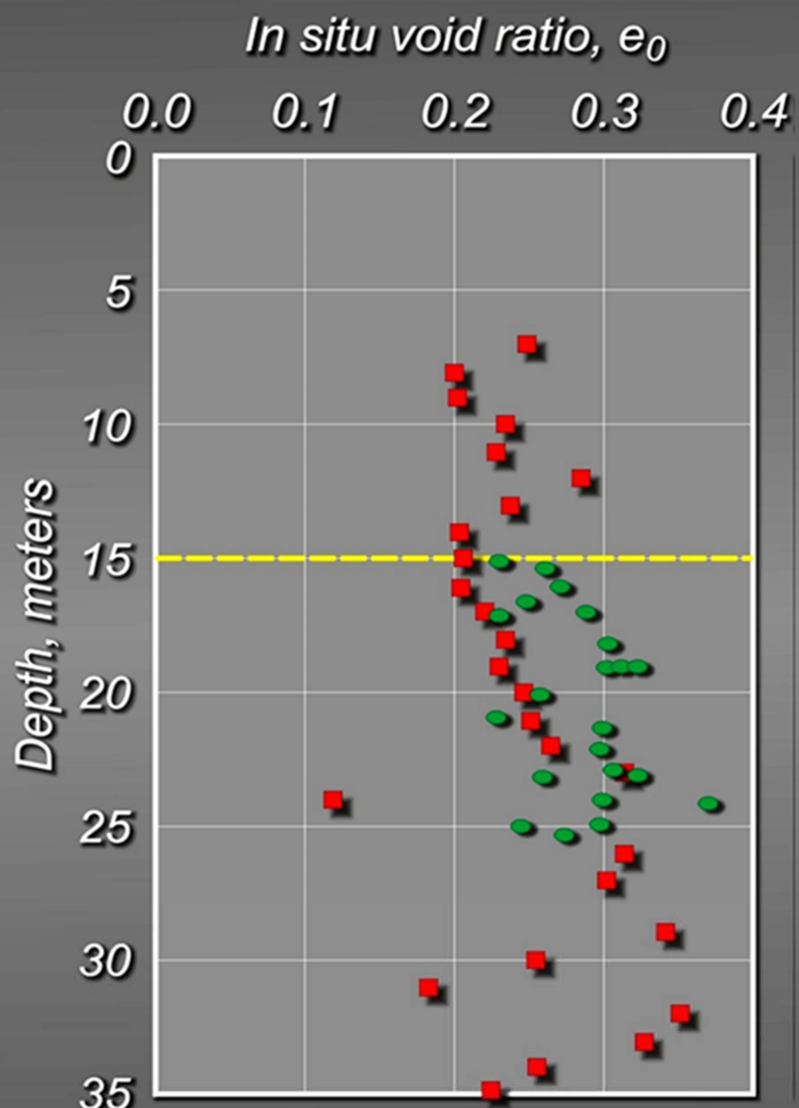
Induced Partial Saturation under existing structures



Injection of water containing low concentration of dissolved ecofriendly chemicals generating gas bubbles conferring a near to saturated state

MESSINA STRAIT – FROZEN SAMPLES

MESSINA STRAIT BRIDGE – SICILY TOWER
VOID RATIO OF UNDISTURBED* SAMPLES VS. COMPUTED



$$n = \frac{\rho_s - \left[\rho_s^2 - \dfrac{4(\rho_s - \rho_f)K_f}{V_p^2 - 2\left(\dfrac{1-\nu_s}{1-2\nu_s}\right)V_s^2}\right]^{0.5}}{2(\rho_s - \rho_f)} \quad **$$

$\left.\begin{array}{l}\rho_s = \text{soil particles} \\ \rho_f = \text{pore fluid}\end{array}\right\}$ mass density

