REMTECH EXPO

GEOSISMICA

20 Settembre 2018

LIQUEFAZIONE E INSTABILITA' DINAMICA DEI TERRENI

Tecniche di mitigazione del rischio da liquefazione analizzate con prove in centrifuga

vincenzo fioravante – Università degli Studi di Ferrara

RemTech Expo 2018 (19, 20, 21 Settembre) FerraraFiere

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sulla MODELLAZIONE FISICA

Modello = appropriata semplificazione della realtà

Modello Fisico = riproduzione semplificata di una realtà o di parte di essa

➢… la distribuzione delle sollecitazioni interne in una struttura dipende esclusivamente:

- dal tipo della struttura stessa
- dai modi con cui le forze agiscono su di essa

non dalla scala metrica dei sistemi agente o resistente

In conseguenza un modello (ripetizione in scala di una struttura) sollecitato da un sistema di forze in appropriata similitudine meccanica, verrà a trovarsi in uno stato di equilibrio interno analogo a quello della vera struttura

Basterà allora disporre di apparecchiature adatte a leggere e misurare gli stati di sollecitazione nelle varie parti del modello, per conoscere direttamente (a parte il rapporto di scala) lo stato di equilibrio interno della struttura reale ➢

(Nervi, 1955)

SILIMITUDE LAWS

Sistemi *fisicamente simili* : rapporto costante di grandezze della stessa natura fisica in punti geometricamente corrispondenti

Completa similitudine (modello vs. prototipo): rispettate tutte le relazioni di scala con cui il modello riproduce le grandezze fisiche ovvero quando i rapporti adimensionali tra le grandezze che caratterizzano il problema assumono nel modello l'identico valore numerico che presentano nel prototipo

n : grandezze fisiche da cui dipende il problema

q : grandezze fondamentali dimensionalmente indipendenti

$m = n - q$: rapporti adimensionali corrispondenti a m grandezze derivate Π che si possono esprimere come $\Pi_1 = f(\Pi_2, \Pi_3, \ldots \Pi_m)$

La similitudine è verificata se:

$$(\Pi_i)_{modello} = (\Pi_i)_{prototipo}$$

$$\Pi_i^* = (\Pi_i)_{prototipo} / (\Pi_i)_{modello} = 1$$

Mechanical Similitude: 3 d.o.f. L, F, T (or L, M, T)

Force	Non-dimensional ratio $(\Pi_i)_{model} = (\Pi_i)_{prototype}$	Similitude $X^* = X_p/X_m$
Surface: $P = p \cdot L^2$	$\Pi_1 = P/(p \cdot L^2)$	$p^* = P^*/ L^{*2}$
Volume: $W = \gamma \cdot V = \gamma \cdot L^3$	$\Pi_2 = W/(\gamma \cdot L^3)$	$W^* = \gamma^* \cdot L^{*3} = \rho^* \cdot g^* \cdot L^{*3}$ $\sigma^* = \rho^* (g^*) L^*$
Derivated: $F = \sigma A = \sigma L^2$	$\Pi_3 = F/(\sigma L^2)$	$F^* = \sigma^* L^{*2}$ Stress $\Rightarrow$ $\sigma^* = F^*/ L^{*2}$ Yielding $\Rightarrow$ $\sigma_y^* = \sigma^*$ Failure $\Rightarrow$ $\tau^* = \sigma^*$ Elastic modulus $\Rightarrow$ $E^* = \sigma^*$
Inertia: $F = m \cdot a$	$\Pi_4 = F/(m\ a)$	$F^* = M^*\ a^*$ Time $t^* = L^* (\rho^*/\sigma^*)^{1/2}$ Frequence $f^* = 1/T^* = (\sigma^*/\rho^*)^{1/2}/ L^*$ Velocity $v^* = L^*/T^* = (\sigma^*/\rho^*)^{1/2}$ Acceleration $a^* = L^*/T^{*2} = \sigma^*/(\rho^* L^*)$

TERRENO = COMPORTAMENTO NON LINEARE DIPENDENTE DA LITOLOGIA E SFORZI

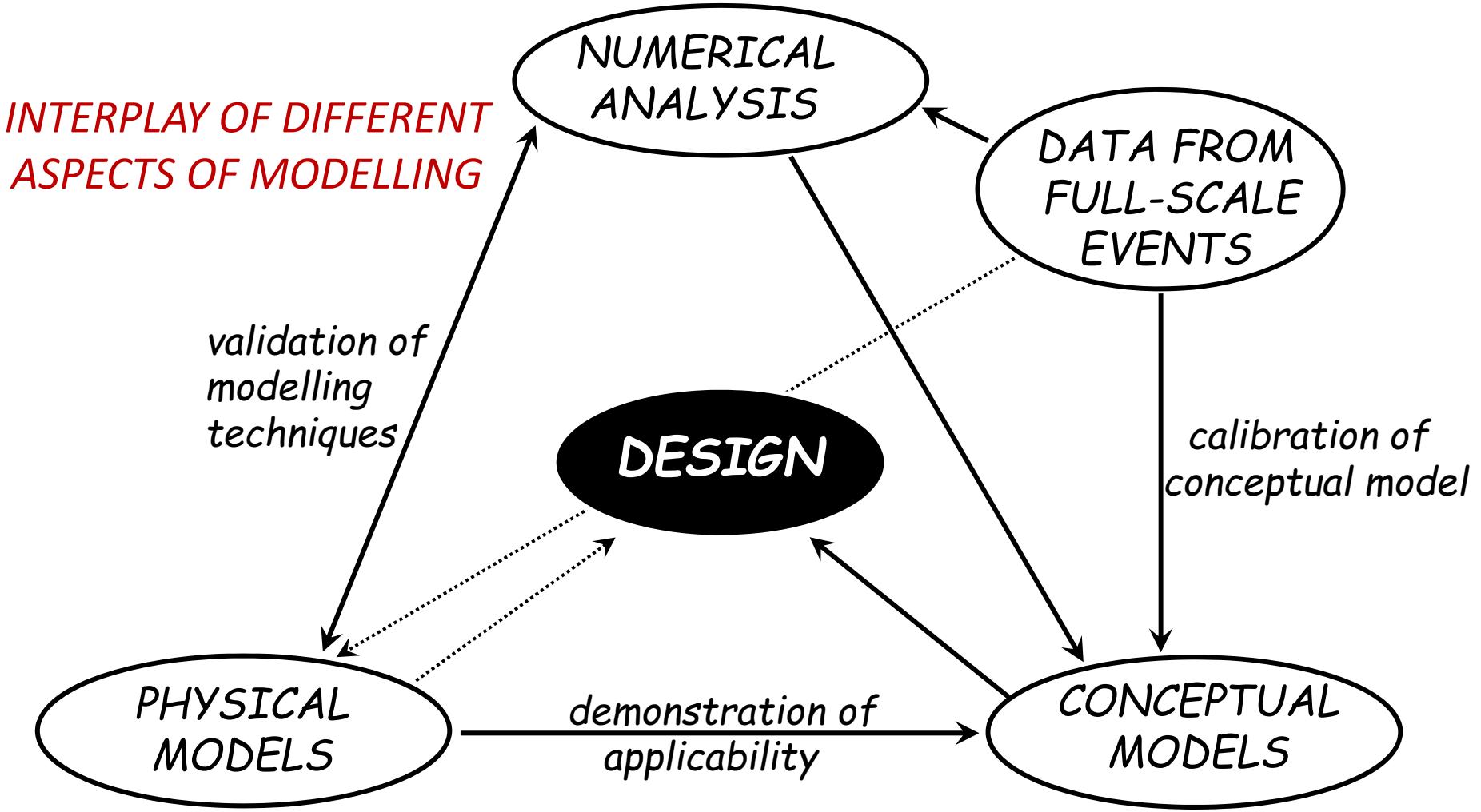
Se terreno modello = prototipo **($\rho^* = 1$)** è possibile simulare correttamente nel modello il comportamento reale del terreno, senza conoscere il suo legame costitutivo, imponendo $\sigma^* = 1 \rightarrow g^* L^* = 1$

se $L^* = N \rightarrow g^* = 1/N$

PHYSICAL MODELLING IN THE ENGINEERING PRACTICE

(i) direct design tool
(ii) validation of numerical methods
(iii) calibration of conceptual models

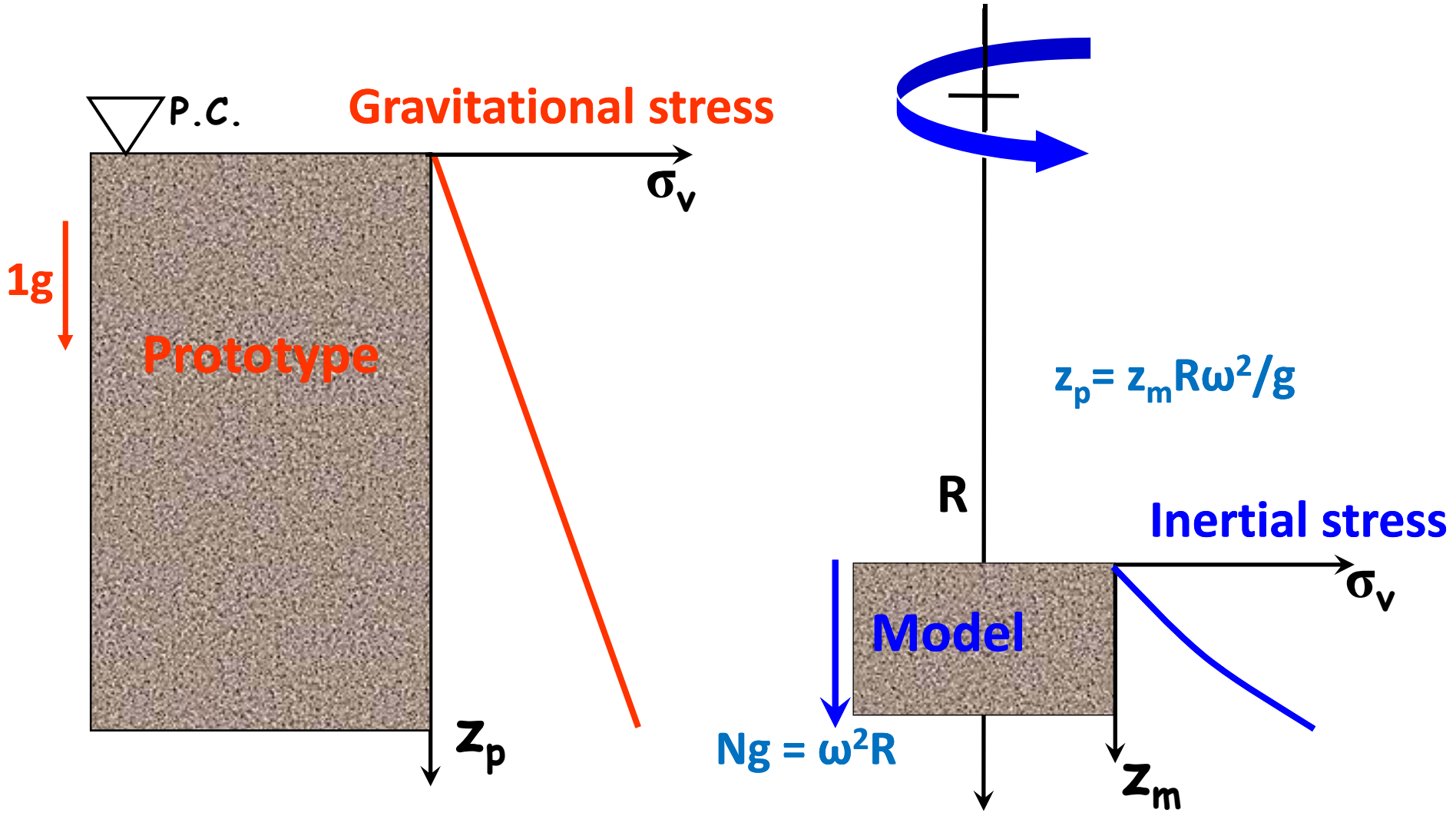
(Roscoe 1968)



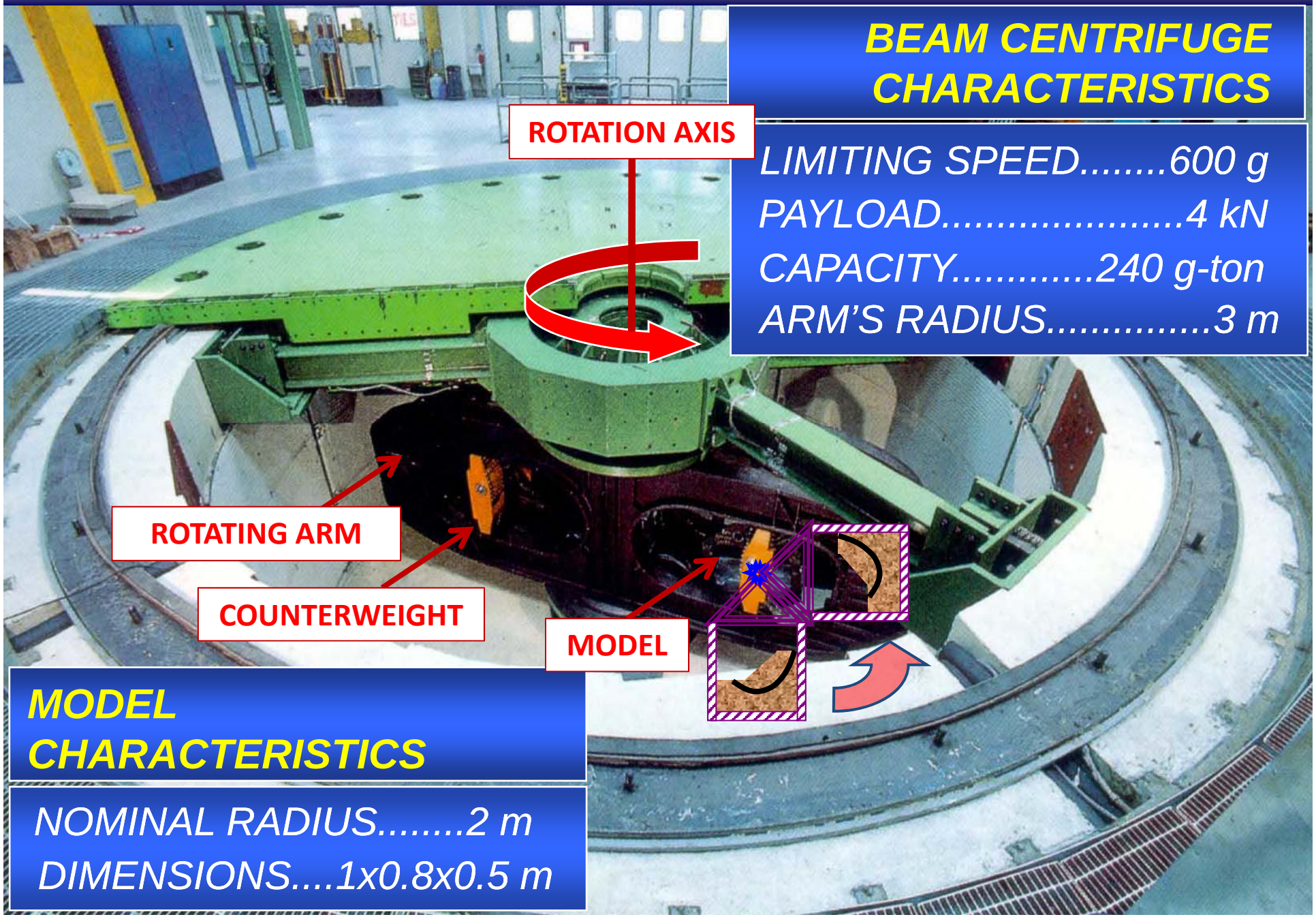
Randolph & House (2001)

TOTAL & EFFECTIVE STRESS PROFILE

$$(\sigma_v)_{prot} = \rho g\, z_p = \rho\, (Ng)(z_p/N) \approx \rho Ng\, z_m = (\sigma_v)_{mod}$$



THE ISMGEO GEOTECHNICAL CENTRIFUGE



BEAM CENTRIFUGE CHARACTERISTICS

LIMITING SPEED.....600 g
PAYLOAD.....4 kN
CAPACITY.....240 g-ton
ARM'S RADIUS.....3 m

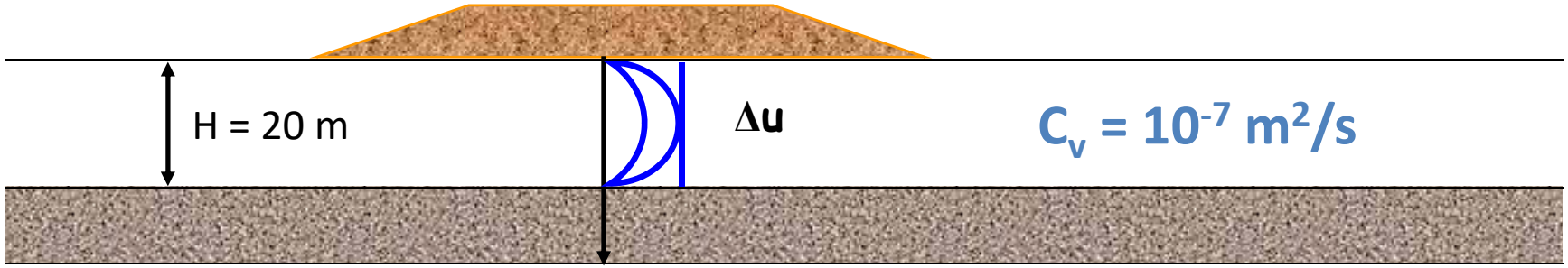
MODEL CHARACTERISTICS

NOMINAL RADIUS.....2 m
DIMENSIONS....1x0.8x0.5 m

THE SCALING FACTORS

	Variable	Scale factor $X^*=X_{prototype}/X_{model}$	1g model	Ng model
L	Length	L^*	N	N
ρ	Soil density	ρ^*	1	1
ε	Strain	ε^*	$N^{1-\alpha}$	1
σ	Stresses (effective and total)	$\sigma^*=x^*\rho^*g^*$	N	1
G	Stiffness	$G^*=x^*\rho^*g^*/\varepsilon^*$	N^{α}	1
ρ_f	Fluid density	ρ^*	1	1
p	Fluid pressure	$p^*= x^*\rho^*g^*$	N	1
u	Soil displacement (continuum)	$u^*=x^*\varepsilon^*$	$N^{2-\alpha}$	N
v	Velocity	$v^*=(x^*\varepsilon^*g^*)^{0.5}$	$N^{1-\alpha/2}$	1
ü	Acceleration	g^*	1	N^{-1}
t	Time (consolidation)	$t^*=\mu^*L^{*2}/G^*$	1	N^2
t	Time (creep)	t^*	1	1
t	Time (dynamic)	$t^*=(x^*\varepsilon^*/g^*)^{0.5}$	$N^{1-\alpha/2}$	N
μ	Dynamic viscosity of fluid	$\mu^*=\rho^*(g^*/x^*\varepsilon^*)^{0.5}$	$N^{((\alpha/2)-1)}$	N^{-1}
K_f	Compressibility modulus of soil	$K_f^*=x^*\rho^*g^*/\varepsilon^*$	N^{α}	1

