Statistical Estimation of Soil Type Using Cross-plots of S-wave Velocity and Resistivity in Japanese Levees

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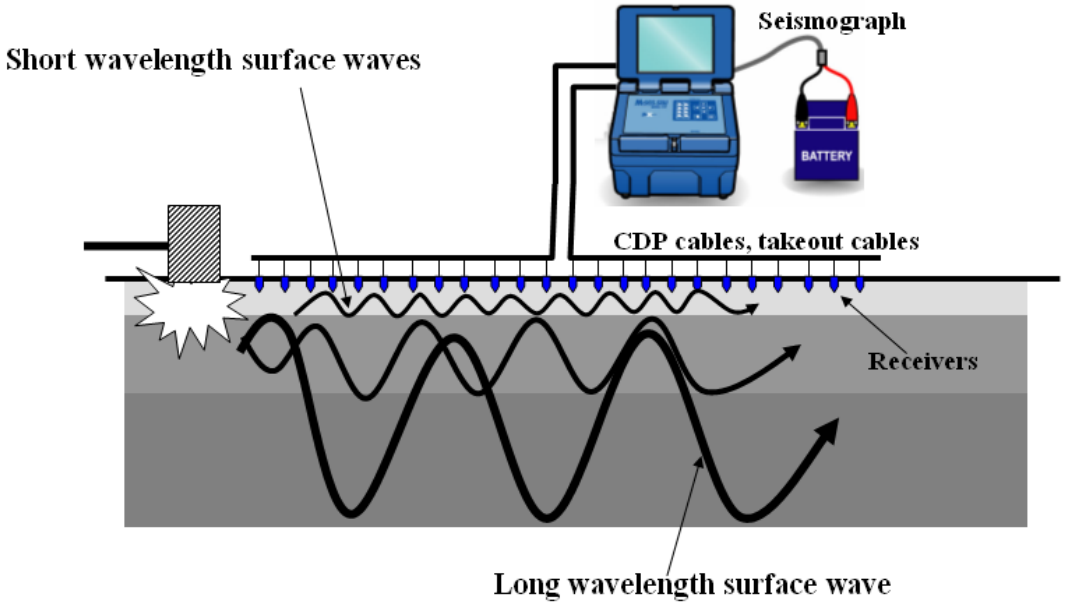
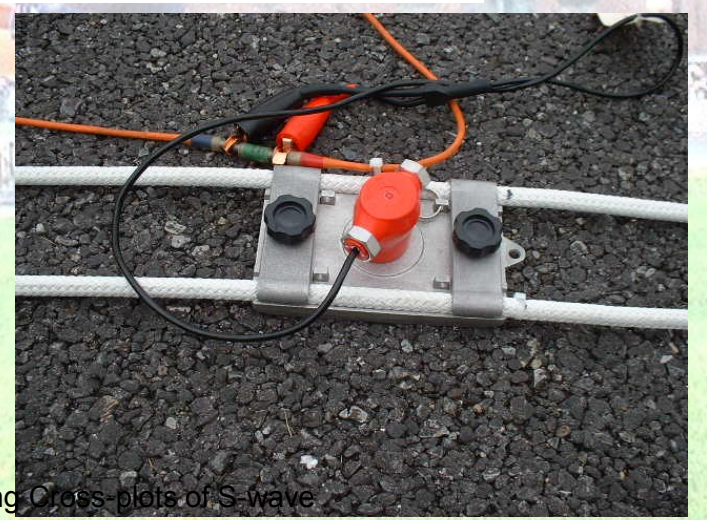
Outline of Integrated Geophysical Method for Levee Safety Assessment

- The method consists of a surface-wave method and resistivity methods, such as a capacitively-coupled resistivity method or an electro-magnetic method.
- The surface-wave method provides S-wave velocity structure of levee body and fundation.
- The capacitively-coupled resistivity method or the electro-magnetic method provides resistivity structure of levee body and foundation.
- A cross-plot analysis of S-wave velocity and resistivity estimates soil type of levee body and foundation.

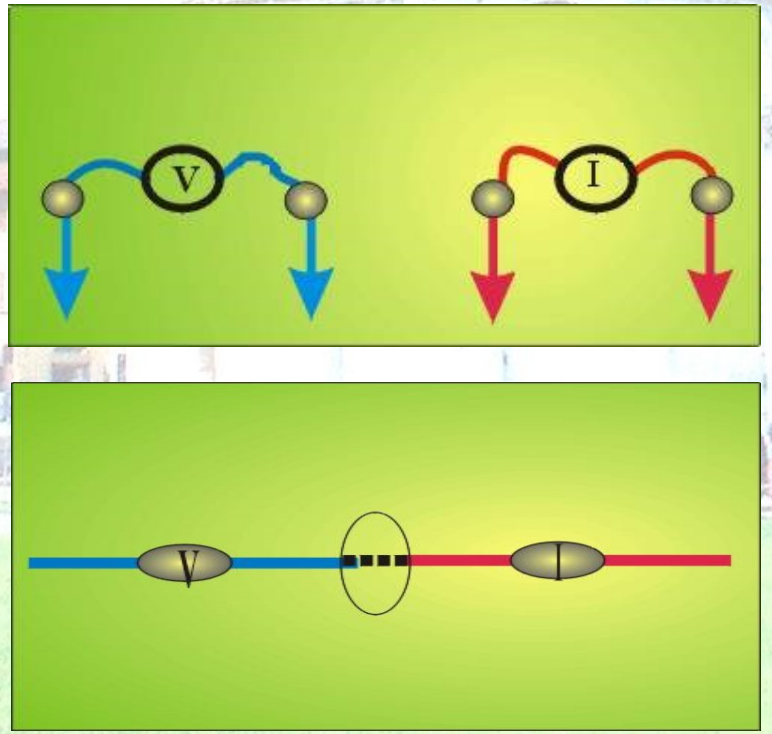
Surface-wave Method Using Land Streamer



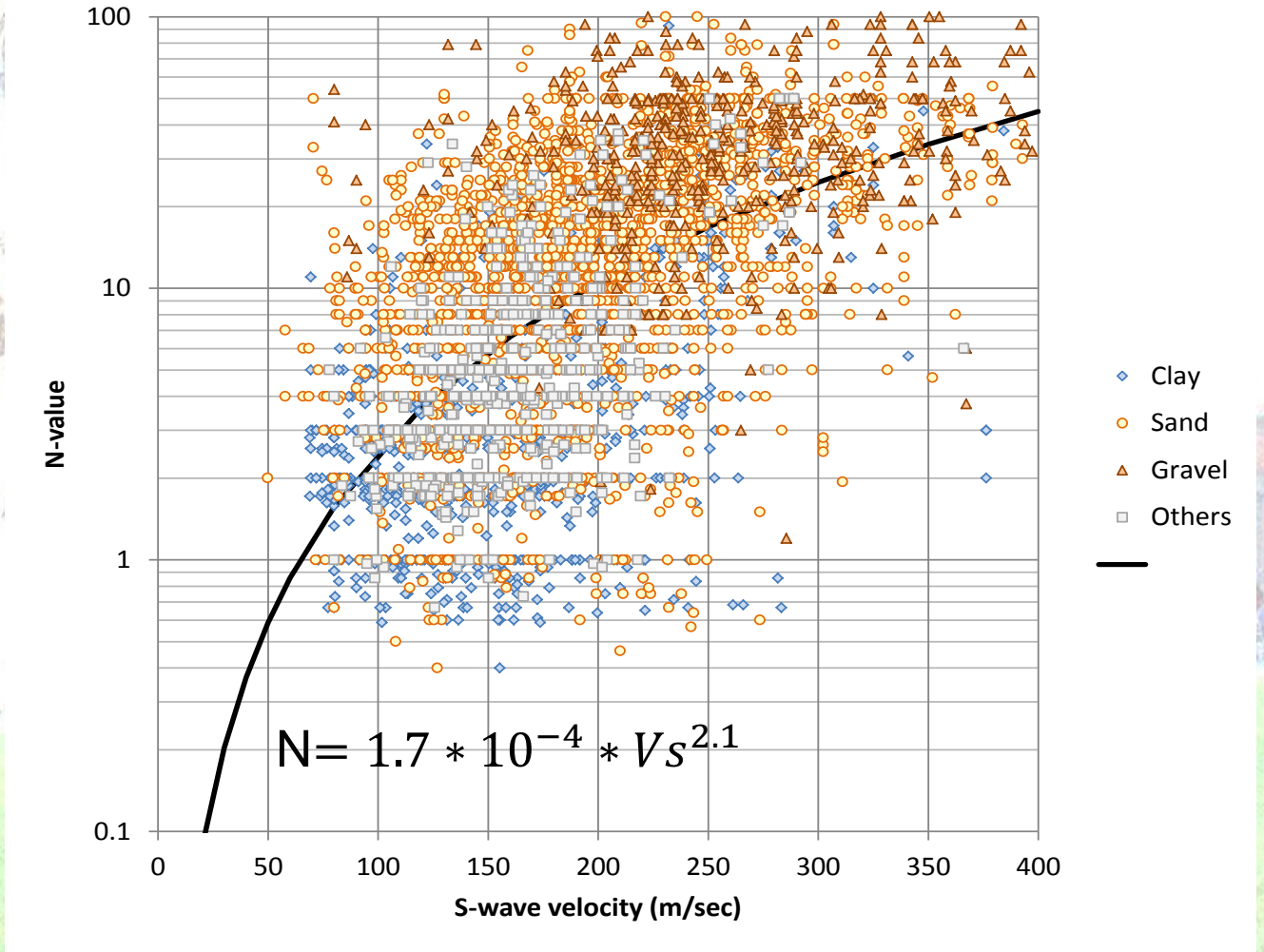


Resistivity Method Using Capacitively Coupled Resistivity (CCR)

