Determining V_{S30} based on empirical equations of the shear-ware velocity with void ratio and effective stress relationships and extrapolation methods for the Taipei Basin

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Outline:

1. Introduction
2. Methodology
3. Preliminary results
4. Future work

MOTIVATION:

What is the V_{S30} ?

The time-average shear wave velocity (Vs) of upper 30 meters of a soil profile.

BSSC,2001

Vs30(m/s)	Class	Description
>1500	A	Hard rock
760-1500	B	Rock
360-760	C	Very dense soil/ soft rock
180-360	D	Stiff soil
<180	E	Soft soil

The Site classification is an important factor in seismic hazard evaluation.

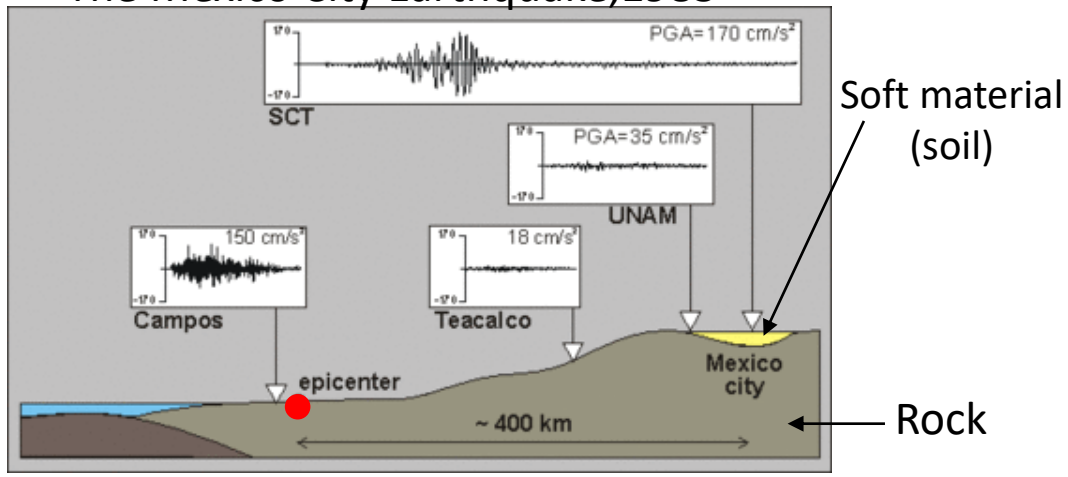
Ground Motion Prediction Equation

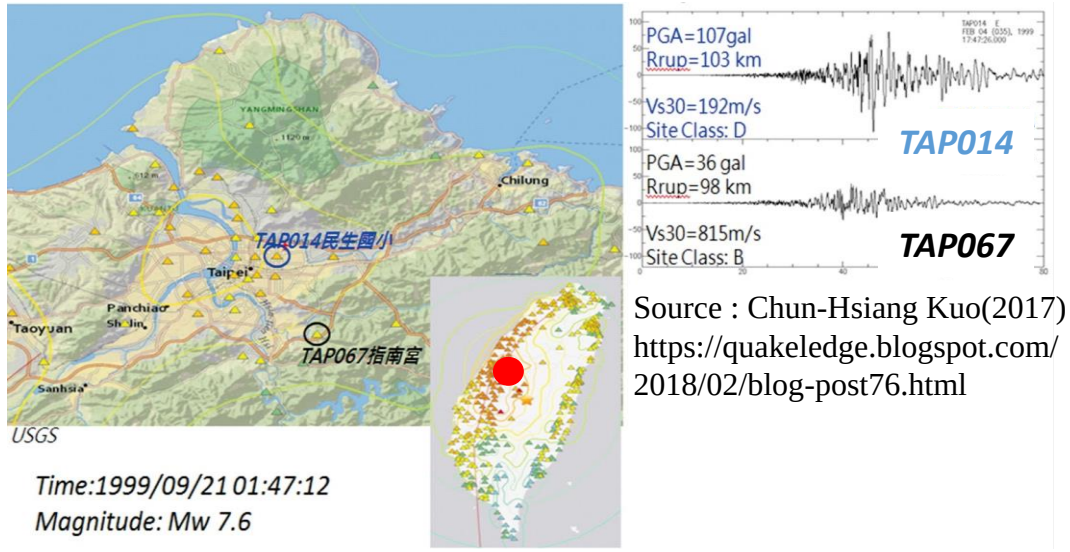
$$ln(Y) = C_1 + C_2M + C_4 \ln(R + C_5 e^{C_6 M}) + C_7 R + C_8 H + \mathbf{C_9 \ln\left(V_{s30}/1130\right)} + C_{10} Z_t + C_{11} F_{nm} + C_{12} F_{rv}$$

Yang (2019)

What is seismic site effect?

The Mexico City Earthquake,1985





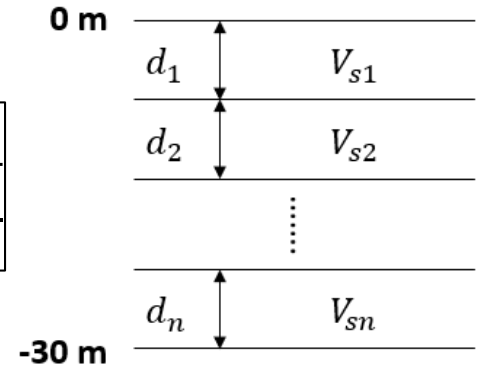
Source : Chun-Hsiang Kuo(2017) https://quakeledge.blogspot.com/2018/02/blog-post76.html

How to estimate Vs30 ?

Geophysical prospecting :

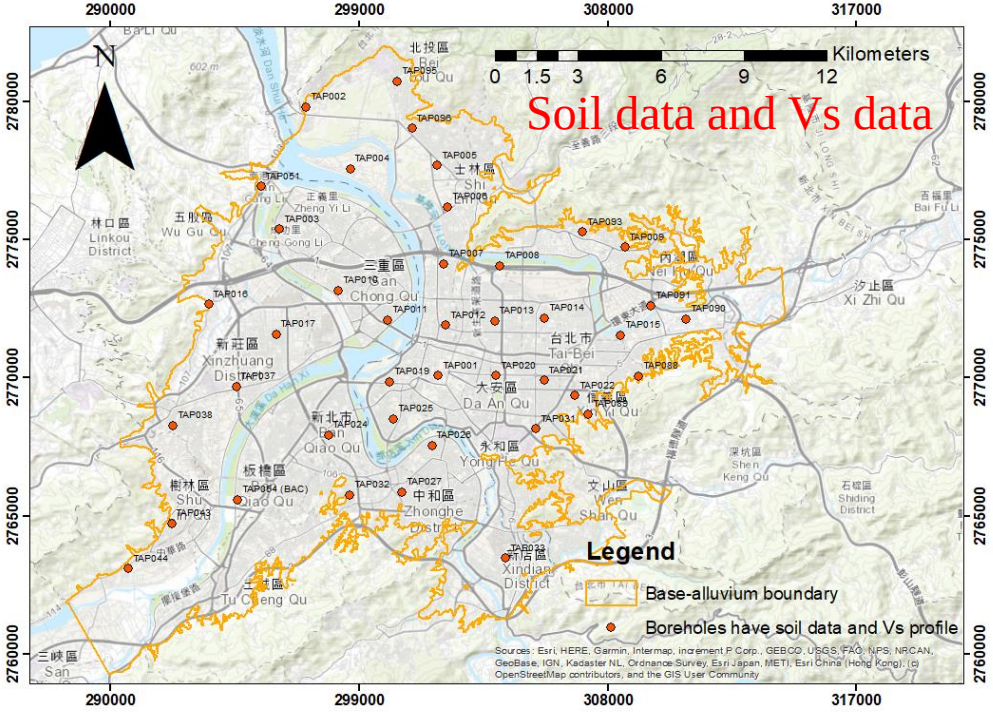
- Seismic refraction method
- **Suspension PS logging**
- Downhole logging
- Crosshole logging

