The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

H4.SMR/1645-12

"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

14 - 25 February 2005

Geotechnical database - Site specific soil data - Uncertainties

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IAEA/ICTP Workshop on
Earthquake Engineering for Nuclear Facilities - Uncertainties in Seismic Hazard Assessment

"Geotechnical database – Site specific soil data - Uncertainties"

Trieste, Italy, 14 – 25 February 2005

Unit 13 - Pierre Labbé

Contents of the Presentation

Introduction : The geotechnical scale

- Site investigations
- Soil profiles
- Site scale effects on seismic motion
- Spatial variability
- Conduct of geotechnical studies

The geotechnical scale

The geotechnical scale

Example of two strong motion arrays at Taiwan:

- SMART 1
- Lotung LSST

Lotung site profiles

- Geologic profile
- Geotechnical profile

The geotechnical scale is in the range of ten(s) to hundred(s) meters

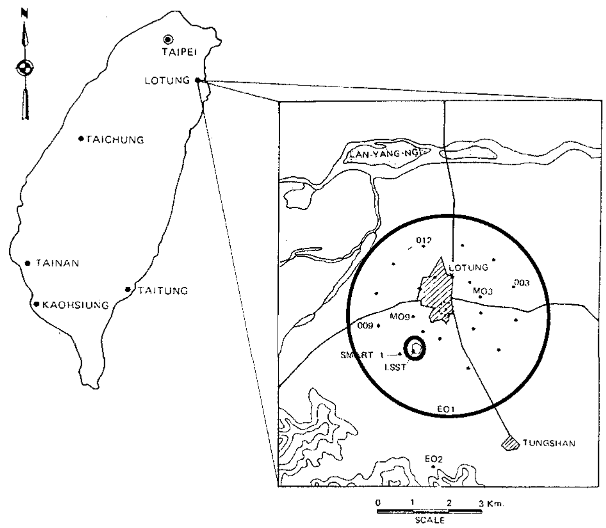


Figure 1-1. Locations of SMART 1 and Lotung LSST strong motion arrays.

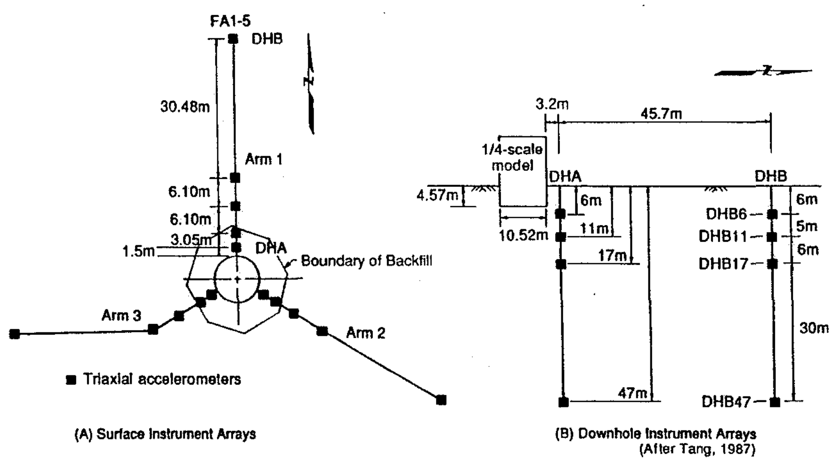


Figure 3-1. Location of Surface and Downhole Instrumentation, Lotung Experiment Site

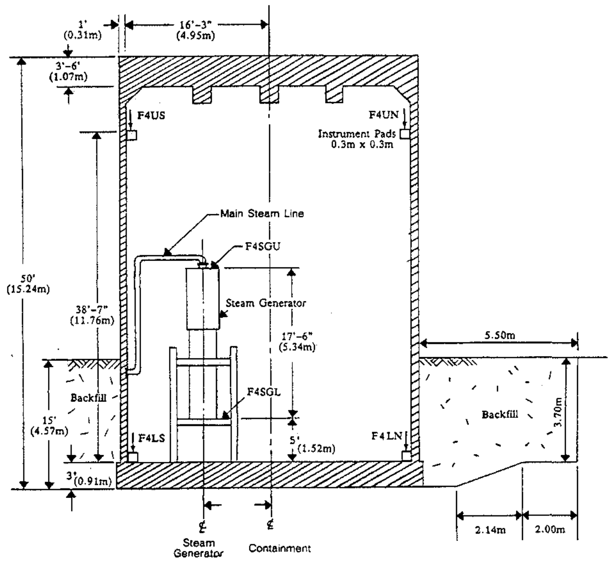


Figure 1-1. Cross-Section of the 1/4-Scale Containment Model

Table 4-1.
LOTUNG LSST EVENTS (1985-1986)

LSST#	SMART#	Date	Dist[1] (km)	Depth (km)	Az[2]	M_L	M_s	m_b	M[3]
1	36	9/20/85	46	4	107	6.3	5.1	5.3	5.3
2	37	10/26/85	29	1	165	5.3	-	4.6	4.6
3	38	11/07/85	81	79	30	5.5	-	4.7	4.7
4	39	1/16/86	26	10	61	6.5	6.0	5.4	6.0
5	-	3/29/86	13	10	159	4.7	-	-	3.9
6	-	4/08/86	33	11	174	5.4	-	4.3	4.3
7	40	5/20/86	71	16	195	6.5	6.4	6.1	6.4
8	41	5/20/86	72	22	192	6.2	-	5.5	5.5
9	-	7/11/86	5	1	146	4.5	-	-	3.7
10	-	7/16/86	6	1	162	4.5	-	-	3.7
11	42	7/17/86	6	2	90	5.0	-	4.1	4.1
12	43	7/30/86	4	2	131	6.2	5.6	5.6	5.6
13 *	-	7/30/86	5	-	90	-	-	-	-
14	44	7/30/86	5	2	119	4.9	-	-	4.1
15 *	-	8/05/86	5	-	120	-	-	-	-
16	45	11/14/86	68	7	174	7.0	7.8	6.3	7.8
17 *	-	11/14/86	80		180		6.3	6.1	6.3
18	-	11/15/86					-	5.3	5.3

Hypocenter and M_L from Inst. of Earth Sciences, Academia Sinica, Taipei, Taiwan.
M_S and m_b from ISC or USGS PDE.
[1] Distance is measured from the centroid of the aftershock zone for large events and from the hypocenter for small events.
[2] Azimuth of the hypocenter from the LSST array.
[3] M is defined as M_S for $M_S>6$ and m_b otherwise. If m_b is not available, then m_b is estimated from M_L.
* Distance is estimated from the S-P time, azimuth is estimated from the F-K spectra.

Coherency

$$\frac{G_{i,j}(u,\omega)}{\sqrt{G_{ii}(0,\omega)G_{jj}(0,\omega)}}$$

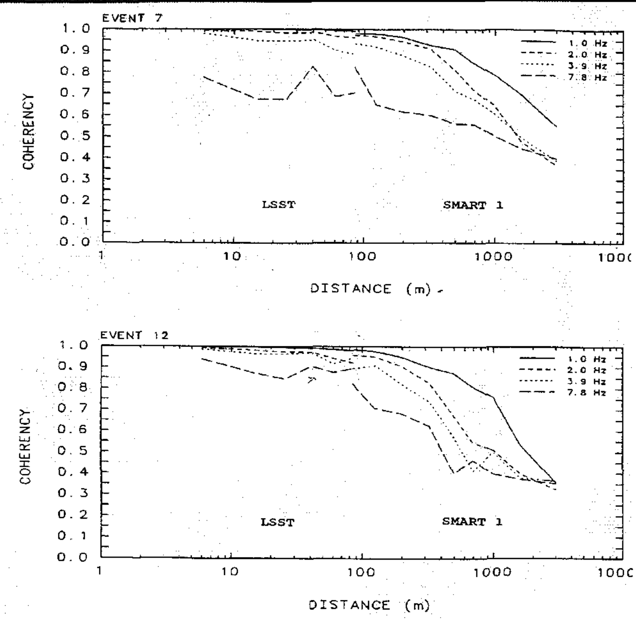
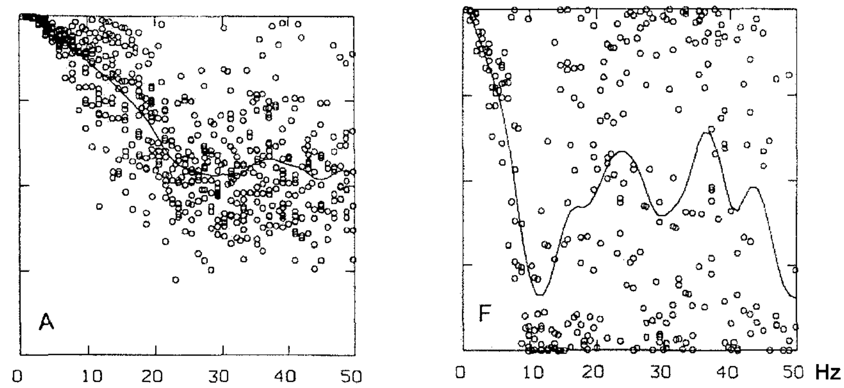
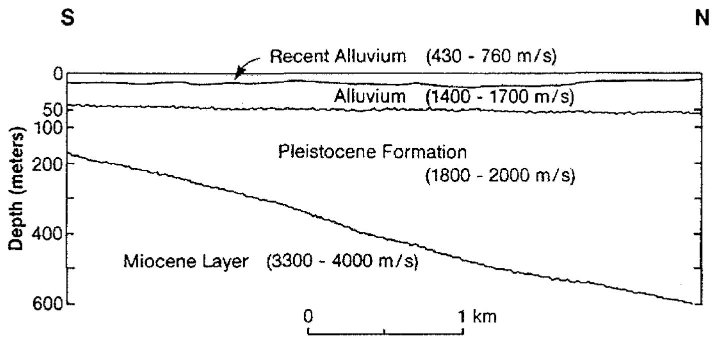


Figure 5-4. Comparison of horizontal coherencies from the LSST array with those from the surroundi SMART 1 array.