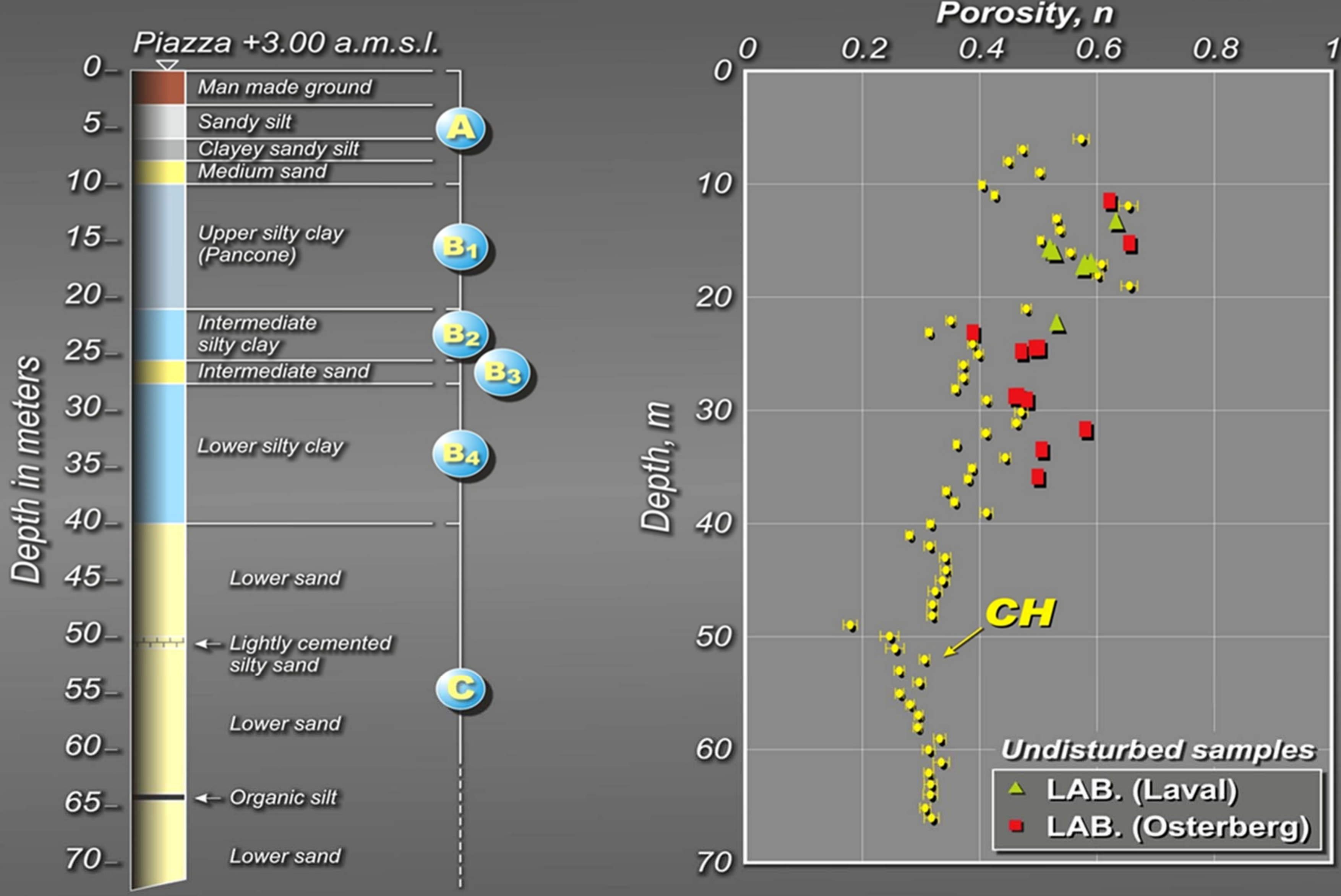
K_f = bulk modulus of pore fluid

ν_s = Poisson ratio of soil skeleton

- Laboratory tests
- From V_s and V_p, CH tests

(*) Retrieved by means of in situ freezing; (**) Foti et al. (2002) formula

PISA CLAY - POROSITY FROM CH TESTS



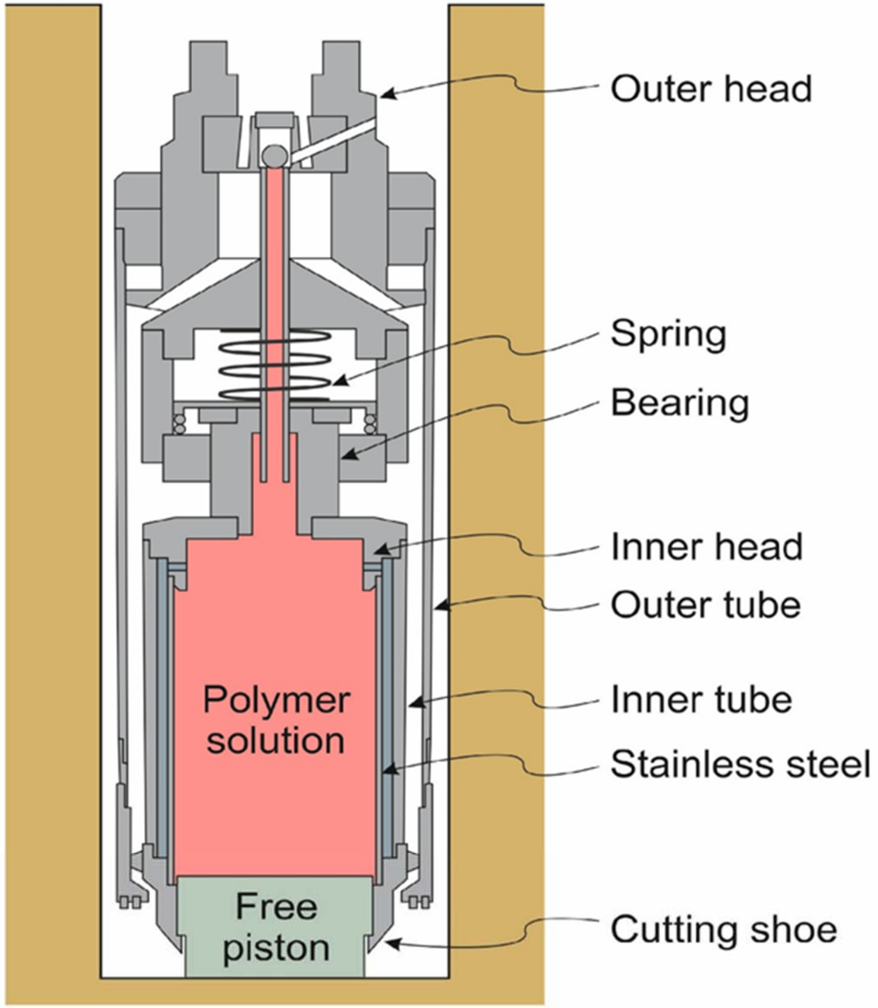
SAMPLING OF TAILINGS FROM THE BEACH

ZELAZNY MOST COPPER TAILINGS POND

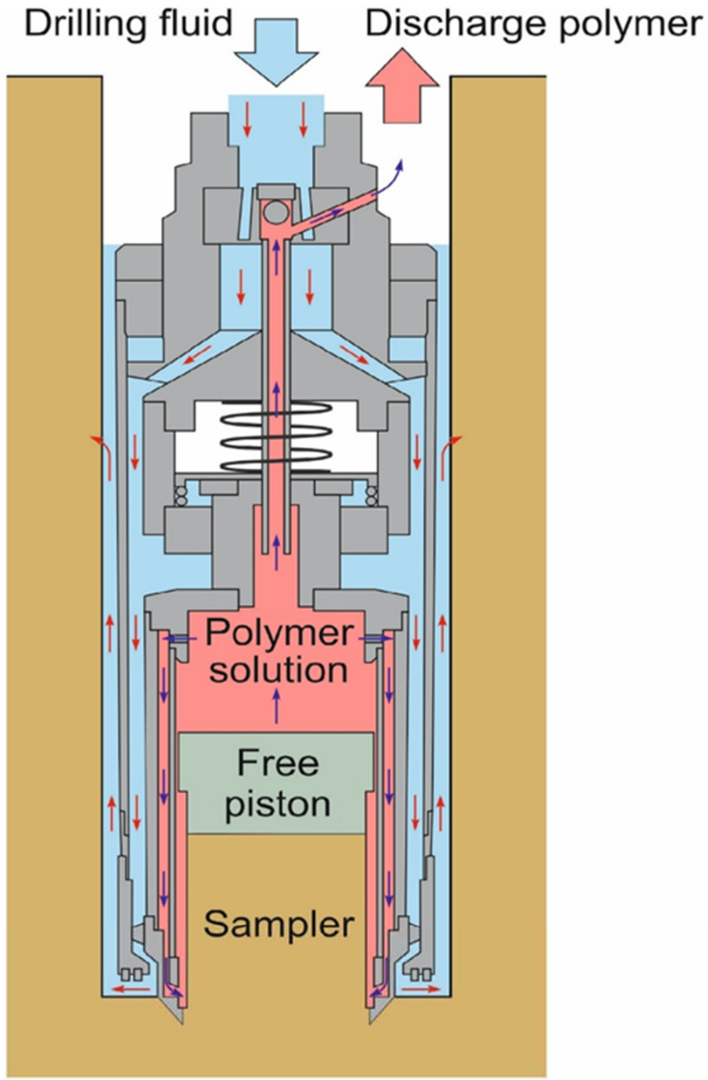
- **3m deep trenches excavated in the beach**
- **Thin wall (2mm) stainless steel cylinders (D=70mm, H=140mm) with sharp cutting edges pushed into the soil**
- **Retrieved samples subject to consolidated undrained triaxial tests**