CONSOLIDATION TIME



N = 1, H = 20 m

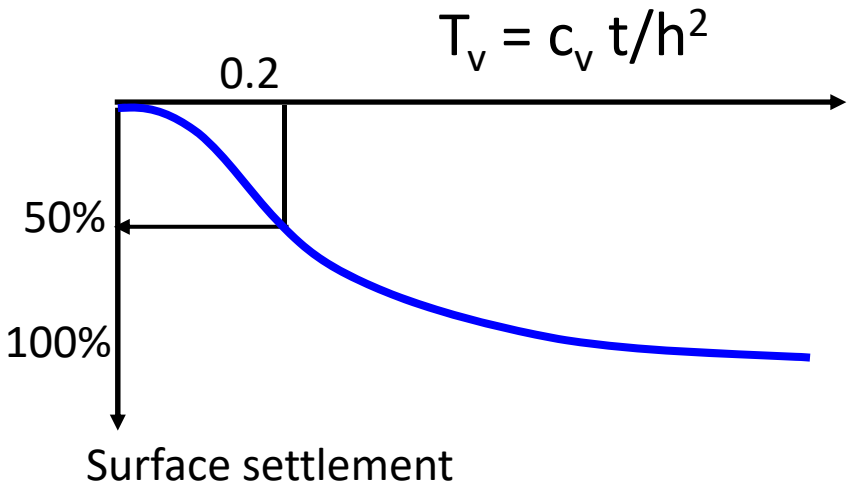
$$t = \frac{0.2 \cdot 10^2}{10^{-7}} \cong 6 \text{ years}$$

N = 100, H = 0,2 m

$$t = \frac{0.2 \cdot 0.1^2}{10^{-7}} \cong 5.6 \text{ hours}$$

N = 200, H = 0,1 m

$$t = \frac{0.2 \cdot 0.05^2}{10^{-7}} \cong 1.4 \text{ hours}$$



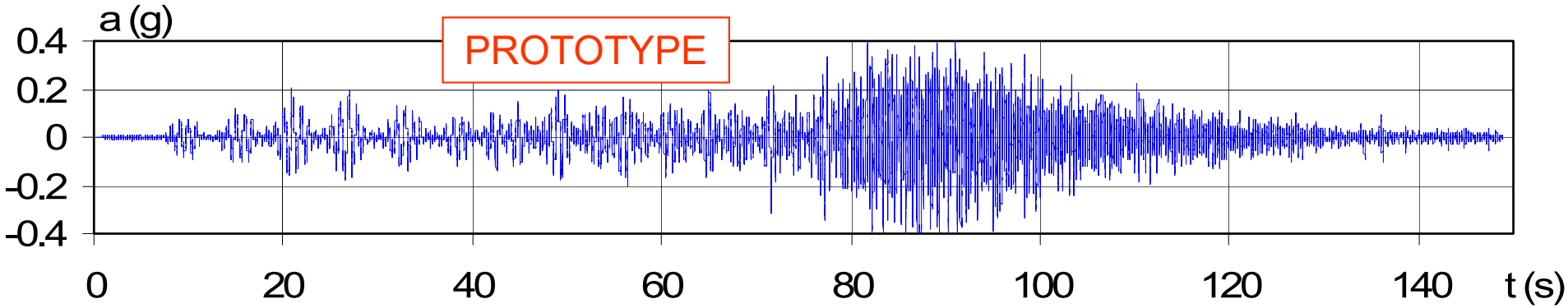
SCALE FACTORS

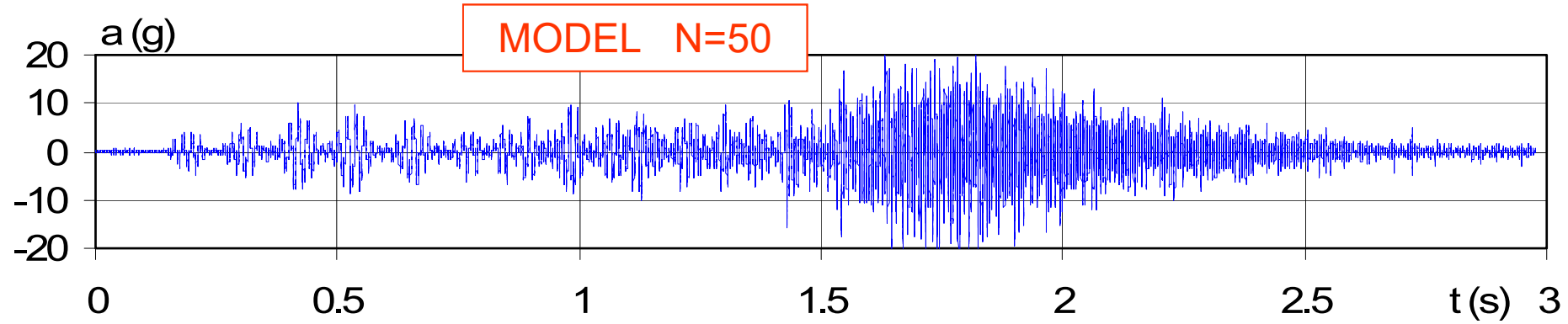
linear dimension: $L^* = N$ acceleration: $a^* = N^{-1}$ frequency: $f^* = N^{-1}$

velocity: $v^* = 1$ time (dynamic): $t^* = N$ time (diffusion): $t^* = N^2$

N=50

Heartquake	cycles	f	A	t
Prototype	10	1	0,1 m	10 s
Model	10	50	2 mm	0,2 s





The first series of (13) tests is a reference point of the experiments and has to be devoted to the reproduction in centrifuge of the liquefaction conditions of a sandy layer in homogeneous and two layers deposits (*from the Grant Agreement*)

Test number	GA models	Model Types	Soils	Ground Motions	Test names
1	1	1 (homogeneous soil)	1 Ticino Sand	17	M1_S1_GM17
2	1	1	1	34	M1_S1_GM34
3	1	1	1	31	M1_S1_GM31
4	1	1	2 Pieve di Cento Clean Sand	17	M1_S2_GM17
5	1	1	2	23	M1_S2_GM23
6	1	1	2	34	M1_S2_GM34
7	2	1	3 Pieve di Cento Sand (12%fc)	17	M1_S3_GM17
8	2	1	3	23	M1_S3_GM23
9	2	1	3	34	M1_S3_GM34
10	3	2 (two layers)	1	34	M2_S1_GM34
11	3	2	1	31	M2_S1_GM31
12	3	2	3	34	M2_S3_GM34
13	4	1F (homogeneous soil+ foundaton)	1	31	M1F_S1_GM31
14	4	1F	1	31+	M1F_S1_GM31+
15	5	2F (two layers+ foundaton)	1	31+	M2F_S1_GM31+

The second series of (10) tests will be devoted to evaluate the effects of vertical and horizontal drains on the excess pore pressure build up during shaking in homogeneous and two layers deposits in free field and underneath a shallow foundation

Test number	Model Types	Type of drains	interaxes	Ground Motions	file names
1	1 (homogeneous)	V	5D	31	M1_S1_VD1_GM31
2	1	V	10D	31	M1_S1_VD2_GM31
3	1	H	5D	31	M1_S1_HD1_GM31
4	1	H	10D	31	M1_S1_HD2_GM31
5	2 (two layers)	V	5D	31	M2_S1_VD1_GM31
6	2	V	10D	31	M2_S1_VD2_GM31
7	2	H	5D	31	M2_S1_HD1_GM31
8	2	H	10D	31	M2_S1_HD2_GM31
9	1F (homogeneous soil+ foundaton)	V	5D	31+	M1F_S1_VD1_GM31+
10	1F	H	5D	31+	M1F_S1_HD1_GM31+
11	2F (two layers+ foundaton)	V	5D	31+	M2F_S1_VD1_GM31+
12	2F	H	5D	31+	M2F_S1_HD1_GM31+

The third series of (10) tests will be concentrated on the effects of the mitigation technique known as Induced Partial Saturation on the sandy layer

Test number	Model Types	Number of nozzle	Ground Motions	file names
1	1 (homogeneous)	1	31	M1_S1_IPS1_GM31
2	1	1	31+	M1_S1_IPS1_GM31+
3	1	4	31	M1_S1_IPS4_GM31
4	1	4	31+	M1_S1_IPS4_GM31+
5	2 (two layers)	1	31	M2_S1_IPS1_GM31
6	2	1	31+	M2_S1_IPS1_GM31+
8	2	4	31	M2_S1_IPS4_GM31
9	2	4	31+	M2_S1_IPS4_GM31+
10	1F (homogeneous soil+ foundaton)	4	31+	M1F_S1_IPS4_GM31+
11	1F	4	31++	M1F_S1_IPS4_GM31++

PHYSICAL MODELLING via SEISMIC CENTRIFUGE TESTS

(A) SEISMIC RESPONSE – LIQUEFACTION TRIGGERING

Soils: (1) Ticino sand
(2) Pieve di Cento clean sand
(3) Pieve di Cento sand with 12% Fine Content

miniaturised Cone Penetration Test

Soil Profiles: (1) Homogeneous sand
(2) Two Layers (top with fine material + sand underneath)

Ground Motions: GM 17, 23, 34, 31, 31+

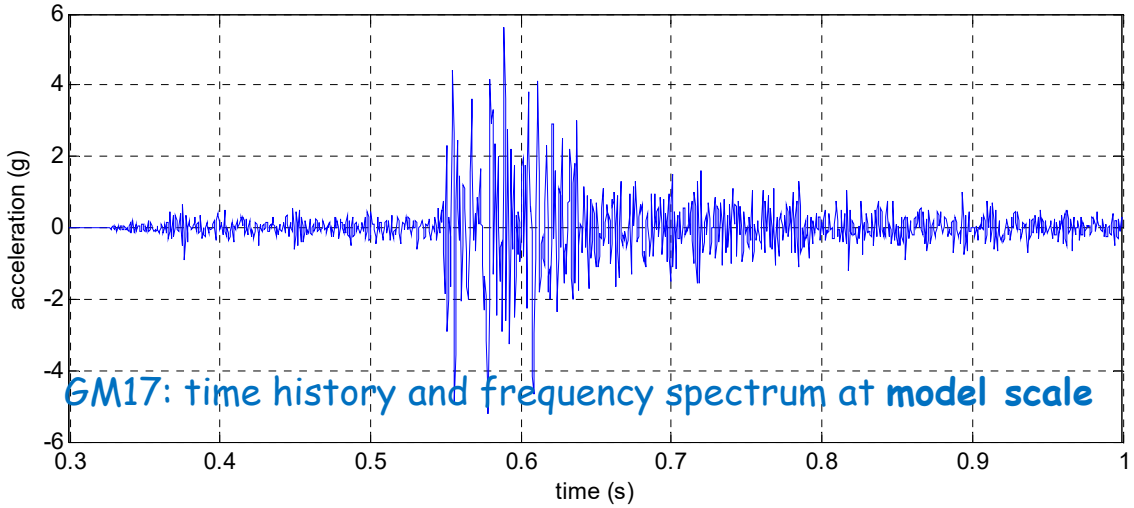
(B) EFFECTIVNESS of MITIGATION TECHNIQUES

1. Vertical DRAINS
2. Horizontal DRAINS
3. Induced Partial Saturation (IPS)

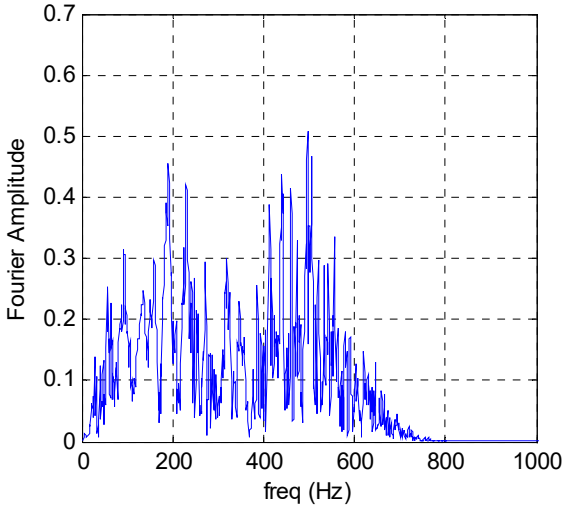
MODELS — FREE FIELD — STRUCTURE

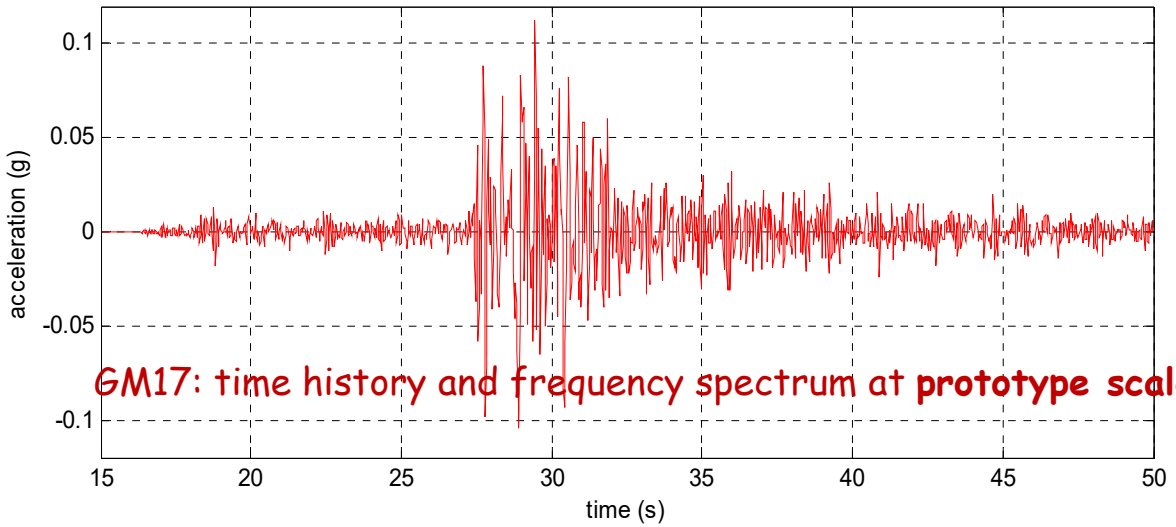
in HOMOGENEOUS SOIL & TWO LAYERS PROFILE

Four different Ground Motion have been applied to the models, they have been analytically derived from the 2012 Emilia earthquake (northern Italy) by the partners of UNIPV

