Underground Structures Under Earthquake Loading

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Outline

- Earthquake wave characteristics.
- Site condition of Bangkok soil layer
- The respond of site condition due to Earthquake wave.(Site effect)
- Building and Tunnel design code(Thailand,2007)
- Effect of under ground structure due to earthquake wave
- Summary

Earthquake wave characteristics

- Body wave

  1) P-wave : Primary waves , longitudinal waves or Compression waves

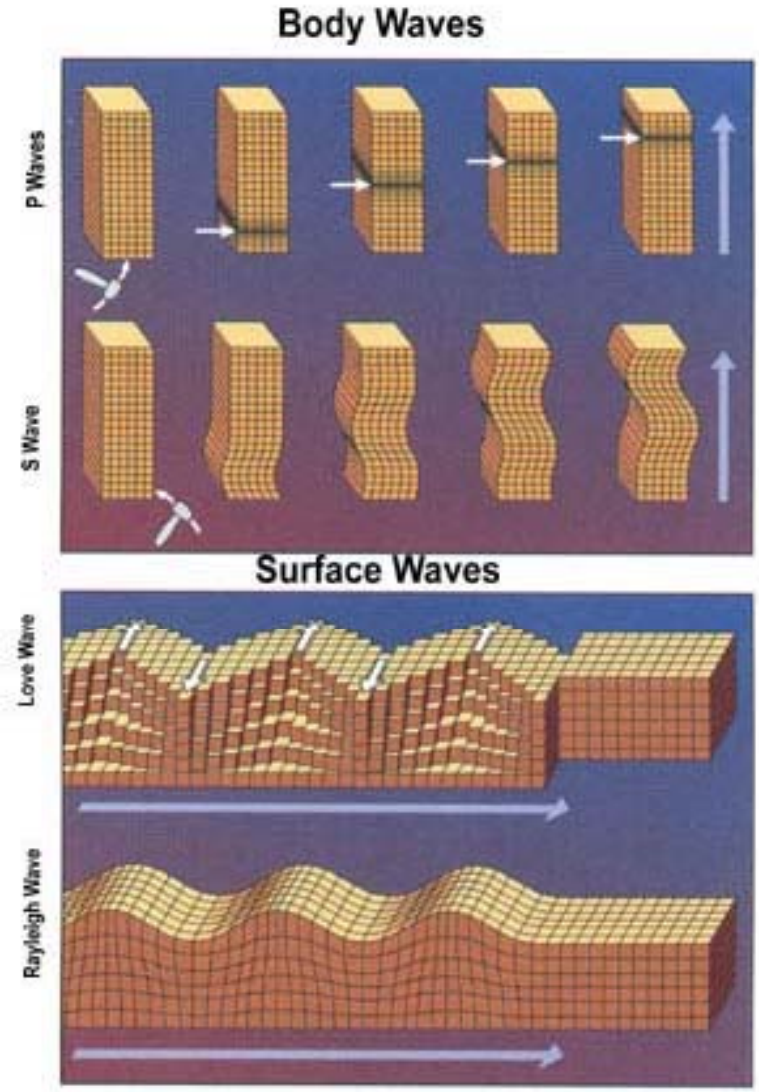
  2) S-wave : Shear or secondary waves, transverse waves