GEOTEKO (2011)

GEL PUSH SAMPLER



a) Lowering down the sampler to the bottom of borehole

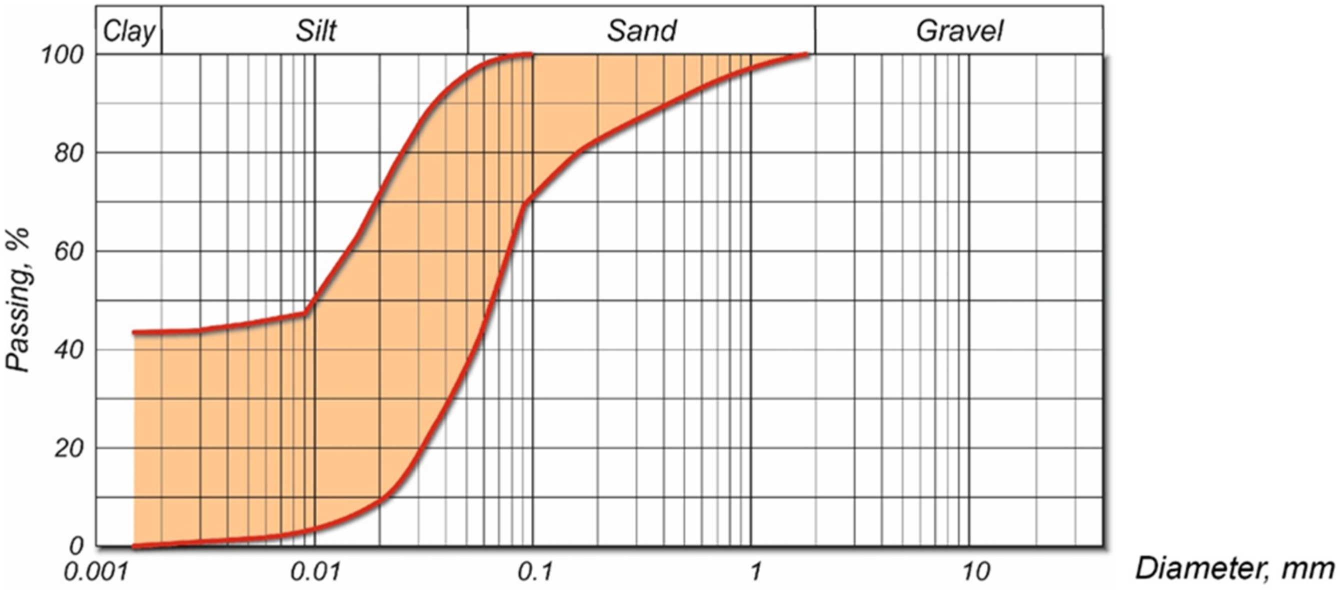


b) During sampling (flow of drilling fluid and polymer solution)

→ Flow of drilling fluid
→ Flow of polymer solution

ZELAZNY MOST COPPER TAILINGS POND

OVERALL GRADING OF TAILINGS



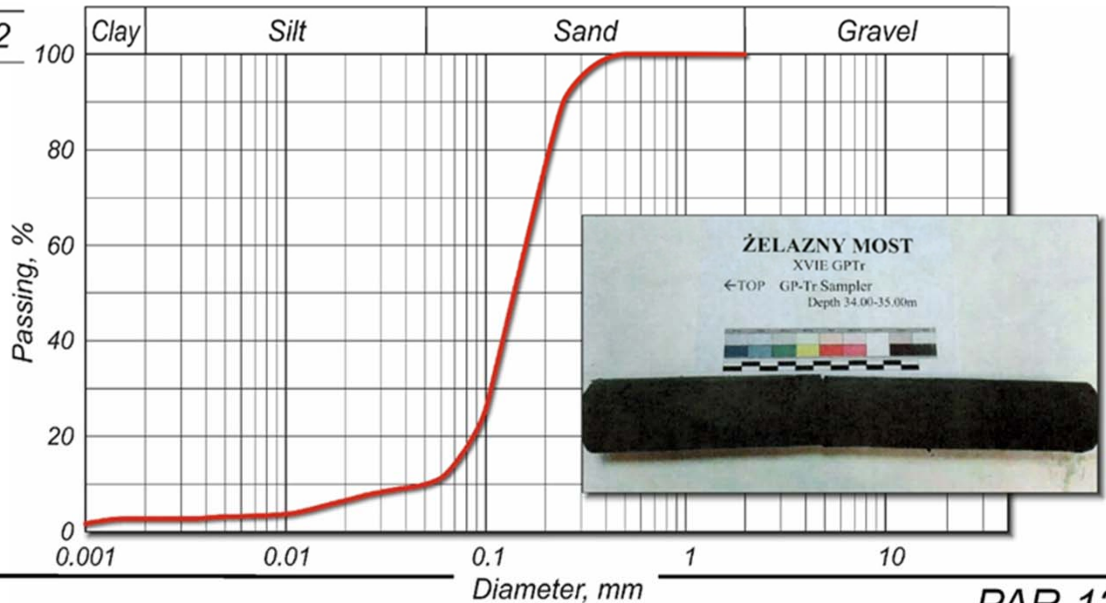
GEL-PUSH SAMPLE OF SILTY SAND – 3rd TRIAL*