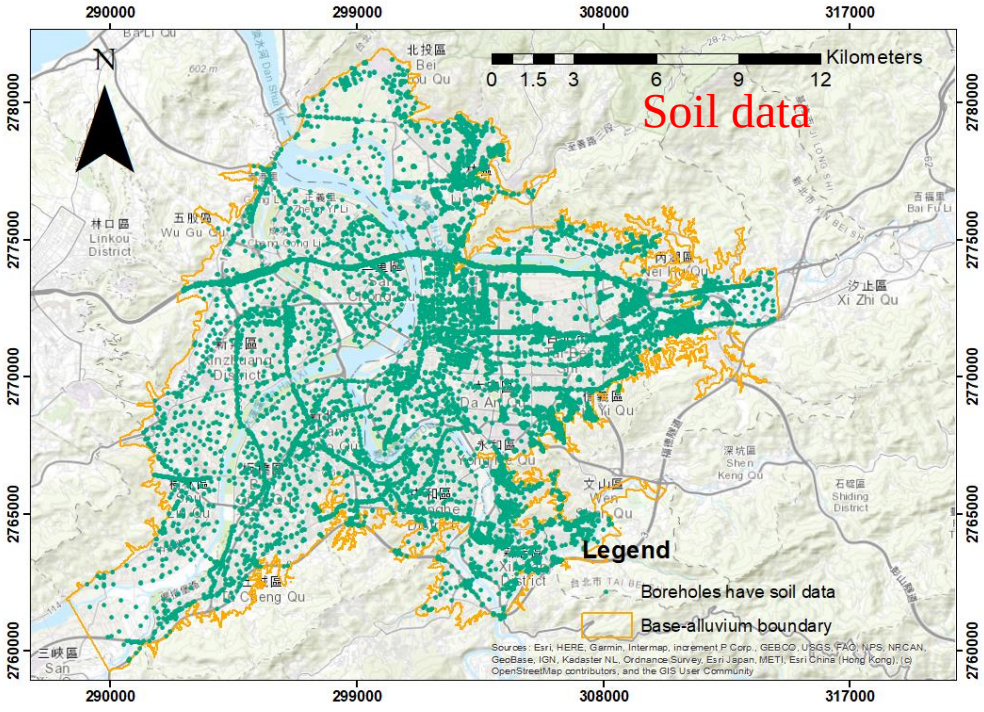
$$V_{s30} = \frac{30}{\sum_{i=1}^{n} \frac{d_i}{V_{si}}}$$



It is **time-consuming** and need a lot of **money** in **large area** investigation

Study Area: Taipei Basin





The Vs estimate from other parameters :

$V_s = aN^b D^c$	Ohta and Goto (1978)
$V_s = aN^b$	Lee and Tsai (2008)
$\ln(V_s) = \mathrm{f}(N_{60}, \sigma_v', FC, \mathrm{PI}, \mathrm{OCR})$	Tsai et al. (2019)

The Vs estimate by extrapolation methods :

$logV_{s30} = a + blogV_{s(d)}$	Boore (2004)
Bottom constant velocity	Kuo et al. (2009,2011)
Conditional independence property	Dai et al.,2013

D: Depth

N: SPT-N value

σ_v' : Vertical effective stress

FC: Fines content

OCR: Over Consolidation Ratio

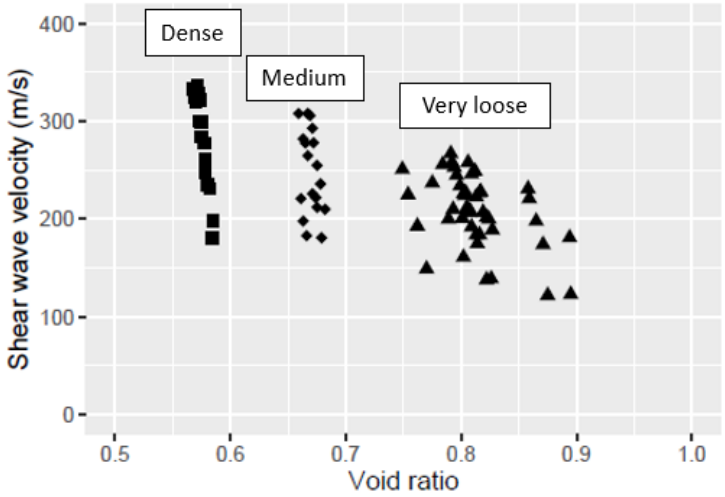
PI: Plasticity index

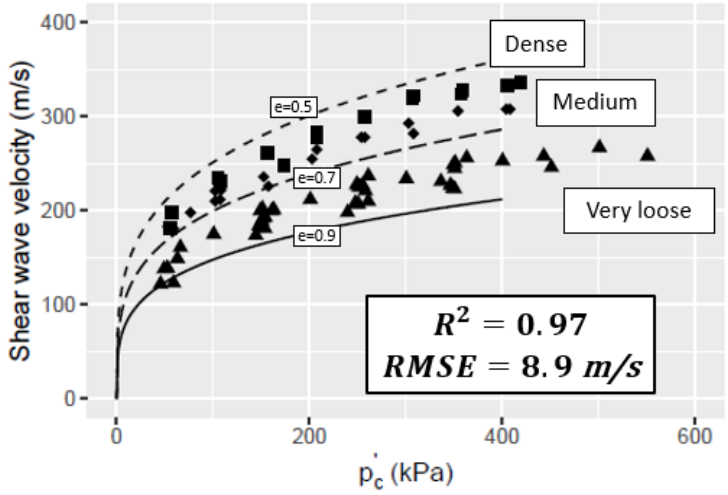
PURPOSE:

Correlation between Vs, e and σ_v' (laboratory data)

Experiment results: Vs-e & Vs-σ'

Robertson et al. (1995)





e : Soil void ratio

σ_v' : Vertical Effective Stress

σ_h' : Horizontal Effective Stress

P_c' : Mean Effective Stress

Soil data and Vs data → Regression analysis → $V_s = (m_1 - m_2 \boldsymbol{e})(\frac{\boldsymbol{P_c'}}{100})^{n_a}$