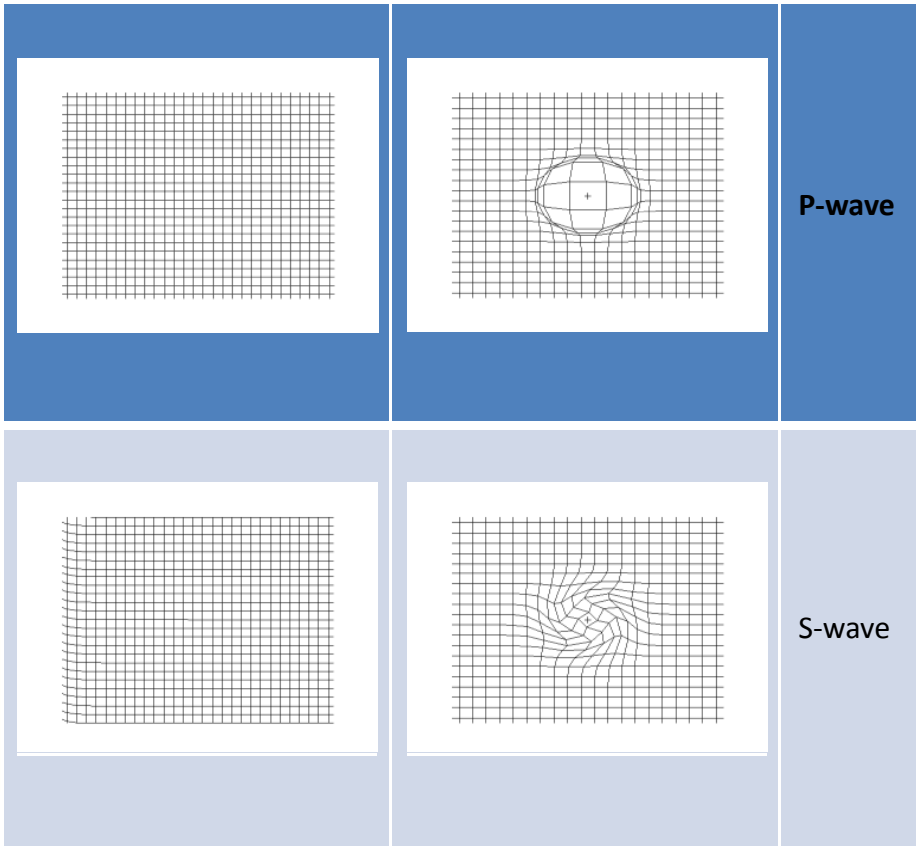
- Surface wave

  1) Rayleigh wave : ground roll

  2) Love wave : circular shearing of the ground

Earthquake wave characteristics

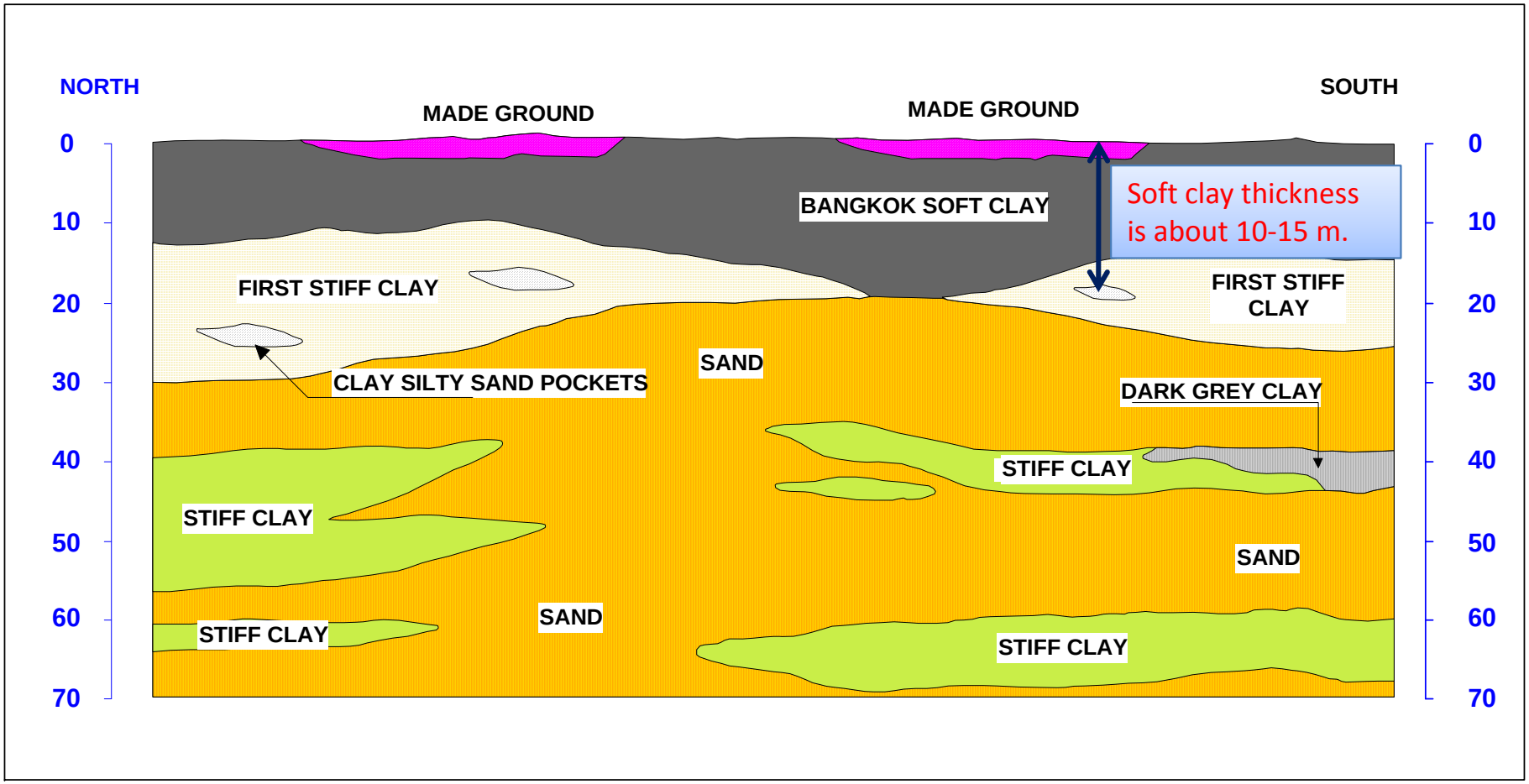




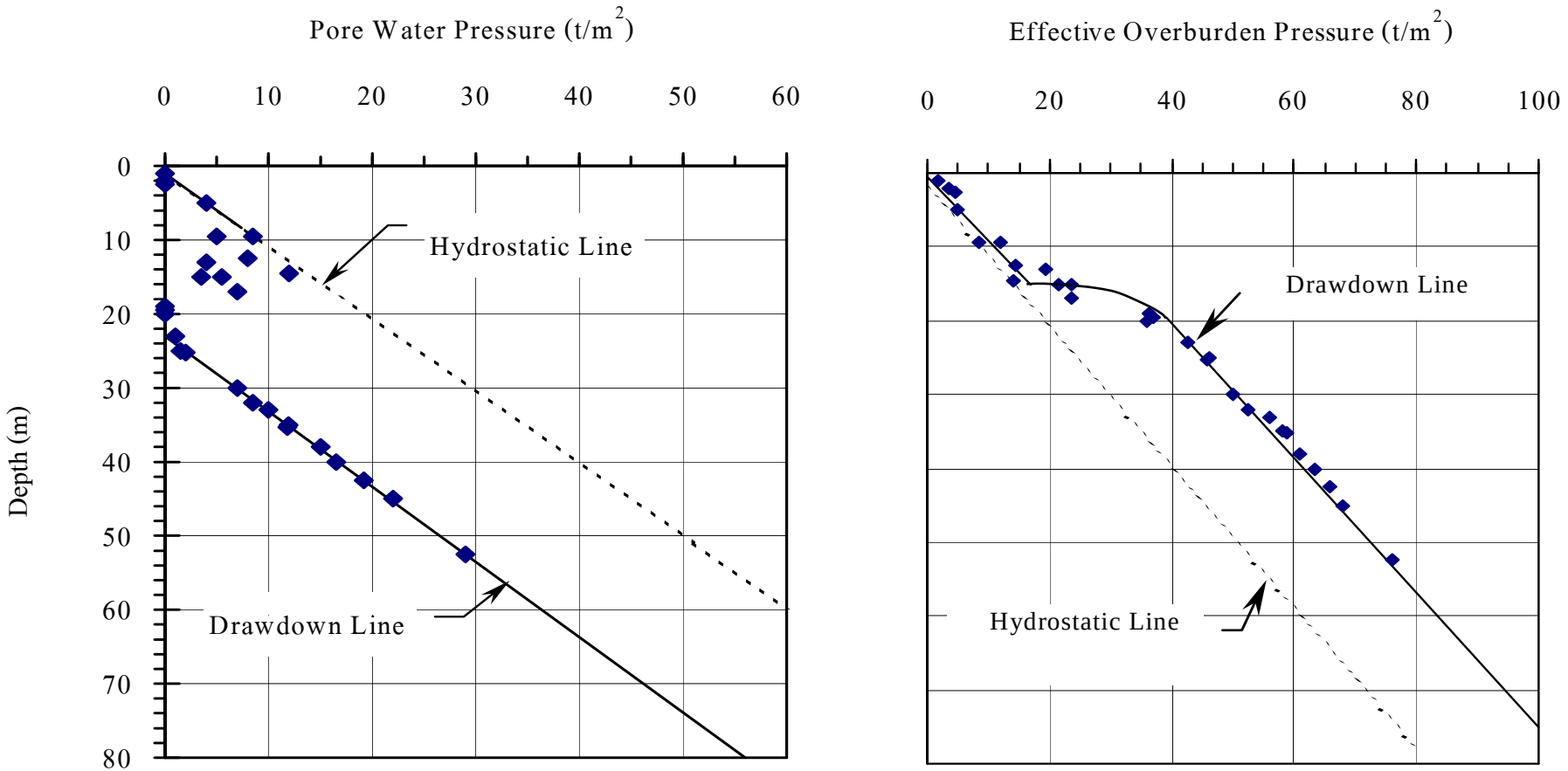
Site condition of Bangkok soil layer

- Soil profile
- Dynamic property of Bangkok soil layer
  - Maximum shear modulus, G_{max}
  - Shear wave propagation velocity, Vs