$e_0 = 0.895$; $\gamma = 18.6\ kN/m^3$; $G = 2.745$; $5.25 \leq SFR \leq 7.62$

Lenght 520 mm; Diameter 72 mm

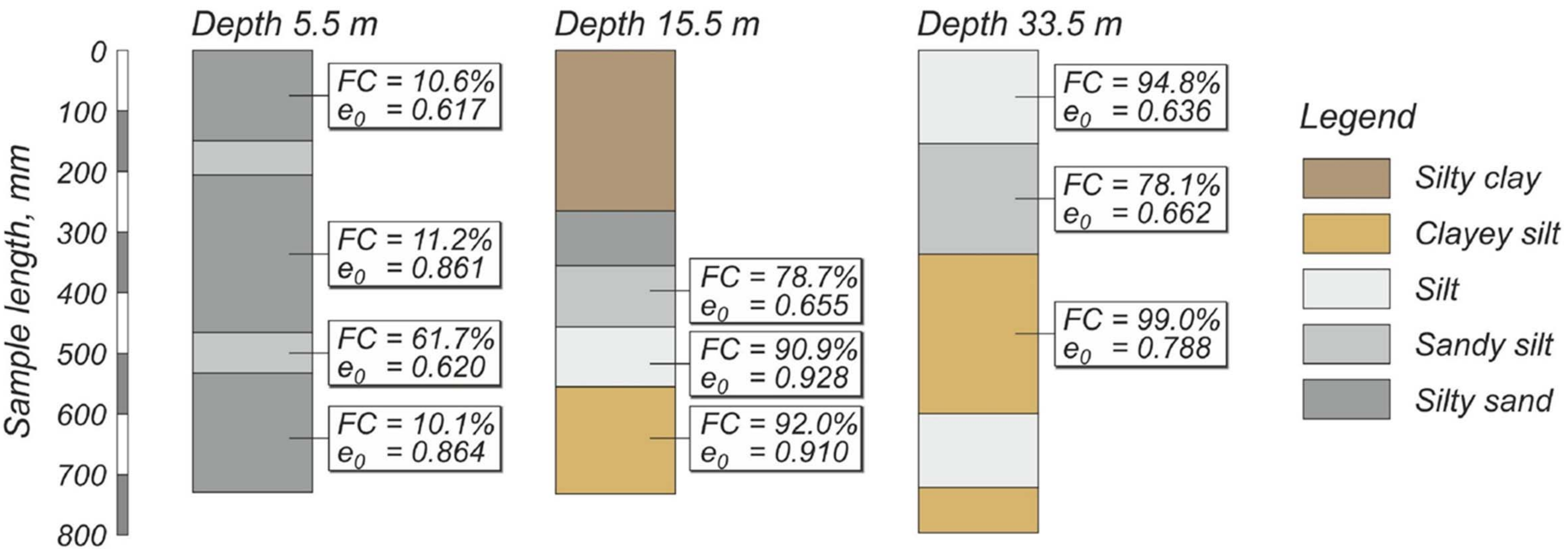
Coarse tailings used to build the dam shell