Boreholes (Soil data) in Taipei Basin

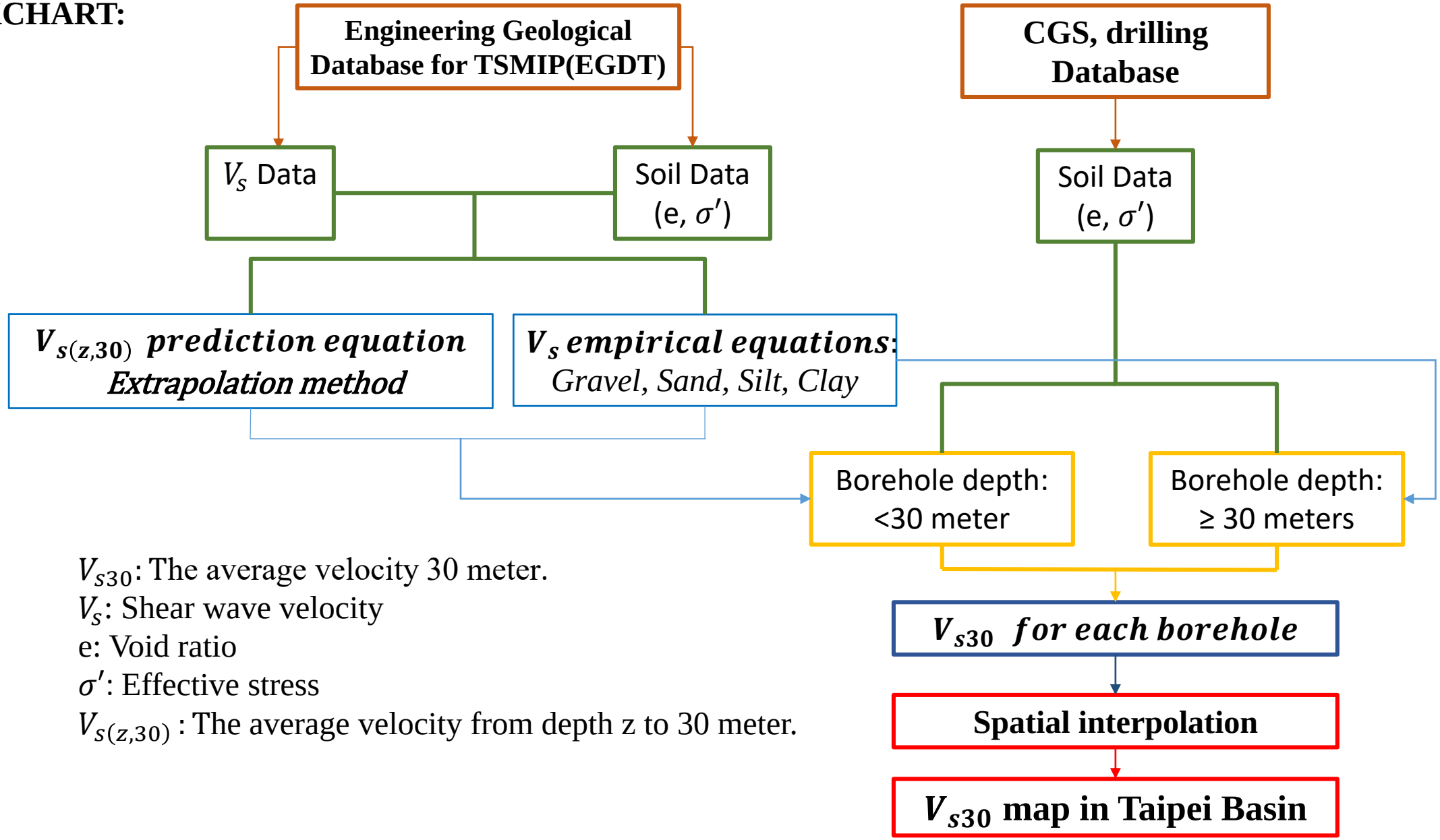
- Depth ≥ 30 m → V_s equations
- Depth < 30 m → V_s equations + **Extrapolation methods**

V_{s30} for each borehole → Spatial interpolation → **V_{s30} map in Taipei Basin**

2

Methodology

WORKCHART:



V_{s30}: The average velocity 30 meter.
V_s: Shear wave velocity
e: Void ratio
σ': Effective stress
$V_{s(z,30)}$: The average velocity from depth z to 30 meter.

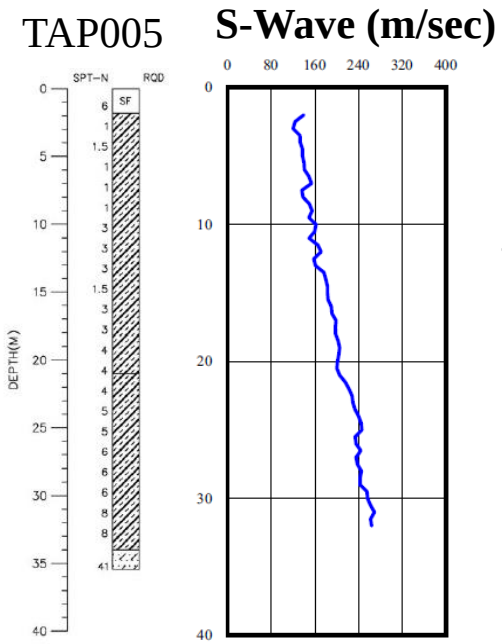
Engineering Geological Database for TSMIP (EGDT)

41 boreholes

Soil profile characteristics are determined by subsurface investigation and field/lab testing program.