General Bangkok subsoil condition



General Bangkok subsoil condition



Dynamic property of Bangkok soil layer

$$G_{\max} = \frac{\gamma}{g} \cdot V_S^2$$

Other soil

$$G_{\max} = 3{,}230 \frac{(2.97 - e)^2}{1 + e} OCR^k \cdot \sigma'^{0.5}_m$$

For Soft bangkok clay

$$V_s = 68.7 \times S_u^{0.475}$$

$$G_{\max} = 2200 \times S_u$$

Dynamic property of Bangkok soil layer

For sand

$$G_{\max} = 1{,}000(K_2)_{\max}(\sigma_m^{'})^{1/2}$$

$$(K_2)_{\max} = 20 \cdot (N_1)_{60}^{1/3}$$

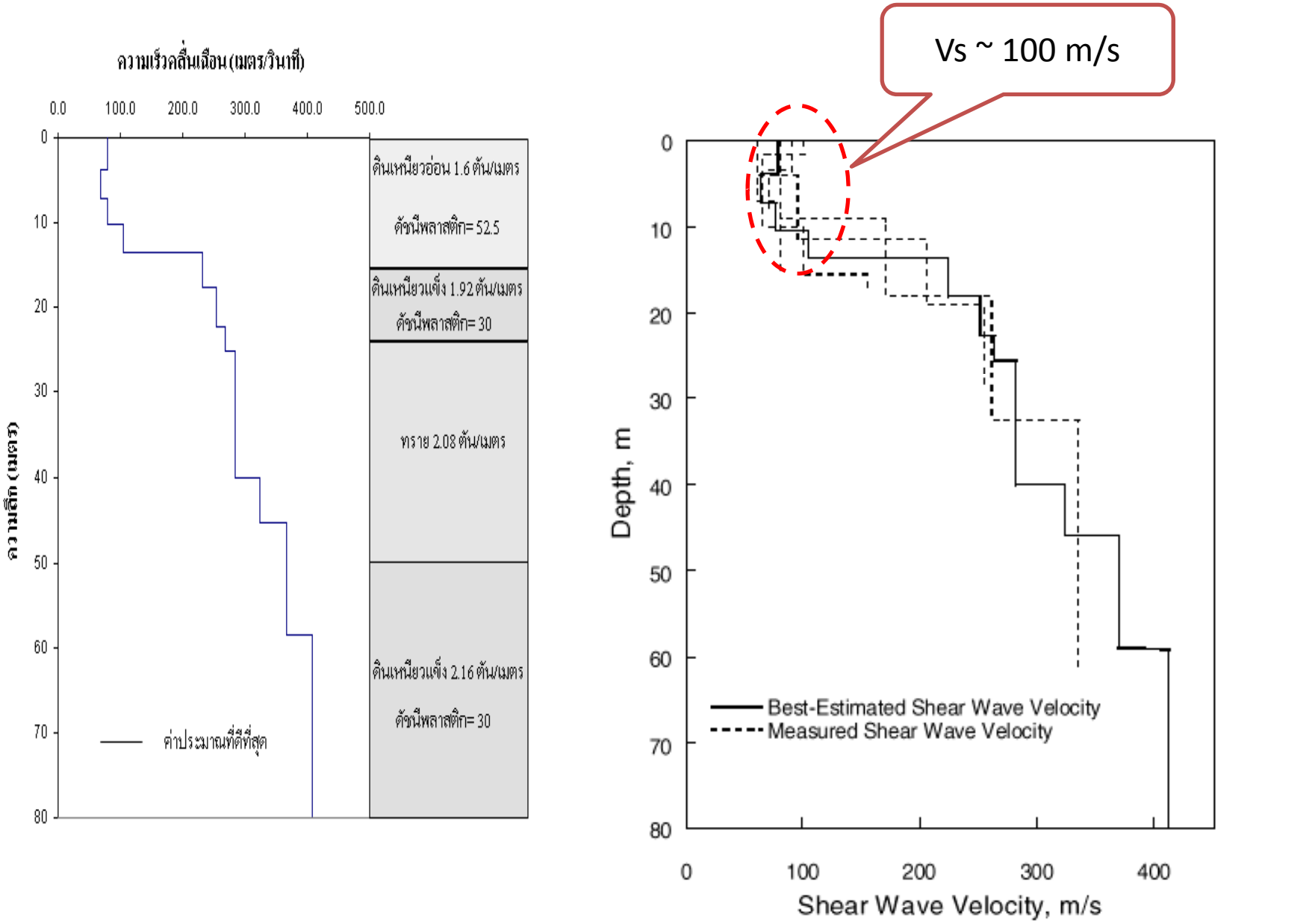


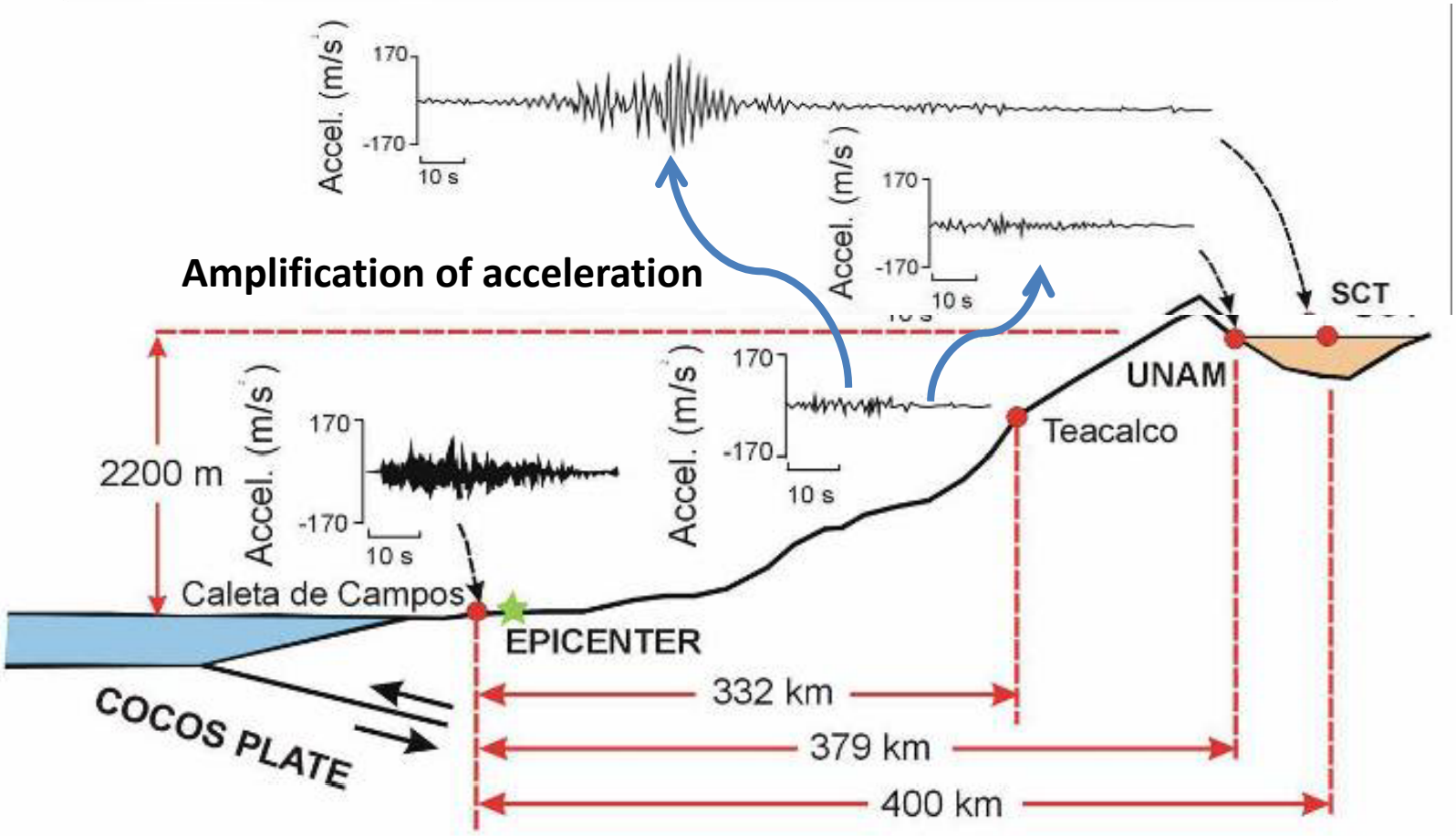
Figure 1: Comparison of measured shear wave velocity profile to best-estimate profile for Bangkok based on empirical correlations.

The respond of site condition due to Earthquake wave

- Peak rock-like acceleration
- Amplification factor,Amp
- Predominant period, Td
- Design response spectrum

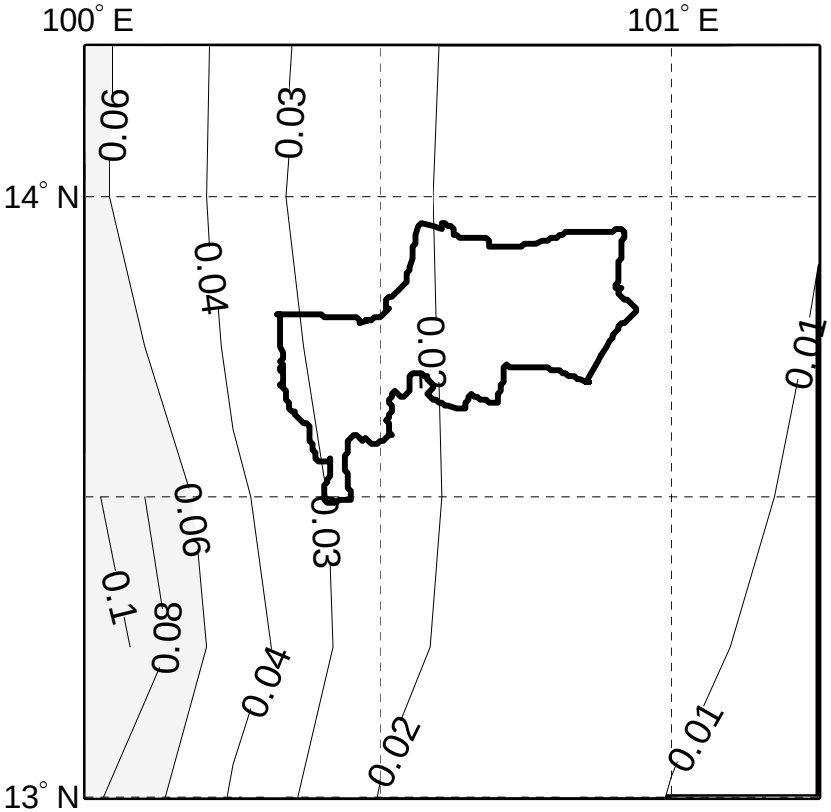
Example Site effect of Maxico city

Mexico (city) earthquake (19.IX.1985, M=8.1) …. Dist 400 Km.