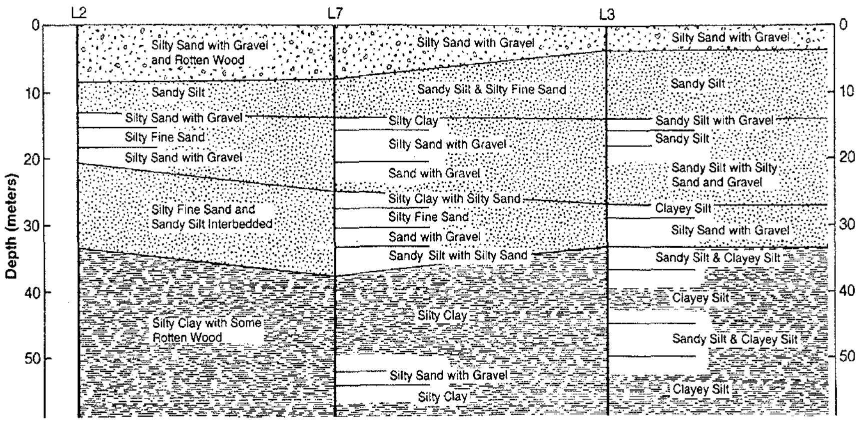


Coherency for a separation distance range (A) 0-10 m and (F) 70-100 m



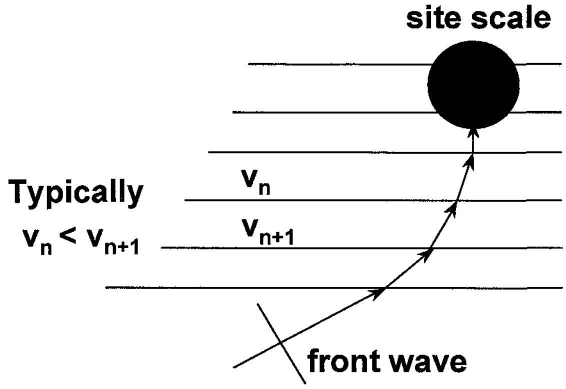
a) Geological Profile and Compressional Wave Velocity Along North-South Section

After Tang (1)



PROFILE I

The geotechnical scale

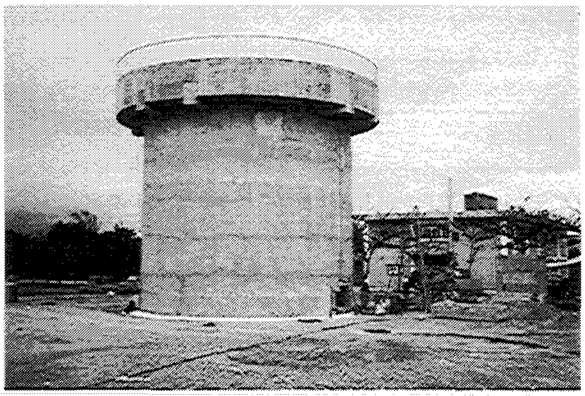


Conventional (and questionable) assumption:
vertically propagating S and P waves

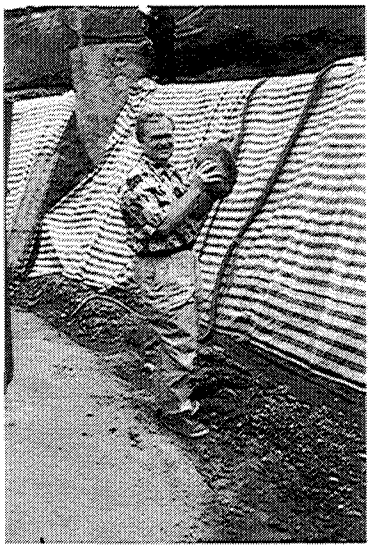
Site investigation

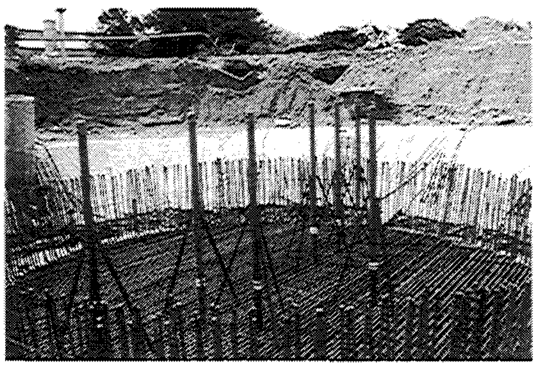
Site investigation

Hualien site investigation, Taiwan (China)



- Overview of the site
- Investigation techniques

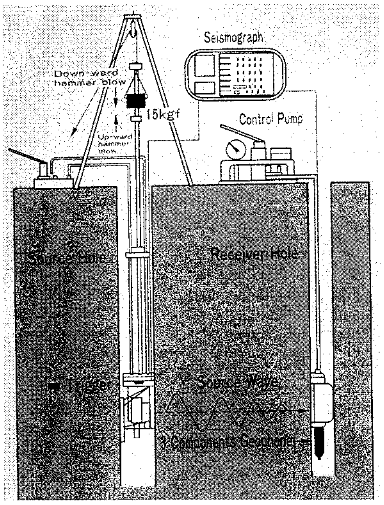




Hualien site investigation

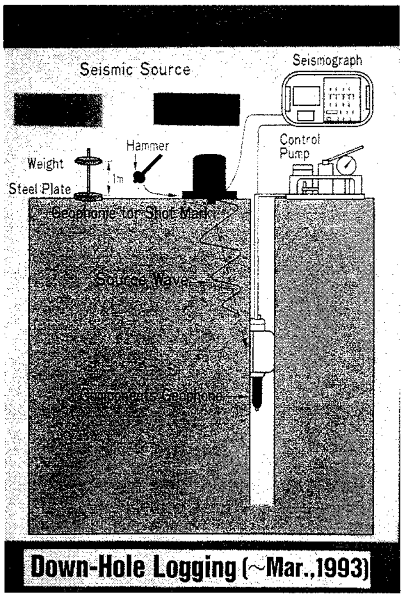
Hualien site investigation

Cross hole logging, March 1993

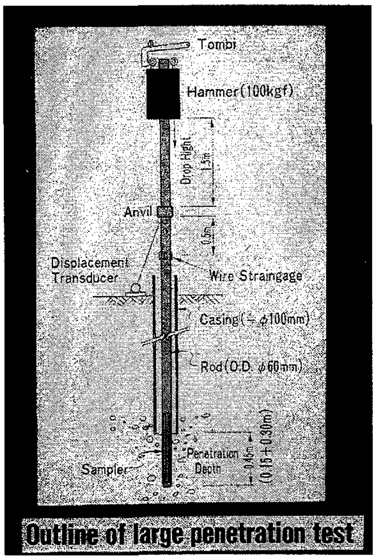


Hualien site investigation

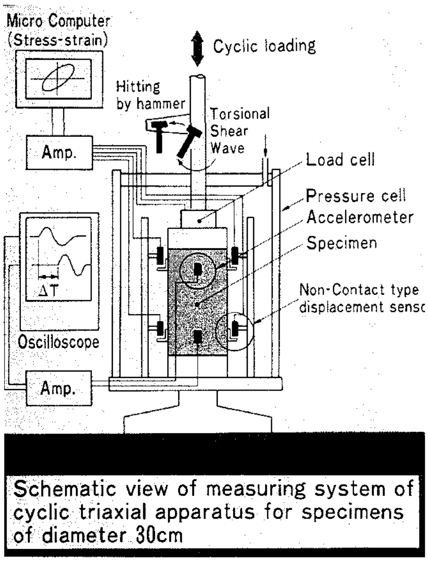
Down hole logging



Hualien site investigation



Outline of large penetration test

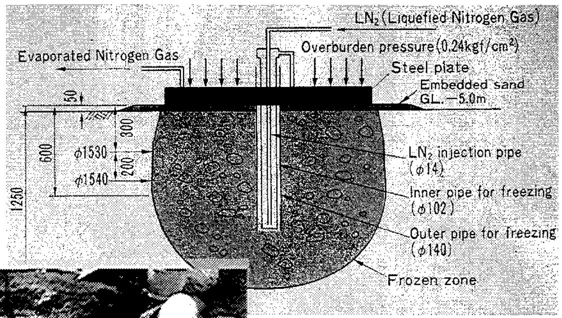


Schematic view of measuring system of cyclic triaxial apparatus for specimens of diameter 30cm