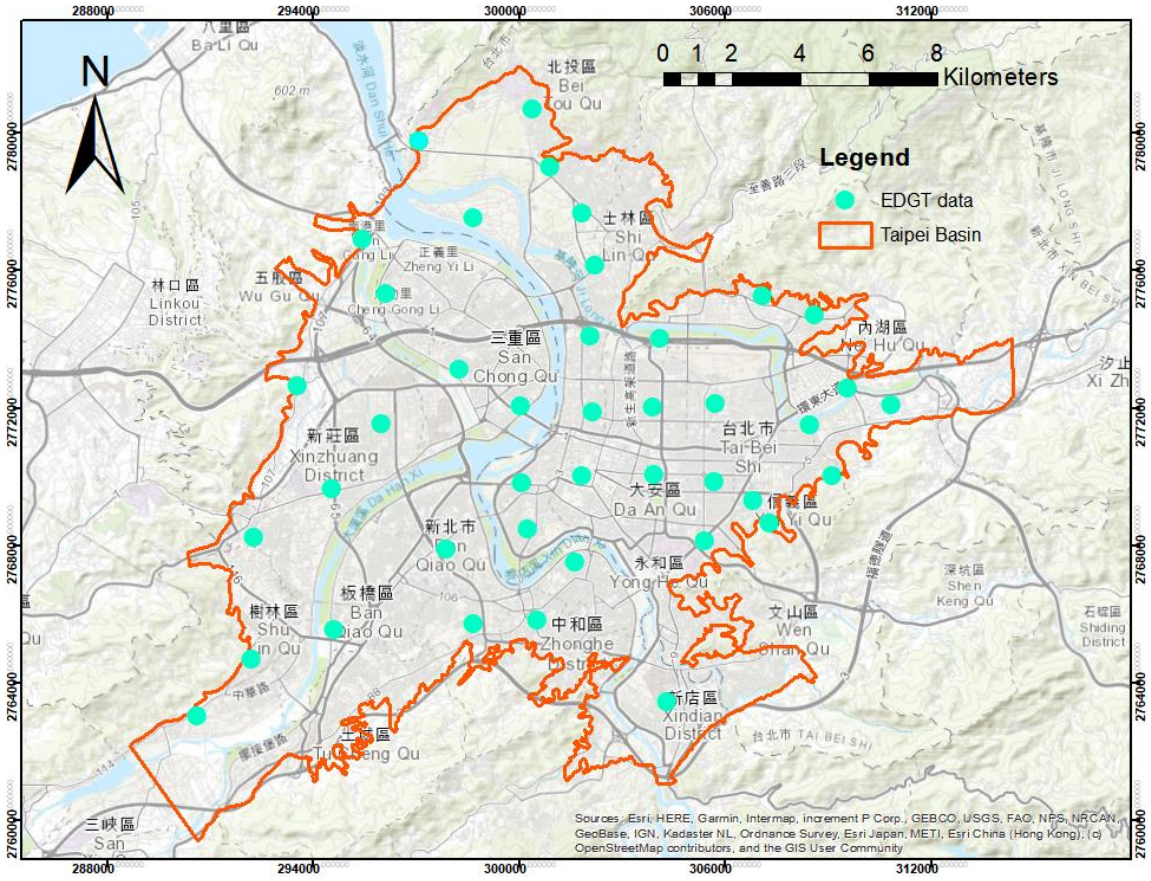
➡ Soil Data(e, σ')

Suspension PS logging method



Sandy clay and silt clay

Silty sand and sand-silt mixture



➡ V_s Data

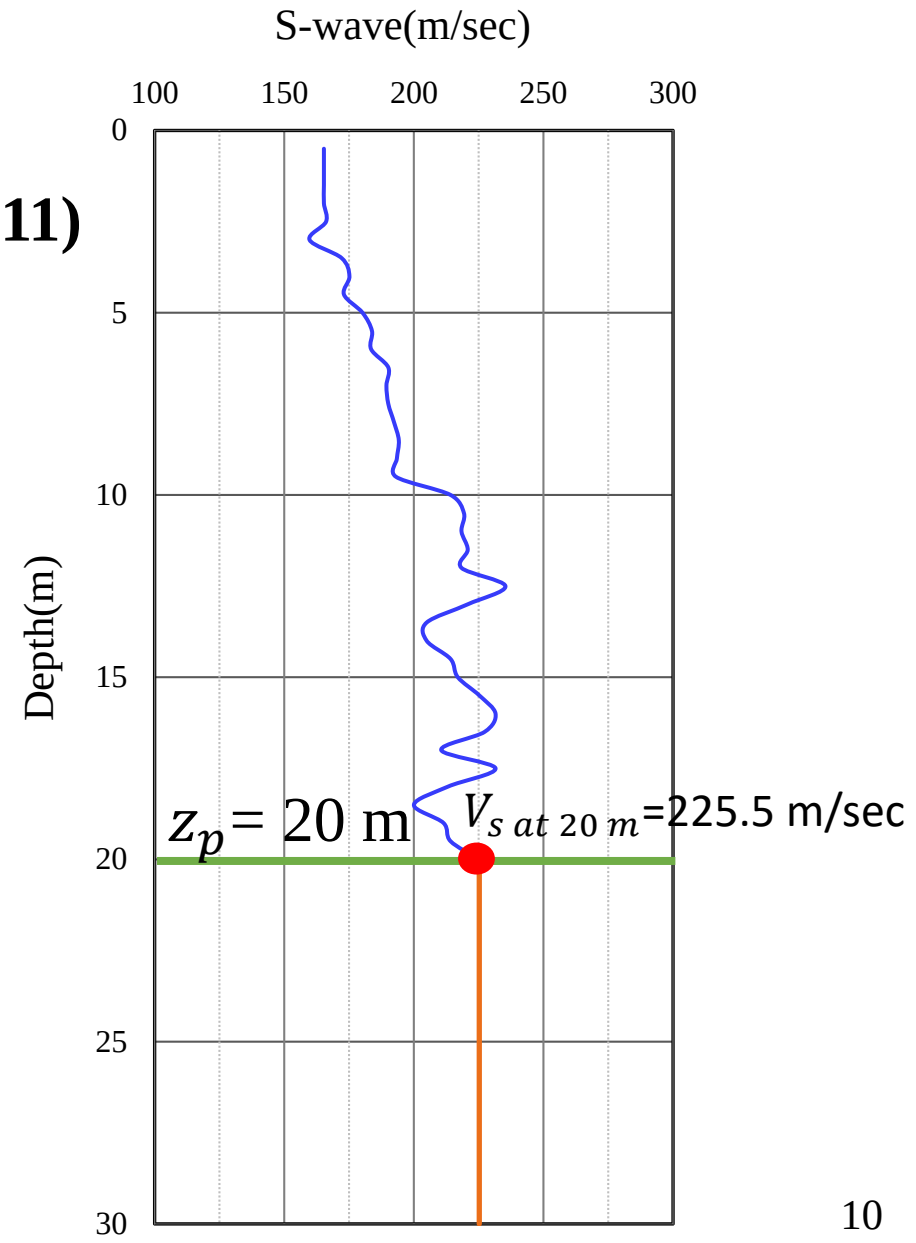
2.1: Extrapolation methods

Bottom constant velocity (BCV) model (Kuo et al., 2009,2011)

- The assumption of model that V_s is constant from z_p to 30m

$$V_{s30} = \frac{30}{\Delta t_z + \frac{30 - z_p}{V_{s(z_p)}}} \qquad (1)$$

Δt_z the shear wave travel time from z_p to the surface



Conditional independence property model (CIP) (Dai et al.,2013)