(*) 3rd trial, carried out close to the dam crest, Section XVIE



UNDISTURBED TAILINGS CORES RETRIEVED USING G-P TR SAMPLER*

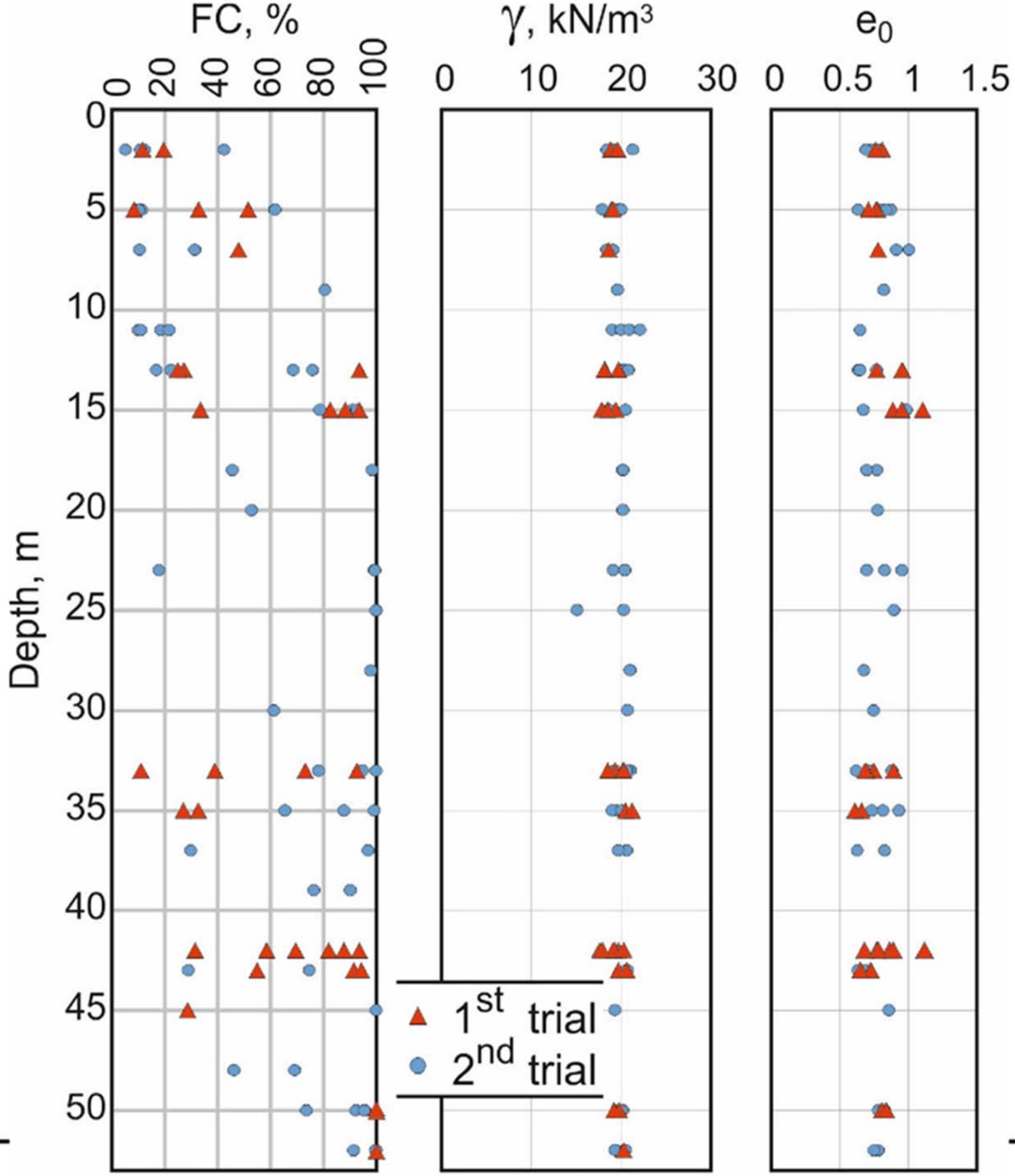
ZELAZNY MOST COPPER TAILINGS POND



(*) 3rd Trial, January 2014

Index properties of ZM tailings of G-P

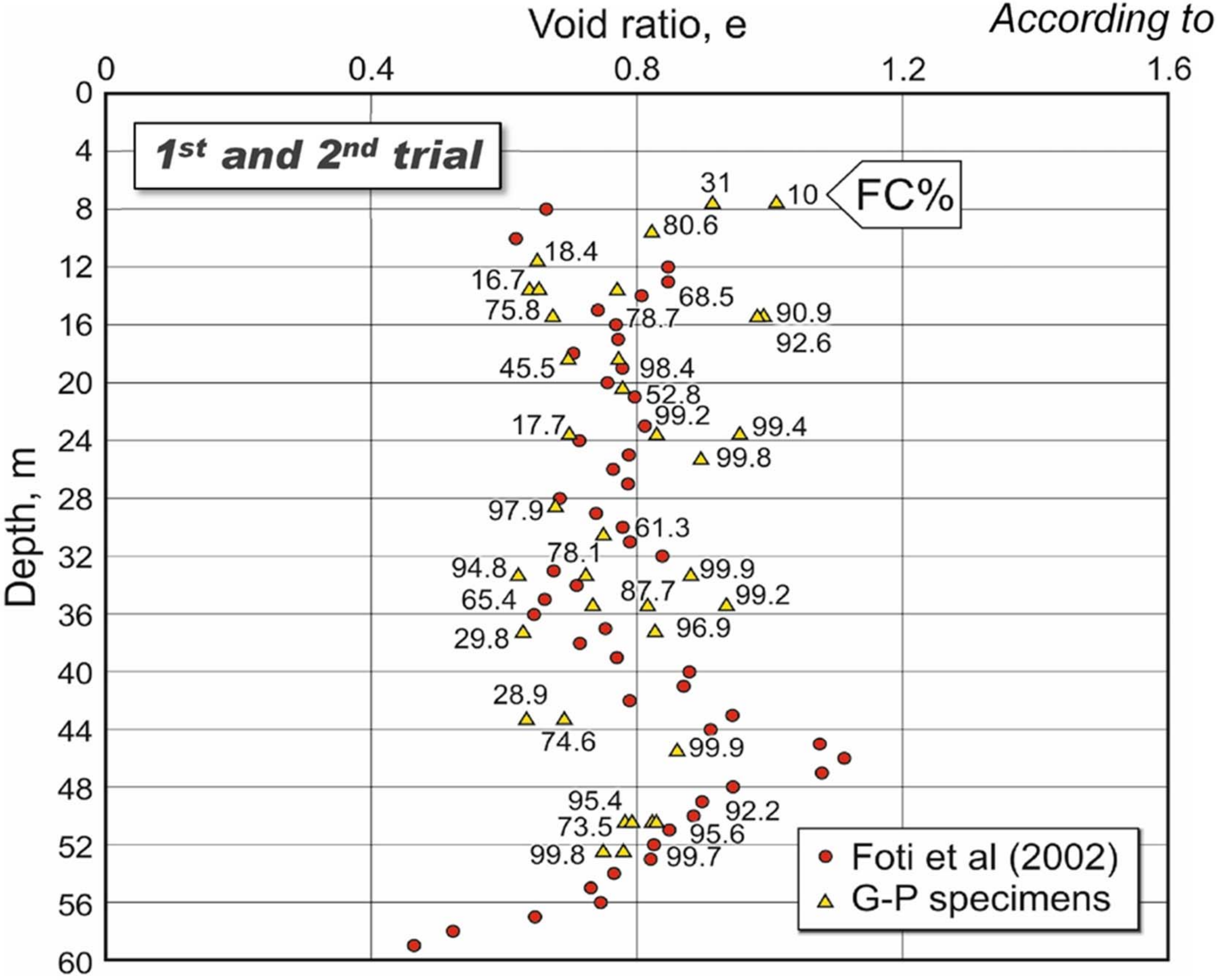
ZELAZNY MOST COPPER TAILINGS POND



VOID RATIO OF G-P SAMPLES and COMPUTED FROM CHT

ZELAZNY MOST COPPER TAILINGS POND

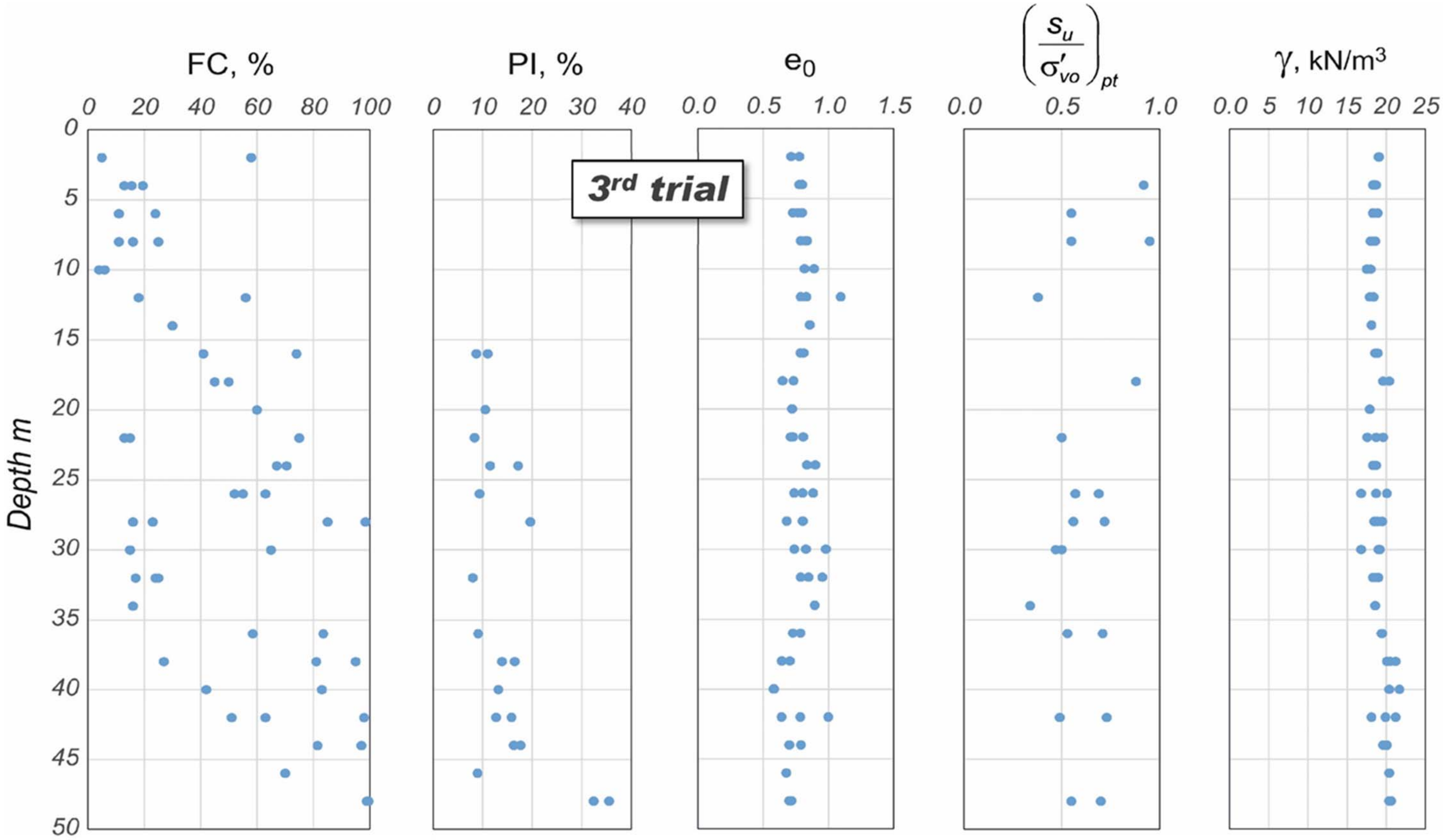
According to Foti et al (2002)



INDEX PROPERTIES OF ZM TAILINGS

ZELAZNY MOST COPPER TAILINGS POND