Hualien site investigation

Large size sampling

Hualien site investigation



Freezing sampling performed at GL – 5m after excavation

Site investigation – Sources of data

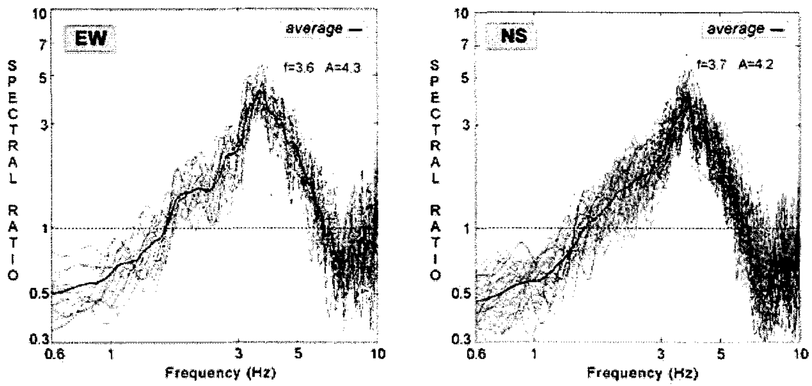
IAEA Safety Guide

TECHNIQUES FOR GEOPHYSICAL INVESTIGATIONS

Type of test	*Parameter measured*	*Types of problems*
Cross hole seismic test	Dynamic elastic properties	Site categorization, soil–structure interaction
Nakamura method	Low level (ambient noise) vibrations	Site categorization, soil–structure interaction
Microgravimetry	Acceleration due to gravity	Complex subsurface

Site investigation – Sources of data

Nakamura method,
Costal Plain, Israel, 2002



Site investigation – Sources of data

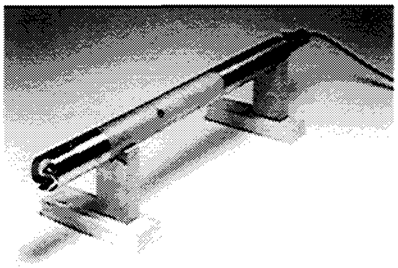
IAEA Safety Guide

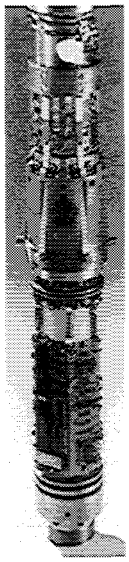
TECHNIQUES FOR GEOTECHNICAL INVESTIGATIONS

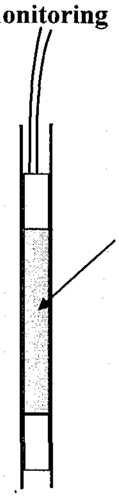
Type of test	*Type of materials*	*Parameter measured*	*Types of problems*
Flat jack test	Rock	In situ normal stress	Deformability
Pressure meter test	Clay, sand, gravel, rock	Elastic modulus; compressibility	Settlement; bearing capacity
Dynamic penetrometer test	Clay, sand, gravel	Cone resistance; relative density	Liquefaction
Vane shear test	Soft clay	Shear strength	Bearing capacity, slope stability

Site investigation – Sources of data

Pressuremetre

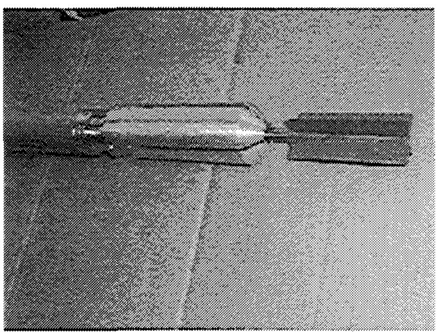


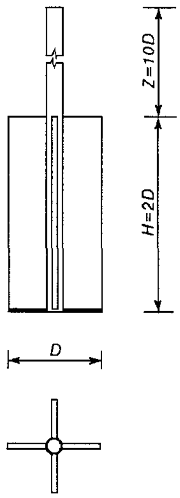




Site investigation – Sources of data

Vane test





Site investigation – Sources of data

IAEA Safety Guide

TECHNIQUES OF LABORATORY INVESTIGATION

Type of test	*Parameter measured*	*Purpose*
Atterberg limits (clayed soils)	Water content (through liquidity and plasticity indexes)	Compressibility and plasticity
Proctor test, ASTM test	Humid and dry densities, water content, relative density.	Settlement, consolidation, bearing capacity
Oedometer	Oedometric, Young's modulus, consolidation coefficient	Settlement, consolidation
Shear test box, triaxial tests	E, ν, ϕ, under drained and undrained conditions	Settlement, bearing capacity
Cyclic triaxial tests, resonant column	Dynamic Young's modulus, Poisson ratio, internal damping, pore pressure	Site categorization, SSI, liquefaction

Soil profile

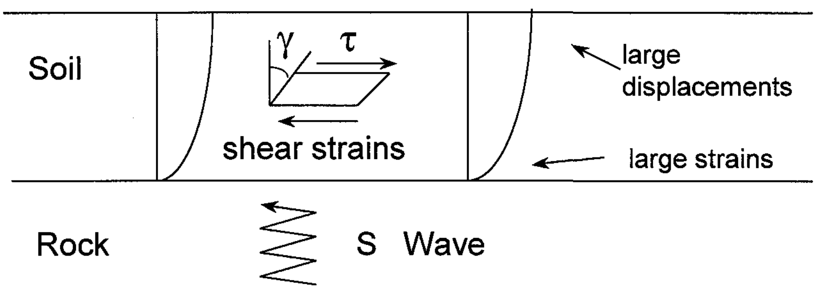
Soil profile, description

Description of a profile

- Thickness and variation of layers
- Nature, type of materials (sand, clay…)
- Ground water regime
- Body waves profile
- G- γ curves
- Relative density
- Cyclic shear strength
- Stress history of the site: OCR
- Index of plasticity

Soil profile, G-γ curves

What is a G-γ curve ?

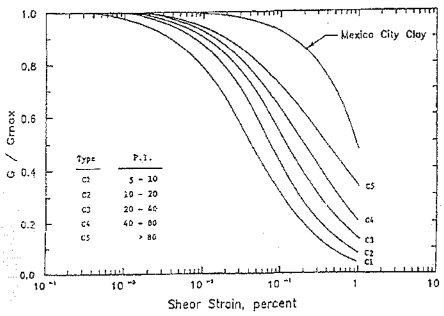


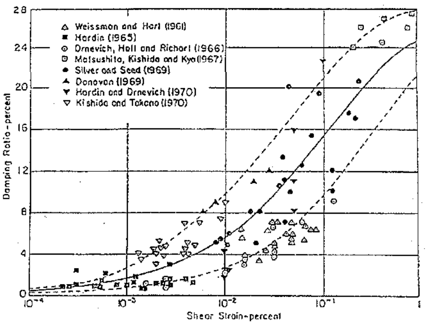
Constitutive relationship: $\tau = G\,\gamma$. For low γ: $G=G_{max}$.

G decreases vs γ, damping increases.

Soil profile, G-γ curves

Typical G-γ (clay) and η - γ (sand) curves





Soil profile, examples

Examples of soil profiles

- Narimasu site, Japan
- Lotung site, Taiwan (China)
- Some NPP sites in France

Soil profile, examples

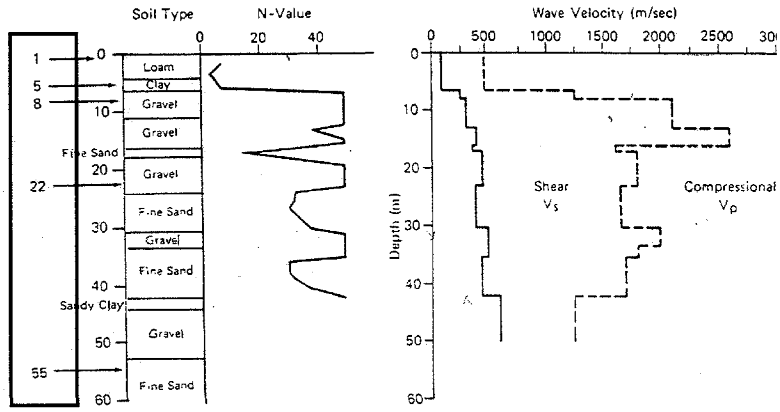


Figure 2-1. Shear and Compressional Wave Velocity Profiles at Narimasu Site

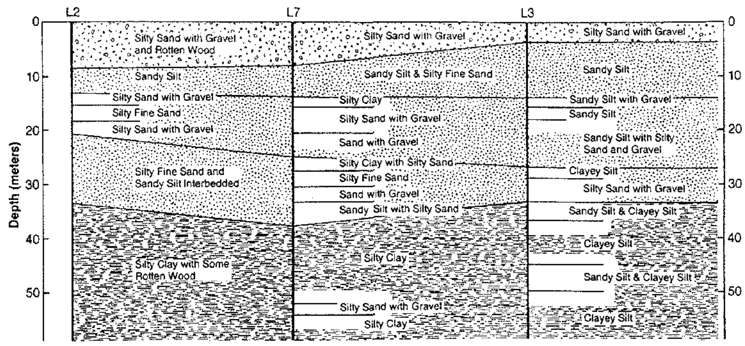
Narimasu site, Japan

EXPLANATION

→ Locations of Downhole Instrument

Soil profile, examples

Lotung LSST site, Taiwan, China (1)