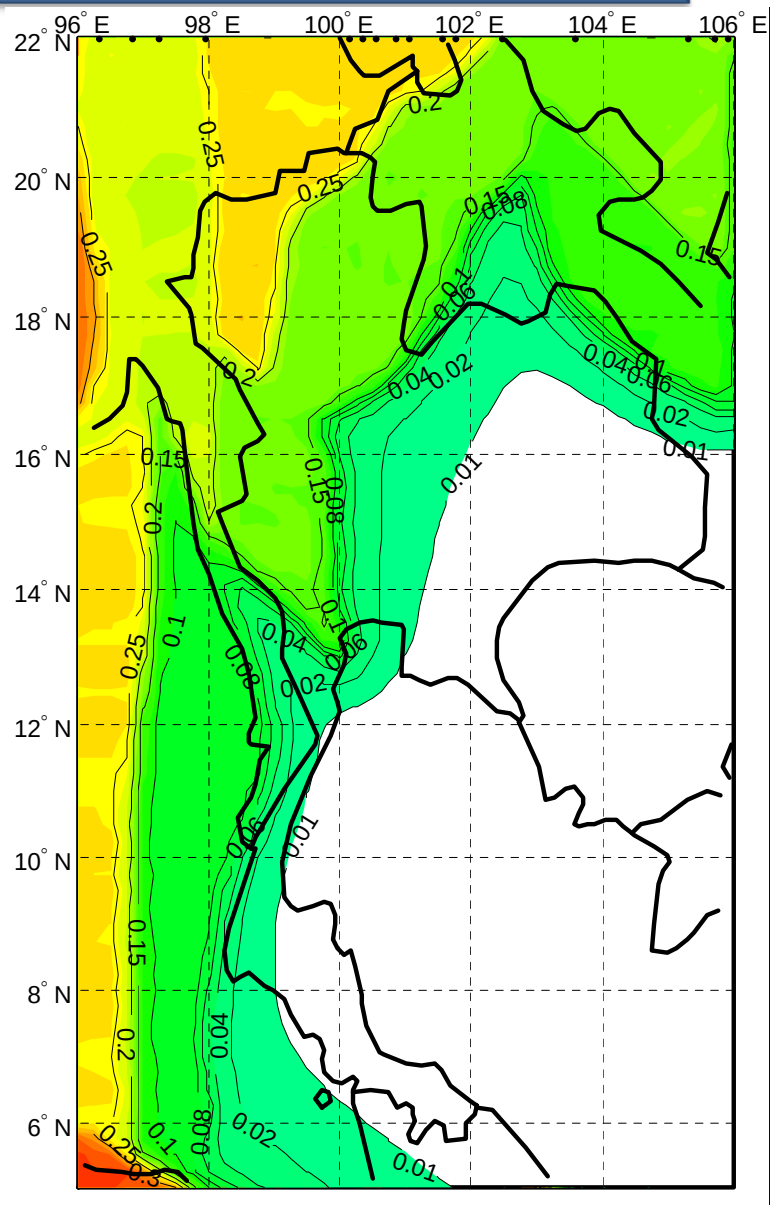


Peak rock-like acceleration

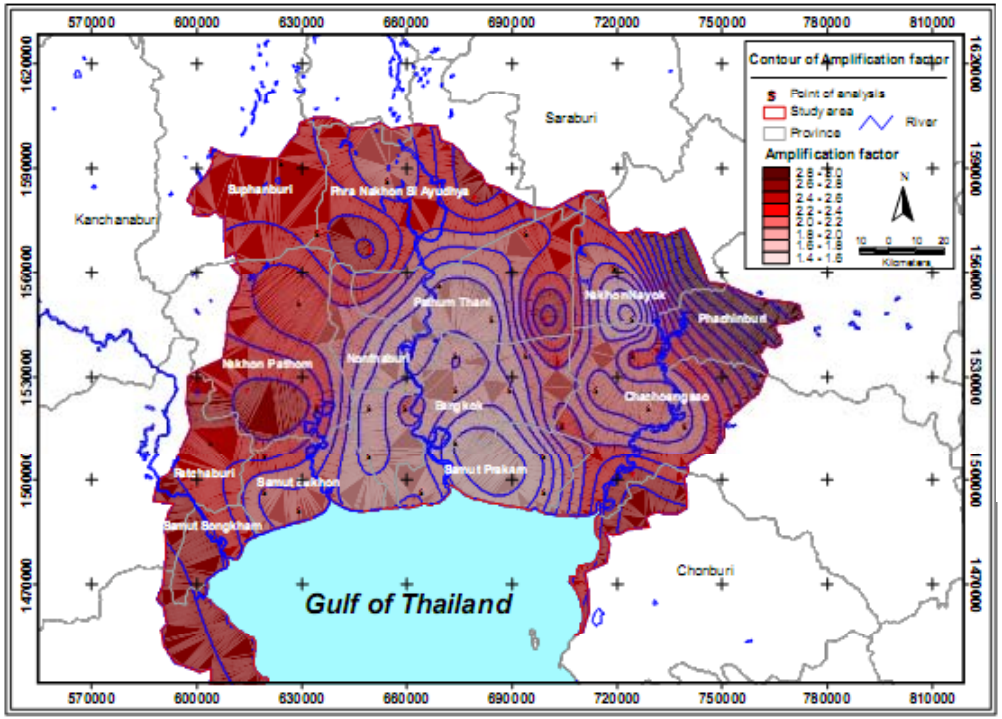
PHA Map for 10% probability of exceedance in 50 years



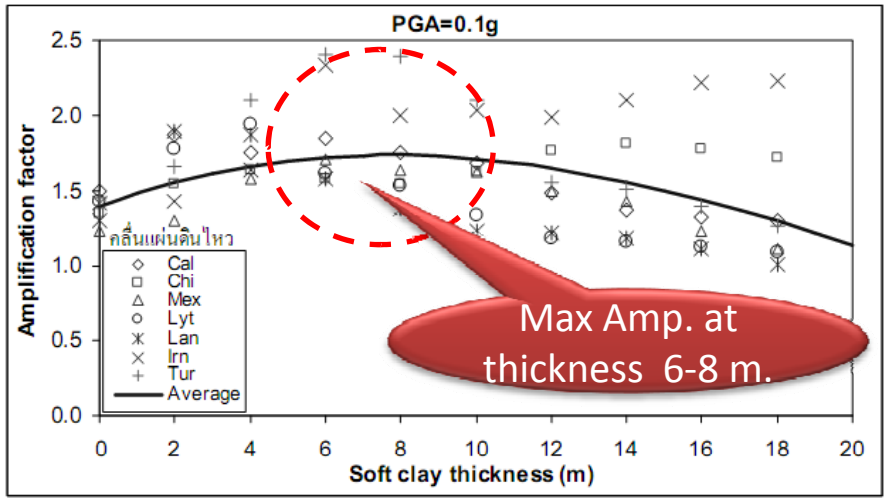
Maximum ~ 0.03g



Amplification factor,Amp



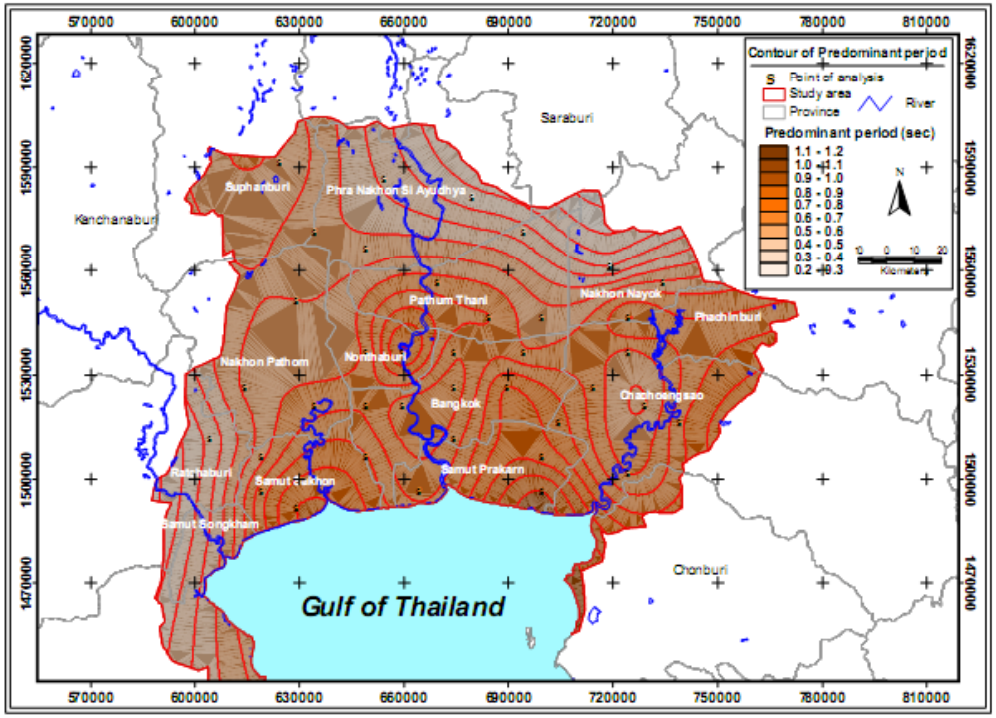
Amplification factor of soft clay layer



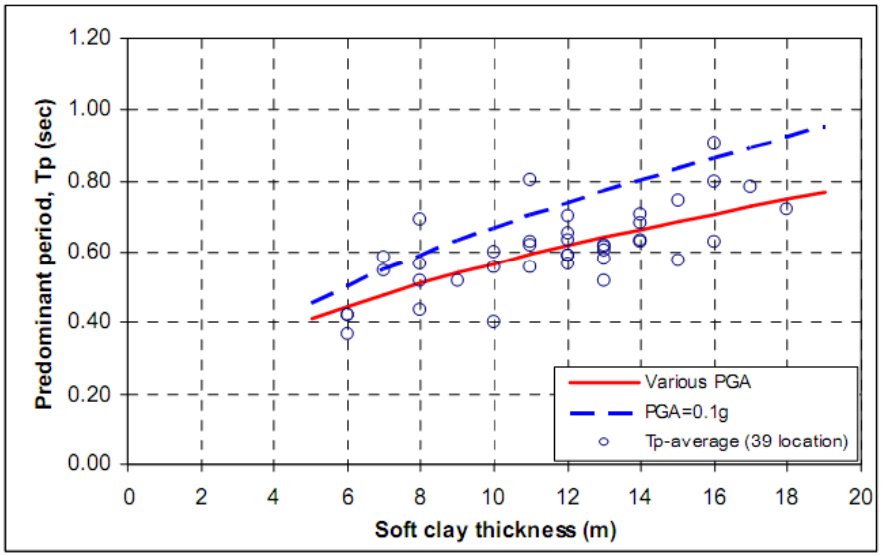
The variation of Amplification factor with Thickness of soft clay layer(varied from 0-20m.)