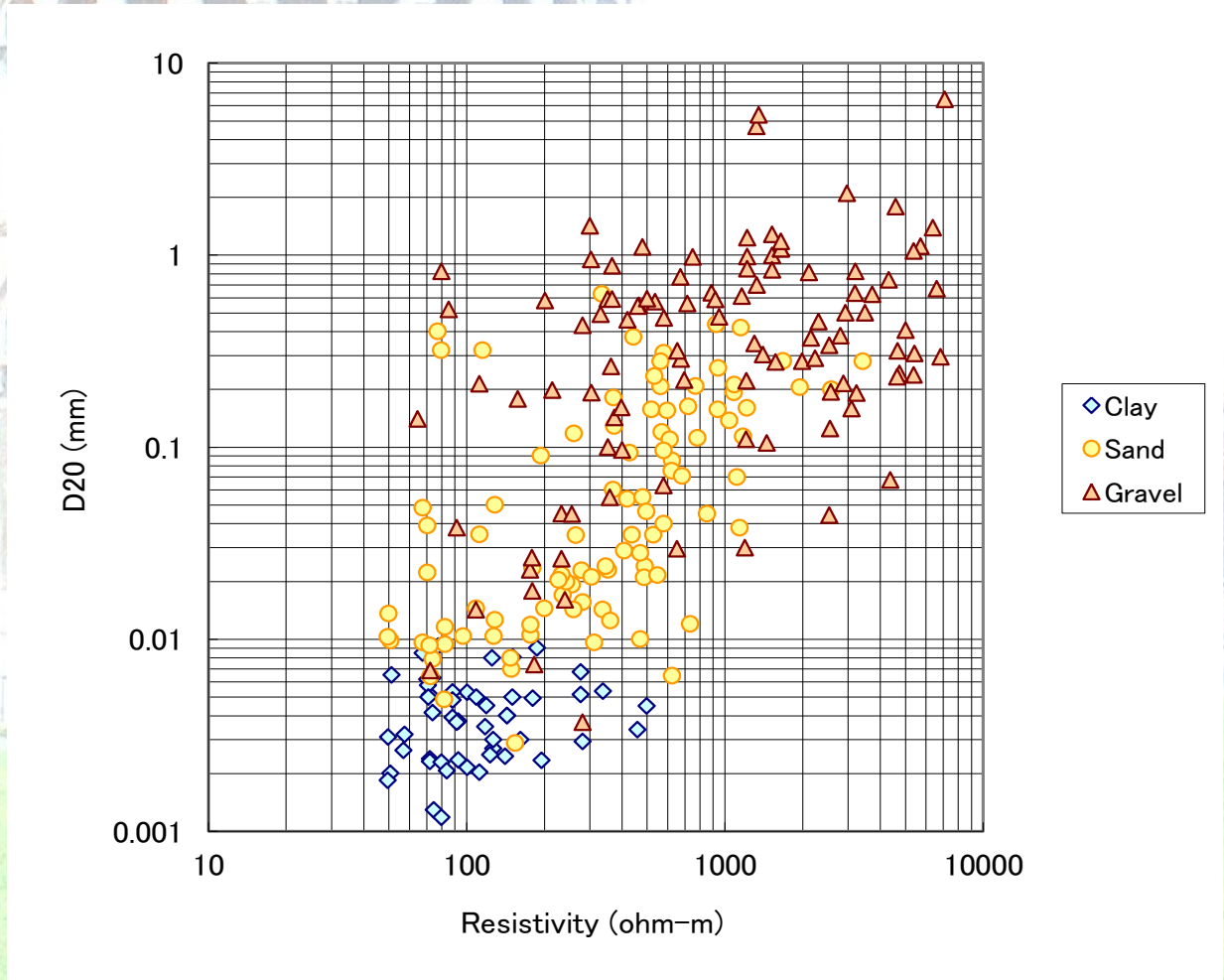
In CCR, capacitors are used as electrode and metallic stakes are not used. The OhmMapper was used as a CCR instrument



S-wave Velocity and N-value (blow-count) obtained by SPT

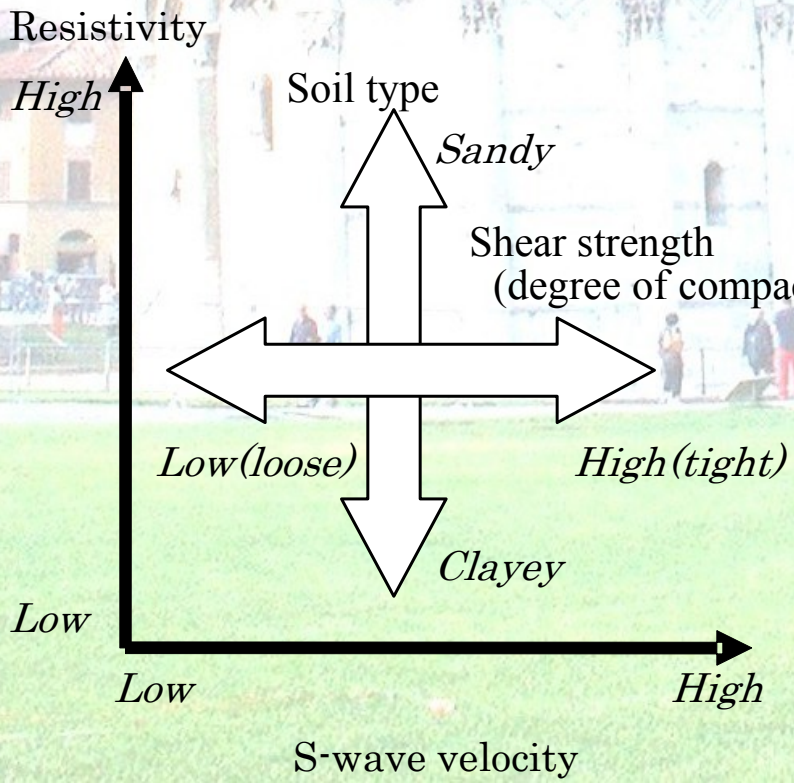


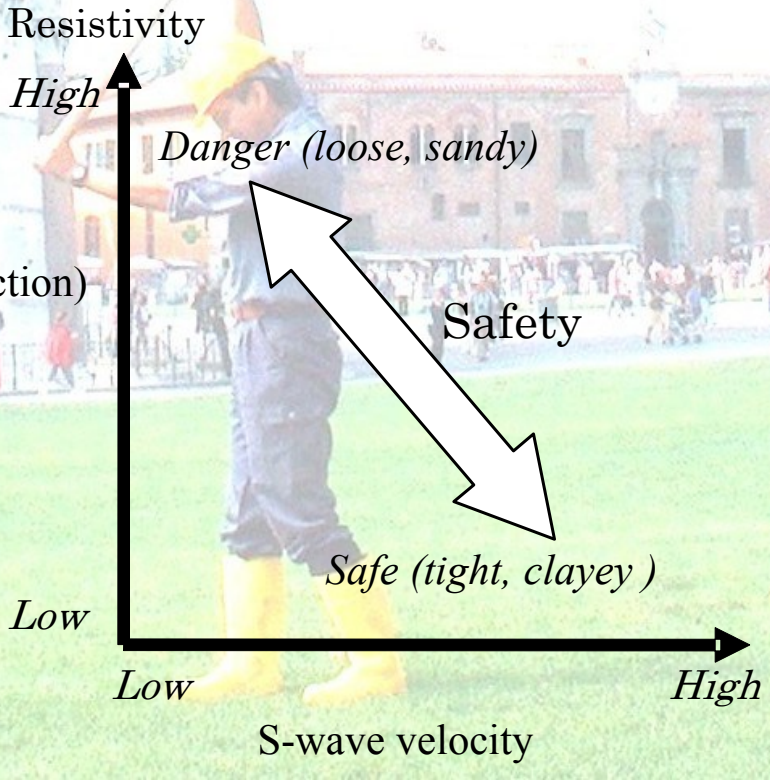
20% Grain Size (D20) and Resistivity



S-wave velocity and Resistivity for Levee Safety

- From the Archie's equation, resistivity of soil mainly indicates soil type.
- S-wave velocity is mainly affected by shear strength or porosity.
- Safety of levees can be evaluated by S-wave velocity and resistivity.