PROFILE I

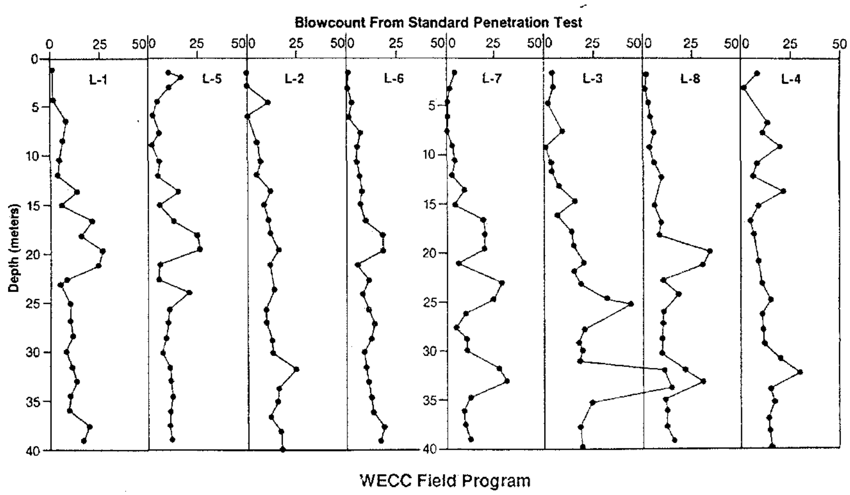


Figure 7-3

Blowcounts Recorded during Standard Penetration Tests at Lotung Site

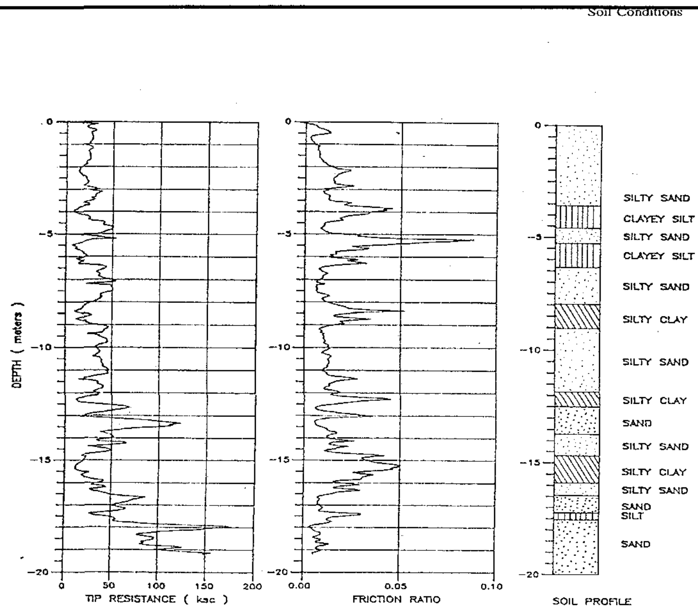
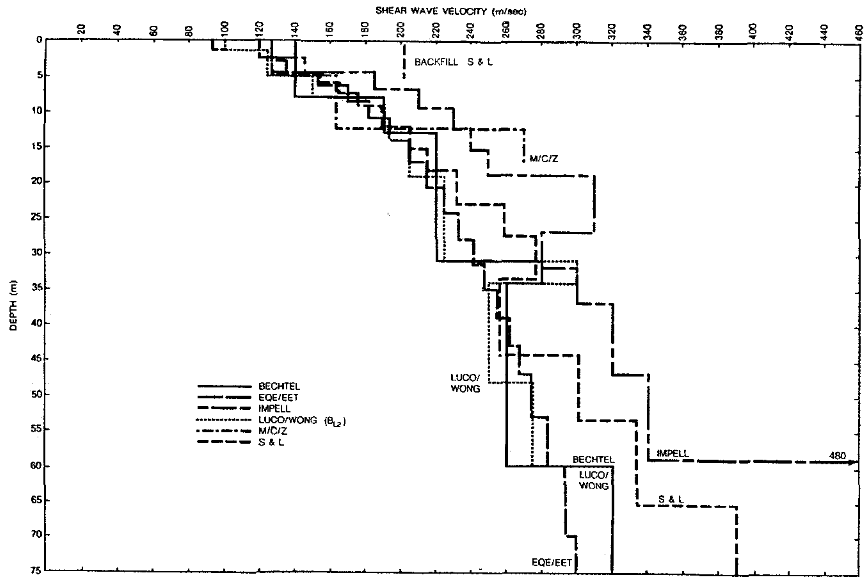
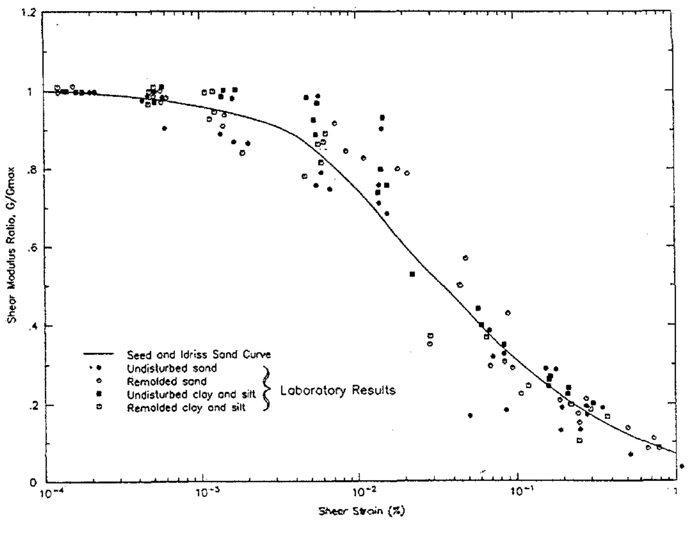


Figure 7-6

Tip Resistance, Friction Ratio, and Estimated Soil Profile of Test No. 2.


SHEAR WAVE VELOCITY (m/sec)
DEPTH (m)
BACKFILL S & L
M/C/Z
LUCO/
WONG
BECHTEL
LUCO/
WONG
IMPELL
480
S & L
EQE/EET
BECHTEL
EQE/EET
IMPELL
LUCO/WONG (B_{L2})
M/C/Z
S & L


Shear Modulus Ratio, G/Gmax
Shear Strain (%)
Seed and Idriss Sand Curve
Undisturbed sand
Remolded sand
Undisturbed clay and silt
Remolded clay and silt
Laboratory Results