Tr GEL-PUSH SAMPLER, 3rd Trial, ≈ 20m from dam crest



POROSITY OF SATURATED SOILS FROM SHEAR AND COMPRESSION WAVES VELOCITY

- ***Poroelasticity theory approach,*** *[Foti et al (2002), Foti and Lancellotta (2004)]* ***to assess in situ porosity based on measured V_p and V_s velocities***

- ***As to inverse problems, reliability of obtained results controlled by key input parameters, V_p and, to a lesser extent, V_s***

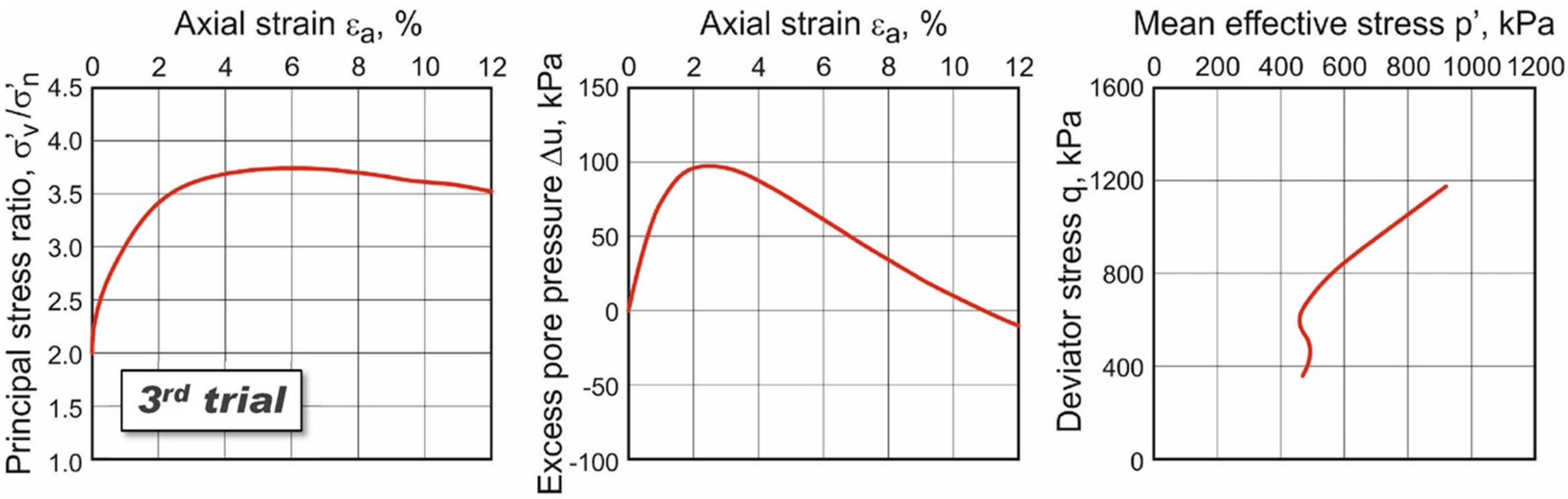
- ***Carried out properly devised cross-hole tests, most suitable to obtain independent, highly accurate V_p and V_s measurements***