S-wave velocity and Resistivity for Levee Safety

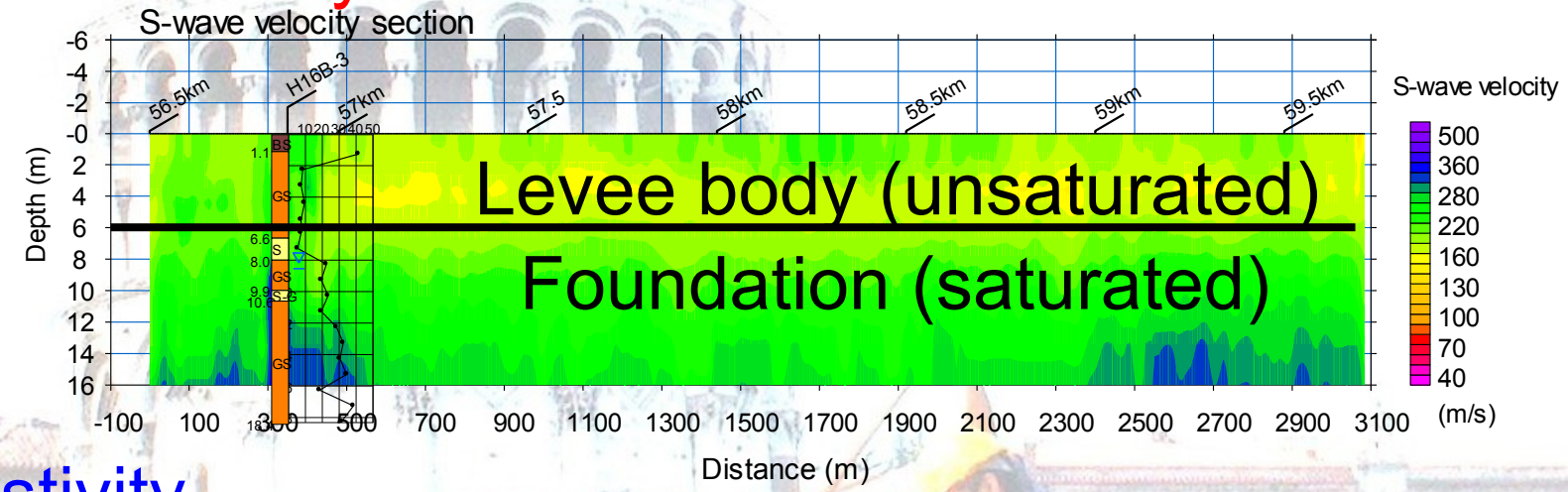
- A soil type (clay, sand or gravel) or grain size distribution (clay contents or D_{20}) is the most important information for levee safety evaluation from an engineering point of view.
- The soil type or the grain size distribution is used in many engineering analyses
- In most of such analyses, the soil type or the grain size distribution is obtained by the borings or laboratory tests.
- Physical properties obtained through the geophysical methods (e.g. S-wave velocity or resistivity) do not directly relate to the soil type and the grain size distribution.
- We are going to estimate the soil type in terms of a statistical approach using geophysical and geotechnical data collected in Japan.

Statistical Estimation of Soil Type

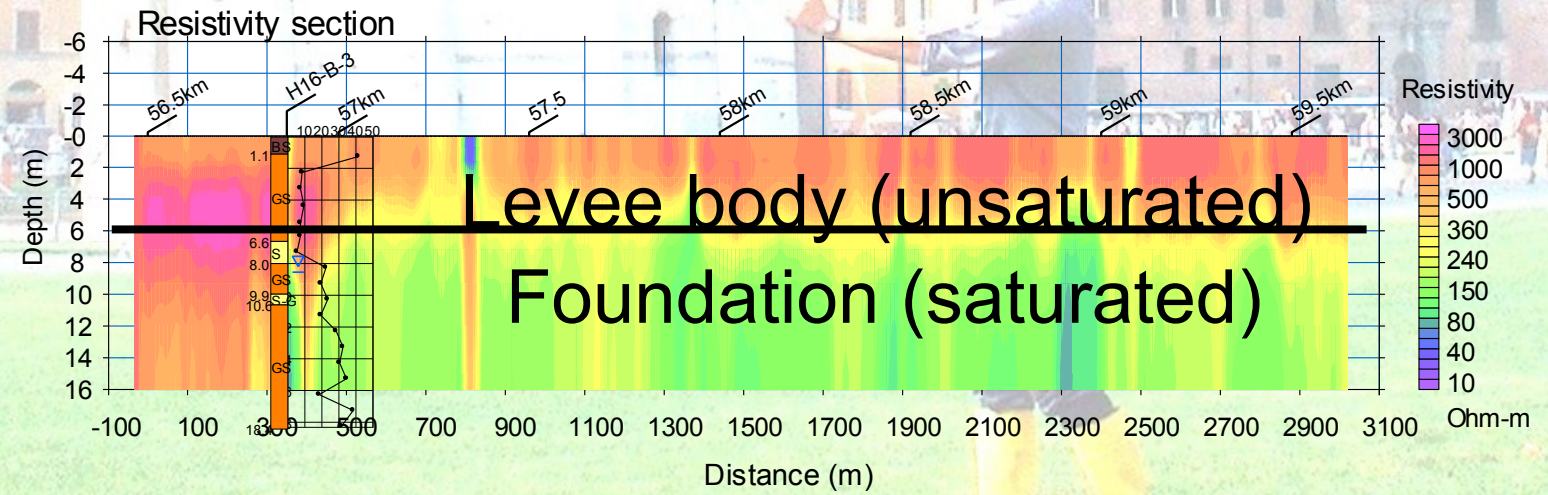
- Soil type of levee body and foundation is statistically estimated using cross-plots of S-wave velocity and resistivity in Japan
- S-wave velocity and resistivity are collected from surface wave methods and resistivity methods.
- Total survey line length of the geophysical methods is about 600km on 37 rivers in Japan.
- The blow counts and soil types are collected from about 400 boring logs carried out on geophysical survey lines.
- The total number of extracted data is about 4000.

Example of Geophysical Sections

S-wave velocity

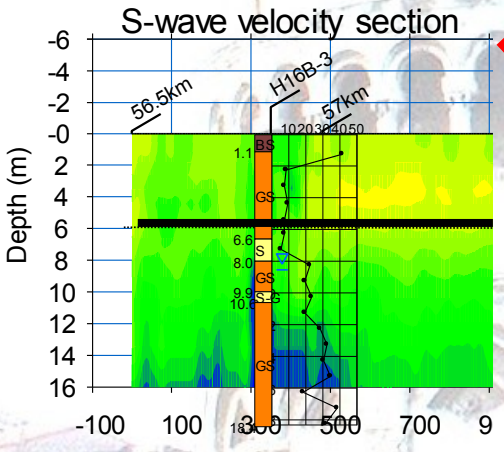


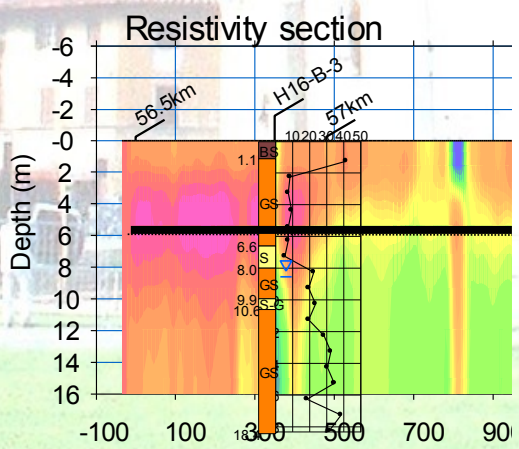
Resistivity



Statistical Estimation of Soil Type Using Cross-plots of S-wave Velocity and Resistivity in Japanese Levees