- The assumption that the V_s profile is a Markov process staring from z = 0

- The instantaneous velocity at depth Z_p, the average velocity from surface to the depth Z_p (V_{SZ}) cannot be effectively in estimating the average velocity from depth Z_p to 30 m ($V_{s(z_p,30)}$

$$\log(V_{s(z,30)}) = c_0 + c_1 \log V_{SZ} \quad (2)$$

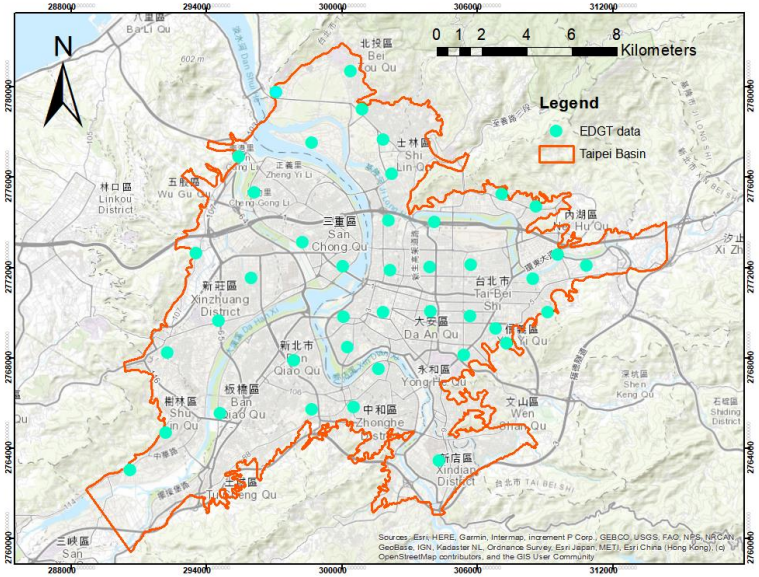
c_0, c_1, : regression coefficients

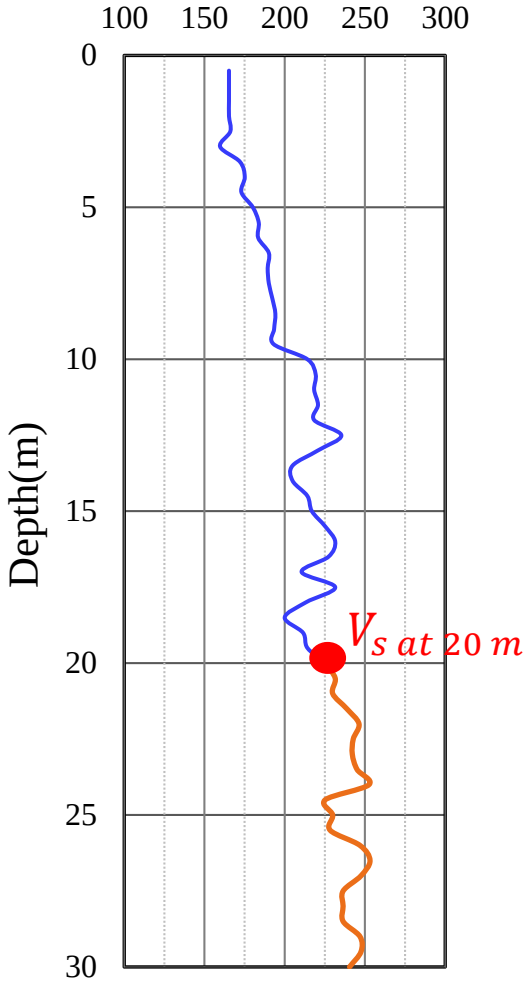
- Using the average velocity from z to 30 m to estimate V_{s30}

$$V_{s30} = \frac{30}{\Delta t_z + \frac{30 - z_p}{V_{s(z_p,30)}}} \quad (3)$$

Δt_z the shear wave travel time from z_p to the surface

Boreholes have Vs data





2.2 Correlation between Vs (Shear wave velocity), e(void ratio) and σ_v' (effective stress)

Data collecting and selecting

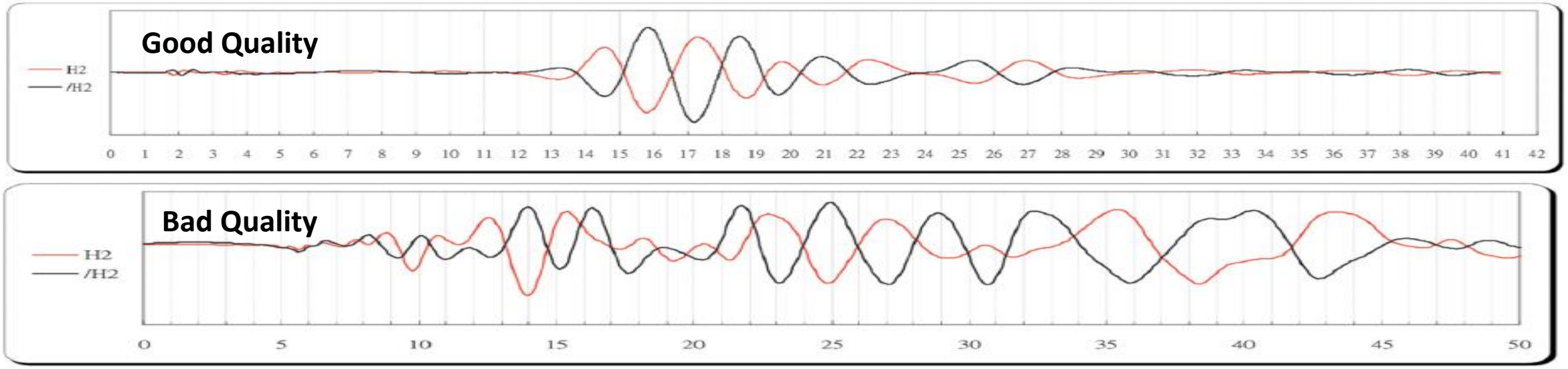
- **Velocity Data Quality**
- **USCS; void ratio; vertical effective stress from laboratory test**
- **Stratum Description**

Velocity Data Quality:

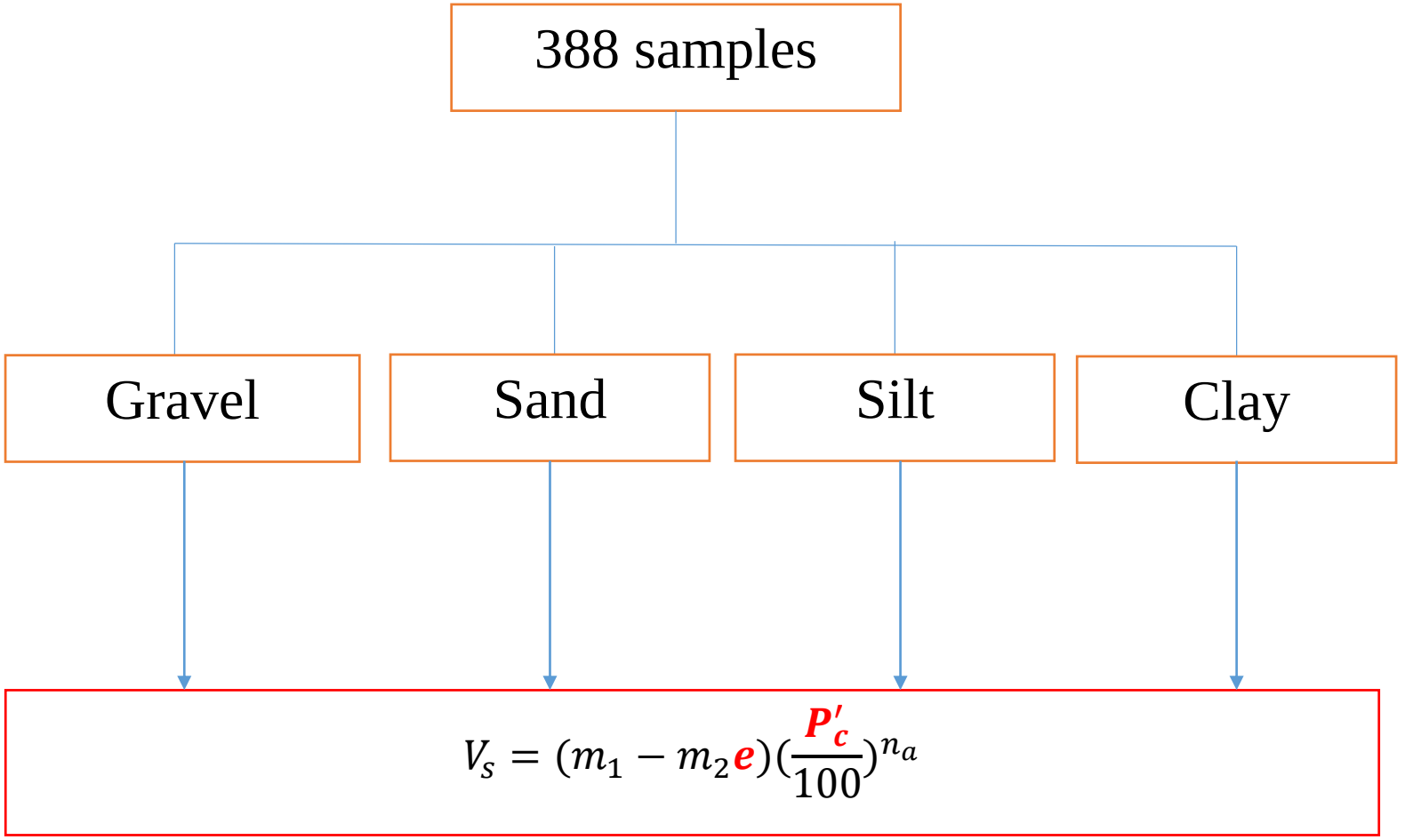
Check the **original waveform** of velocity measurement via **visually inspected the first arrival** and **cross-correlation**.

Data in 2000 ~ 2004: the result from **Lee and Tsai(2008)**
Data in 2005 ~ 2008: the result from **Kuo (2021)**

Example of good and bad quality data



After data collecting and checking:



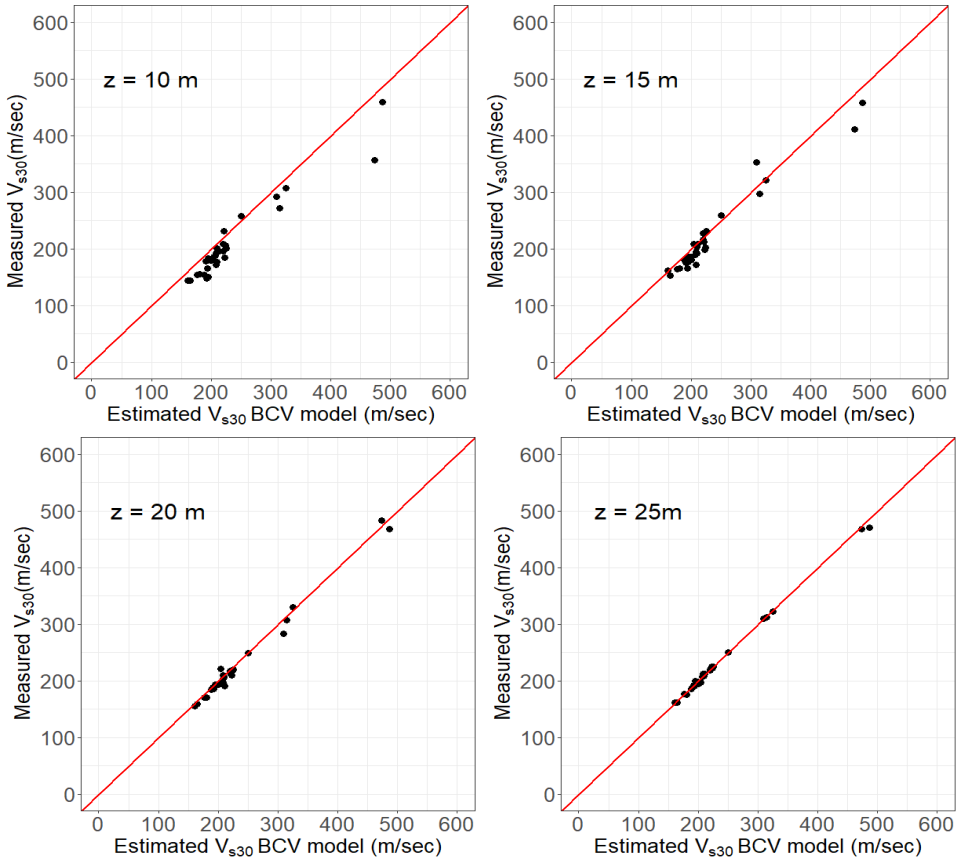
Regression analysis:

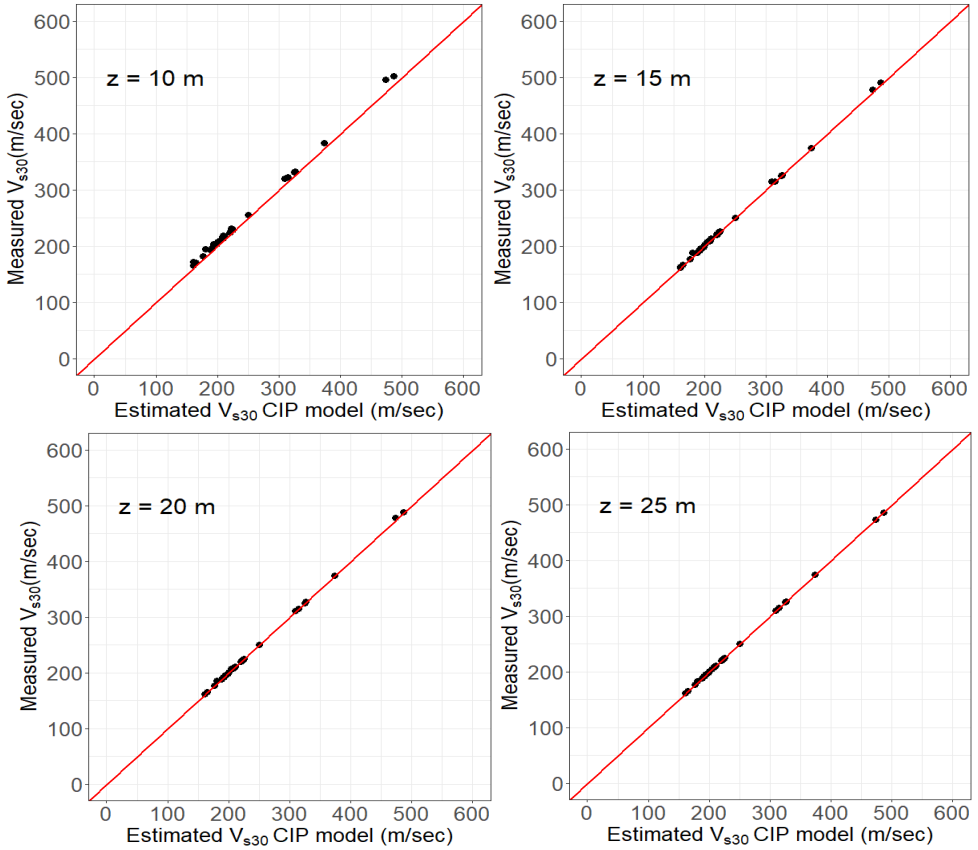
R Language

3

Preliminary result

3.1: Result of extrapolation methods in Taipei Basin:





BCV MODEL

CIP MODEL

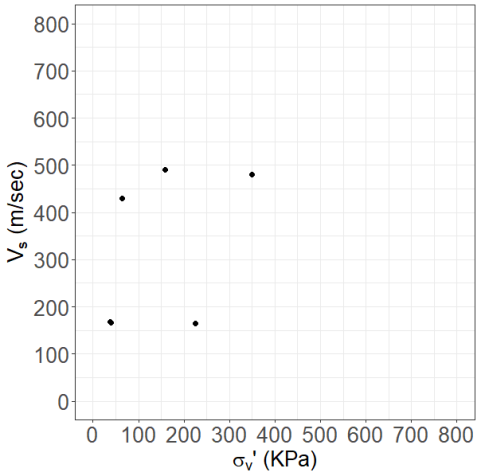
CIP MODEL

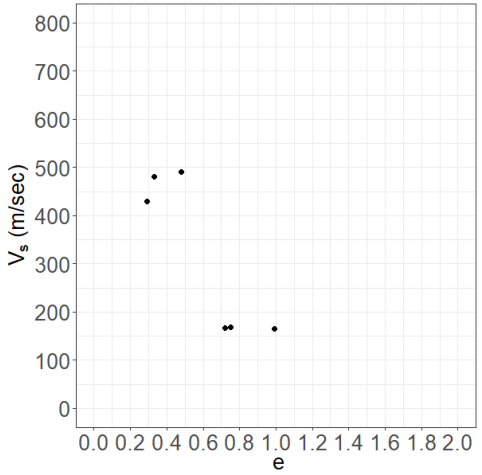
Z=10 -15(m): $\log(V_{s(z,30)} = 1.11\log V_{SZ} - 0.25$

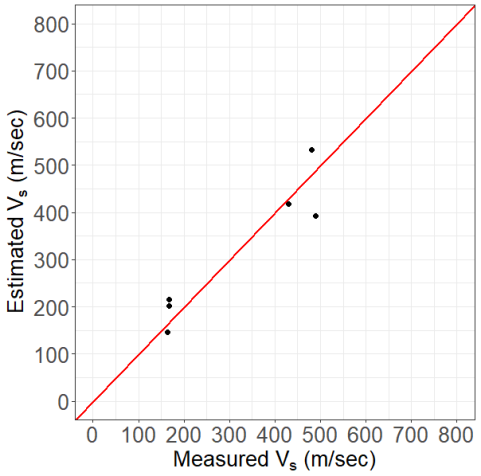
Z=16 – 29 (m): $\log(V_{s(z,30)}) = 1.01\log V_{SZ} - 0.003$

3.2 : V_s *empirical equations*: *Gravel, Sand, Silt, Clay*

Gravel: 6 samples





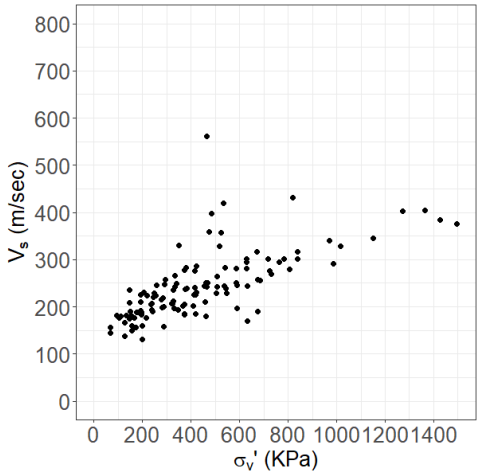


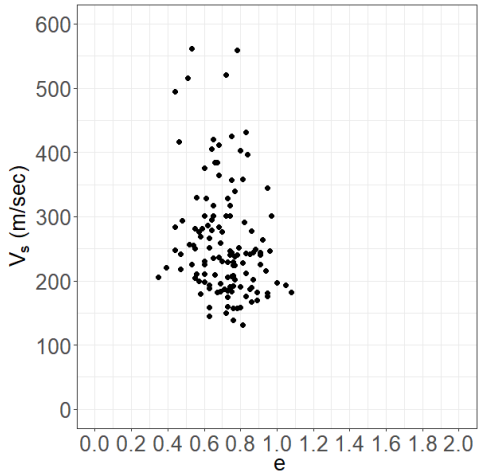
$$V_s = (584.7 - 461.1e)\left(\frac{\sigma'}{100}\right)^{0..17}$$