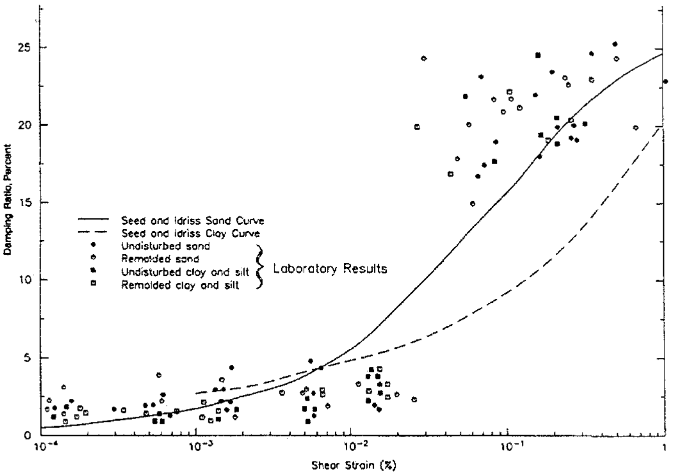


Figure 3-2. Strain-Dependent Shear Modulus Ratio and Damping Ratio Data

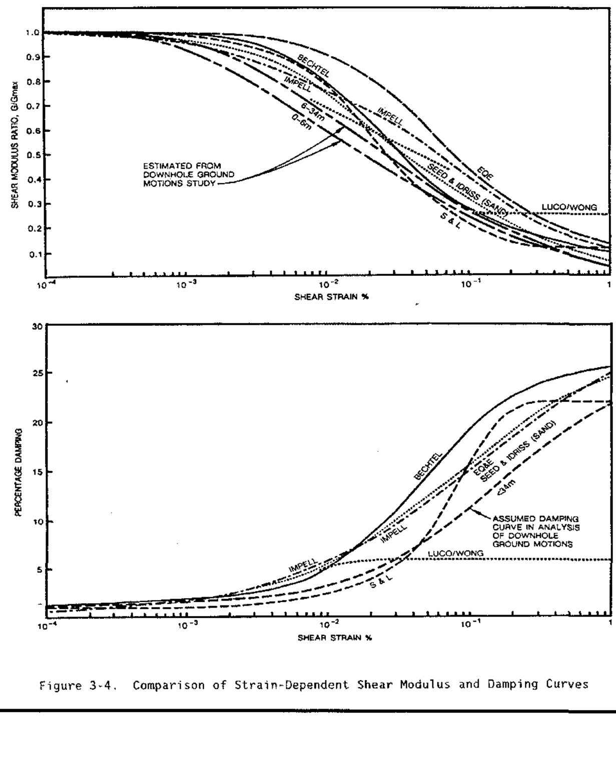


Figure 3-4. Comparison of Strain-Dependent Shear Modulus and Damping Curves

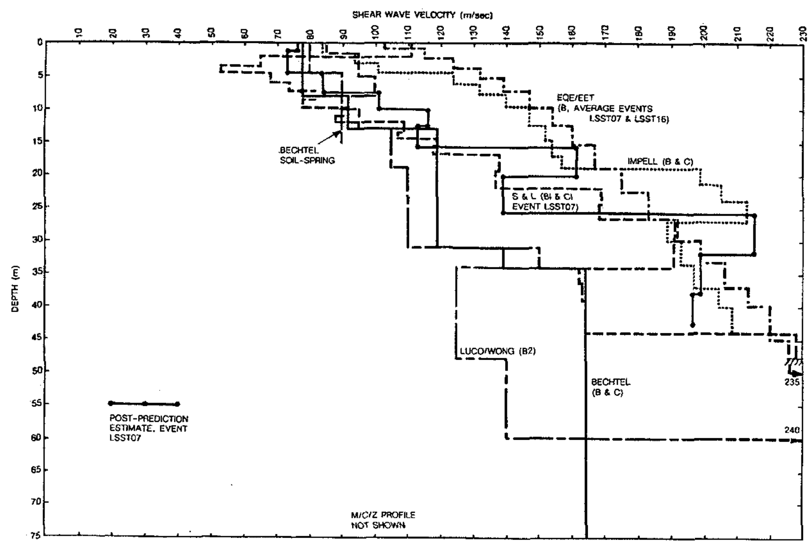
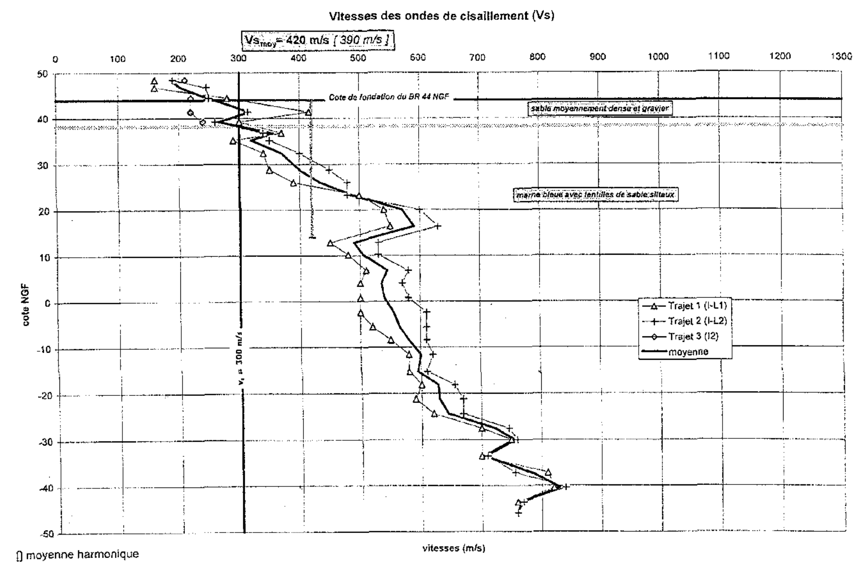


Figure 3-5. Strain-Dependent Shear Wave Velocity Profiles for Seismic Response

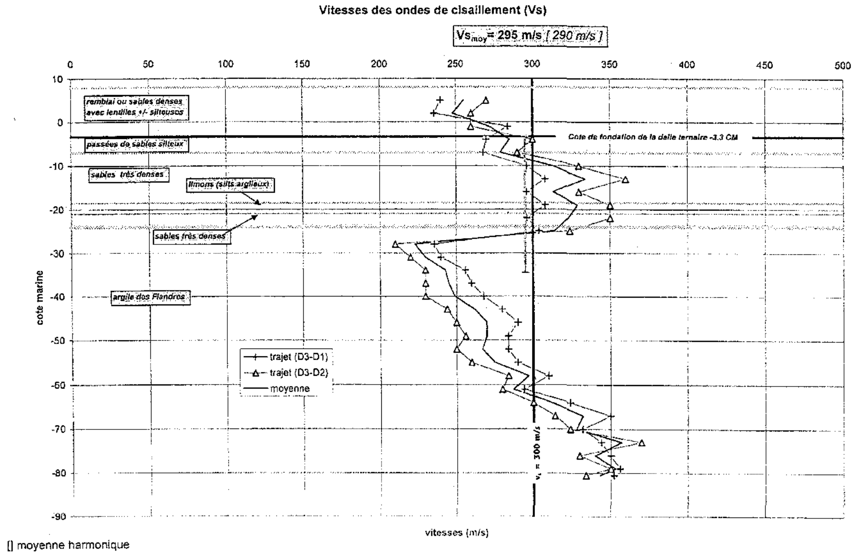
Soil profile, examples

NPP sites in France, soft site



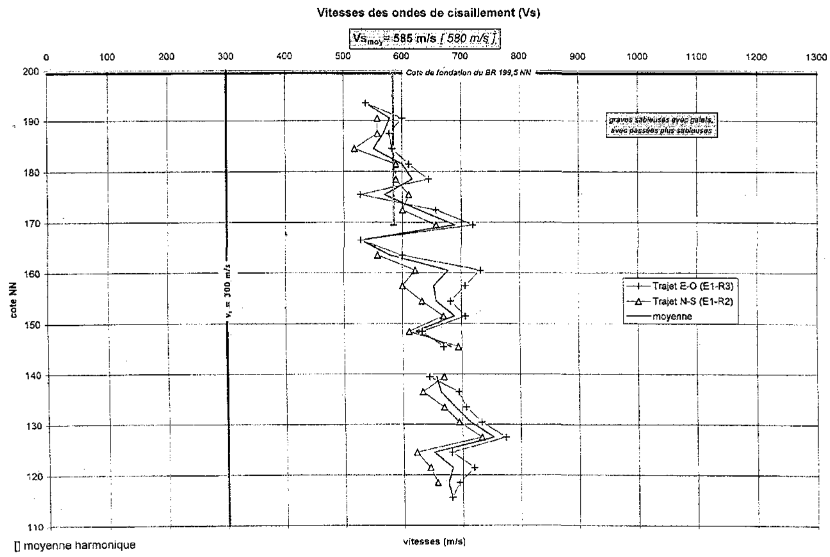
Soil profile, examples

NPP sites in France, complex soft site



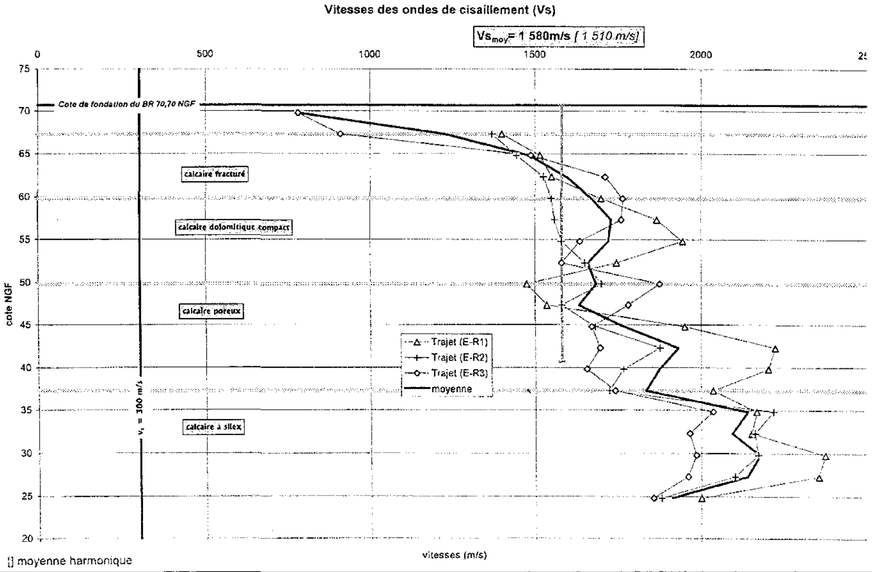
Soil profile, examples

NPP sites in France, medium site



Soil profile, examples

NPP sites in France, stiff site



Soil profile, dealing with uncertainties (1)

IAEA Safety Guide:

Uncertainties in the mechanical properties of the site materials should be taken into account through parametric studies , at least on the shear modulus value.