Extracting Vs, Resistivity and Soil type



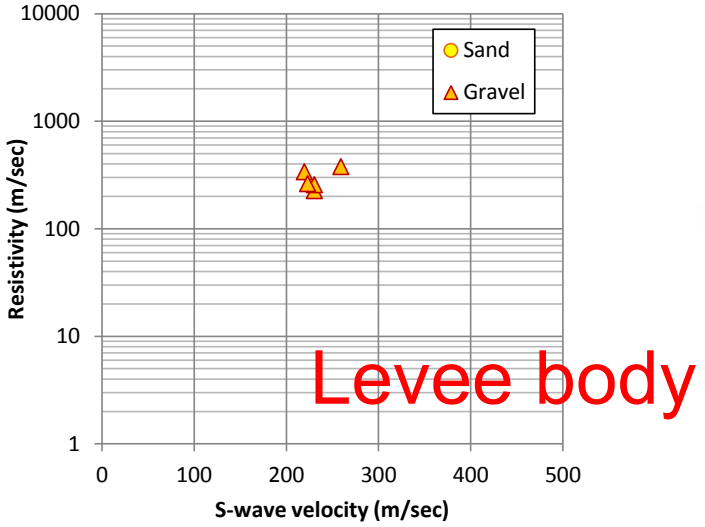


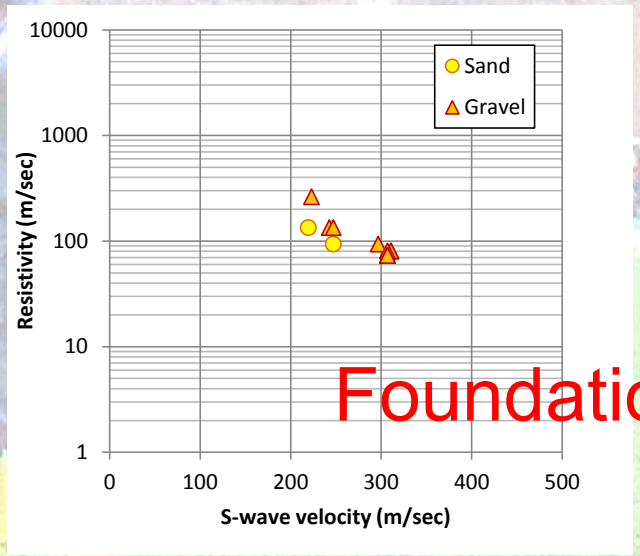
Depth (m)	N-value	S-wave velocity (m/sec)	Resistivity (ohm-m)	Soil type	
1.3	42	230	226	Gravel	Levee body
2.3	9	230	256	Gravel	
3.3	8	220	339	Gravel	
4.4	10	259	378	Gravel	
5.5	8	223	262	Gravel	
6.3	8	223	262	Gravel	Foundation
7.3	6	220	134	Sand	
8.3	23	243	134	Gravel	
9.3	20	247	134	Gravel	
10.3	24	247	93	Sand	
11.3	20	297	93	Gravel	
12.3	29	311	80	Gravel	
13.3	33	311	80	Gravel	
14.3	31	307	80	Gravel	
15.3	35	307	73	Gravel	
16.3	19	307	73	Gravel	
17.3	39	307	73	Gravel	

Statistical Estimation of Soil Type Using Cross-plots of S-wave Velocity and Resistivity in Japanese Levees

Cross-plot of Vs and Resistivity

S-wave velocity (m/sec)	Resistivity (ohm-m)	Soil type	
230	226	Gravel	Levee body
230	256	Gravel	
220	339	Gravel	
259	378	Gravel	
223	262	Gravel	
223	262	Gravel	Foundation
220	134	Sand	
243	134	Gravel	
247	134	Gravel	
247	93	Sand	
297	93	Gravel	
311	80	Gravel	
311	80	Gravel	
307	80	Gravel	
307	73	Gravel	
307	73	Gravel	
307	73	Gravel	

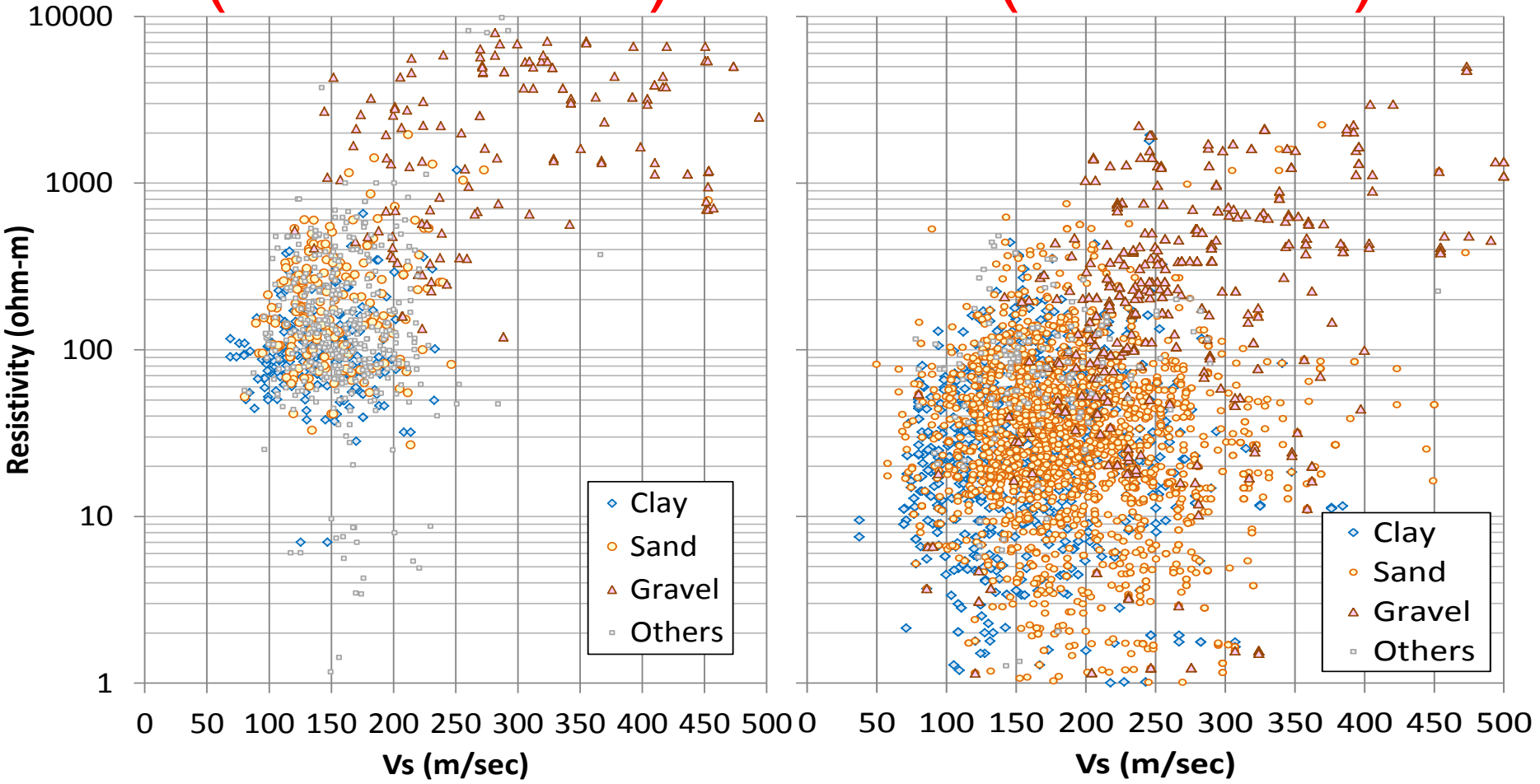




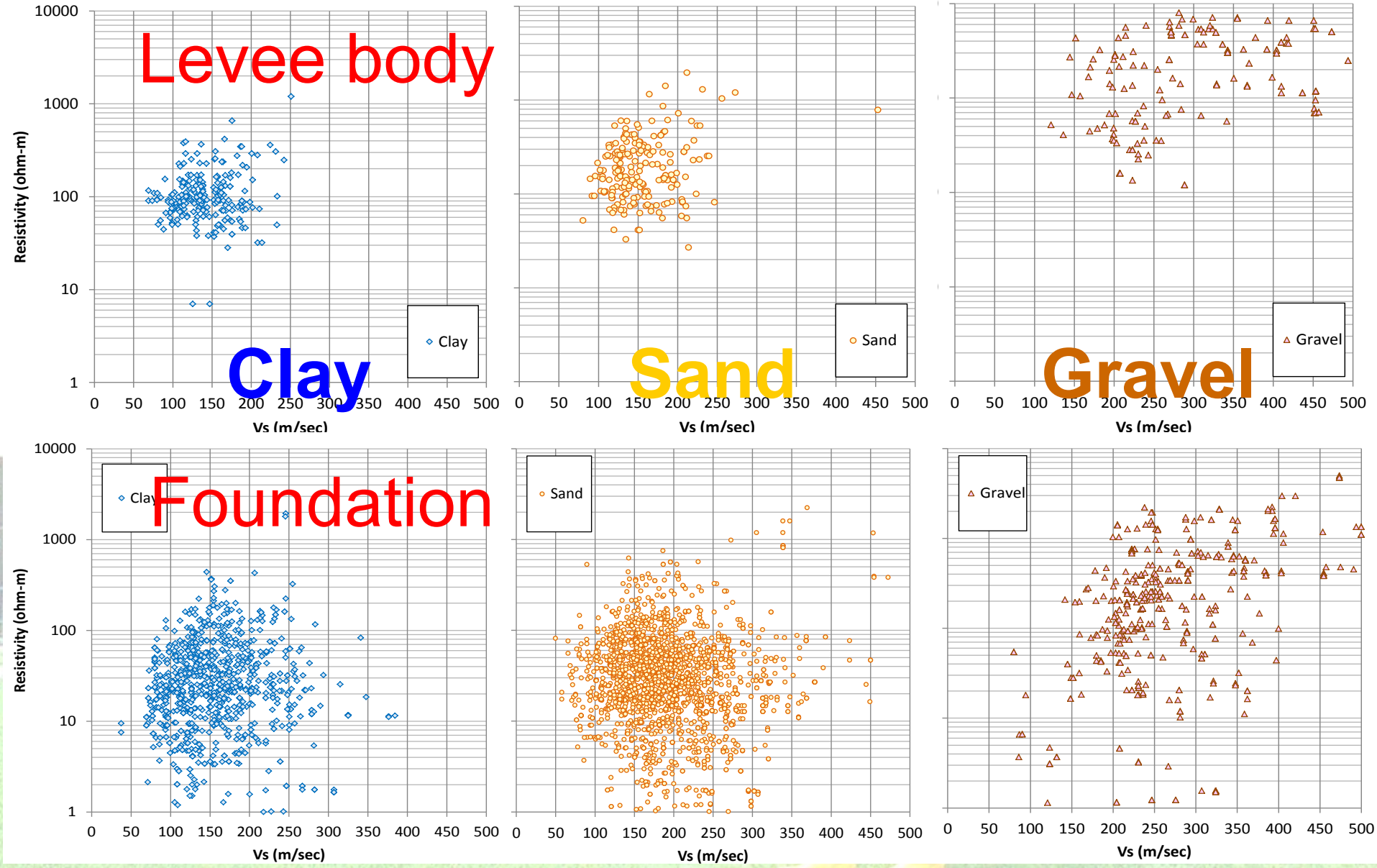
Resistivity and S-wave velocity from 400 Boring Logs