Max. amplification factor is 1.5-2.5 and occur when soft soil layer thickness is about 6-8 m.

Predominant period, Td



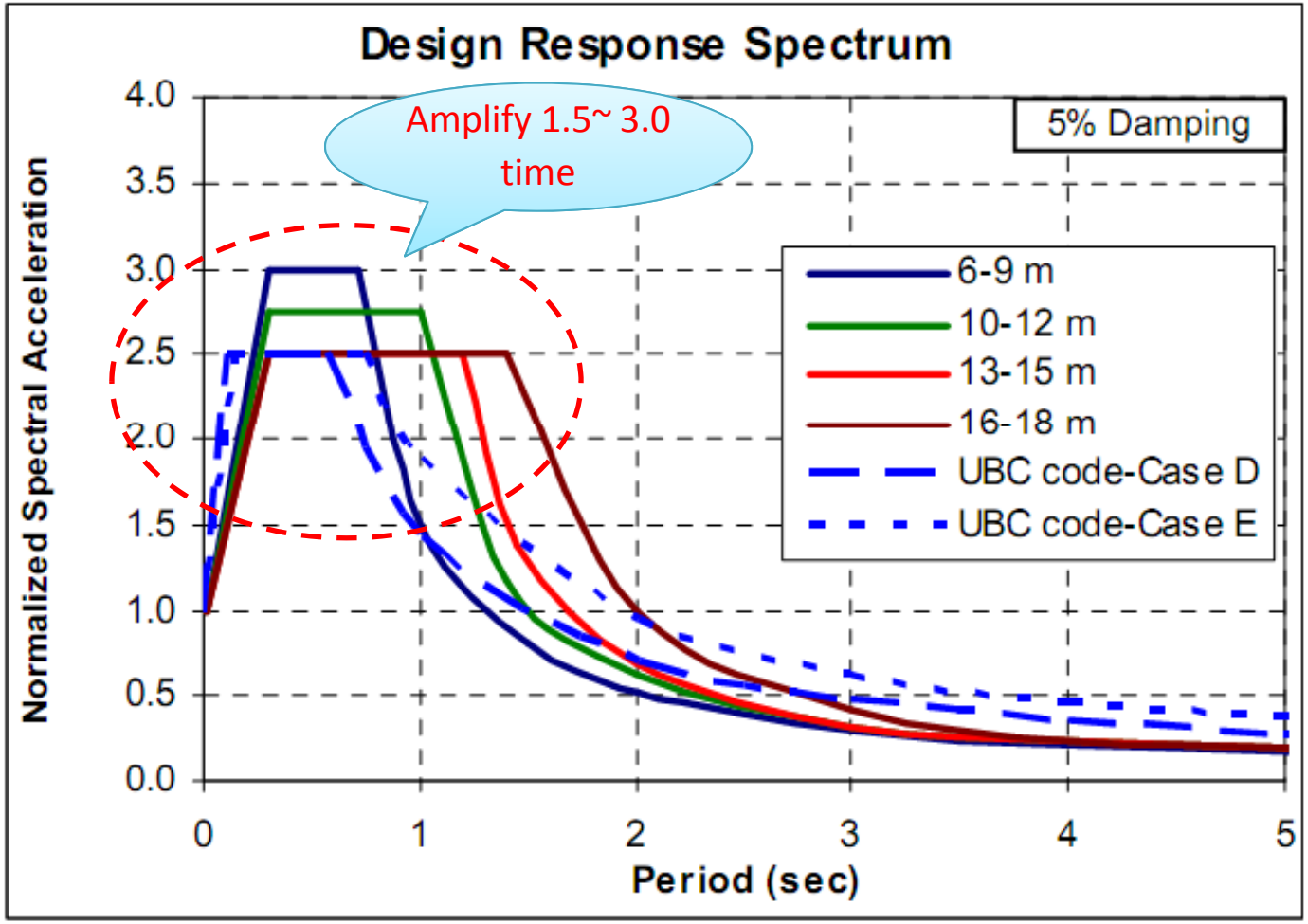
Predominant period of soft clay soil layer



The variation of Predominant period with Thickness of soft clay layer(varied from 0-20m.)

At Predominant period 0.5~1.0 s. corresponded with thickness of BKK soft clay layer varied from 10~15m.

Design response spectrum



0.10g

Building and Tunnel design code(Thailand,2007)

- Design code(Thailand,2007)
- Building
- Tunnel

Building Code

- Design code(Thailand,2007)= แก้ไขกฎกระทรวงฉบับที่ 49(พ.ศ.2540) ใหม่ ตามความใน พรบ. ควบคุมอาคาร ปี พ.ศ. 2550

Design code base on Uniform Building Code(UBC1985) of USA

1.Addition of control area

2.Classifications of control building

3.Calculation force due to earthquake

4. Addition of Standard code; มยผ.1301-50

Use for above ground structure and regularity

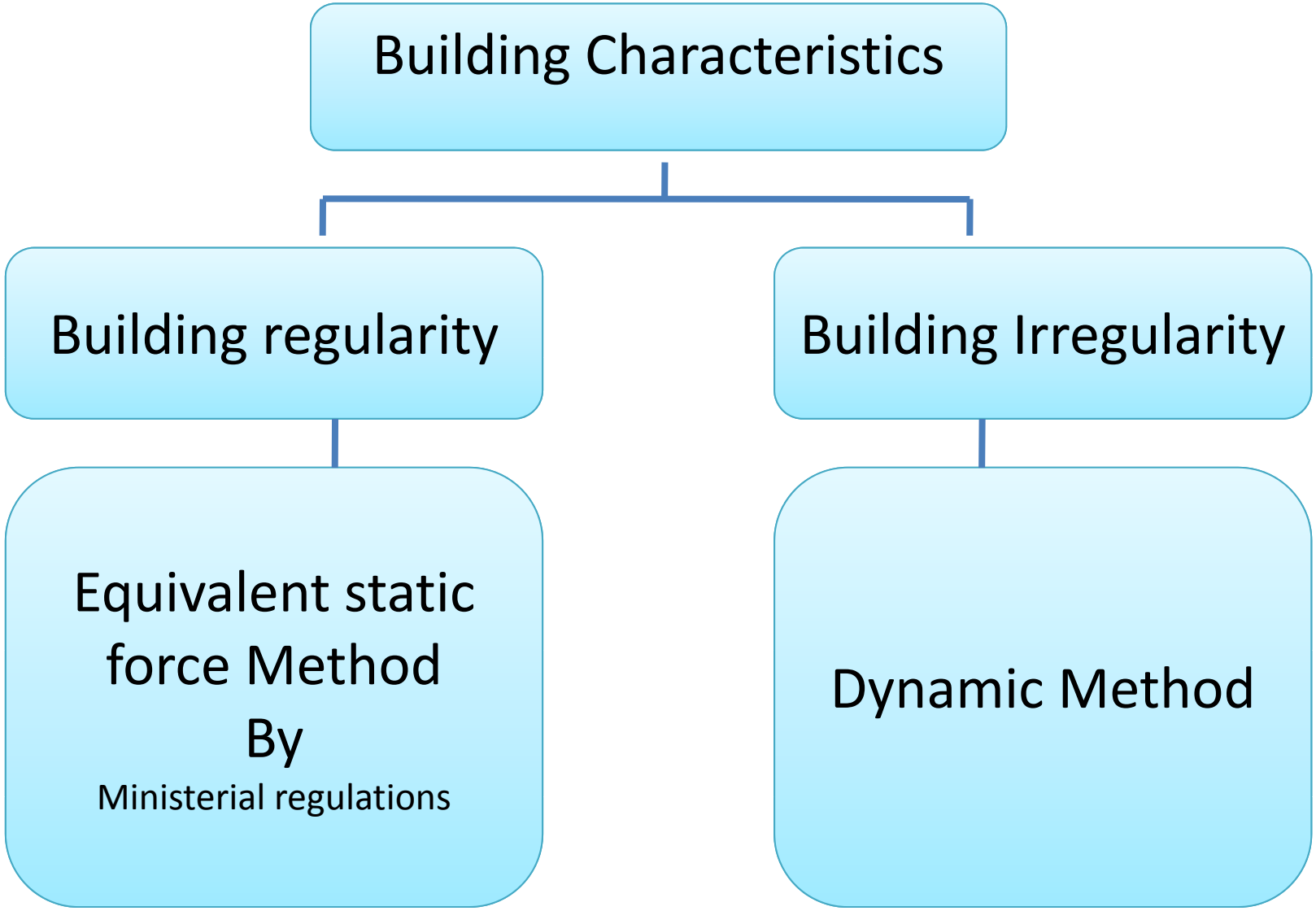
Addition of control area

- Surveillances area(พื้นที่เฝ้าระวัง)
- Zone 1 : Effect due to Soft soil of far fault
- Zone 2 : Effect due to near fault