Between (best estimate value) x (1+C_v)
and (best estimate value) / (1+C_v)

The minimum value of C_v is 0.5

Soil profile, dealing with uncertainties (2)

IAEA Safety Guide:

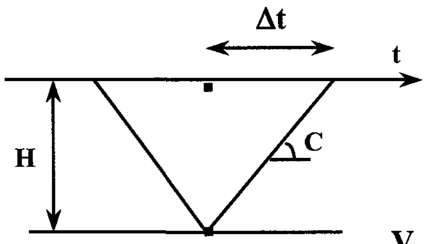
Even though conceptually the profile is unique to a particular site, various related design profiles for different purposes should be adopted to allow for different hypotheses in the analysis.

A given soil profile cannot be assumed without an assessment to be conservative for all the items under consideration; that is, a conservative profile for deconvolution may not be conservative for the site response analysis.

Site scale effects

Site scale effects, reduction in depth

- **Analytical approach of a simple case**



$V_0(t)$

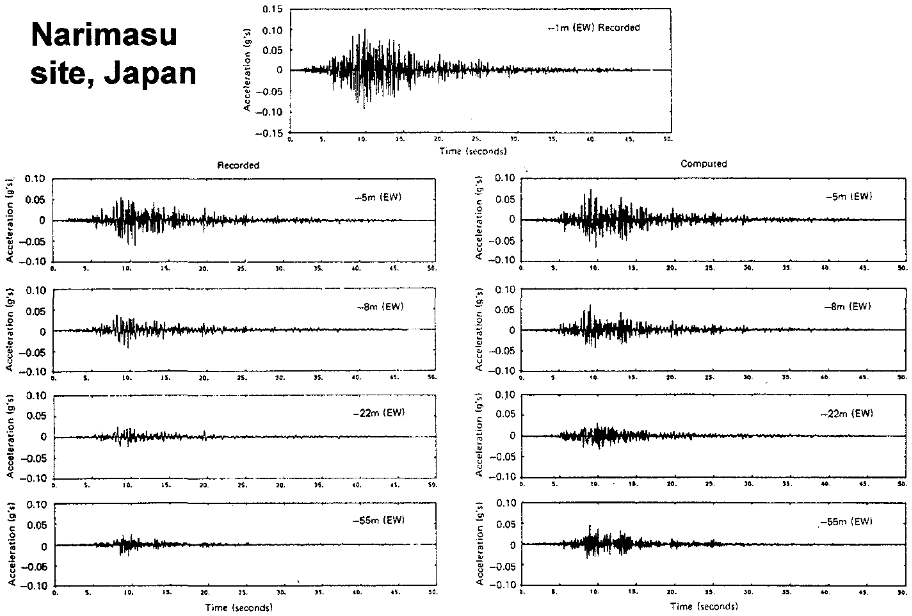
Deconvolution

$$V_H(t) = 1/2\ [V_0(t-\Delta t) + V_0(t+\Delta t)]$$

Method of characteristics

Site scale effects, reduction in depth

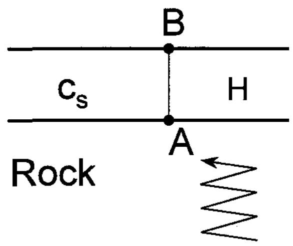
Narimasu site, Japan



Site scale effects, filtering and resonance

- **Analytical approach of simple cases**

Visco-elastic layer on a rigid base

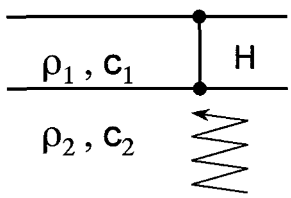


⟶ Transfer function

$$\ddot{D}(B) = \ddot{D}(A)\frac{1}{\cos\omega\frac{H}{c_s}}$$

Site scale effects, filtering and resonance

Elastic layer on an elastic half-space



$$C = \frac{\rho_1 c_1}{\rho_2 c_2}$$

Amplification factor : $$\frac{1}{\sqrt{\cos^2\frac{\omega H}{c_1} + C^2 \sin^2\frac{\omega H}{c_1}}}$$

1/C values around 5 are usual;
in Mexico city 1/C is around 20

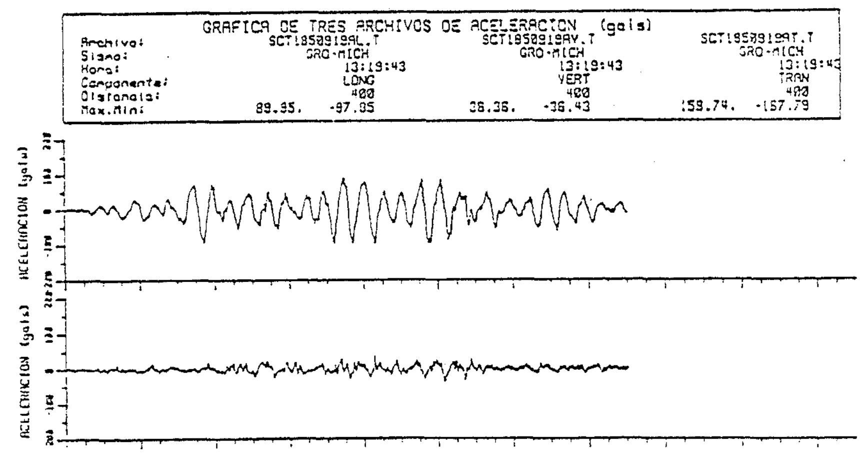
Site scale effects, filtering and resonance

- **Feedback experience**
  - the case of Mexico City
  - two earthquakes at San Francisco
  - the Kobe earthquake

Lessons

- filtering effect is not only site related
- filtering effect is input level dependent

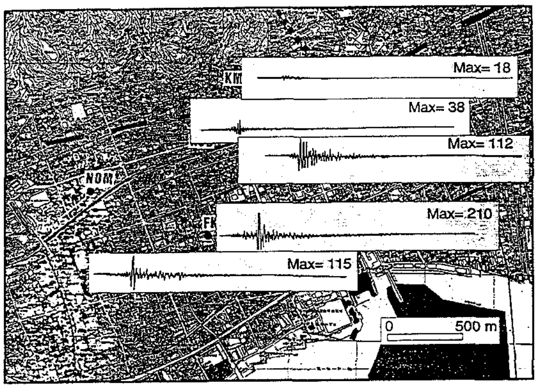
- Example of Mexico



• Example San Francisco

Station	Stratigraphie	Accélération maximale du sol 1957	1989
Alexander Building	Silt argileux + Sable (45 m)	0.07	0.17
Southern Pacific B.	Argile molle	0.05	0.20
Rincon Hill	Rocher	0.10	0.09
Oakland City Hall	Argile, Sable (30 m) + Argile raide (270 m)	0.04	0.26

• Example Kobe aftershock



Amplification factors during the main shock were considerably lower

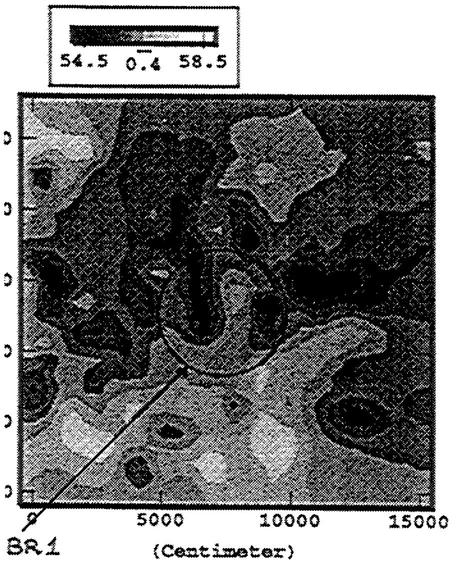
Spatial variability

Spatial variability

- **Soil variability**

Observing soil variability

Variability of the thickness of a chalk layer on a NPP site



Spatial variability

Modelling soil variability

$$V_S(x,y,z) = \overline{V}_S + \sigma_{V_S} f(x,y,z)$$

$$\rho_{V_S} = \exp - (\frac{x}{x_0} + \frac{y}{y_0} + \frac{z}{z_0})$$

Orders of magnitude are in decametres for x_0 and y_0 , in metres for z_0.