Levee body (unsaturated)

Foundation (saturated)



S-wave velocity and Resistivity



Polynomial Approximation of Soil Type

- Polynomial approximation (curved plane) is used to estimate the soil type from the correlation between S-wave velocity and resistivity.
- In the approximation, the soil type is represented by discontinuous numbers one (clay), two (sand) and three (gravel).
- Polynomial equation is a function of S-wave velocity (Vs) and resistivity (ρ) and yields a continuous value S between one and three.

$$S = av_s^2 + bv_s + c\log10(\rho)^2 + d\log10(\rho) + ev_s^2\log10(\rho) + fv_s\log10(\rho)^2 + gv_s\log10(\rho) + h$$

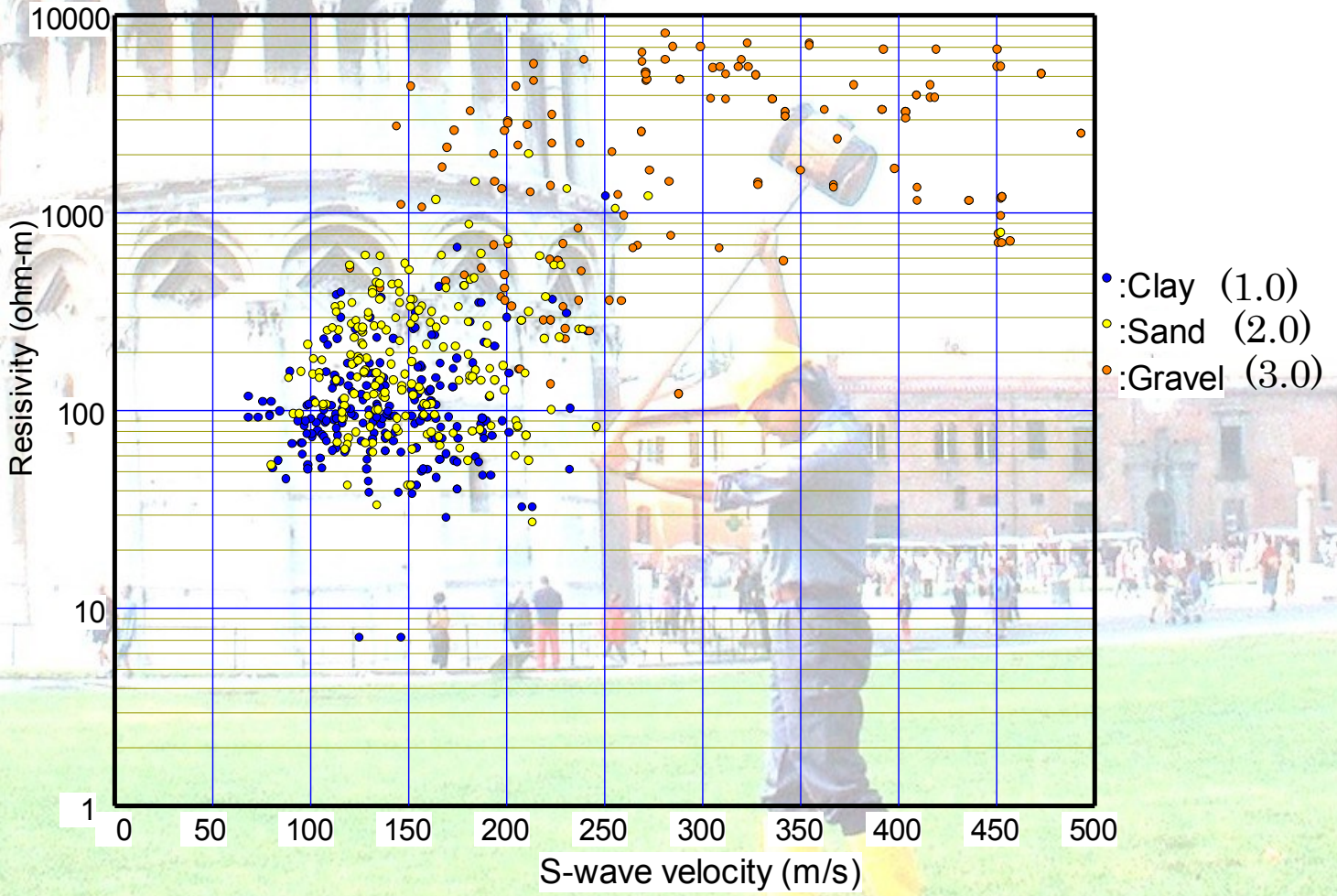
- Coefficients of equation are optimized by least squares method.

Soil Type and Represented Numbers

Soil type	Represented number	Number of data	
		Levee body	Foundation
Clay	1.0	221	915
Sand	2.0	199	2145
Gravel	3.0	143	425
Total	-	563	3485

S-wave velocity and Resistivity

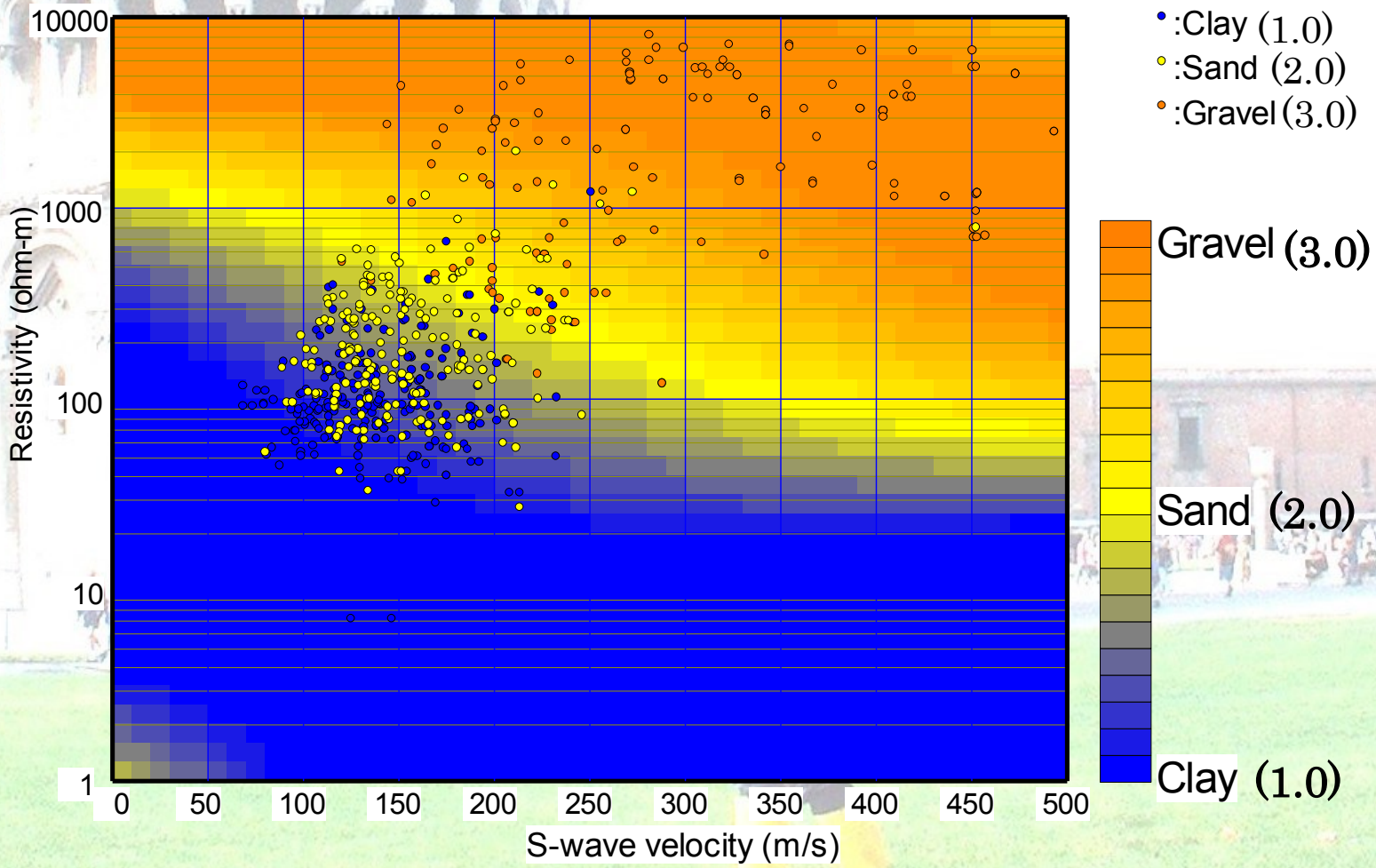
Levee body



Statistical Estimation of Soil Type Using Cross-plots of S-wave Velocity and Resistivity in Japanese Levees