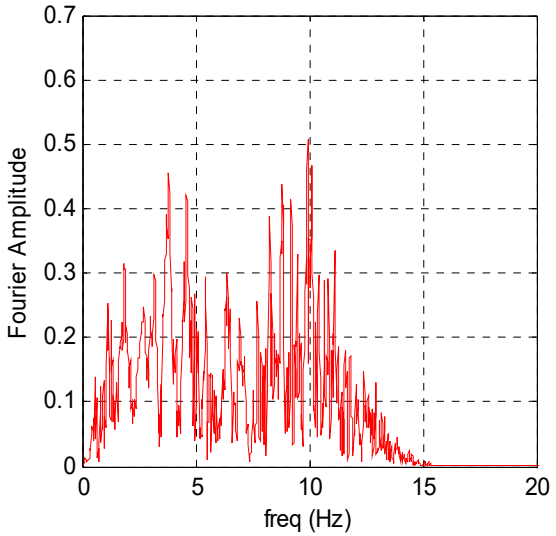


GM17: time history and frequency spectrum at **model scale**

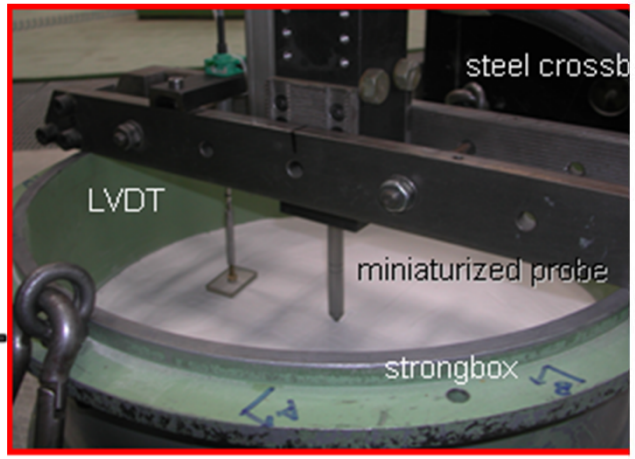


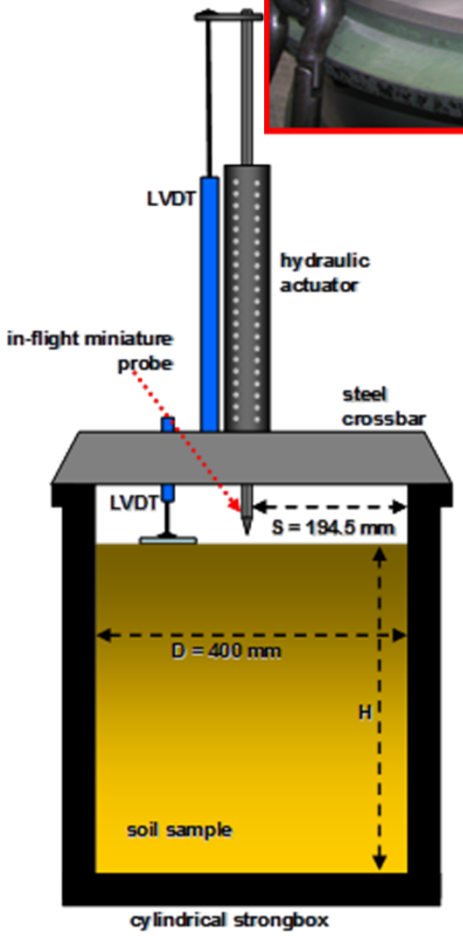


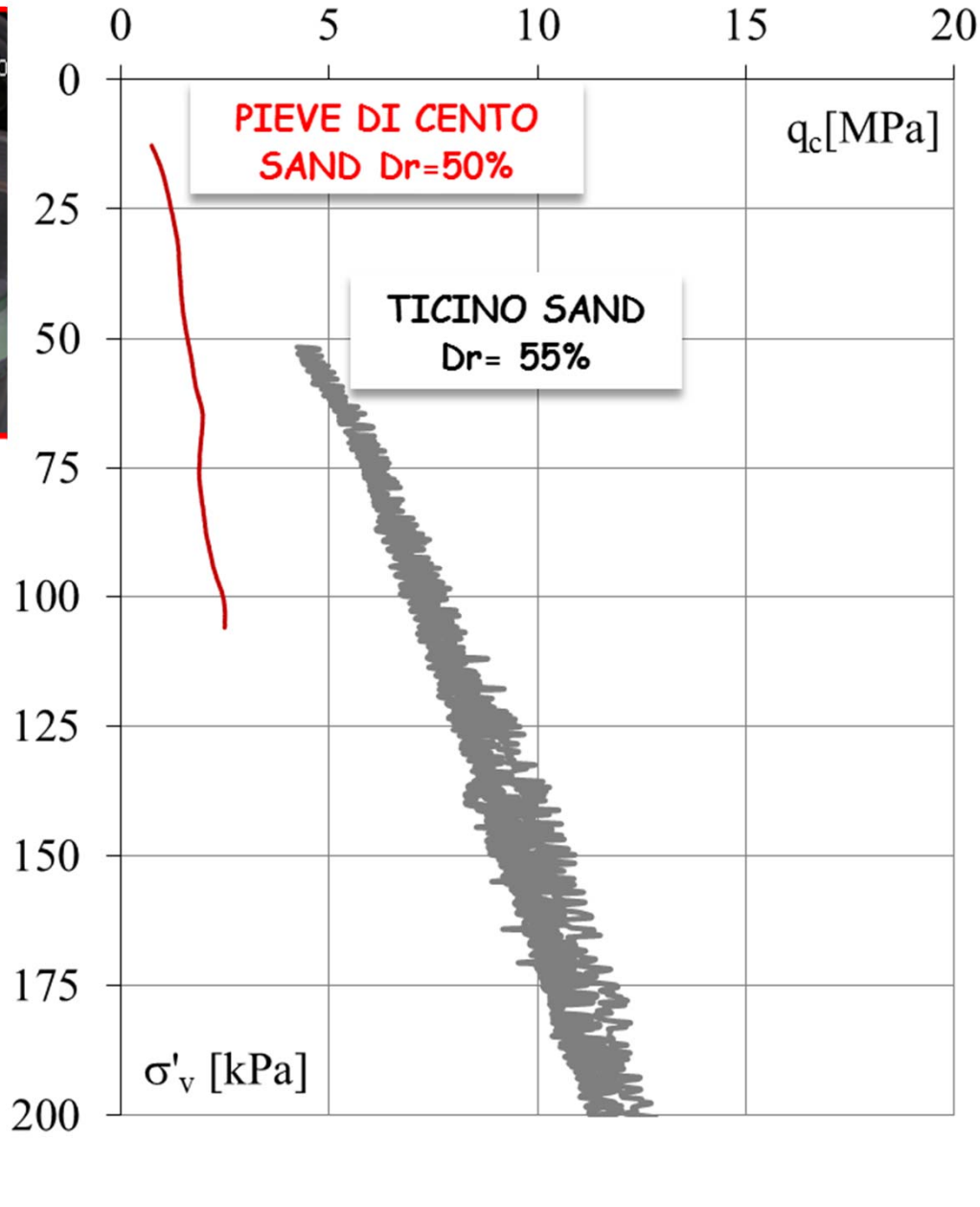
GM17: time history and frequency spectrum at **prototype scale**