- ***Quantifying uncertainties involved in assessing picking arrival time and travel distance can enhance computed porosity reliability***

TX-CK$_0$U-C tests on undisturbed G-P specimen

ZELAZNY MOST COPPER TAILINGS POND

Geoteko (2014)

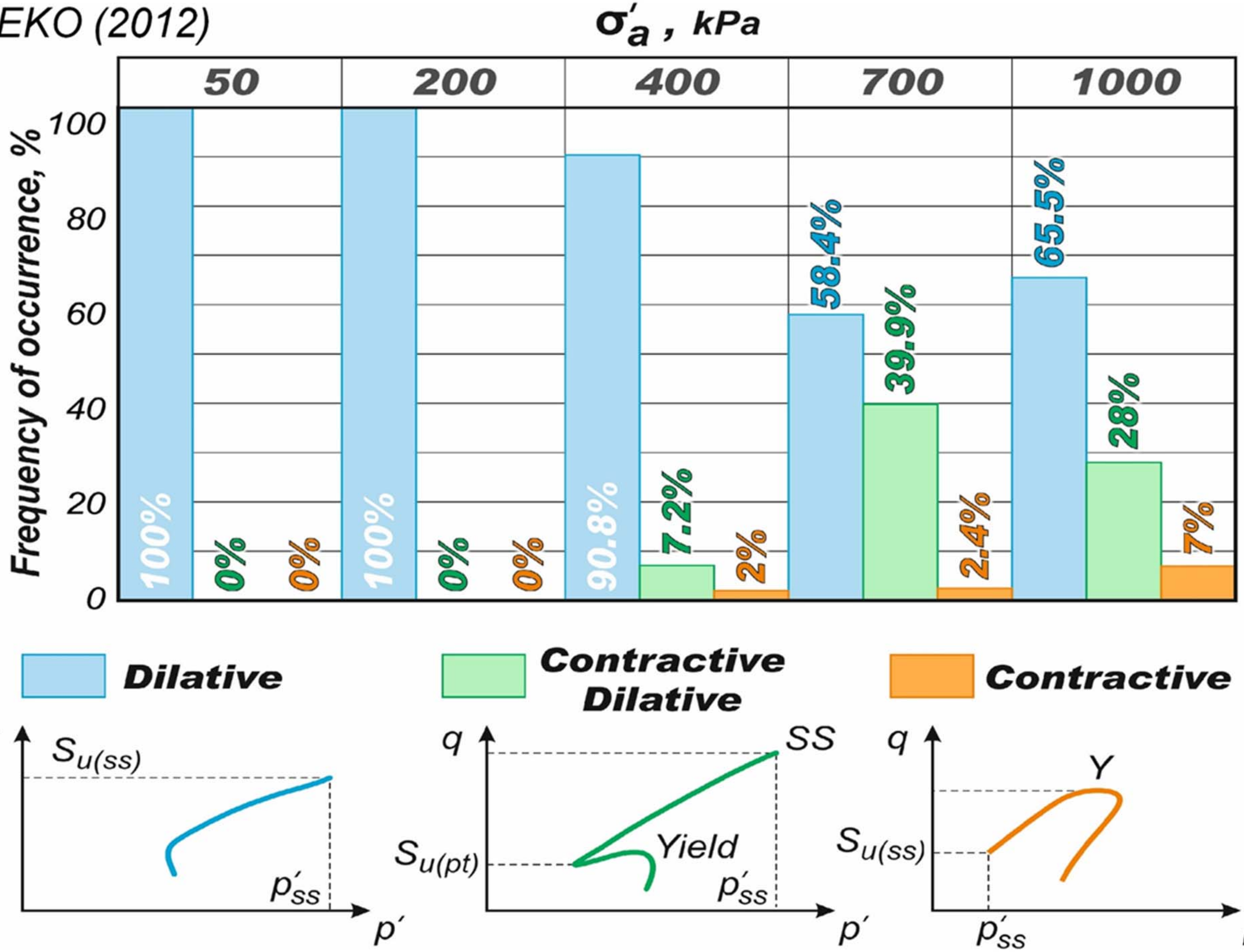