JANNAUD ET AL.: FREQUENCY DEPENDENCE OF THE Q FACTOR IN RANDOM MEDIA 18,23

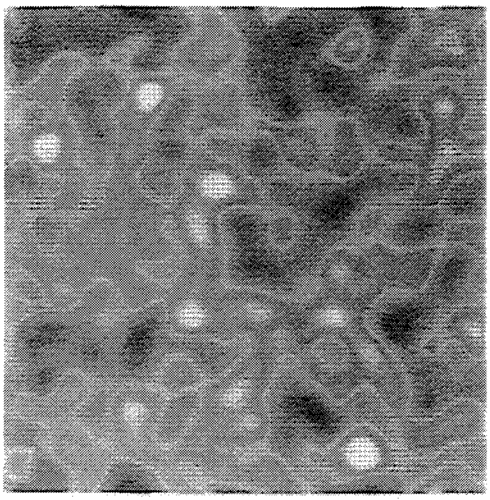
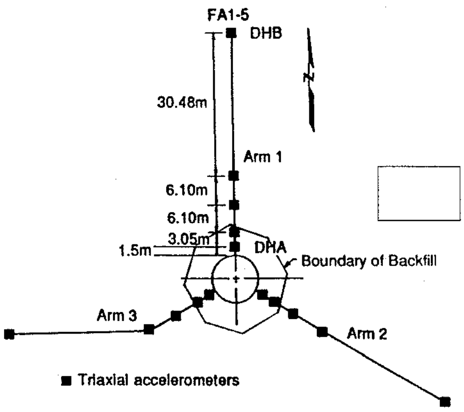


Plate 1. Example of a simulated medium with a Gaussian correlation. Data are for a = 25 m, c_0 = 1500 m/s, q = 2.5%, and H = 5 m (blue, 1360–1430 m/s; green, 1430–1500 m/s; red, 1500–1570 m/s; yellow, 1570–1640 m/s).

Spatial variability

•Seismic motion variability,

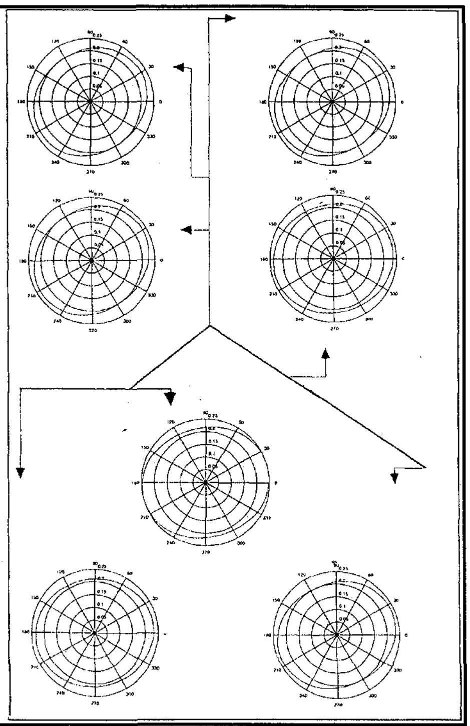
Observing and modelling at Lotung site



Spatial variability

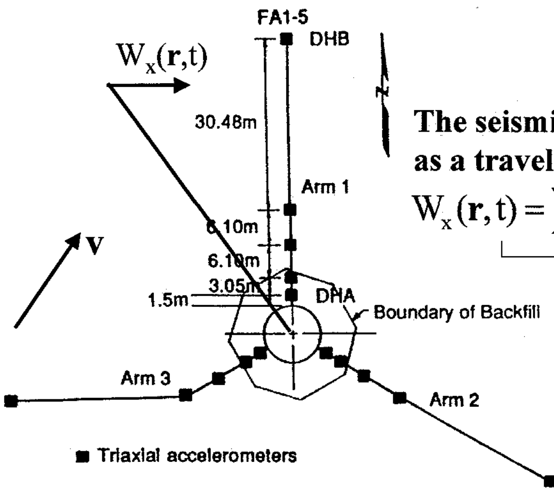
Seismic motion variability at Lotung site,

Quasi isotropy of the ground motion



Spatial variability

Seismic motion variability at Lotung site

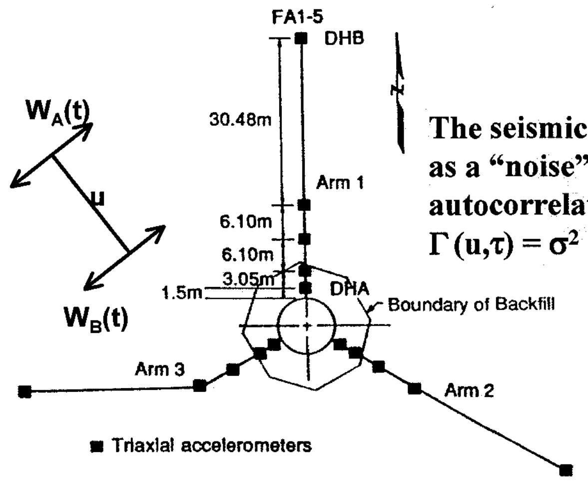


The seismic motion is modelled as a travelling wave:

$$W_x(\mathbf{r},t) = \sum a_k \cos(\mathbf{v}.\mathbf{r} + \omega_k t + \varphi_k)$$

Spatial variability

Seismic motion variability at Lotung site

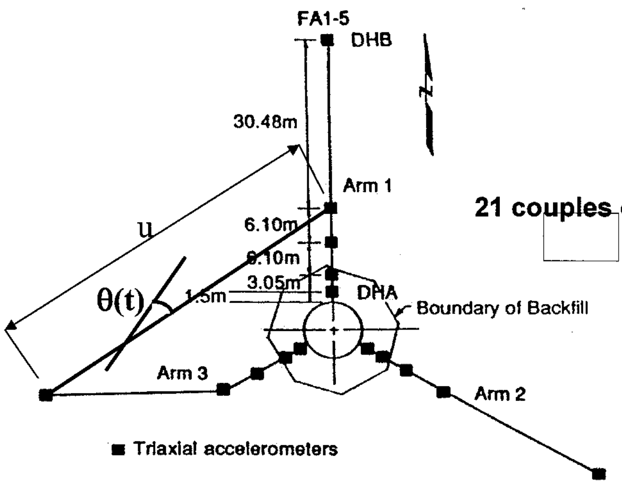


The seismic motion is modelled as a "noise" described by its autocorrelation function:

$$\Gamma(u,\tau) = \sigma^2 \exp(-u/u_0) \exp(-\tau/\tau_0)$$

Spatial variability

Seismic motion variability at Lotung site

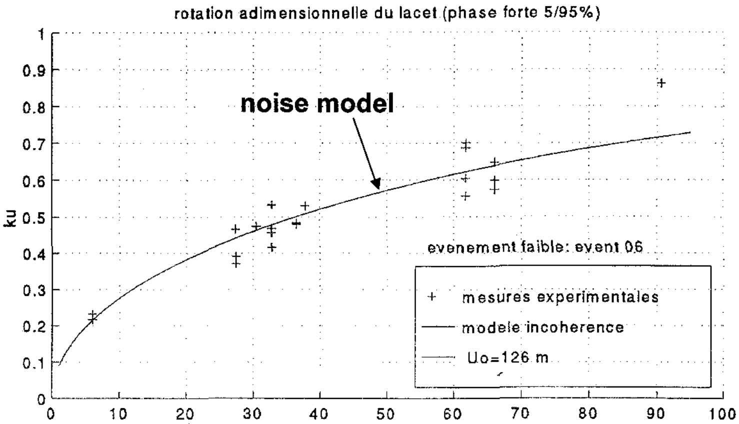


21 couples of stations

Spatial variability

Seismic motion variability at Lotung site

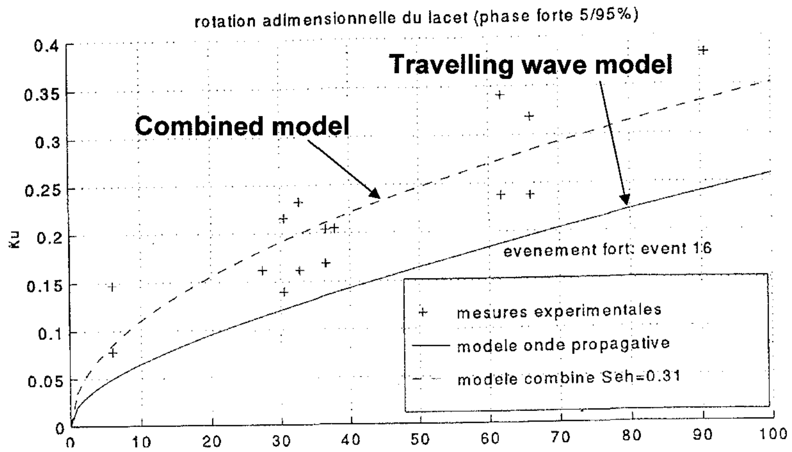
$$k_u = \frac{\sigma_\theta u}{\sqrt{2}\sigma_w}$$



Event 06 , pga = 0.03g : no travelling wave effect

Spatial variability

Seismic motion variability at Lotung site



Event 16 , pga = 0.16g : travelling wave + noise effect

Spatial variability

Modelling seismic motion variability at Lotung site

Summary of the scientific findings

For low level input motions, the noise model is appropriate. No wave effect was identified.