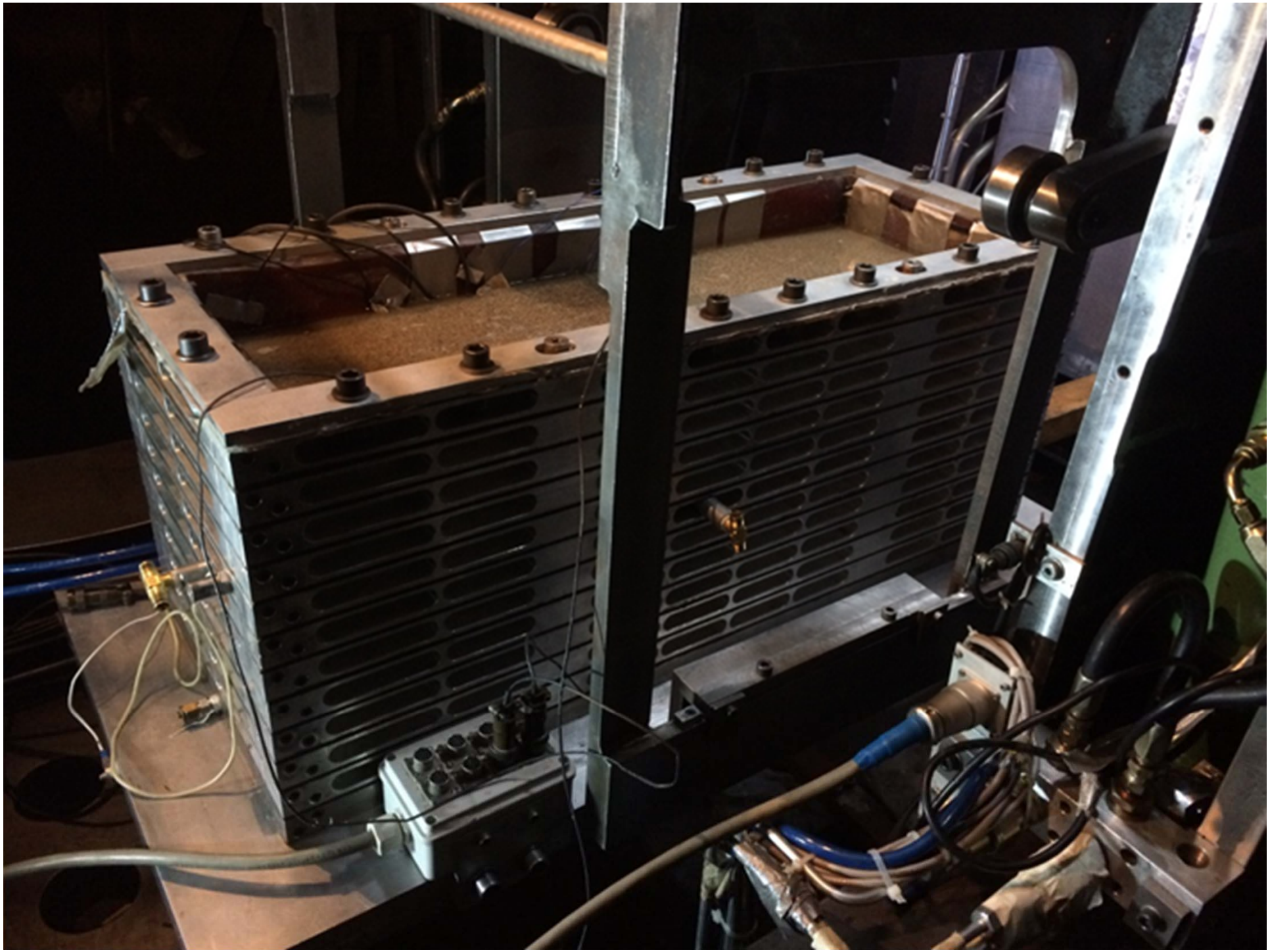


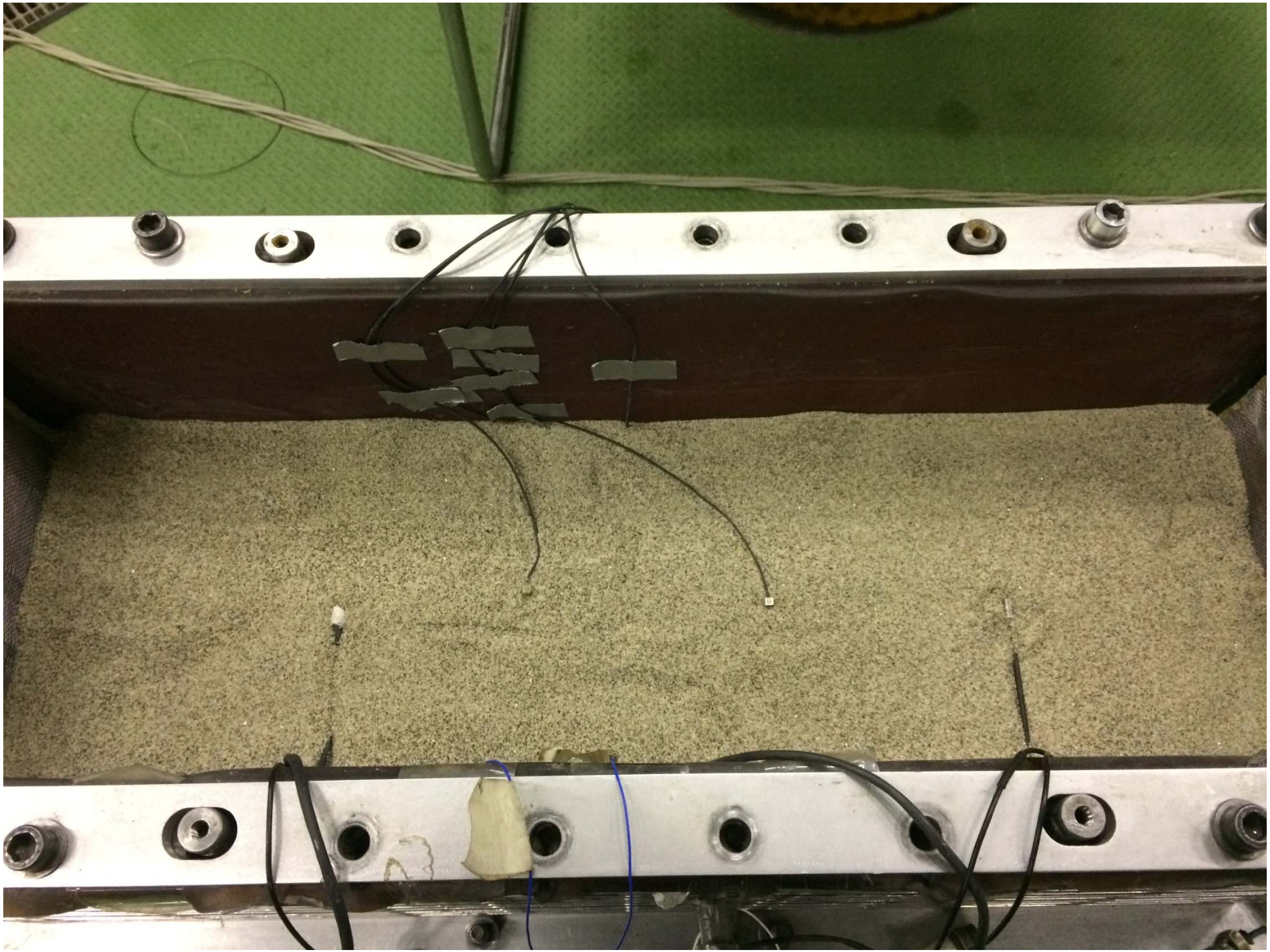
Miniaturized Cone Penetration Tests



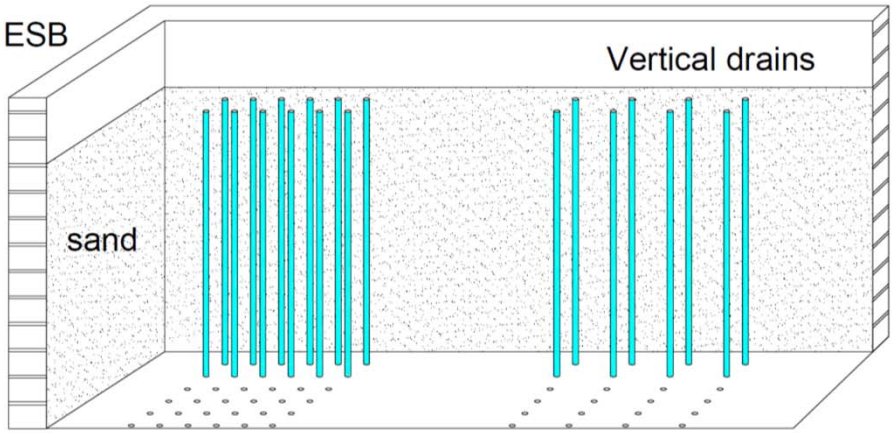


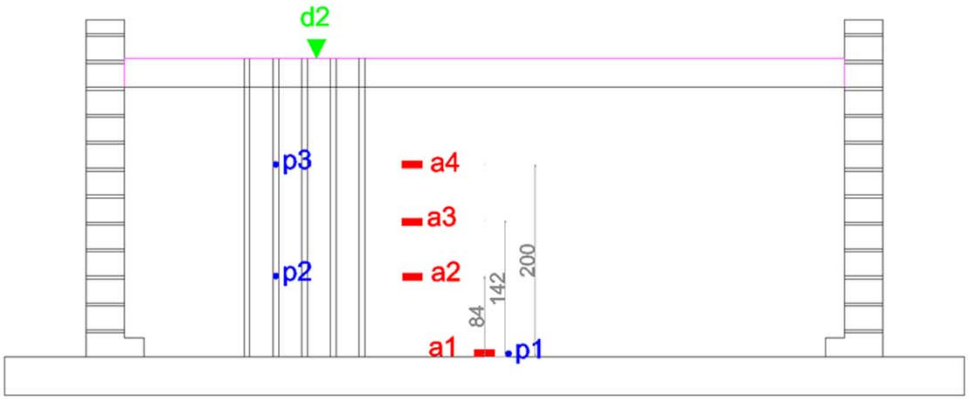


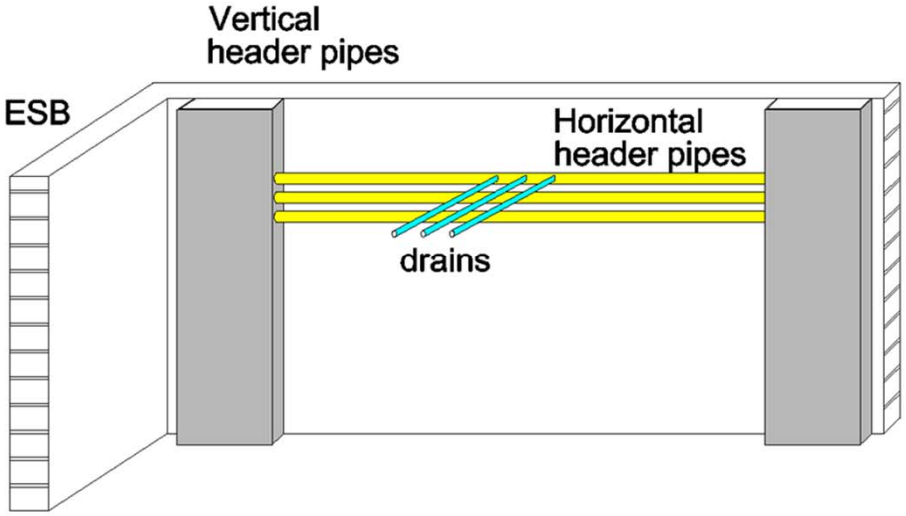


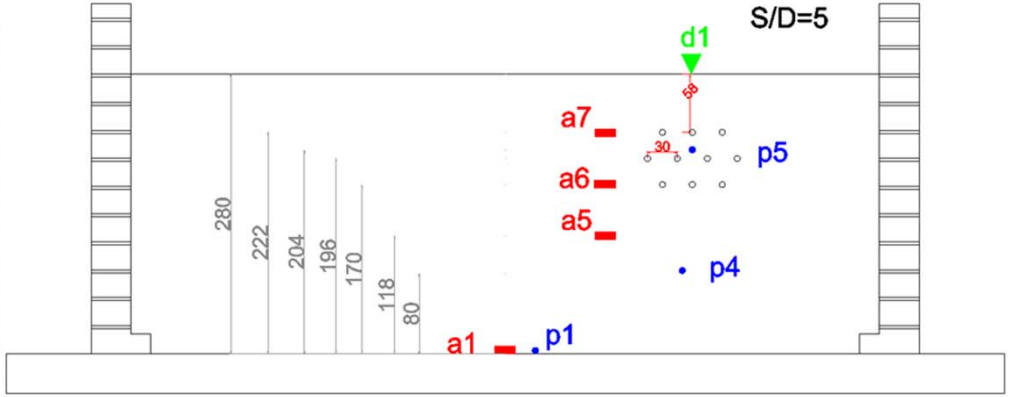


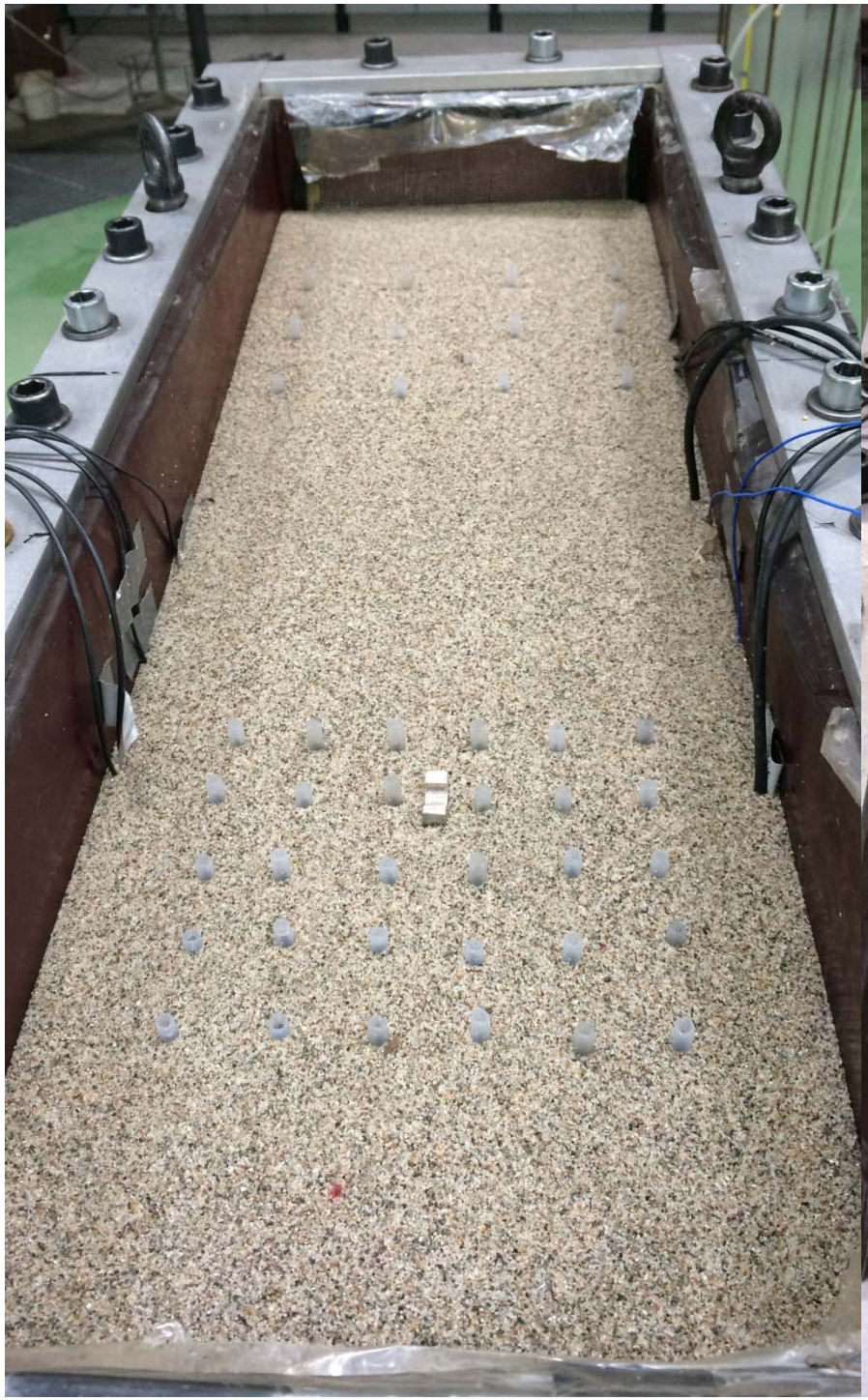
Schemes of vertical and horizontal drains

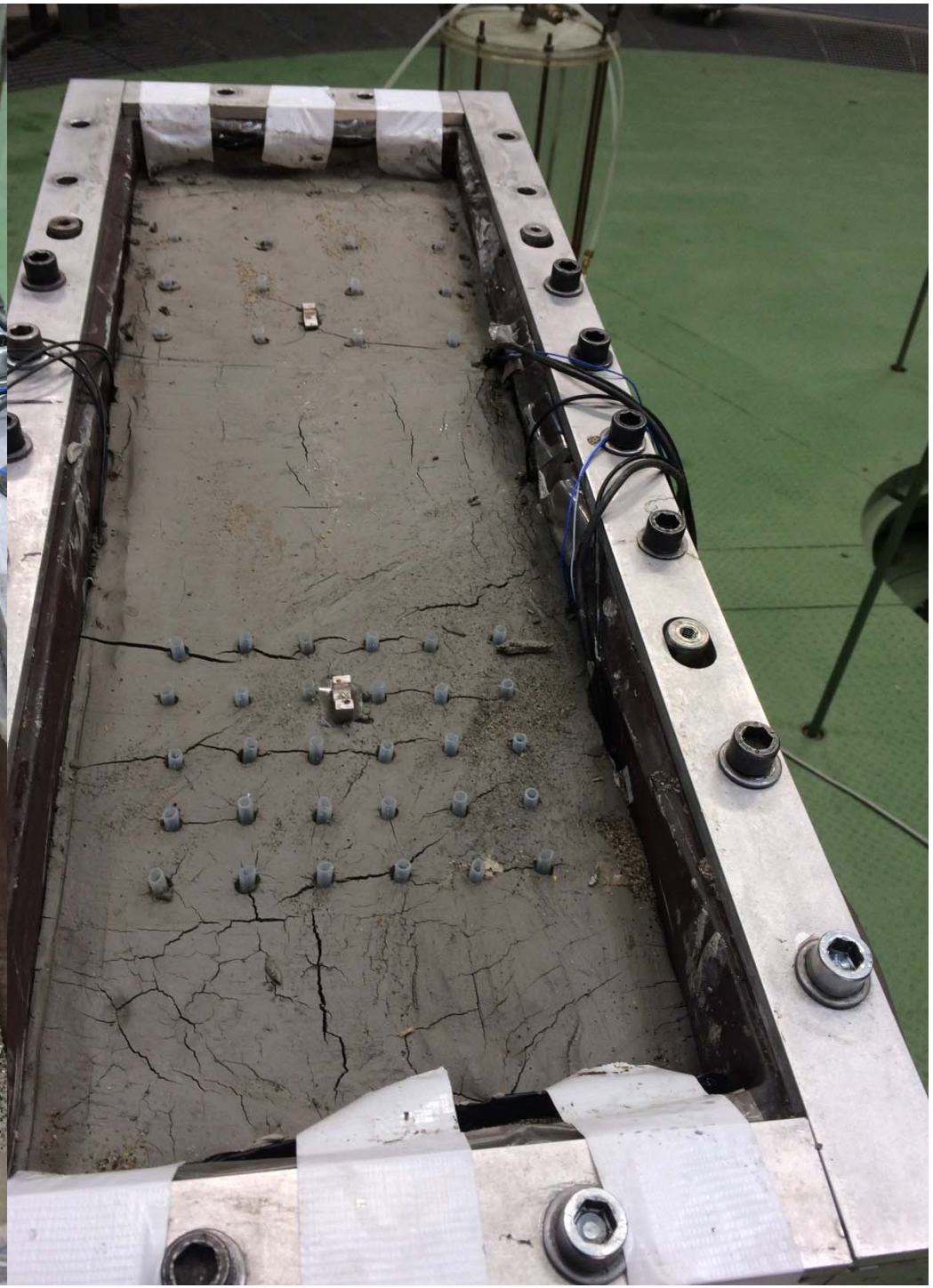


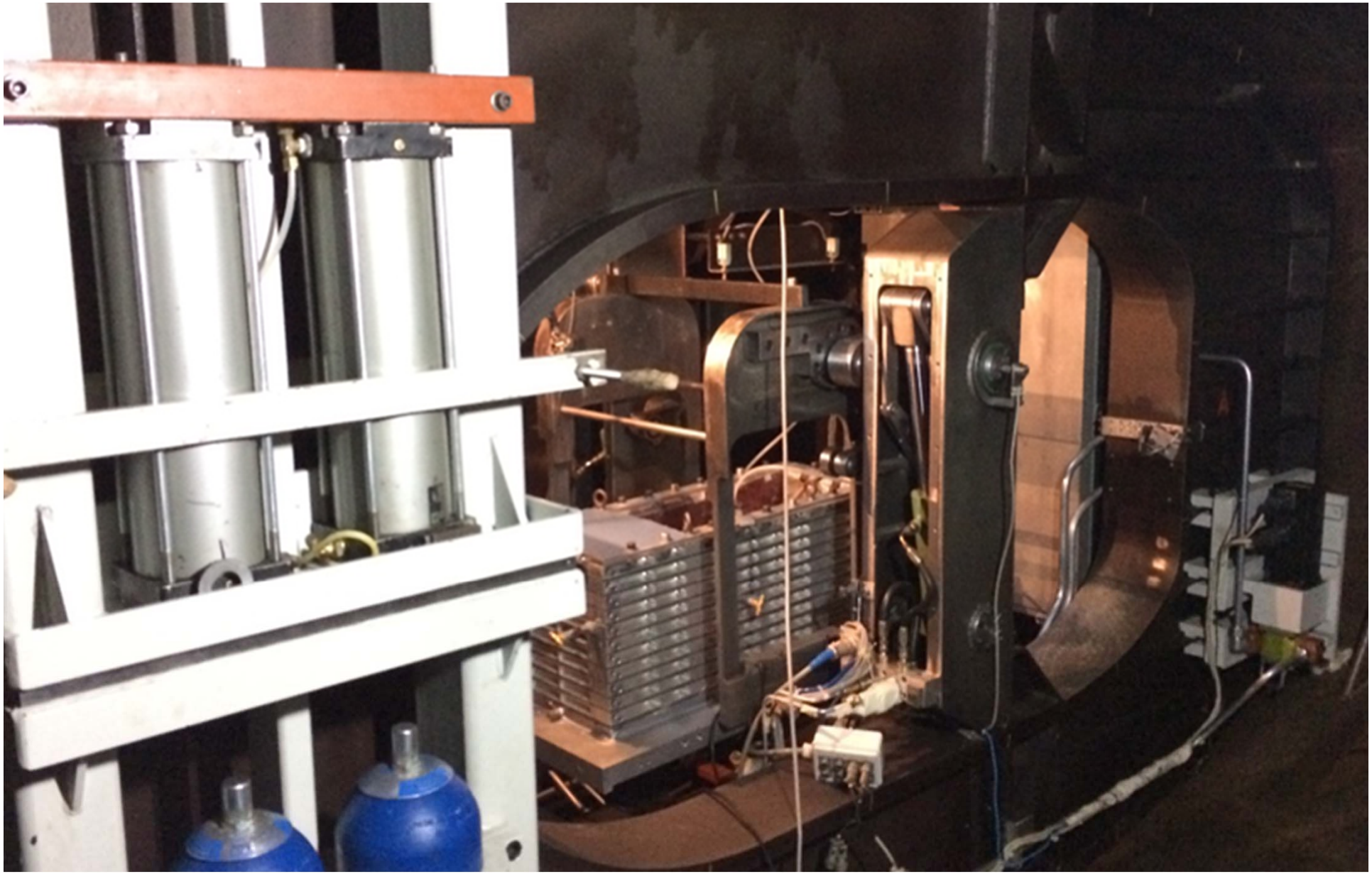






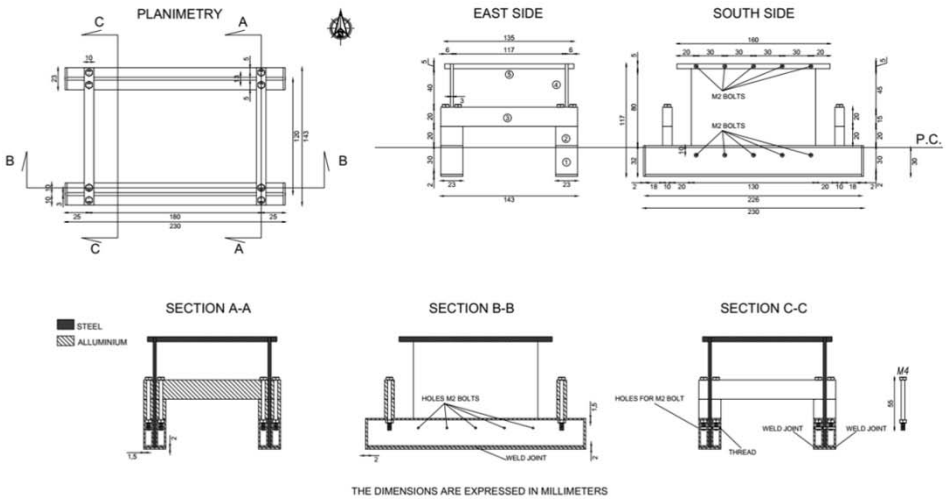


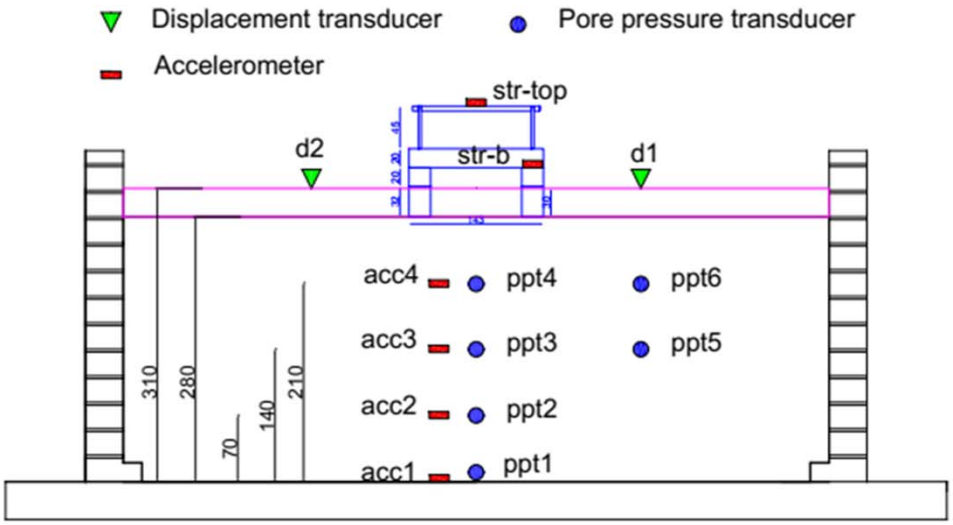


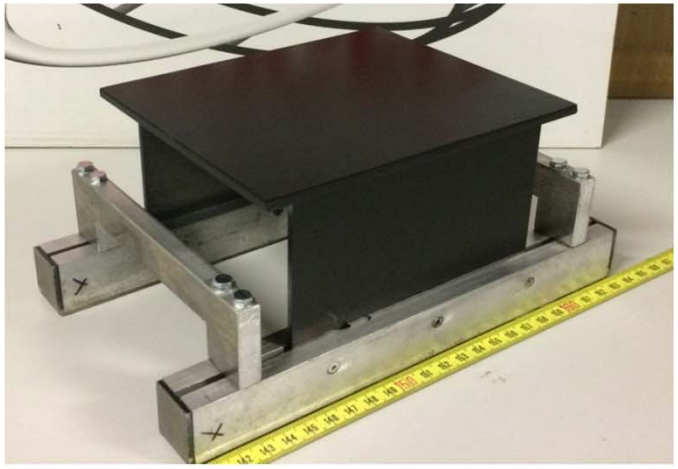


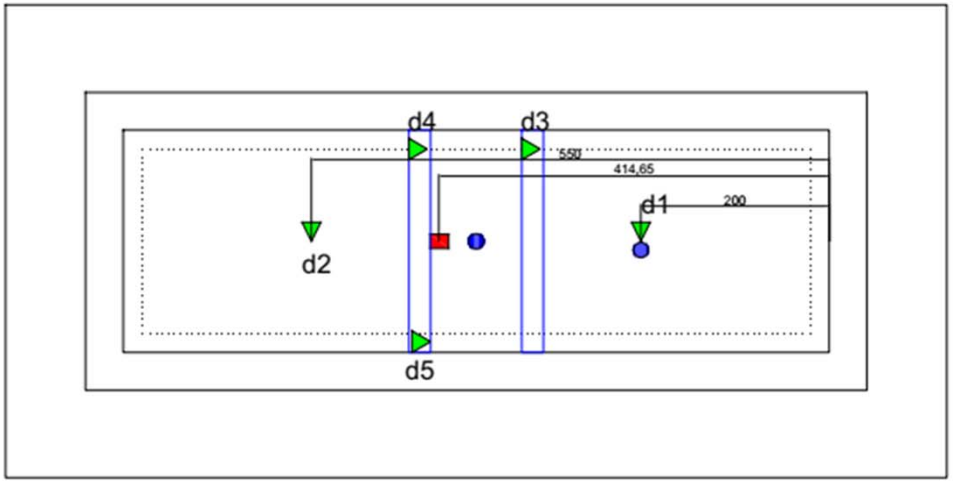
STRUCTURE MODEL FOR CENTRIFUGE TESTS

UNIVERSITY OF NAPOLI "FEDERICO II" (Italy)