Classifications of control building

- Control building each local area
- Add building : Dam, bridge, highway

Calculation force due to earthquake

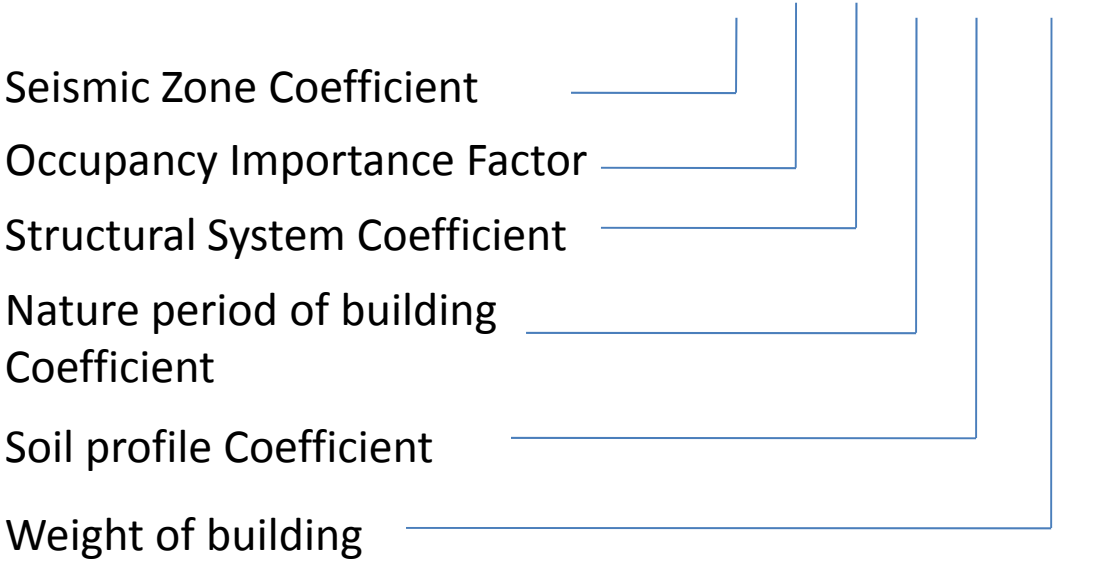


Calculation force due to earthquake by Equivalent static force Method

EQ. Base shear: V = ma

$$V = (a/g)\, W$$

$$V = Z\, I\, K\, C\, S\, W$$



The respond of building and site condition due to Earthquake wave.(Soil-structure interaction)

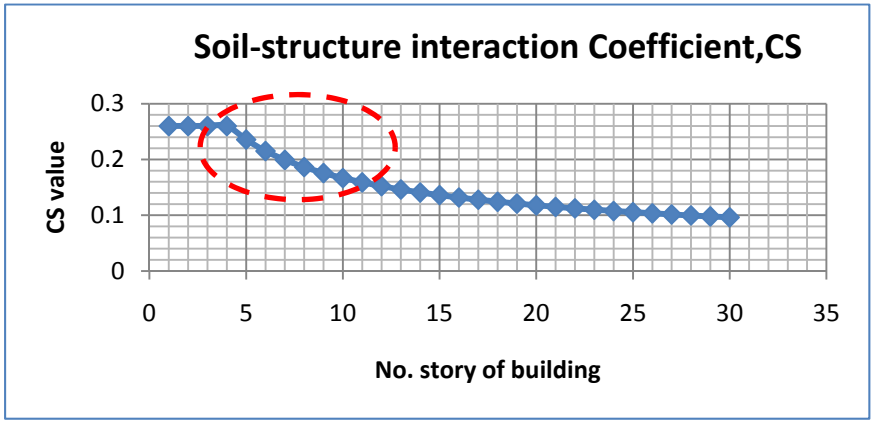
- Nature period of building Coefficient,C
- Soil profile Coefficient,S
- Code use - C*S = 0.14 when C*S < 0.14
  - C*S = 0.26 when C*S > 0.26 (Soft soil)

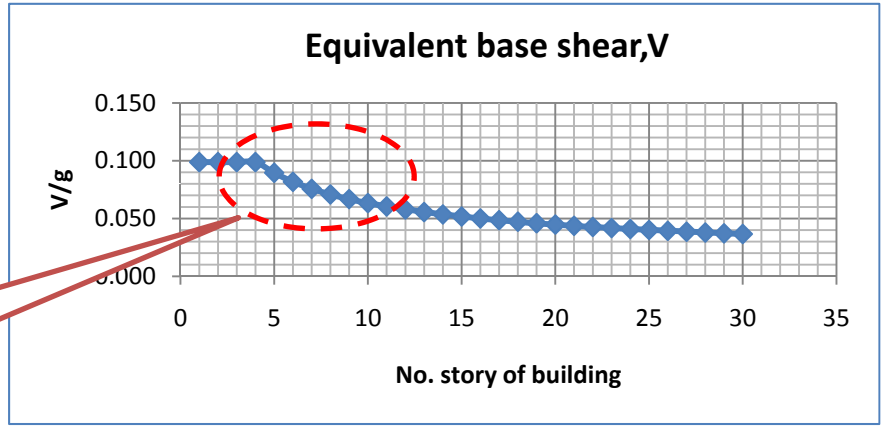
Example for Soft BKK and regular building

V=ZIKCSW

When

Z = 0.38 ; BKK on Zone 2
I = 1.0 ; residence building
K = 1.0 ; limit ductility
C = vary on nature period
S = 2.5 ; Soft clay layer
W = weight of building





The maximum equivalent base shear calculation from equation occurs when the building has 5 -10 stories

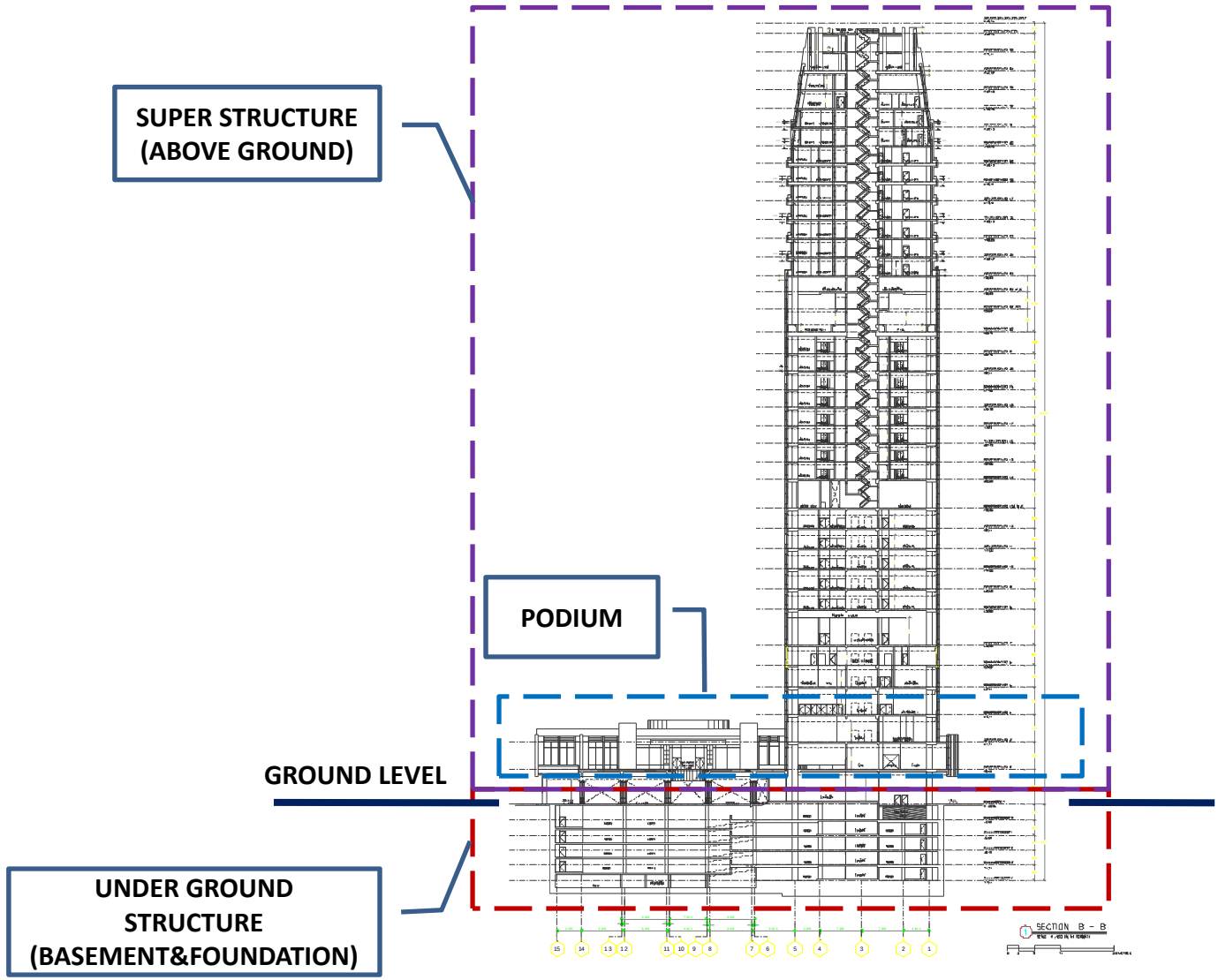
Effect of under ground structure due to earthquake wave