For the high level motions, a combination of travelling wave and noise models is appropriate.

Conclusion:

The model of travelling wave is not sufficient to model the variability of ground motion on a soft site

Conduct of geotechnical studies

Conduct of geotechnical studies

- **Types of sites as per the IAEA Safety Guide**

Type 1	Type 2	Type 3
V_s > 1100m/s	1100m/s>V_s>300m/s	300m/s > V_s
	Assessment of the response of the Site. Deconvolution	Assessment of the response of the Site. Deconvolution
		Site specific response spectra
		Liquefaction assessment

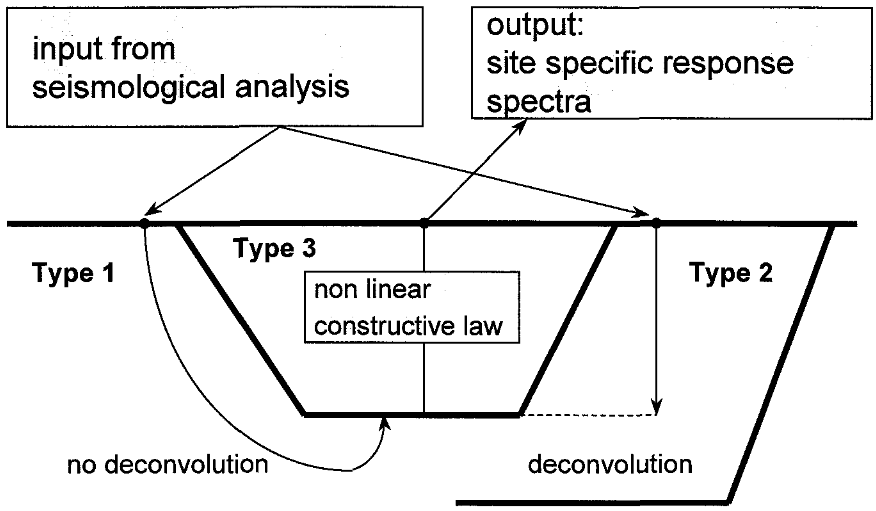
V_s is measured just below the raft and increases with depth

Conduct of geotechnical studies

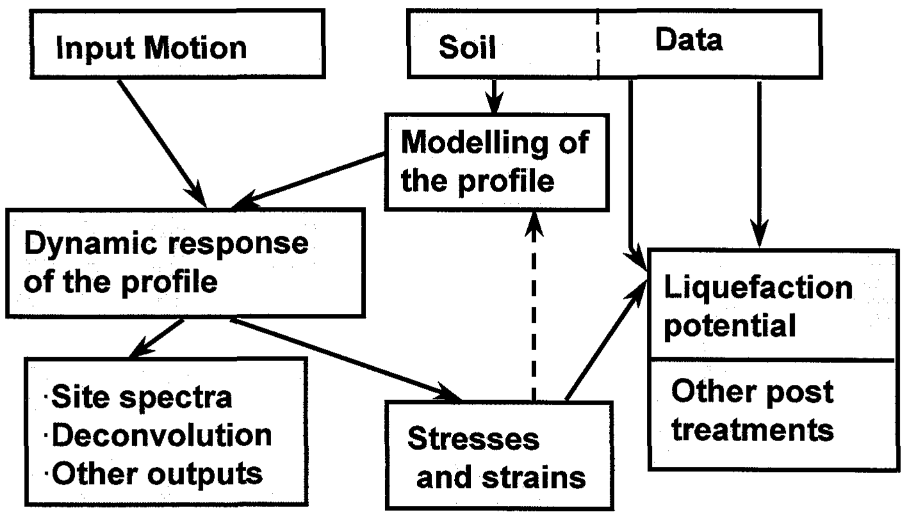
- **The message of the IAEA Safety Guide for Type3 sites:**

  Do not rely on attenuation relationships for such very soft sites. The seismic input motion should be estimated at a Type1 (possibly Type2) outcrop and site specific response spectra should be computed.

Conduct of geotechnical studies



Conduct of geotechnical studies



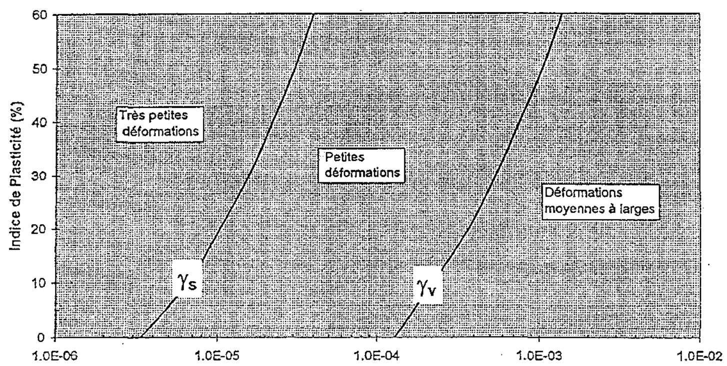
Conduct of geotechnical studies

Cyclic Strain	Behaviour	Type of Analysis
$\gamma < \gamma_s$	practically linear	linear
$\gamma_s < \gamma < \gamma_v$	elastic non-linear plastic without degration	equivalent linear
$\gamma_v < \gamma$	elasto - plastic with degradation	non - linear

$\gamma_s = 5\ 10^{-6}$ to $5\ 10^{-5}$
$\gamma_v = 10^{-4}$ to 10^{-3}
depending on the nature of the soil

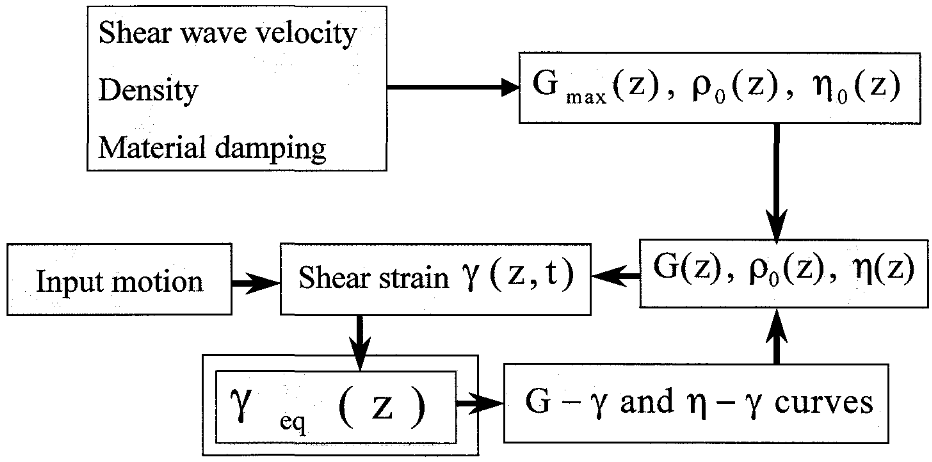
Conduct of geotechnical studies

Types of soil constitutive laws



Conduct of geotechnical studies

Linear equivalent profile



Summary of the Presentation

The geotechnical scale is around ten(s) to hundred(s) metres.

At this scale uncertainties in mechanical characteristics are significant.

The variability of soil characteristics and the variability of seismic ground motion at the geometric scale should be accounted for.

Geotechnical studies usually deal with non linear behaviour; however the use of linear equivalent models is generally possible, to the extent it is carried out by experts in this field.

References

Z. Zembaty, A. Castellani and G. Boffi, 'Spectral analysis of the rotational component of seismic ground motion', Probabilistic Engineering Mechanics, 8, 5-14, (1993).

W. K. Tso and T. I. Hsu, 'Torsional spectrum for earthquake motions', Earthquake Engineering and Structural Dynamics, 6, 375-382, (1978).

C. H. Loh, J. Penzien and Y. B. Tsai, 'Engineering analysis of SMART 1 array accelerograms', Earthquake Eng. & Structural Dynamics, 10, 575-591. (1982).

N. A. Abrahamson, 'Estimation of seismic wave coherency and rupture velocity using the SMART-1 strong motion array recordings', EERC Report No. EERC/UCB/85-02, Earthquake Engineering Research Center, University of California, (1985).

A. Der Kiureghian, 'A coherency model for spatially varying ground motions', Earthquake Engineering and Structural Dynamics, 25, 99-111, (1996).

N. A. Abrahamson, J. F. Shneider and J. C. Stepp, 'Empirical spatial coherency function for applications to SSI analysis' , Earthquake Spectra, 7, 1-27, (1991).

D. G. Anderson and Y. K. Tang, 'Summary of soil characterisation program for the Lotung large-scale seismic experiment', Proceedings: Workshop on Lotung large-scale seismic experiment, EPRI, Palo Alto, California, (1987).

C. H. Loh, 'Analysis of the spatial variation of seismic waves and ground movements from SMART-1 array data', Earthquake Eng. & Structural Dyn., 13, 561-581, (1985).

N. Laouami, Variabilité spatiale du mouvement sismique, approche experimentale et modèles théorique, thèse de doctorat, Univ. Evry Val d'Essone, 1995.