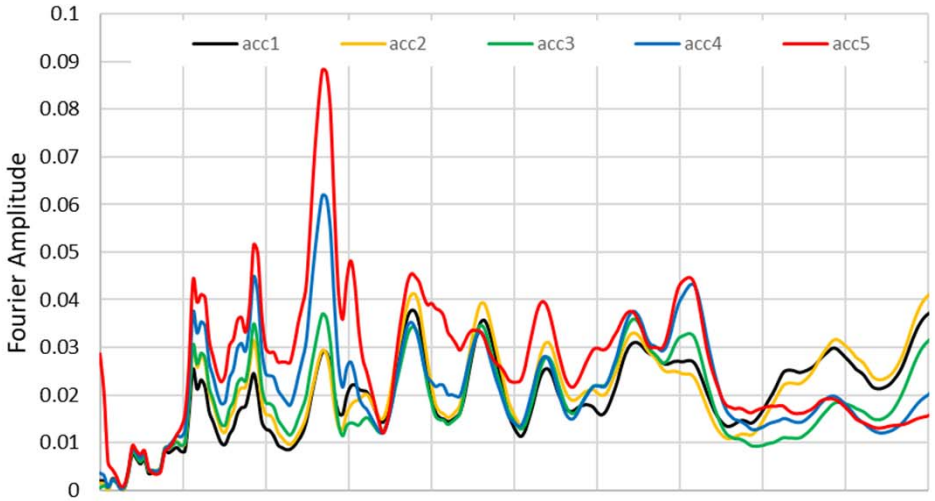


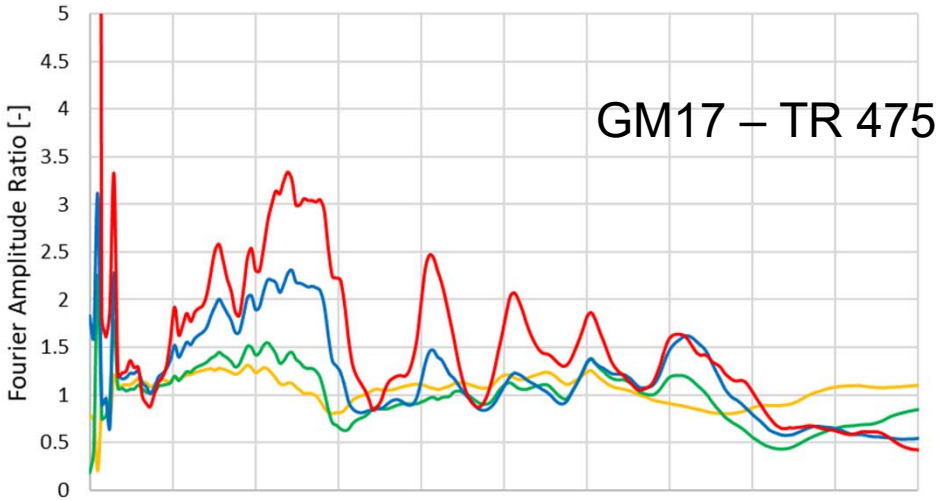


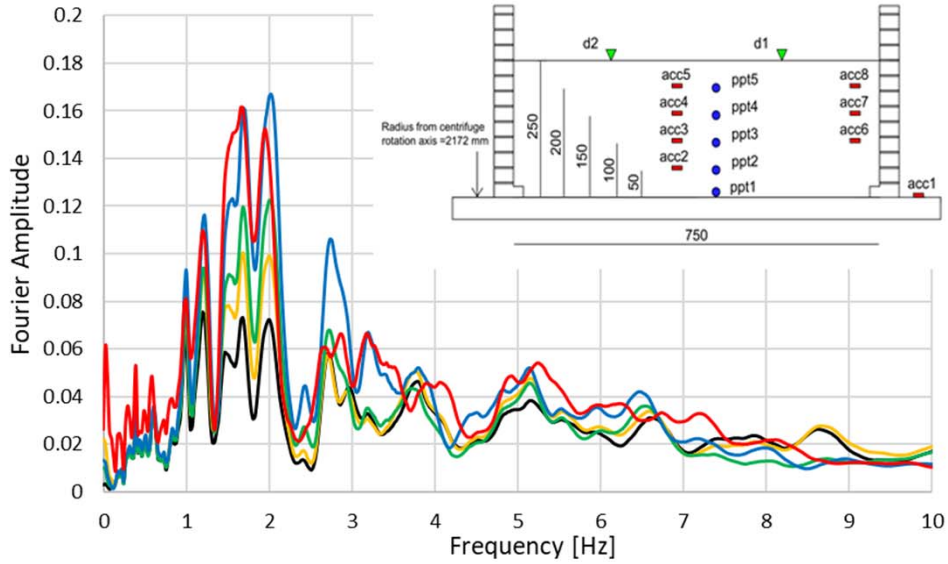


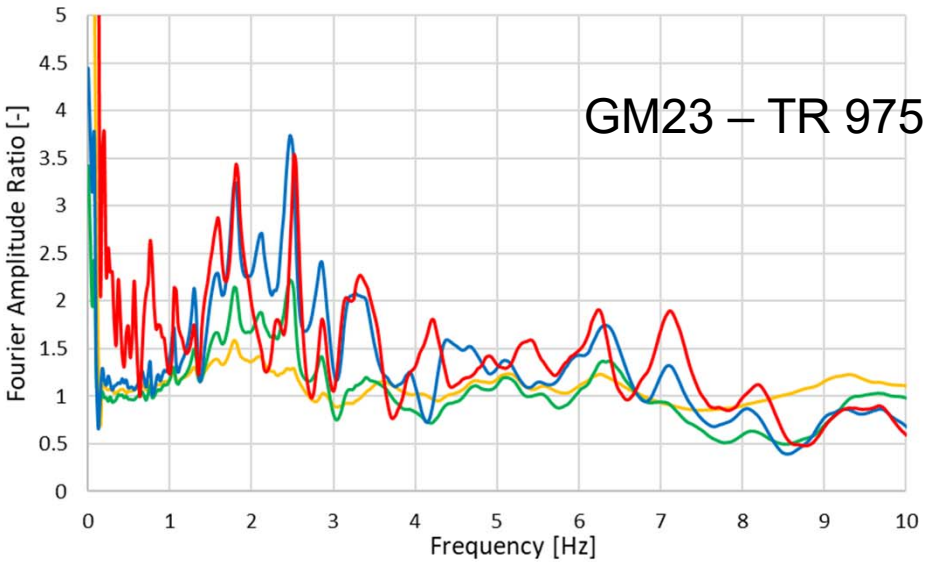


Natural Pieve di Cento Sand





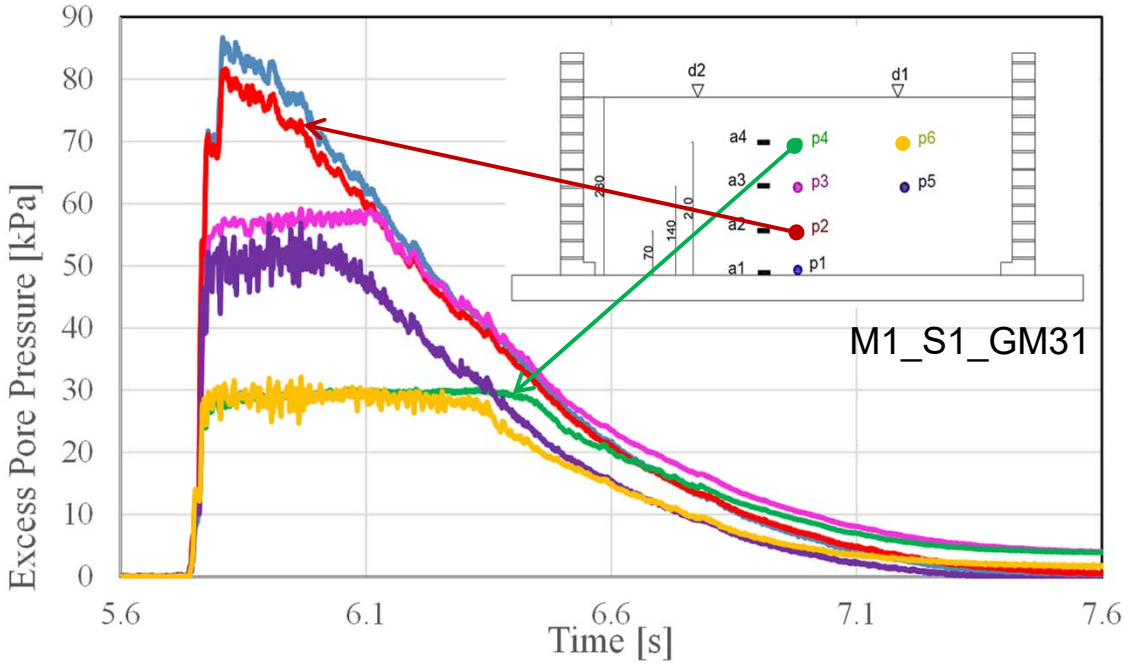


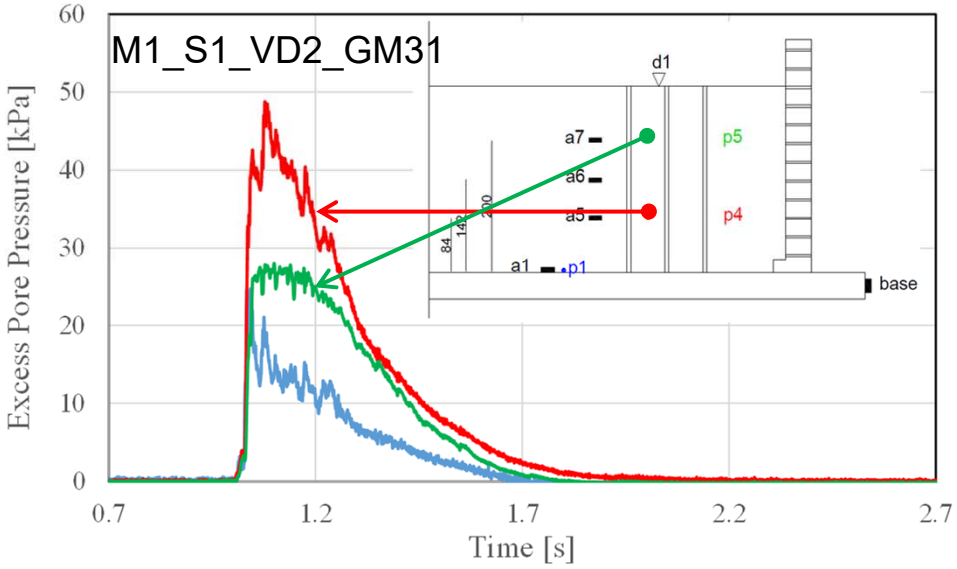


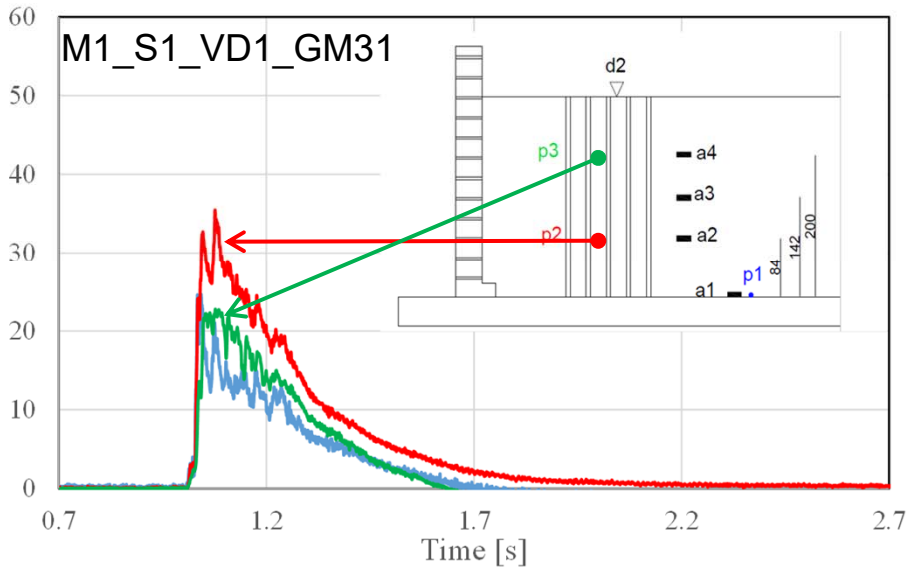

FREE FIELD – HOMOGENEOUS SOIL
FREE FIELD – TWO LAYERS PROFILE
STRUCTURE on HOMOGENEOUS SOIL
STRUCTURE on TWO LAYERS PROFILE

FREE FIELD – HOMOGENEOUS SOIL

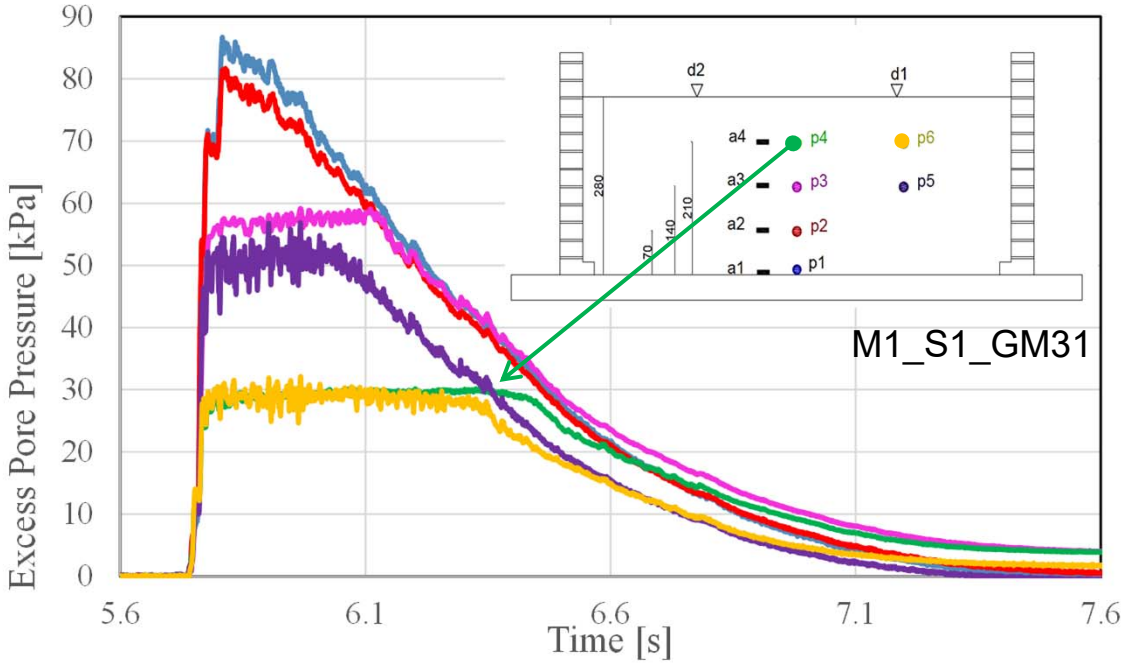
FREE FIELD – HOMOGENEOUS SOIL - VERTICAL DRAINS