Polynomial Approximation

Levee body



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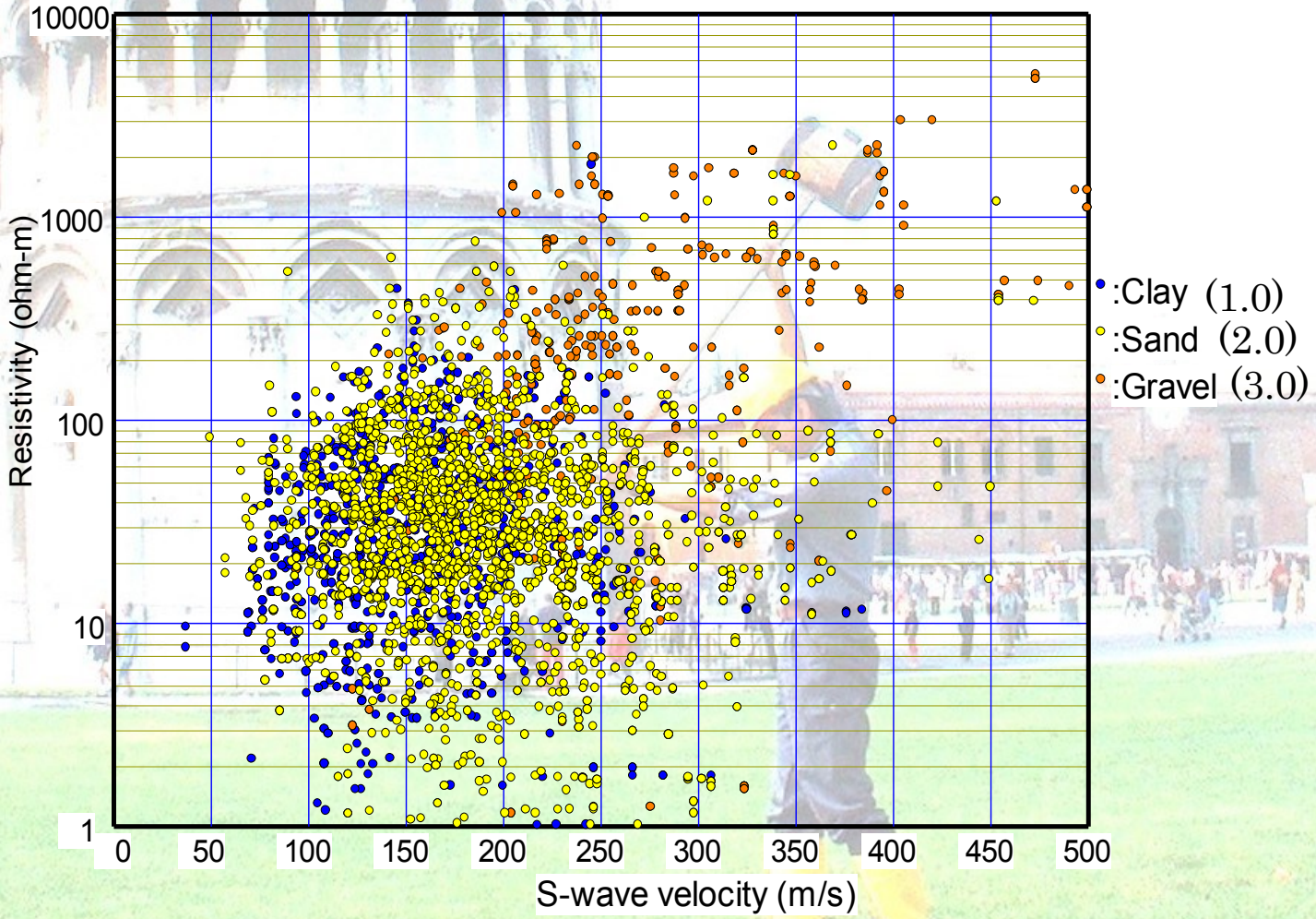
S-wave velocity and Resistivity

Foundation



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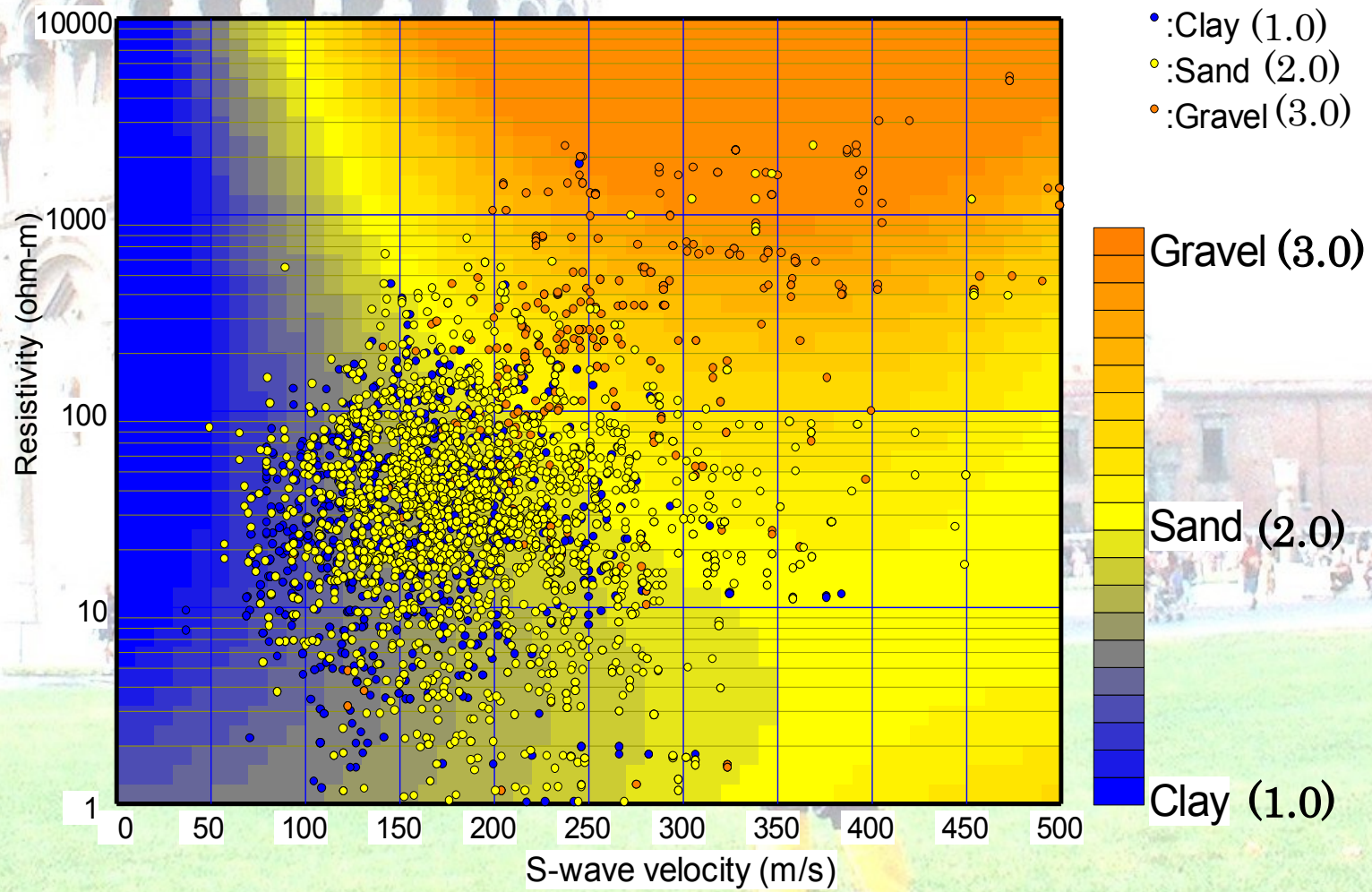
Polynomial Approximation