- Under ground structure of building
  - Basement
  - Deep foundation
  - Connection joint of Basement with pile
- Structure of Tunnel and station
  - Segment of structure in cross section
  - Segment of structure in longitudinal section
  - Connection joint of station with tunnel
- Other structure
  - Pipe line

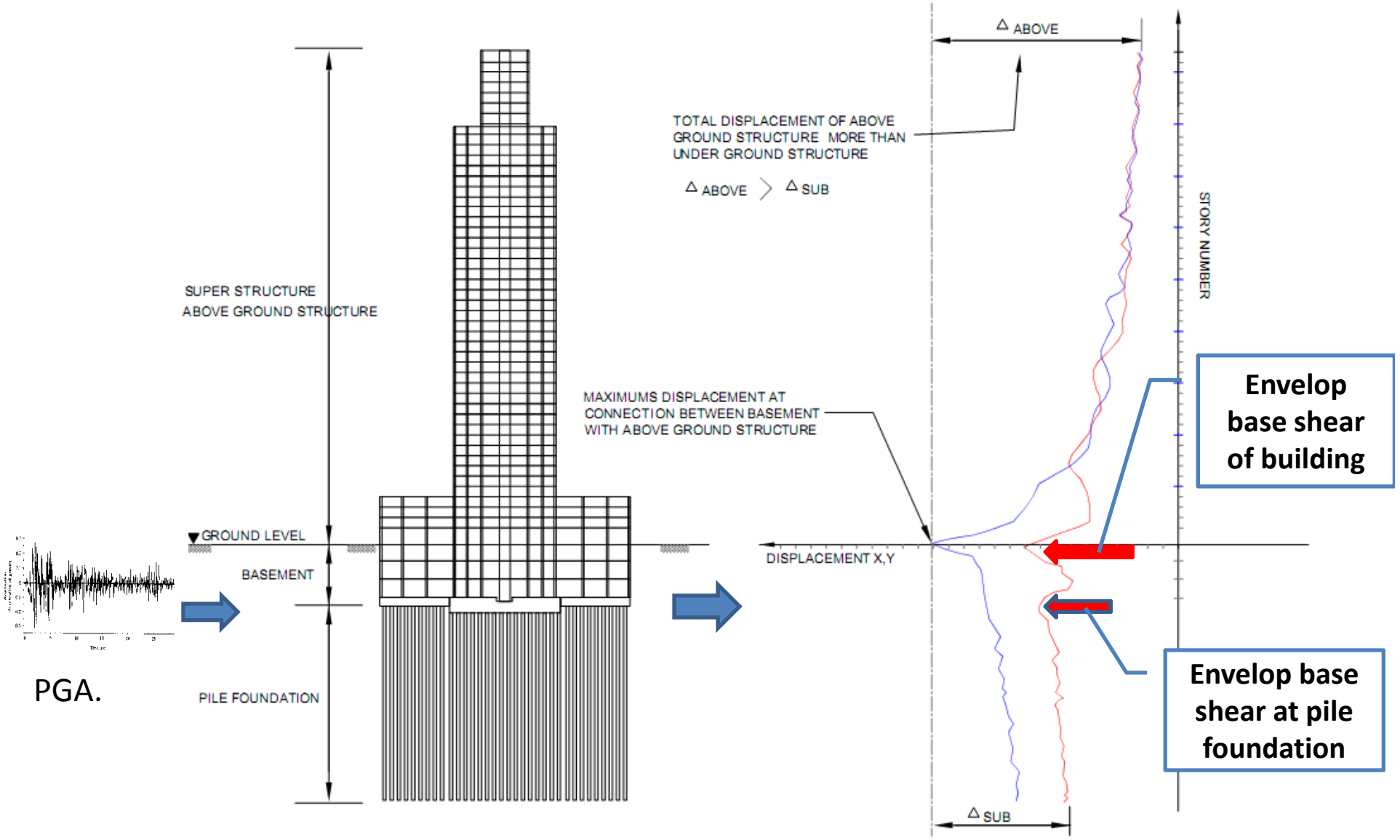
Under ground structure of building

- Basement
  - The soil around confine basement structure
  - Total displacement less than above ground structure
- Deep foundation(Pile)
  - The soil around confine pile structure
  - Total displacement less than basement structure
- Connection joint of Basement with pile
  - Determinate shear at joint connection

Under ground structure of building

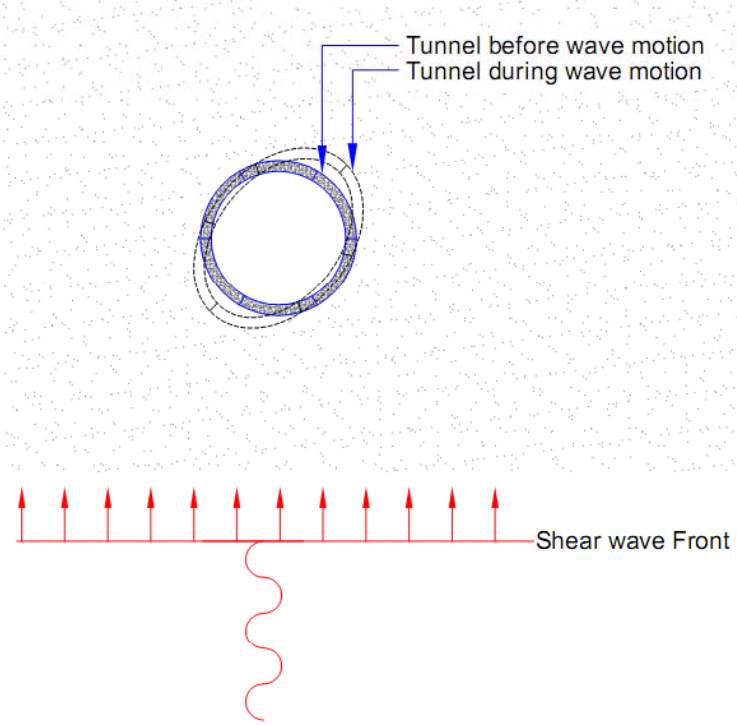


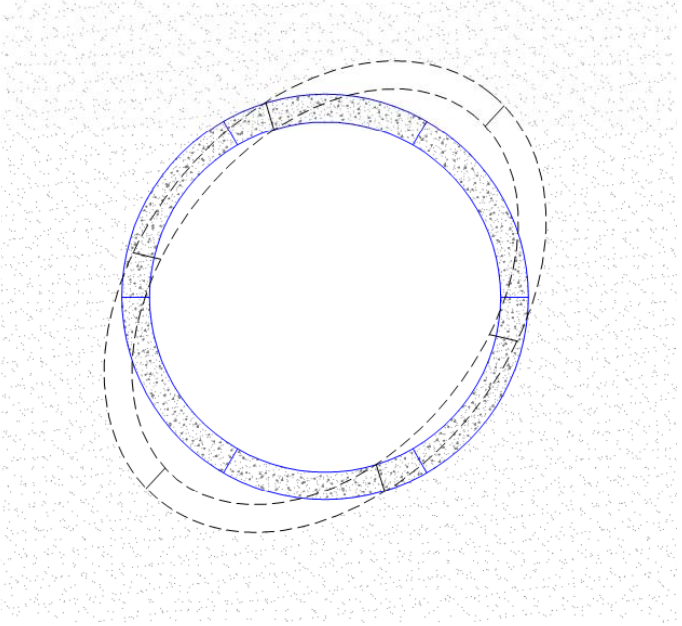
Example responding of building under Earthquake