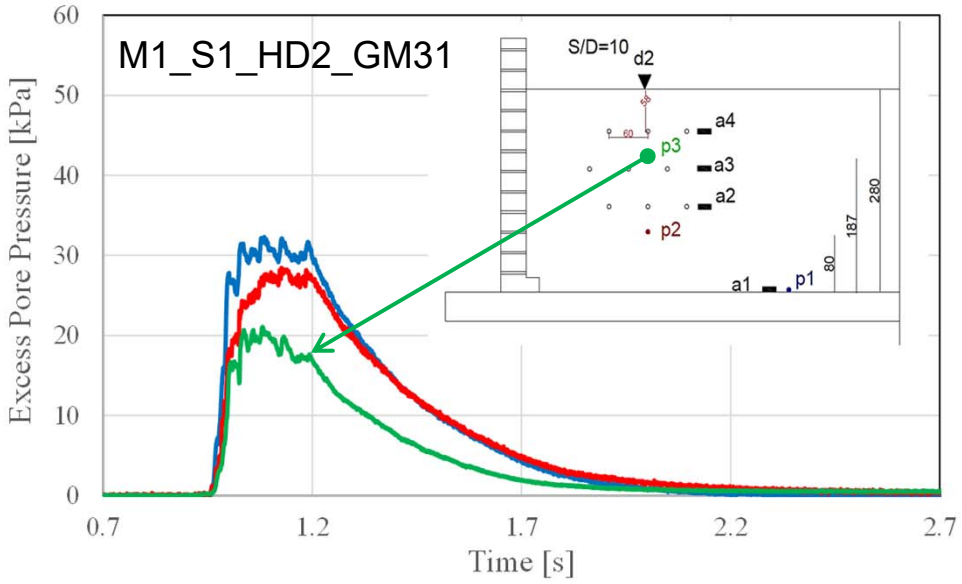


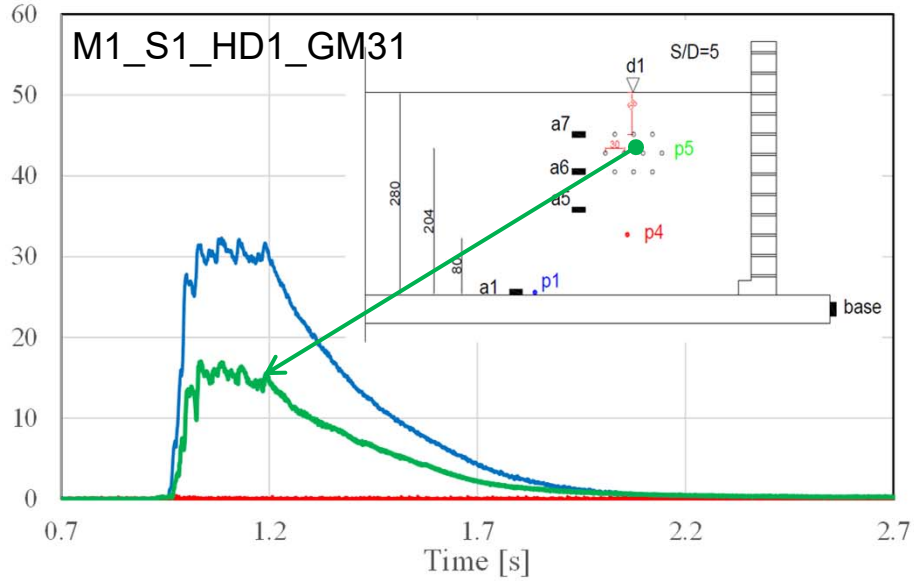




FREE FIELD – HOMOGENEOUS SOIL - HORIZONTAL DRAINS

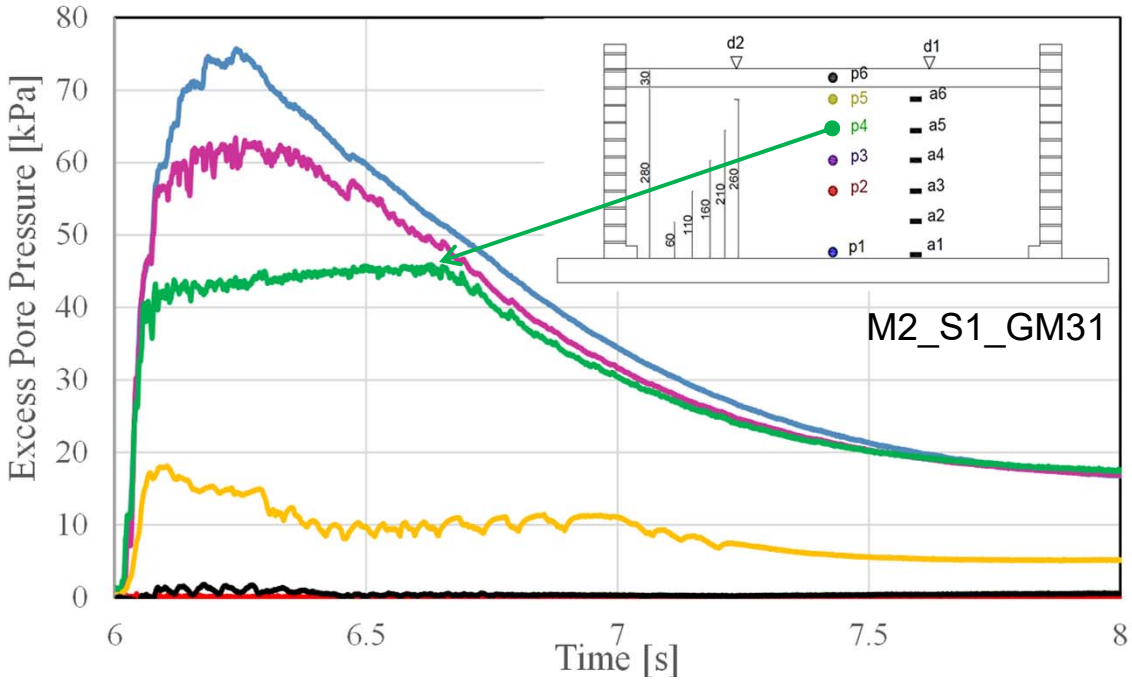


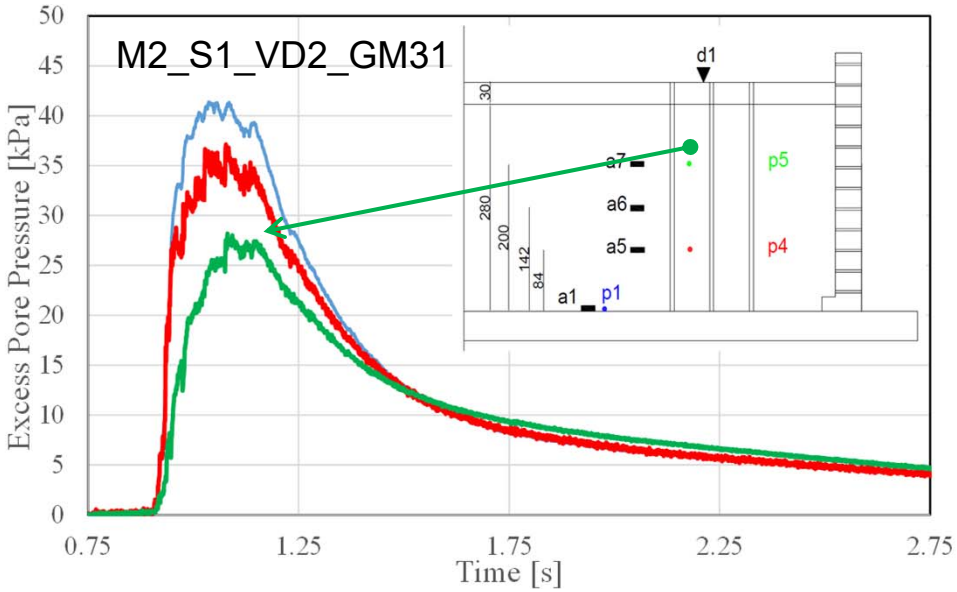


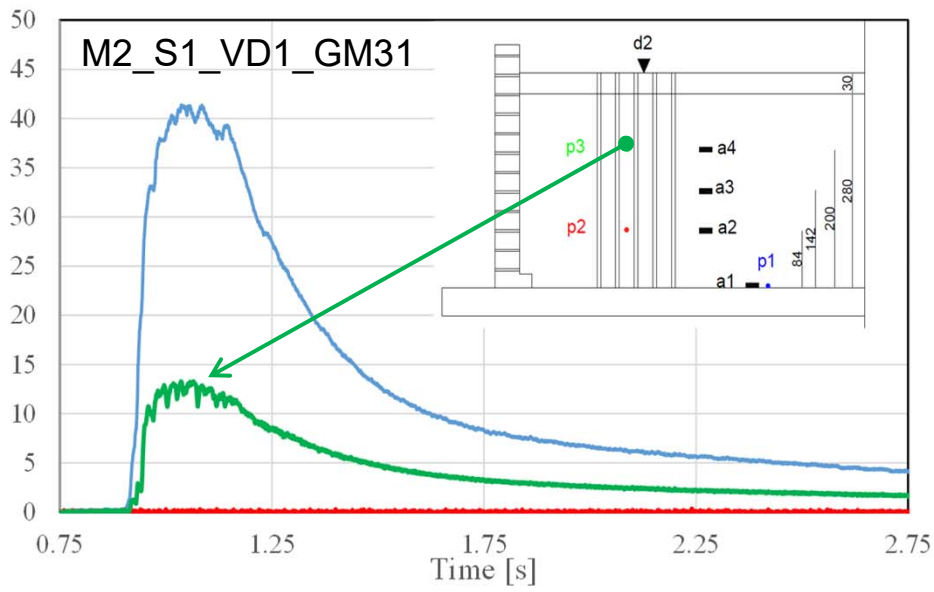



FREE FIELD - TWO LAYERS PROFILE

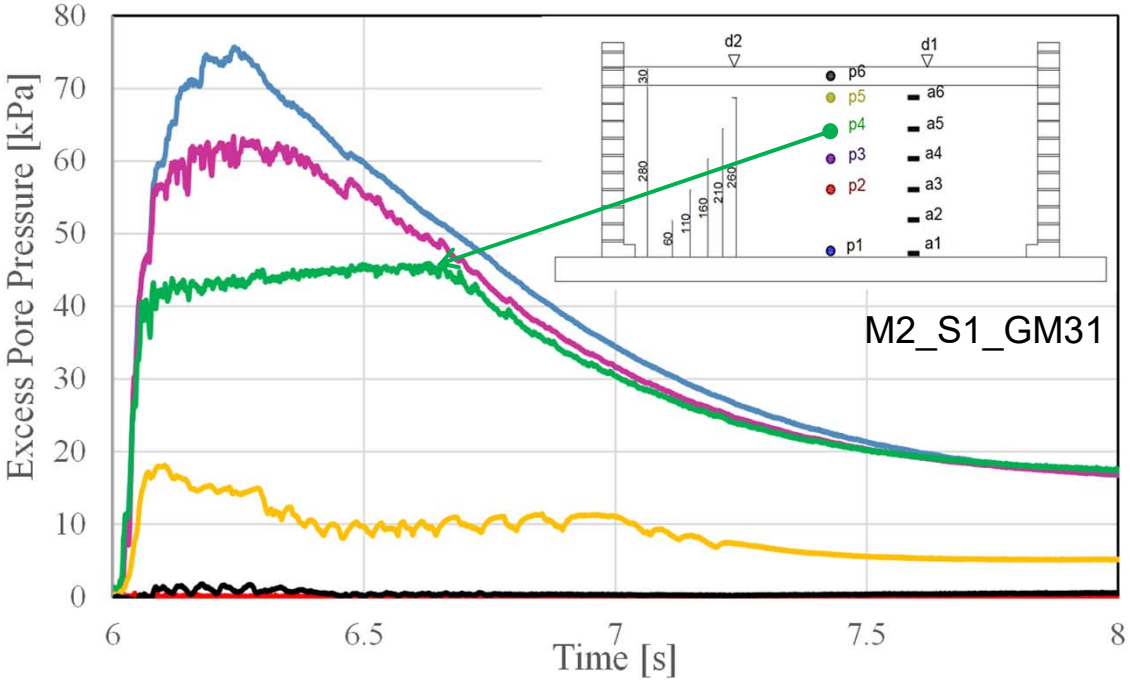
FREE FIELD – TWO LAYERS PROFILE - VERTICAL DRAINS

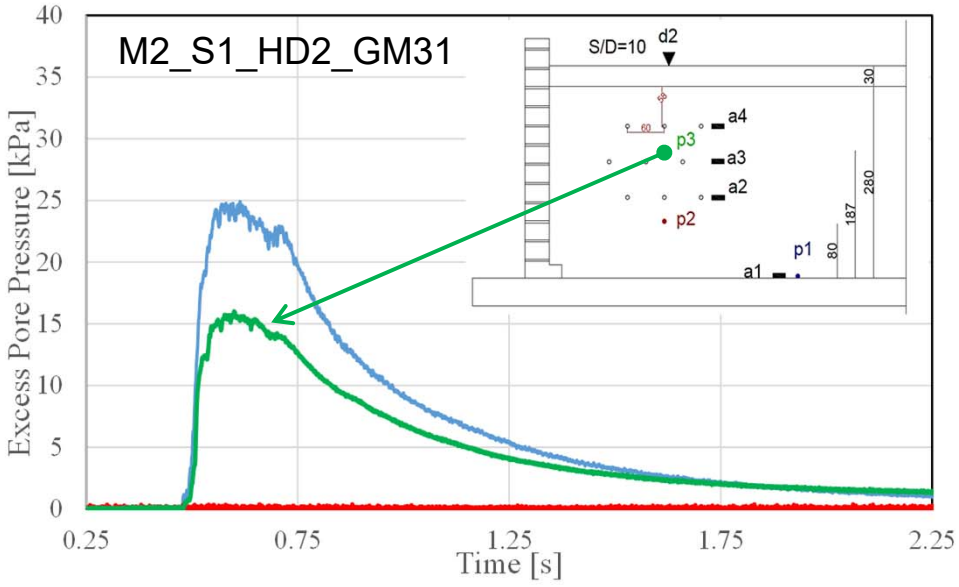


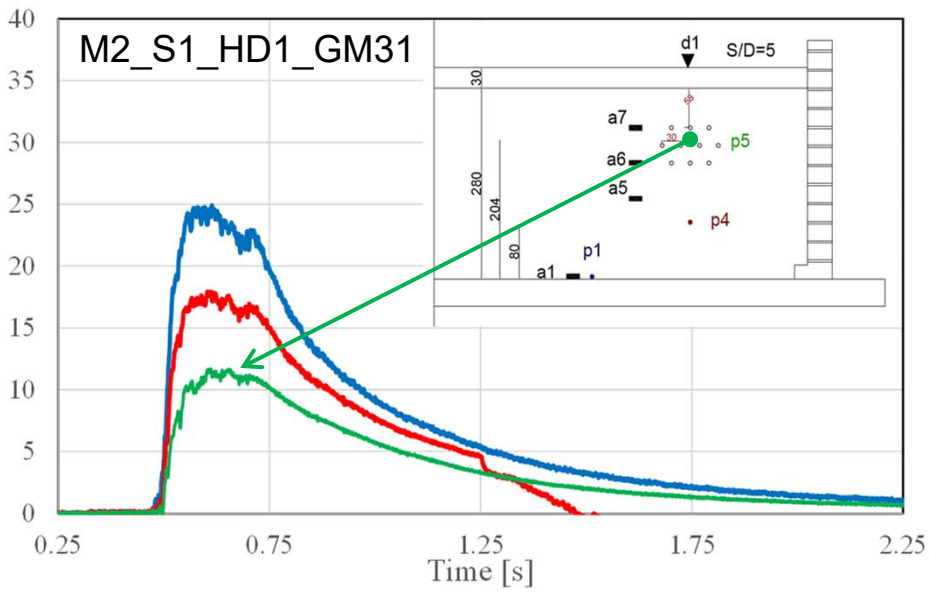




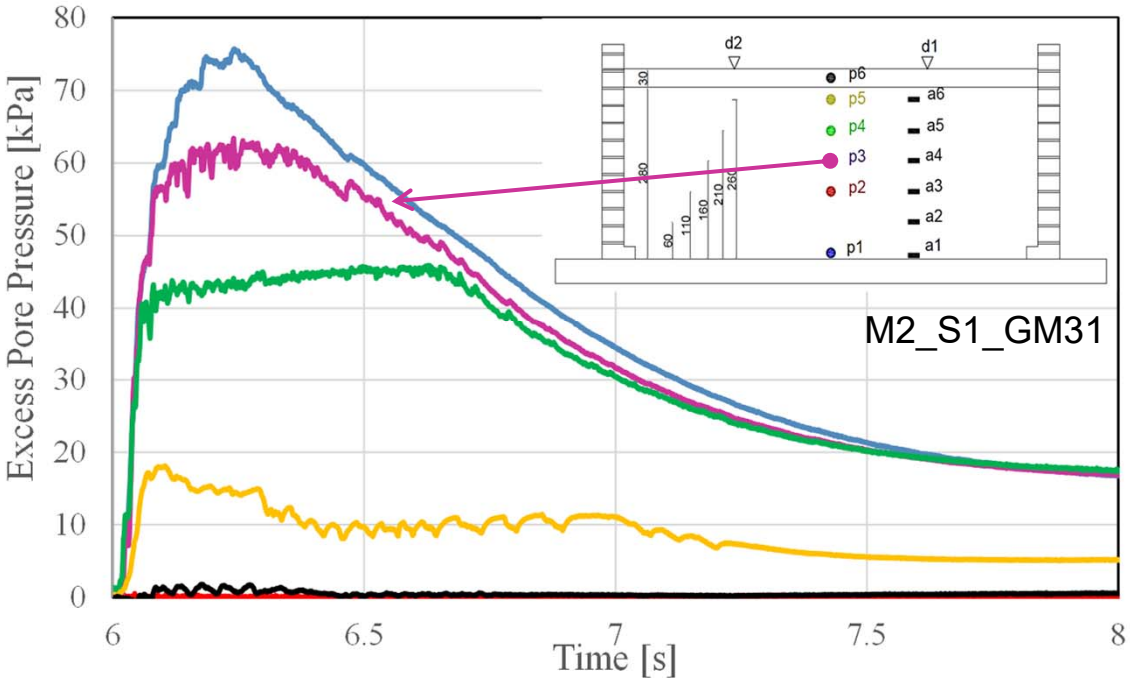
FREE FIELD – TWO LAYERS PROFILE - HORIZONTAL DRAINS