Foundation



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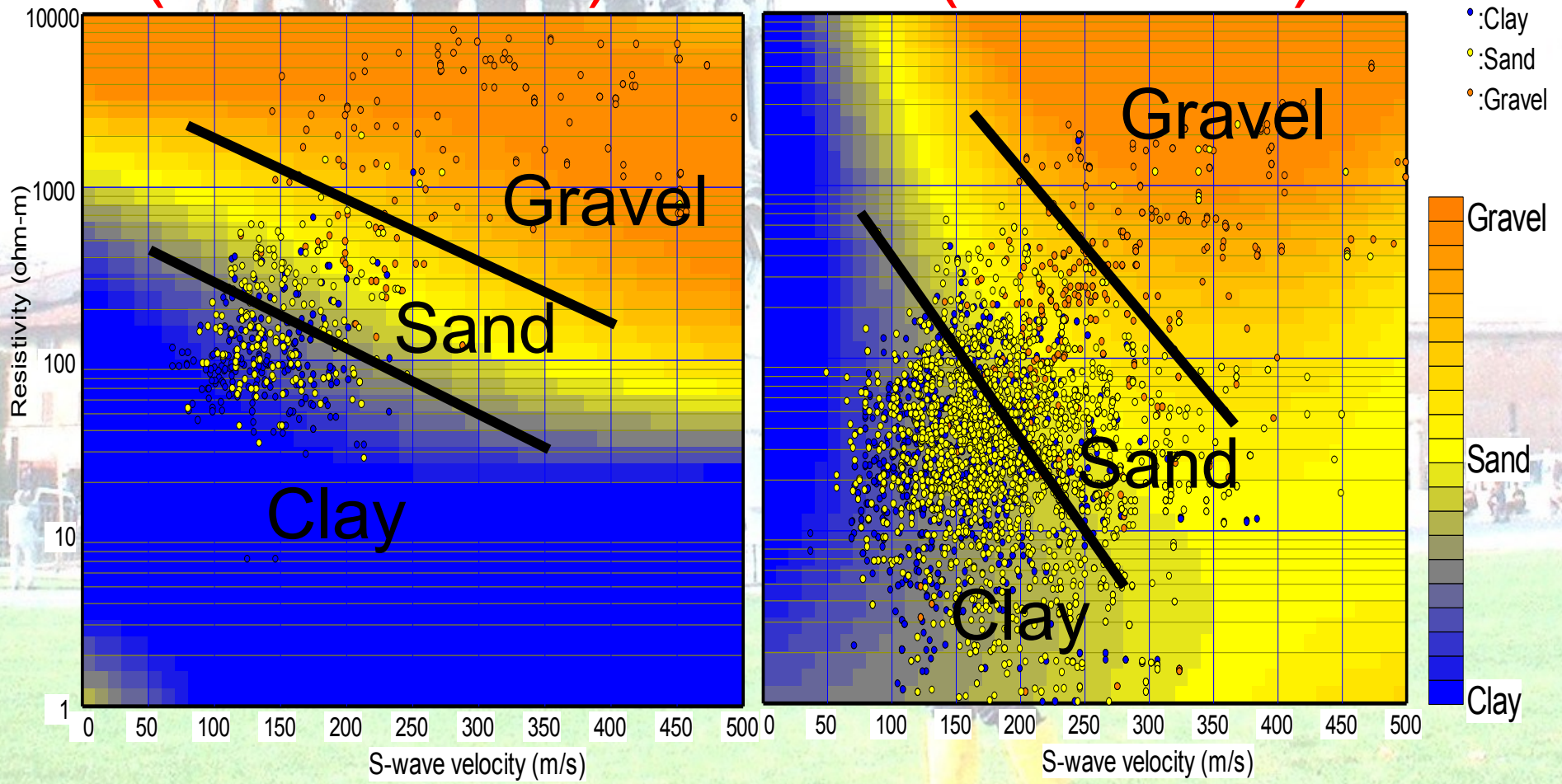
Polynomial Approximation

Levee body (unsaturated)

Foundation (saturated)



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Polynomial Approximation of Soil Type

$$S = av_s^2 + bv_s + c\log10(\rho)^2 + d\log10(\rho) + ev_s^2\log10(\rho) + fv_s\log10(\rho)^2 + gv_s\log10(\rho) + h$$

Levee body

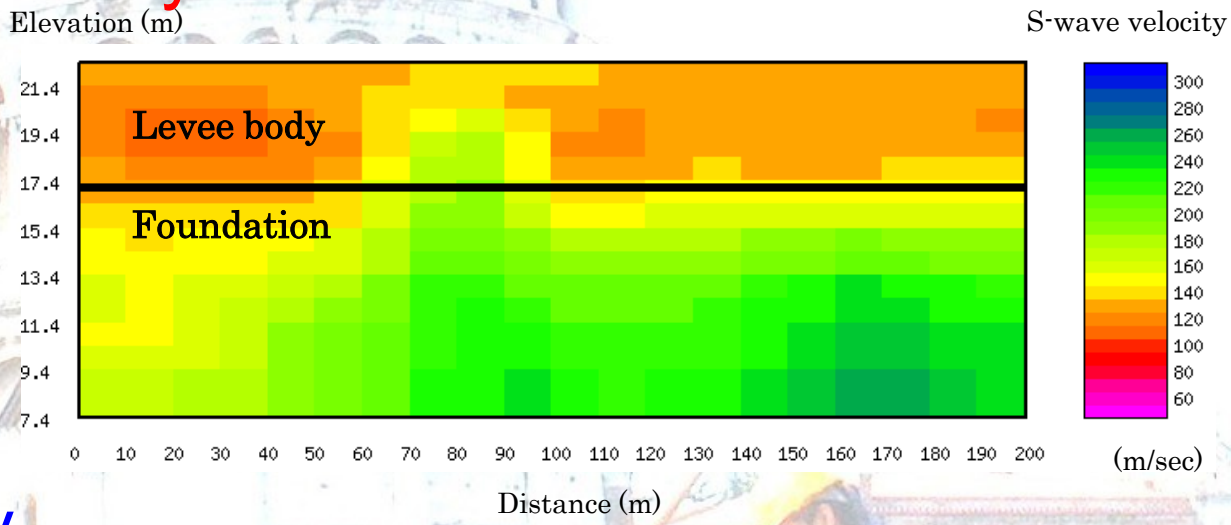
a	−0.0000062
b	−0.0072263
c	0.5333744
d	−1.5275230
e	0.0000016
f	−0.0025515
g	0.0111545
h	1.7115340

Foundation

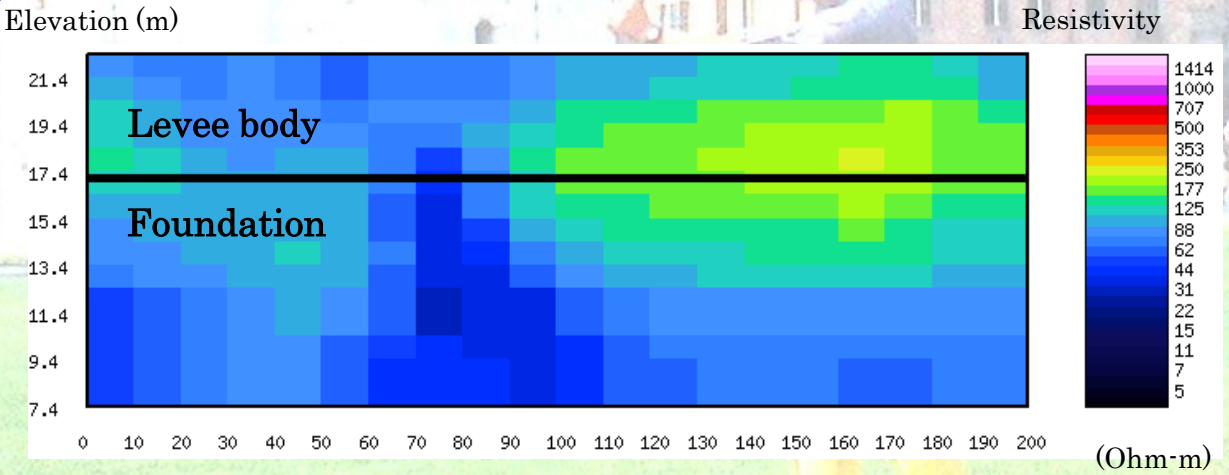
a	−0.0000002
b	0.0019388
c	0.0938875
d	−0.5366671
e	−0.0000064
f	0.0001980
g	0.0032458
h	1.4068120