Depth 5.5m; Fine silty sand: γ = 18 kN/m^3; e_0 = 0.861; FC = 11%; V_s = 240 m/s

UNDISTURBED TAILINGS RESPONSE TO UNDRAINED SHEARING

ZELAZNY MOST COPPER TAILINGS POND

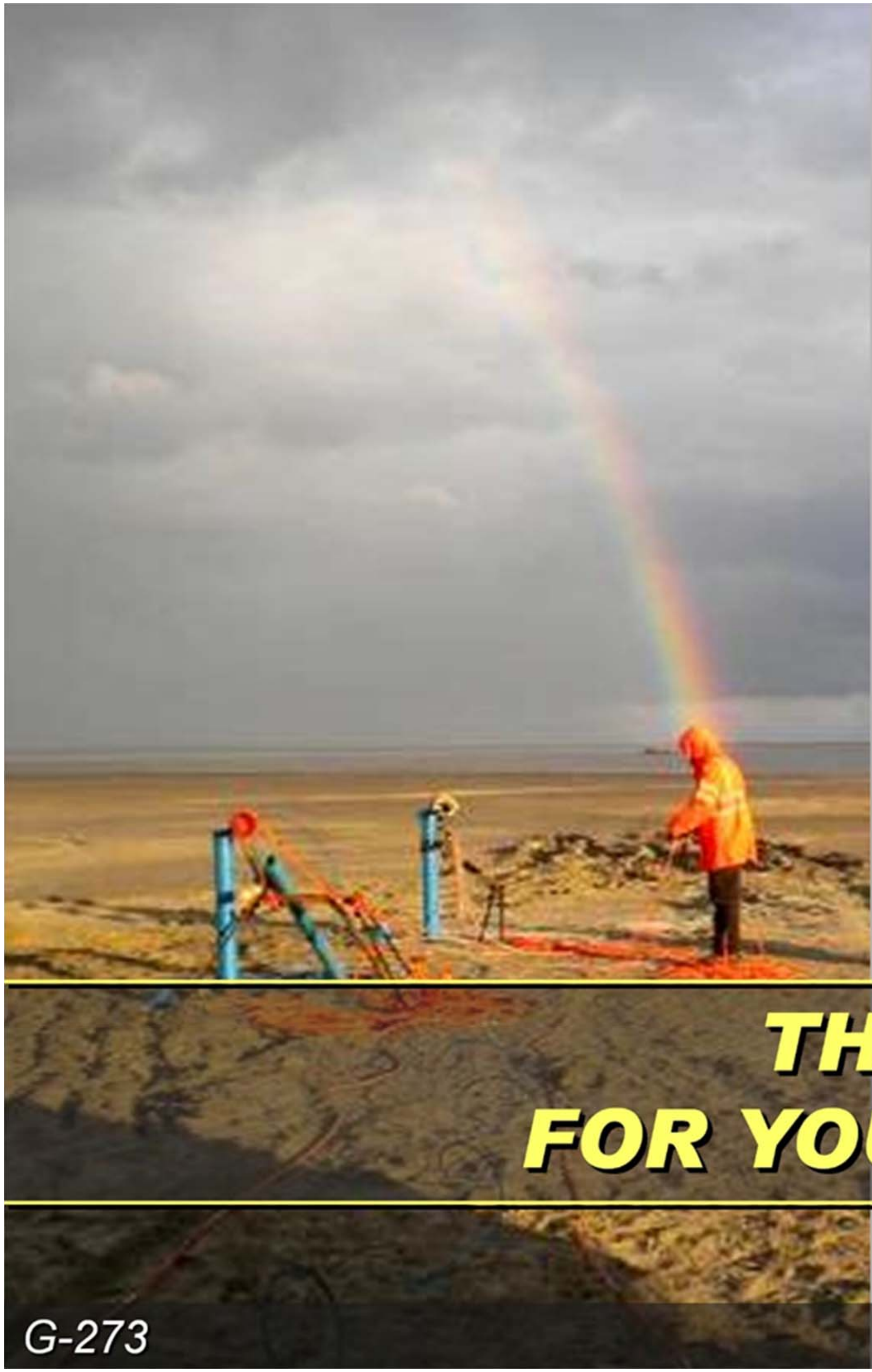
GEOTEKO (2012)

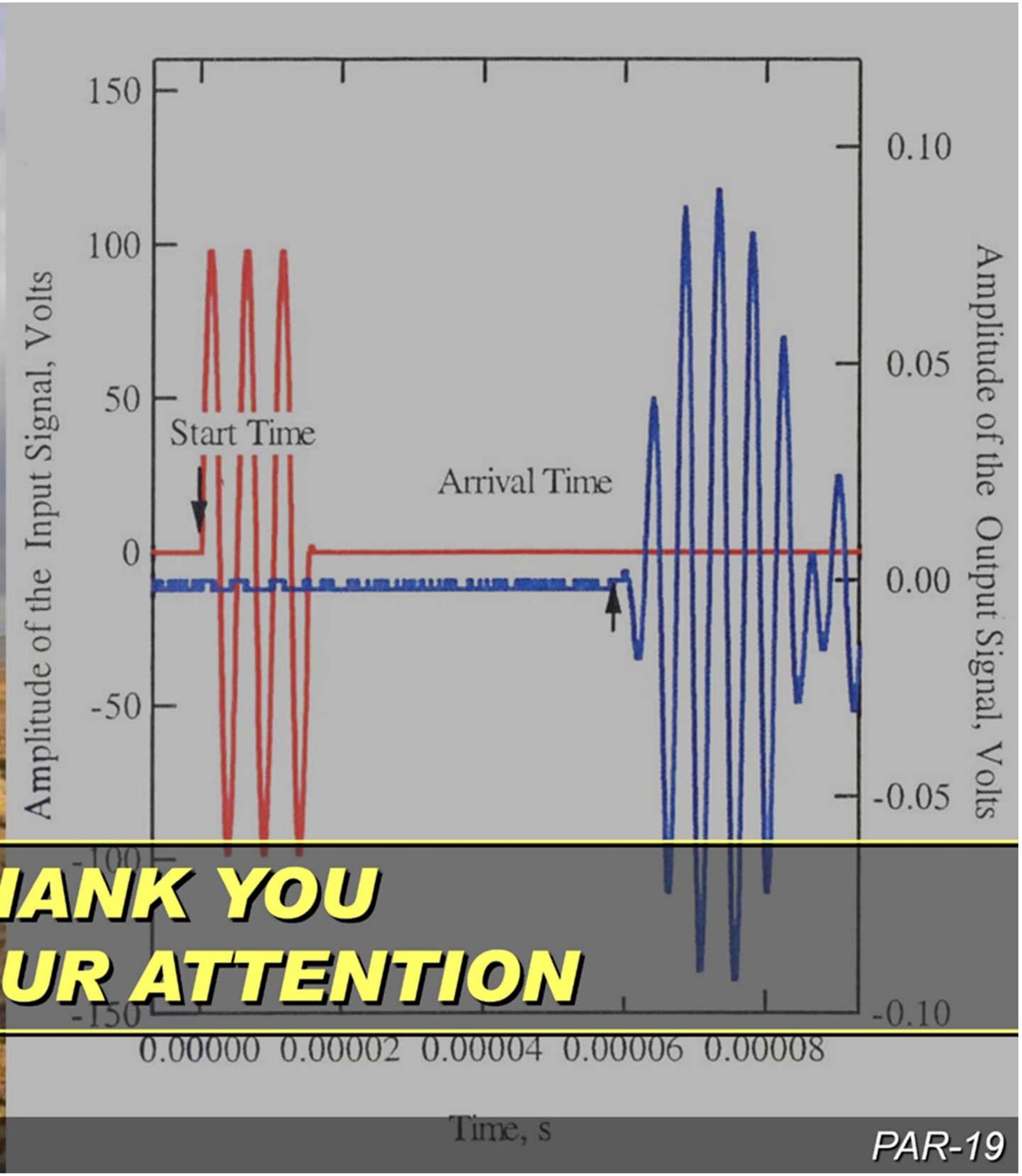


TX-CK0U - K0 = 0.5 - 84 tests

G-254

ZM-76





THANK YOU FOR YOUR ATTENTION