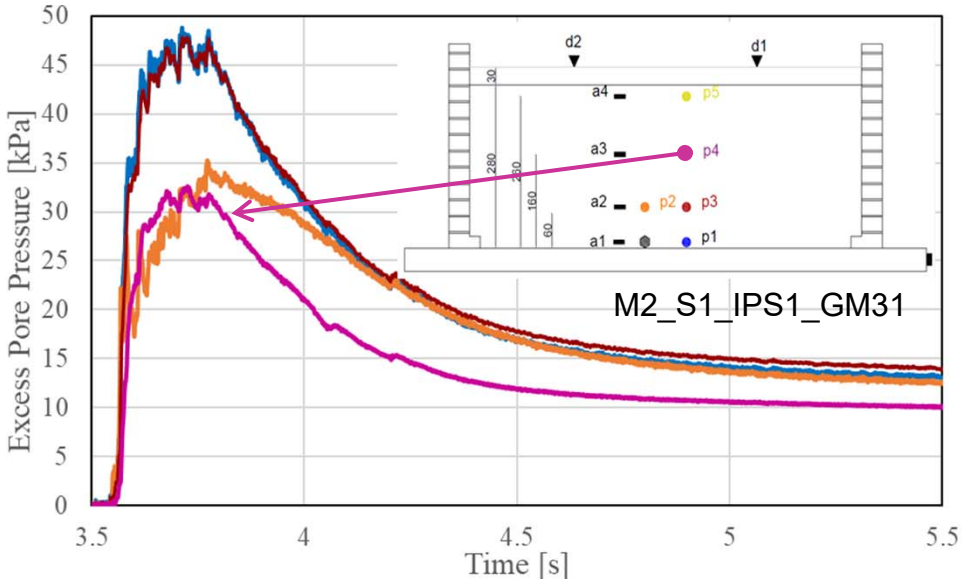


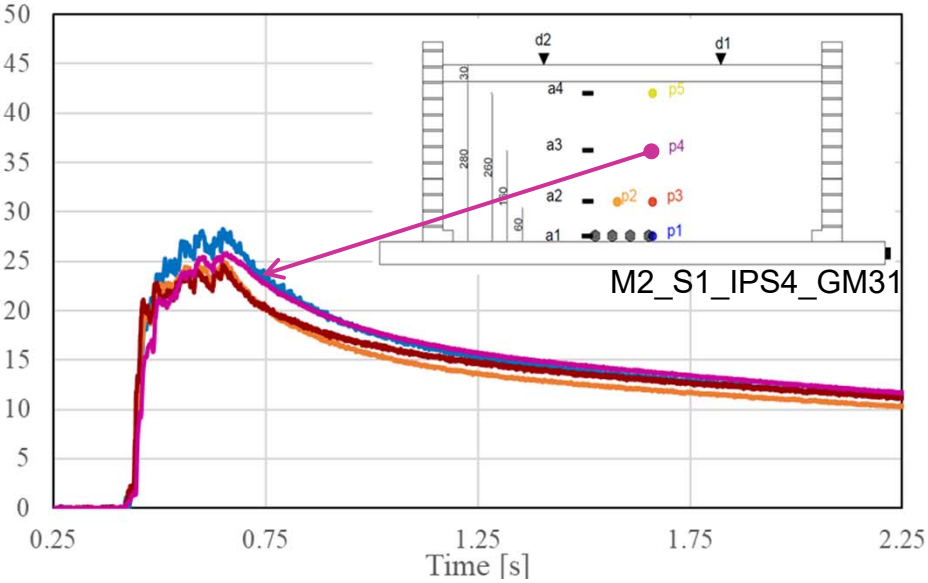




FREE FIELD – TWO LAYERS PROFILE - IPS

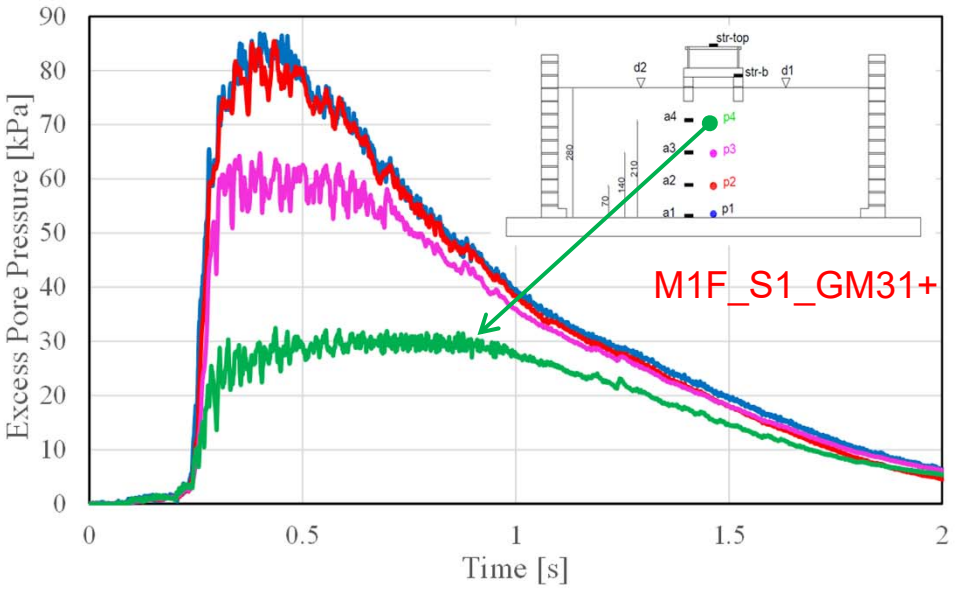




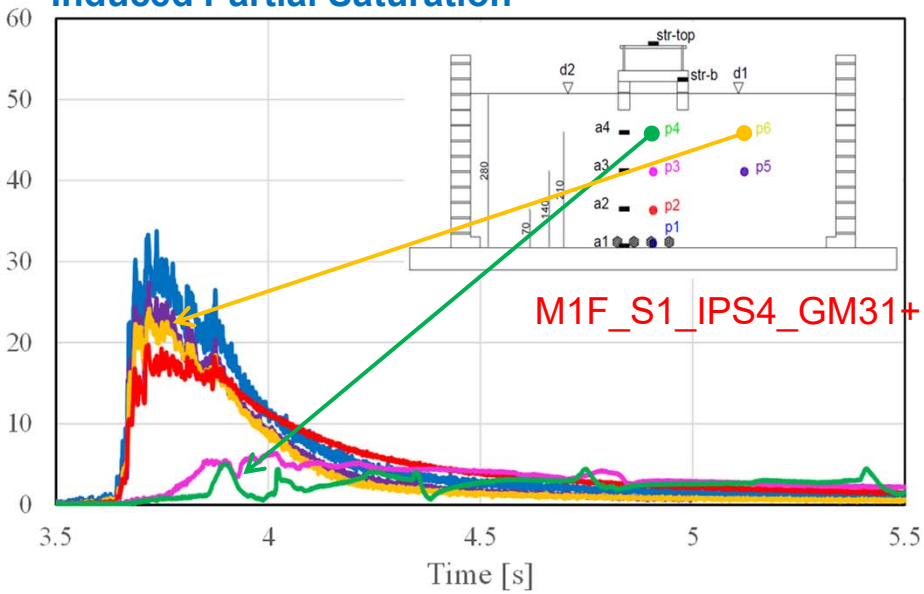



STRUCTURE on HOMOGENEOUS SOIL

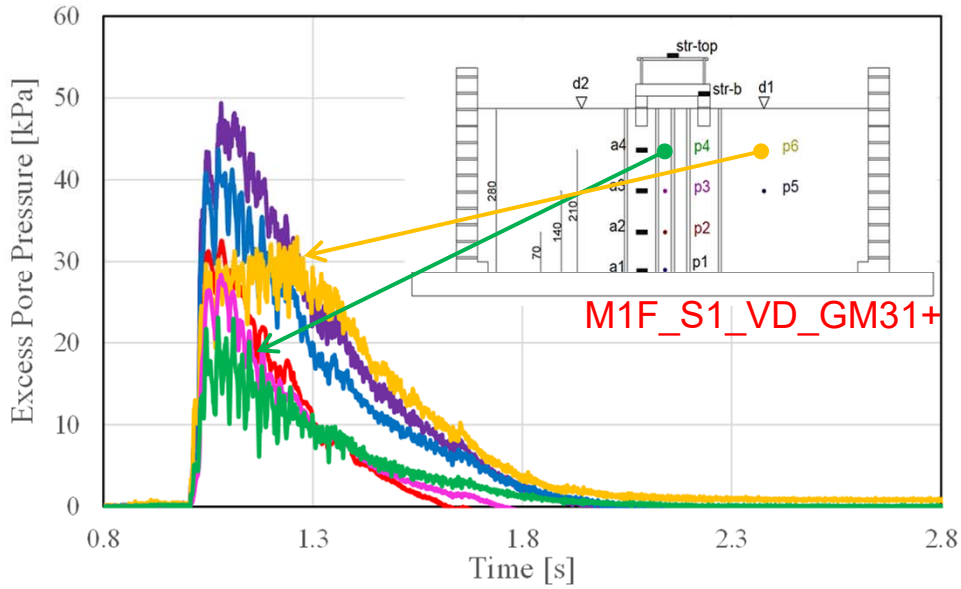
STRUCTURE on HOMOGENEOUS SOIL



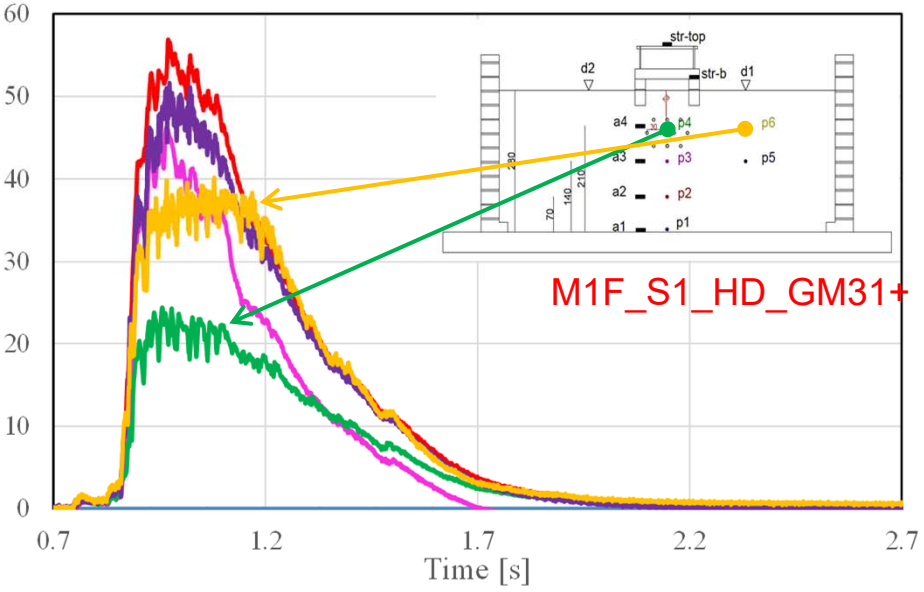
Induced Partial Saturation

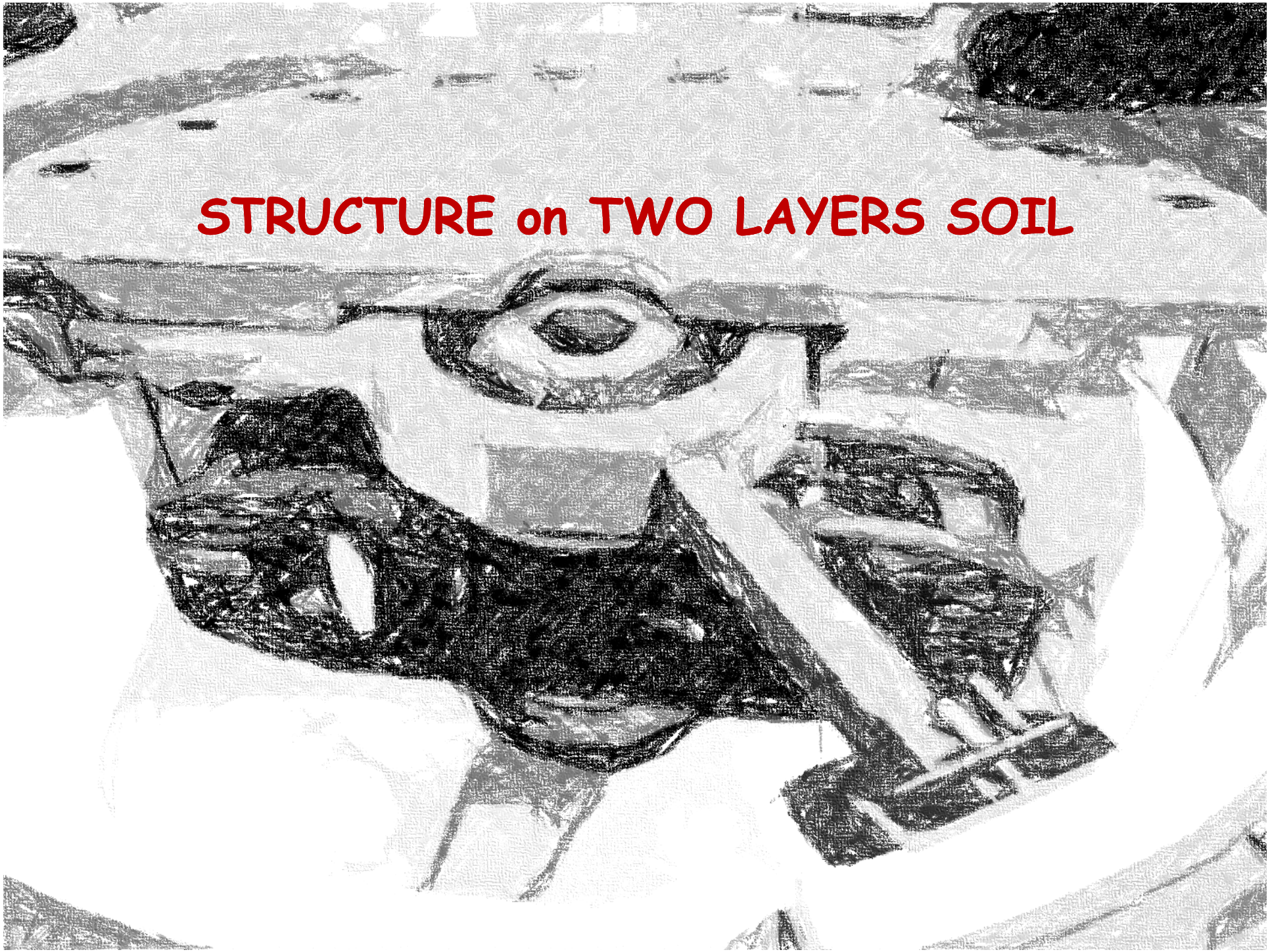


Vertical Drains

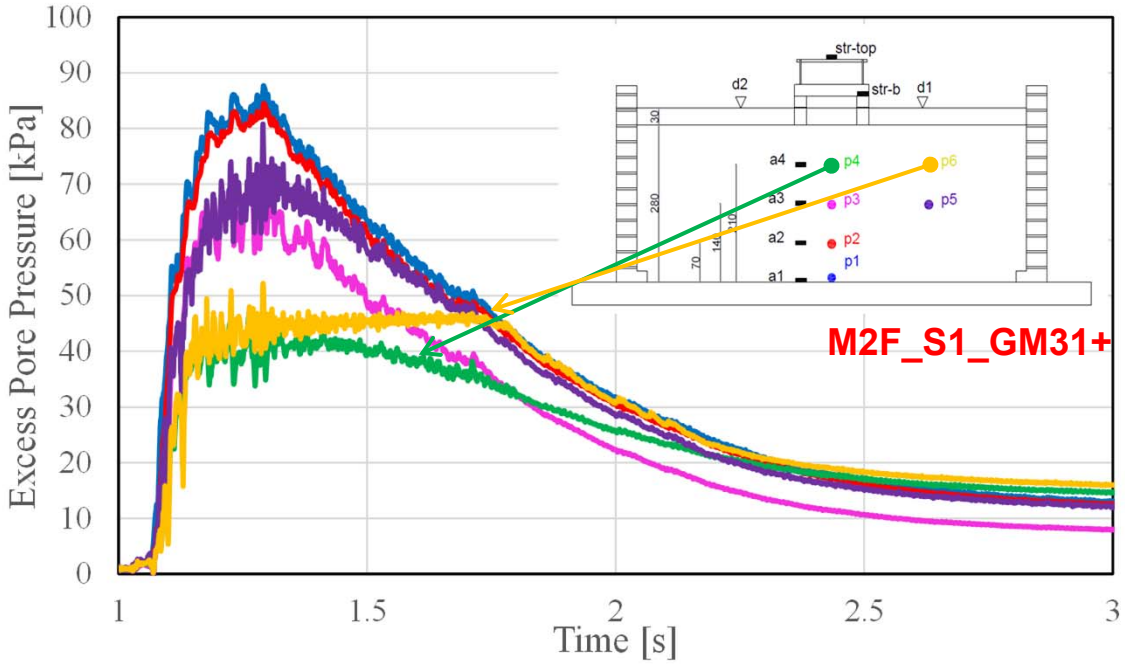


Horizontal Drains

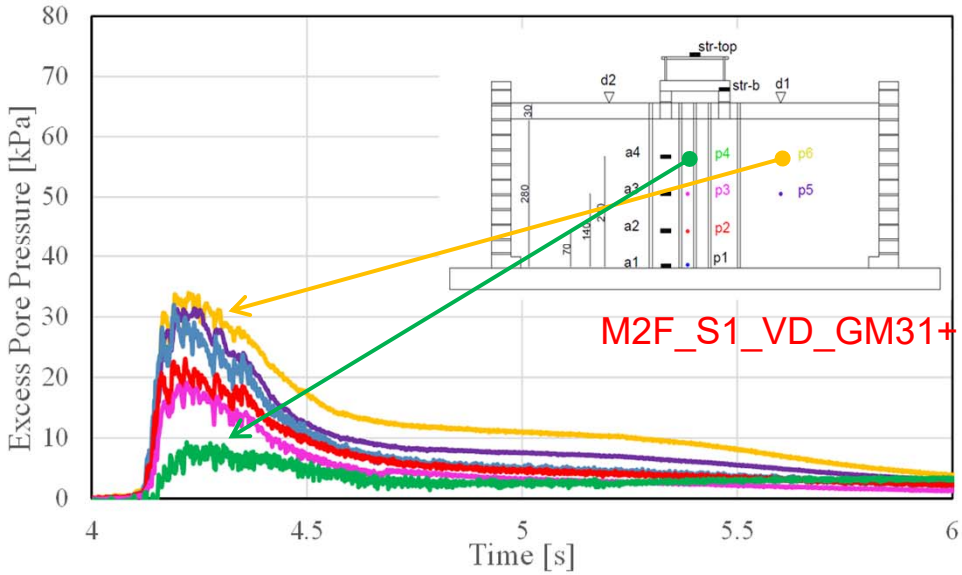



STRUCTURE on TWO LAYERS SOIL

STRUCTURE on TWO LAYERS SOIL



Vertical Drains



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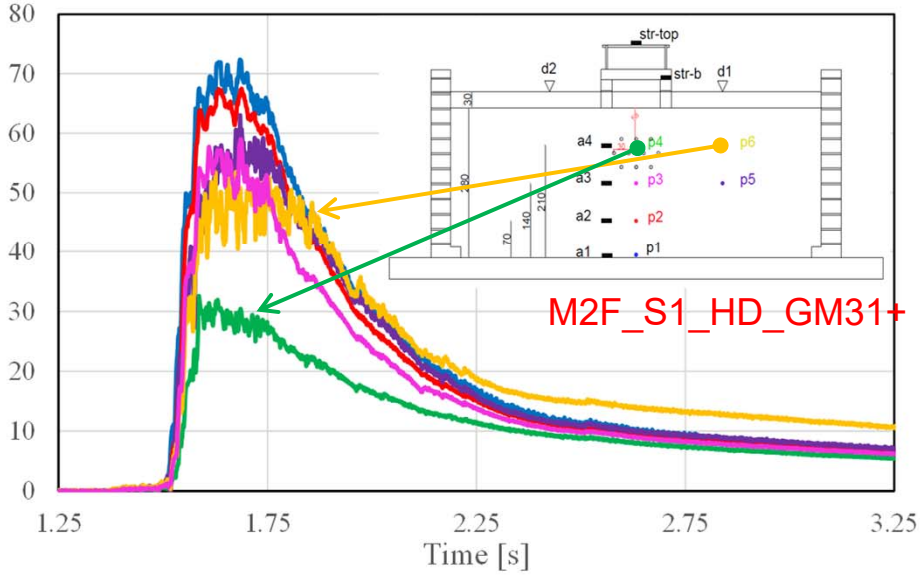
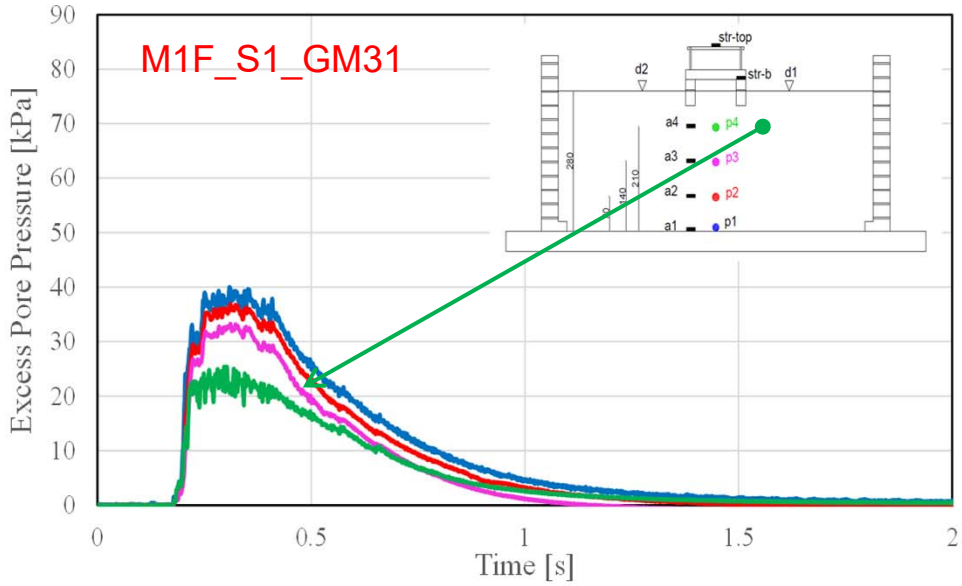