Example of Estimation

S-wave velocity



Resistivity



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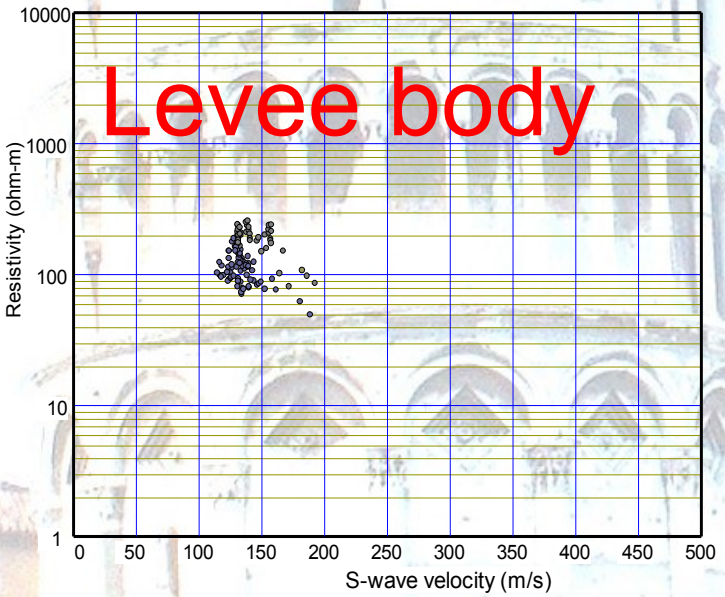
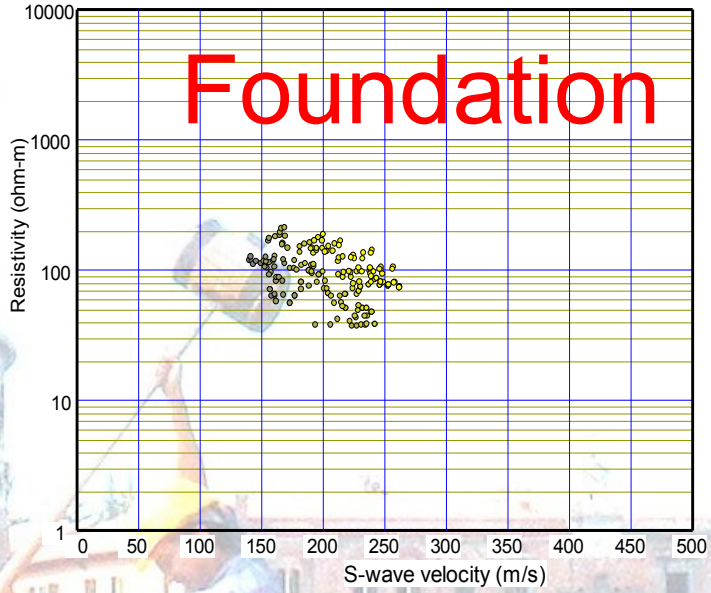
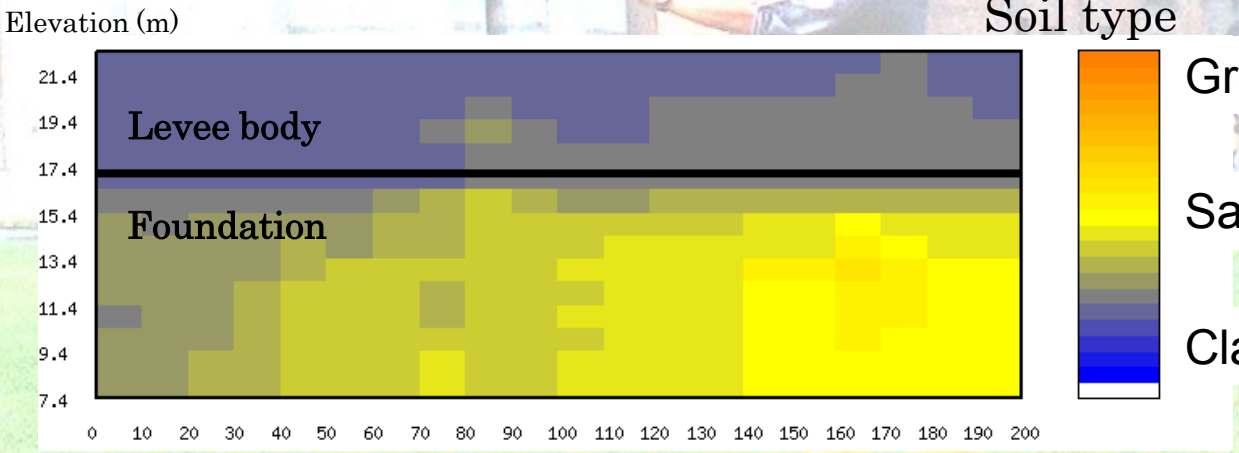
Example of Estimation







Statistical Estimation of Soil Type Using Cross-plots of S-wave Velocity and Resistivity in Japanese Levees

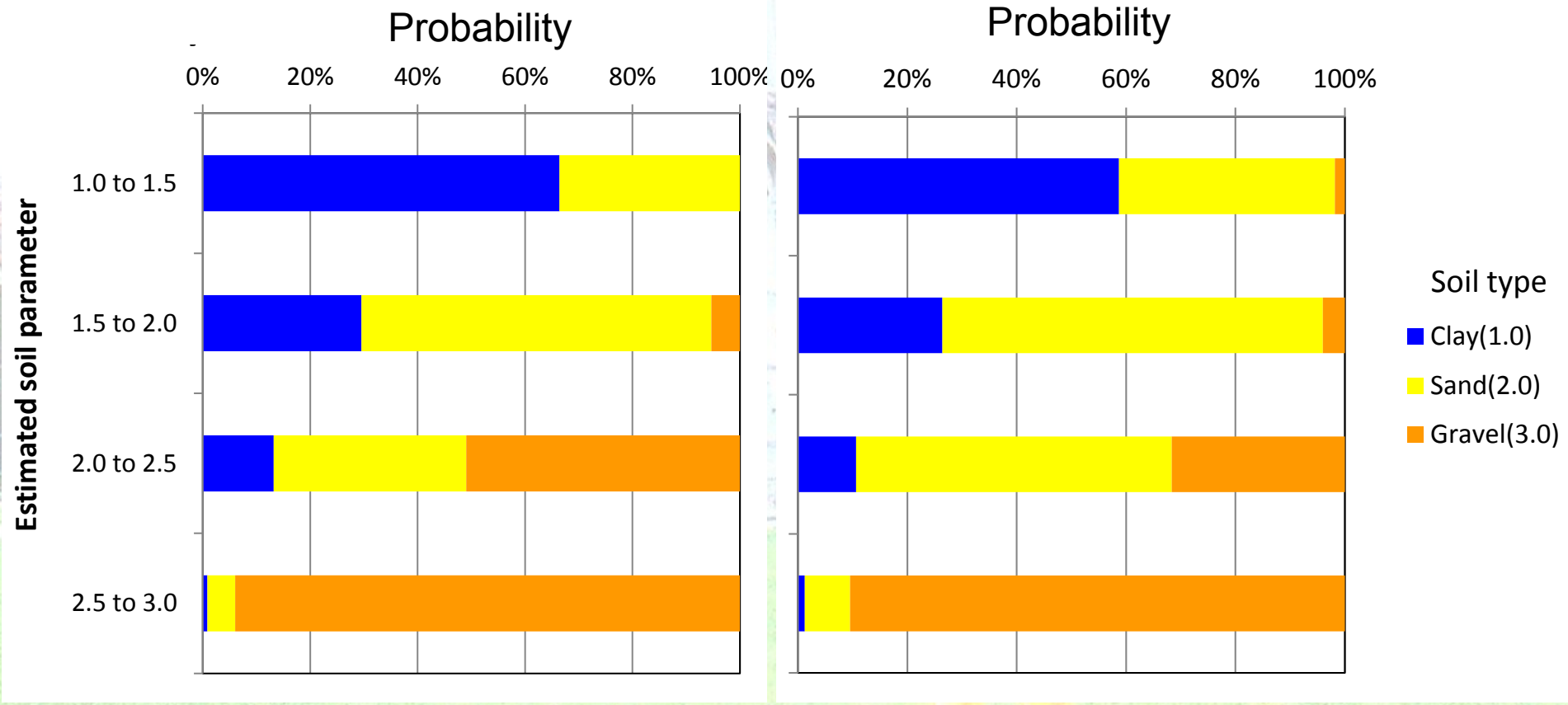
Accuracy of Estimation

- Accuracy of estimation can be statistically evaluated by comparing the estimated soil parameter with actual soil.
- Data were grouped into four groups (1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5, 3.0 to 3.5) by the estimated soil parameter.
- In each group, the numbers of actual soil type (clay, sand, gravel) were counted as probability.

Accuracy of Estimation

Levee body

Foundation



Conclusions

- The soil type of levee body and foundation was statistically predicted using the cross-plots of S-wave velocity and of resistivity.
- The results imply that the physical properties obtained by geophysical methods, such as S-wave velocity and resistivity, can be used not only for qualitative interpretation but also quantitative engineering analyses, such as slope stability or liquefaction analyses.
- Similar approaches can be applied to other purposes besides levee inspection and other countries besides Japan.
- It is important that any results of geophysical investigations are saved as a standard format and registered in database with adequate geotechnical or geological information.