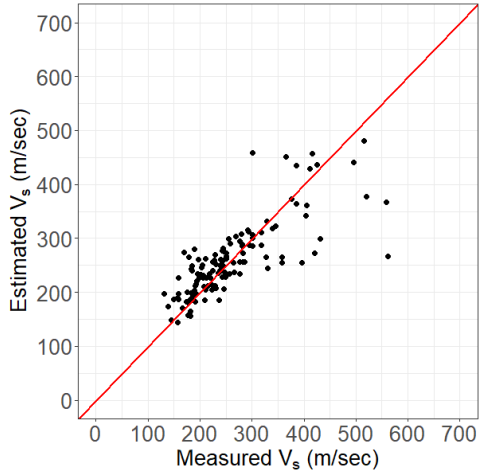
R^2 = 0.88

RMSE(m/sec): 52.2

Sand: 130 samples







$$V_s = (186.53 + 31.9e)\left(\frac{\sigma'}{100}\right)^{0.29}$$

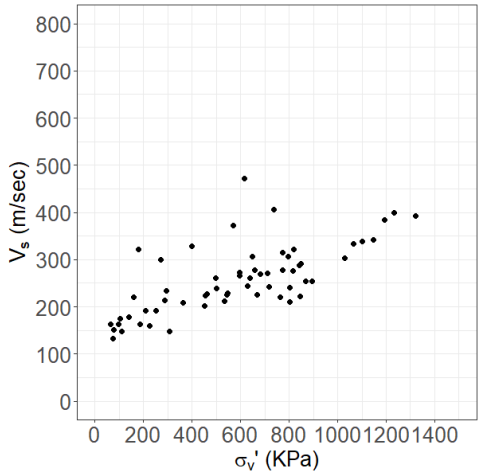
R^2 = 0.61

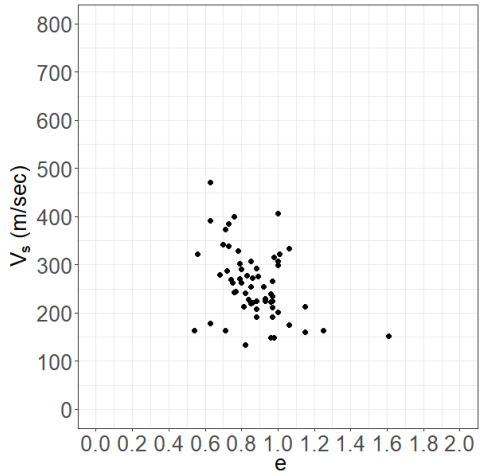
RMSE(m/sec): 54.41

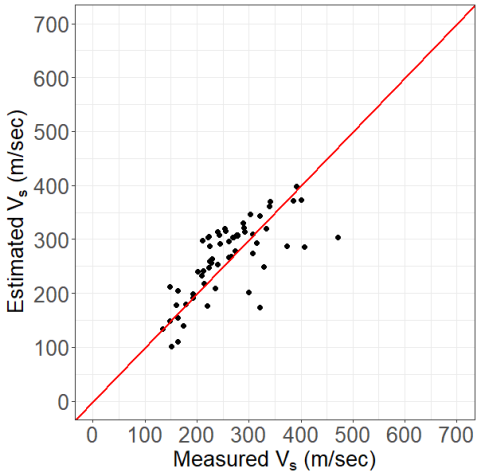
e : Soil void ratio

σ'_v : Vertical Effective Stress

Silt: 62 samples





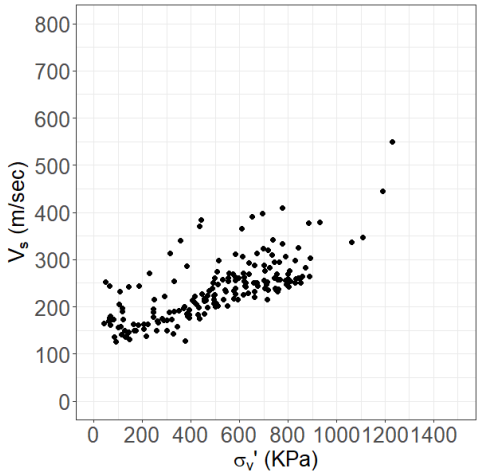


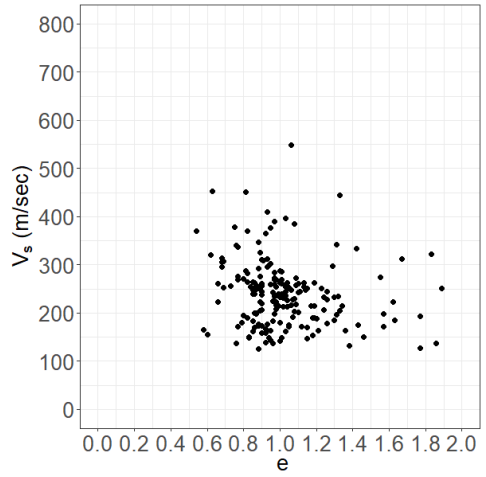
$$V_s = (191.1-49.64e)(\frac{\sigma'}{100})^{0.35}$$

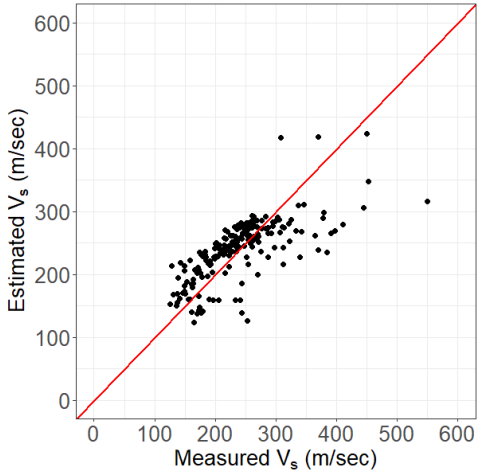
R^2 = 0.41

RMSE(m/sec): 78.10

Clay: 190 samples







$$V_s = (167.8-12.1e)(\frac{\sigma'}{100})^{0.28}$$

R^2 = 0.49

RMSE(m/sec): 49.29

e : Soil void ratio

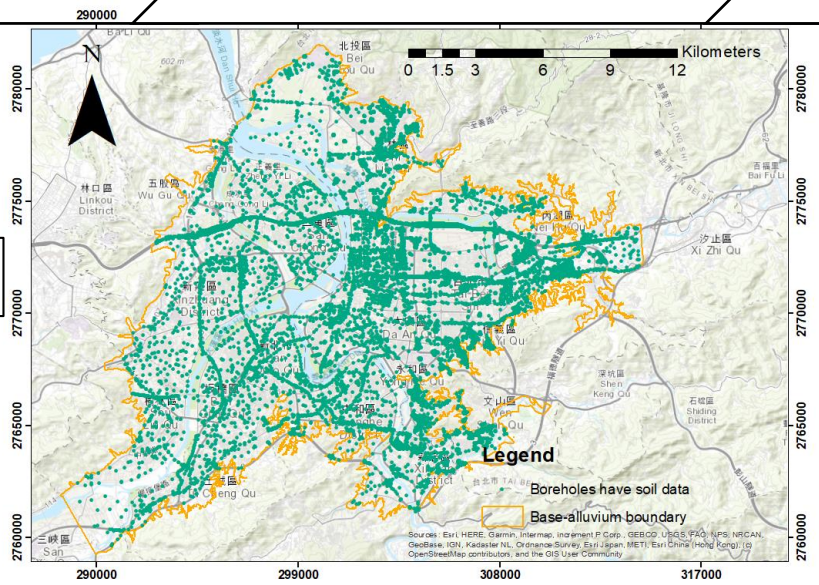
σ_v' : Vertical Effective Stress

4

Future work

經濟部中央地質調查所
Central Geological Survey, MOEA

Total: 10768 boreholes



CGS, drilling Database

Soil Data (e, σ')

$V_{s(z,30)}$ ***prediction equation***
Extrapolation method

V_s ***empirical equations***:
Gravel, Sand, Silt, Clay

Borehole depth: <30 meter

Borehole depth: ≥ 30 meters

V_{s30} ***for each borehole***

Spatial interpolation

V_{s30} map in Taipei Basin

V_{s30}: The average velocity 30 meter.
V_s: Shear wave velocity
e: Void ratio
σ': Effective stress
$V_{s(z,30)}$: The average velocity from depth z to 30 meter.

Thanks for your attention!