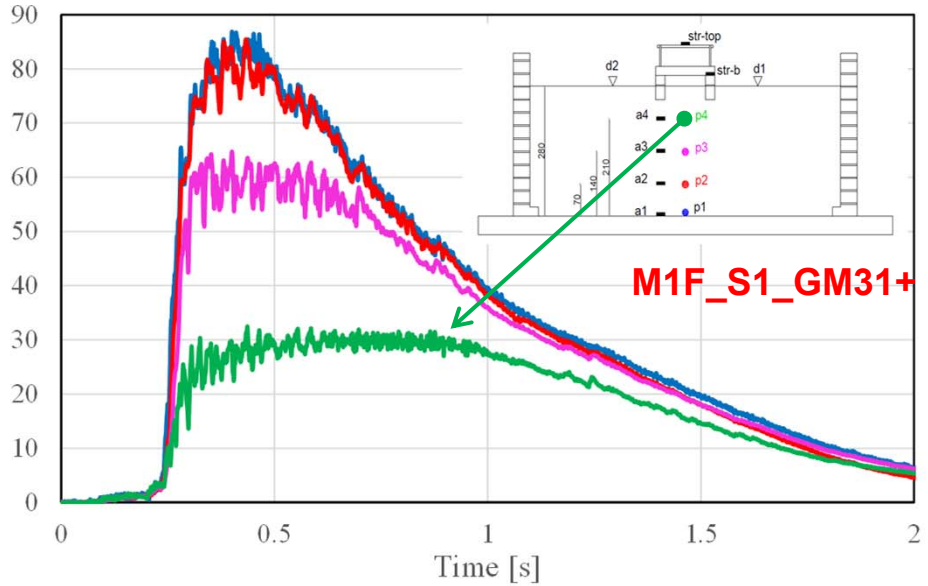
"I più benedetti denari che si spendono da chi vuol fabbricare sono i modegli"

Michelangelo Buonarroti (XVI century)

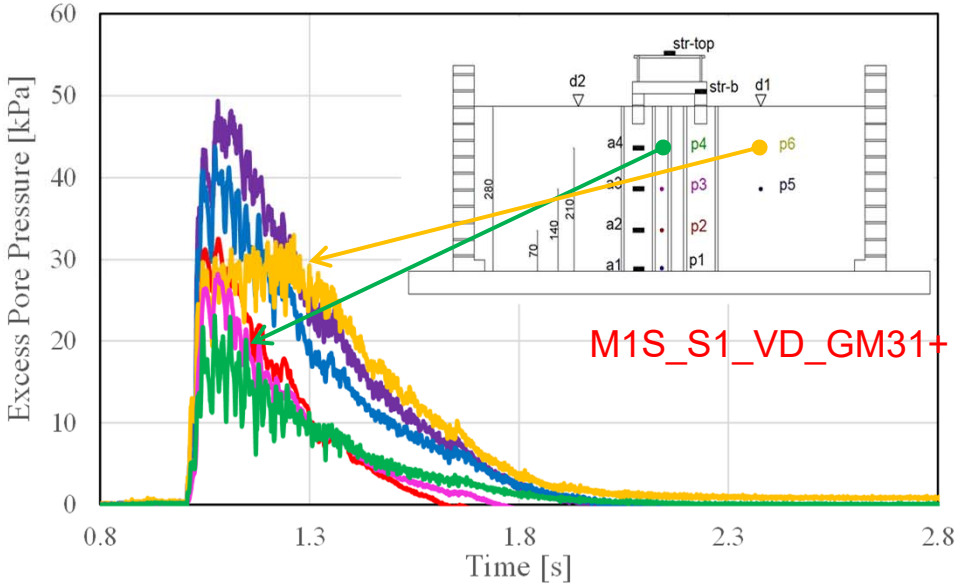
"The money best spent by those who wish to build is that spent to make models"

STRUCTURE on HOMOGENEOUS SOIL

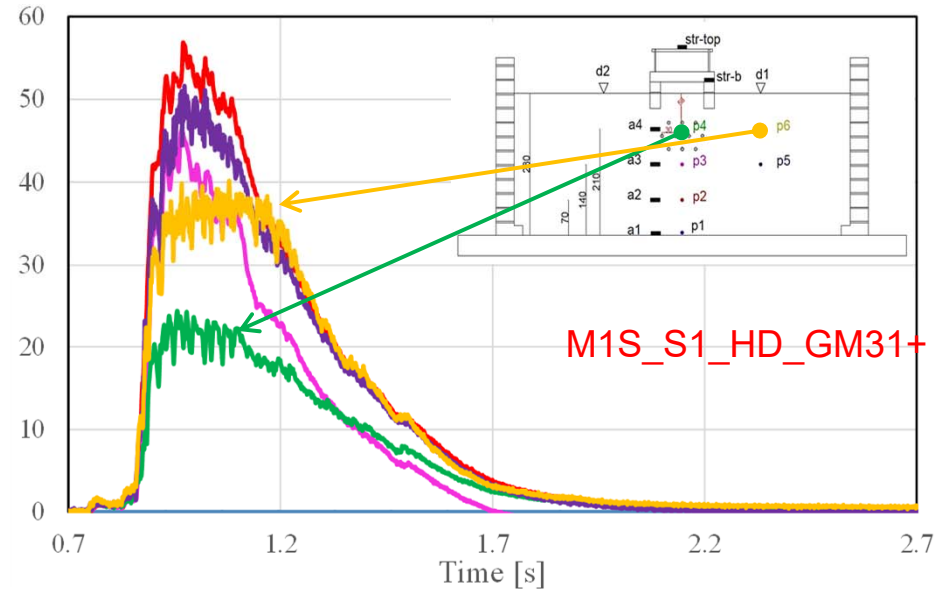




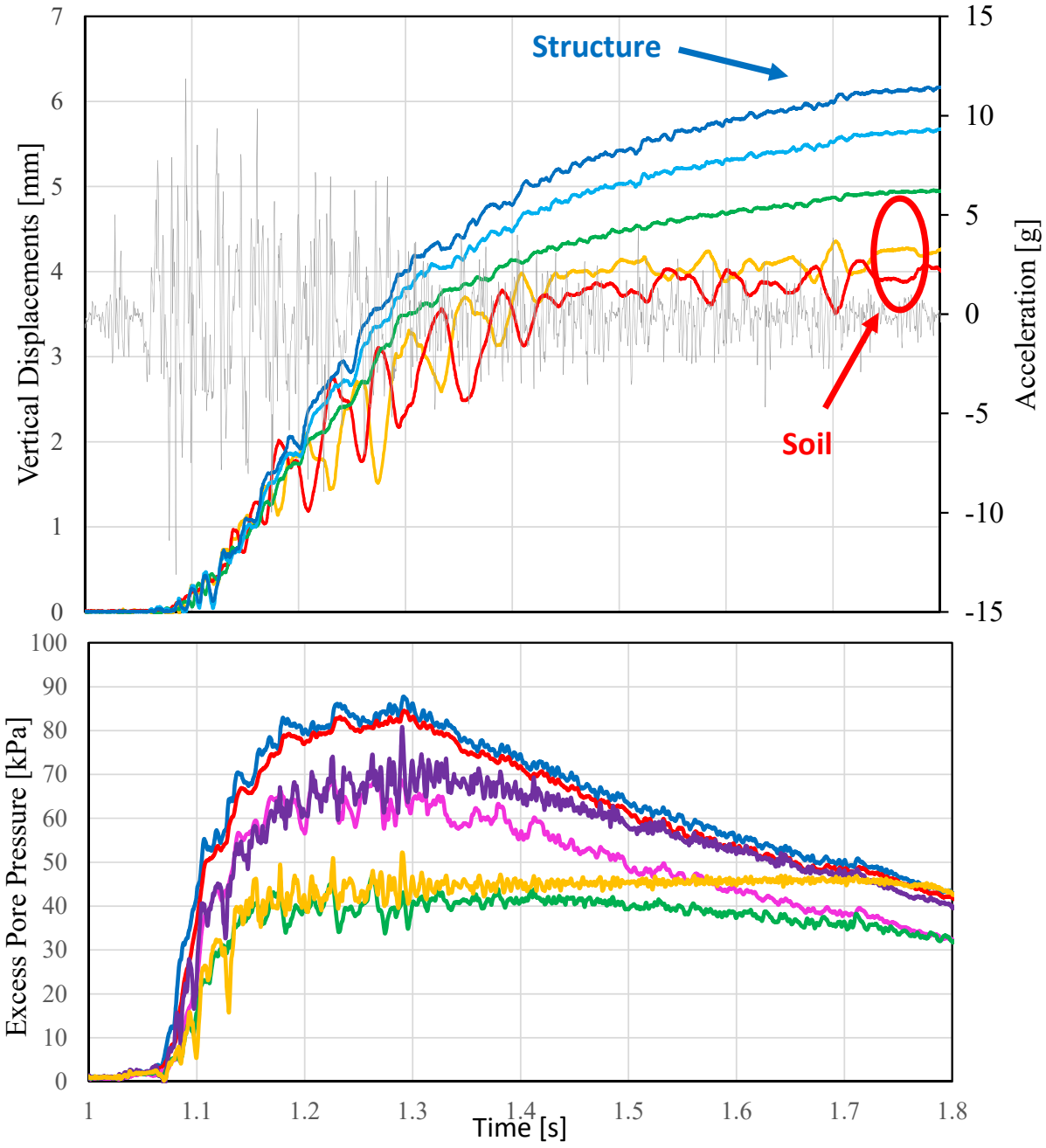
Vertical Drains

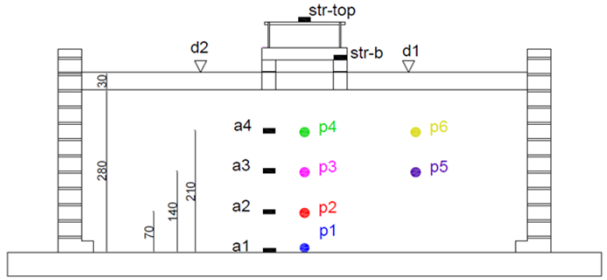


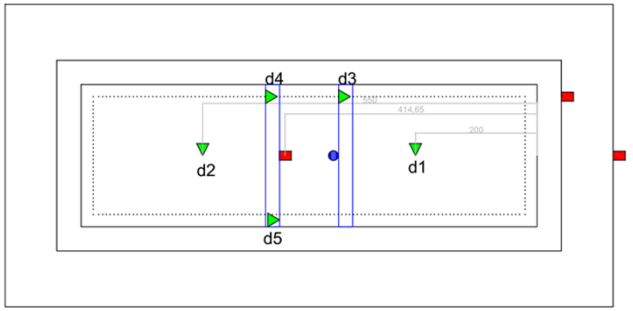
Horizontal Drains



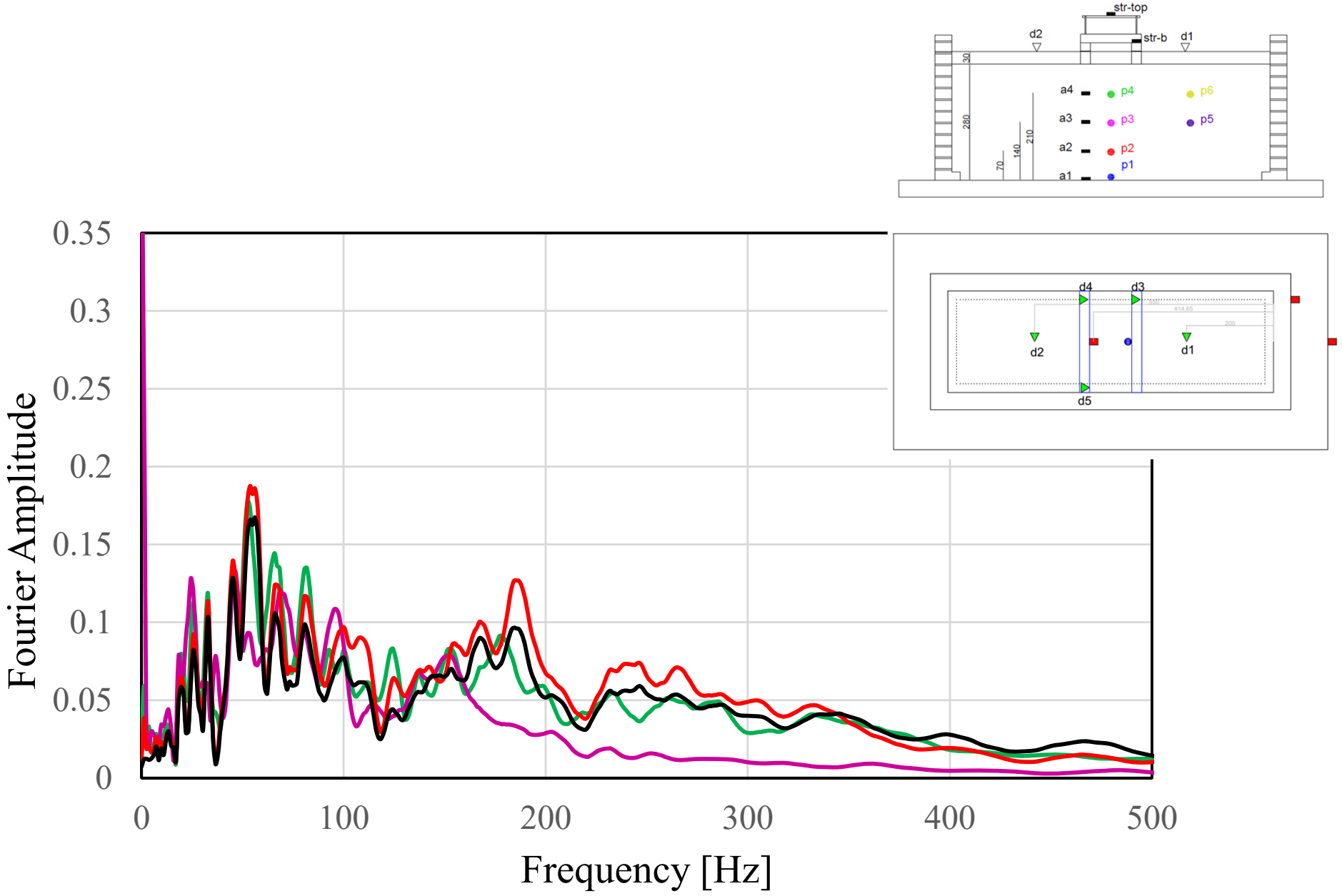
STRUCTURE on TWO LAYERS SOIL



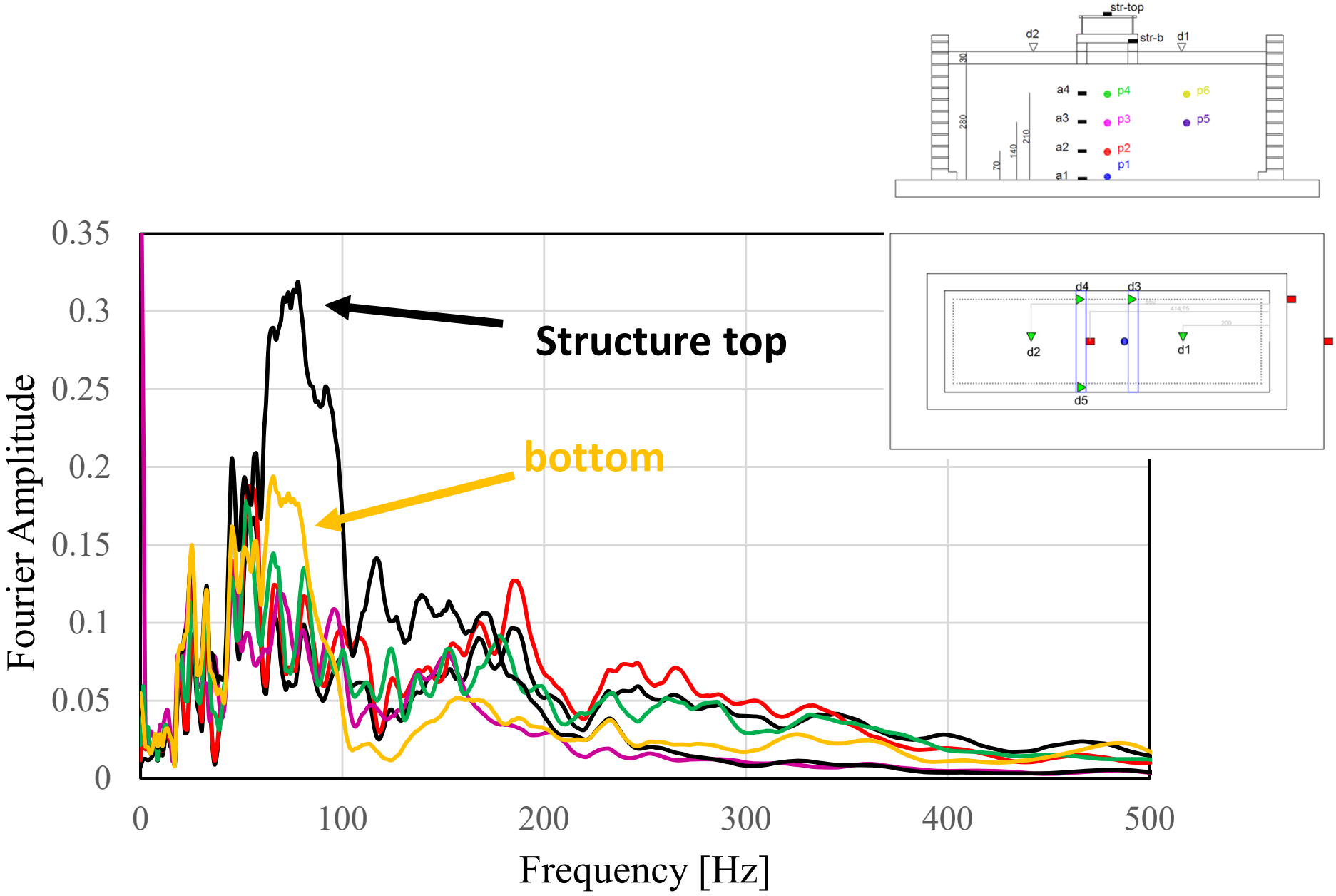




STRUCTURE on TWO LAYERS SOIL



STRUCTURE on TWO LAYERS SOIL



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