Effect of Tunnel due to earthquake wave

- Segment of structure in cross section.
  - Ovaling and Racking deformation

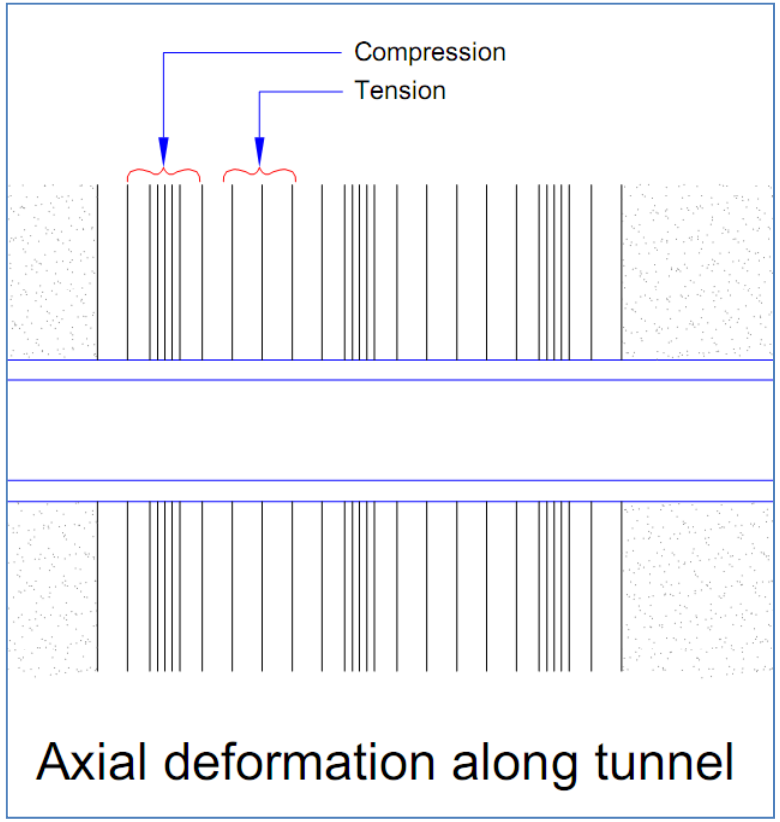




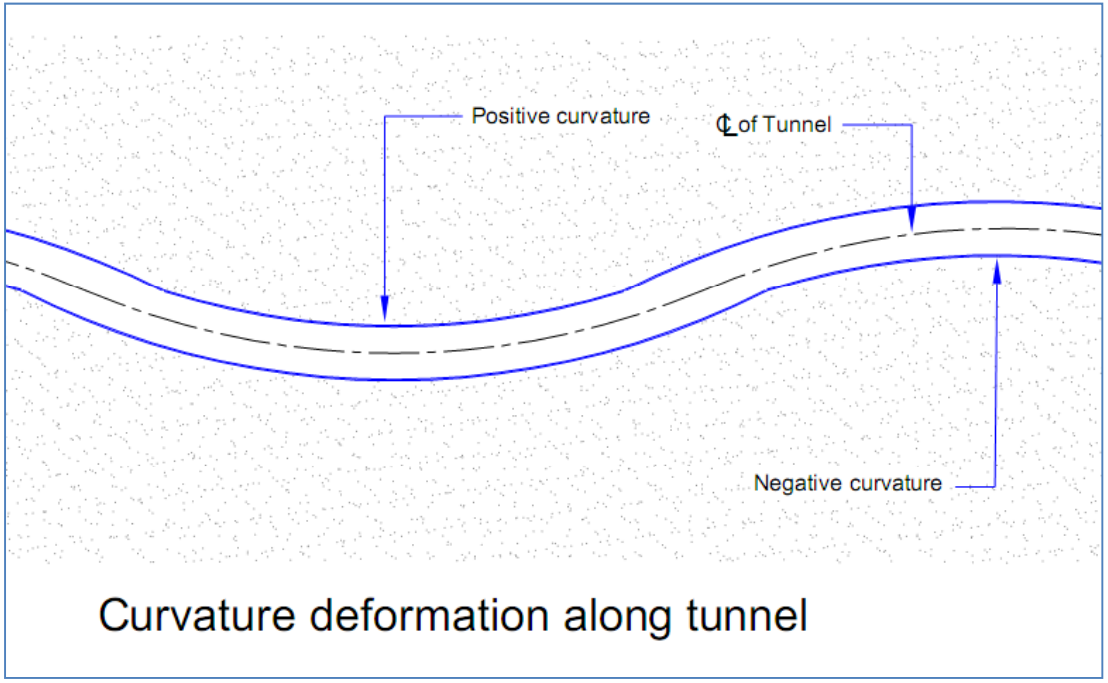
Ovaling deformation of a circular cross section

Tunnel

- Segment of structure in longitudinal section
  - Axial and Curvature deformation



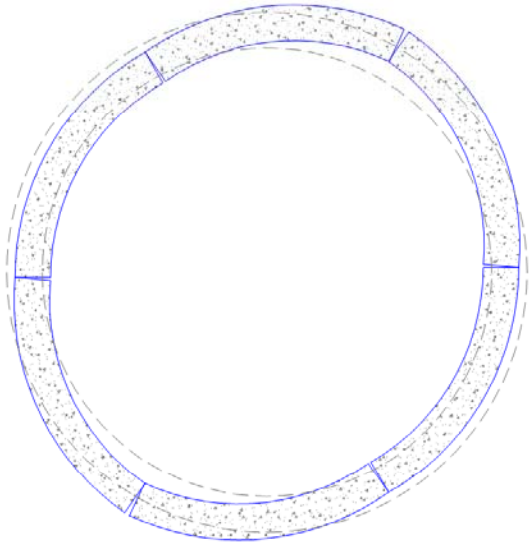
Axial deformation along tunnel

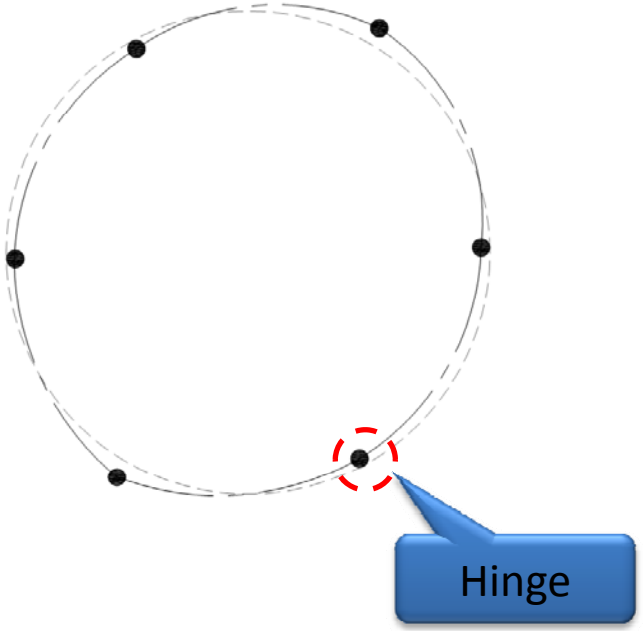


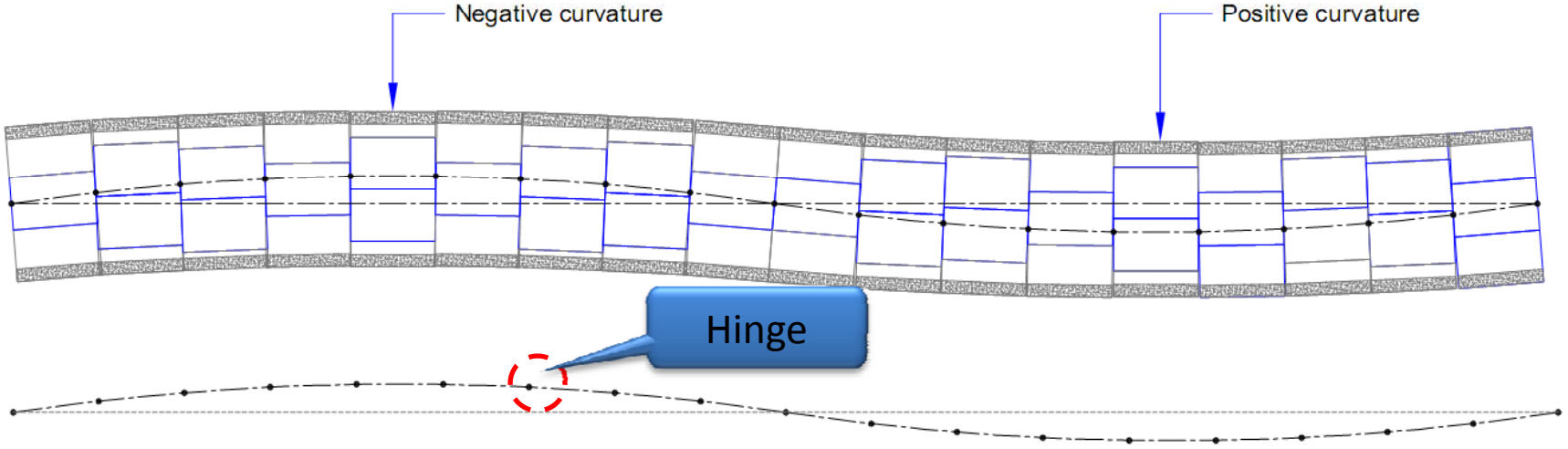
Curvature deformation along tunnel

Tunnel Design

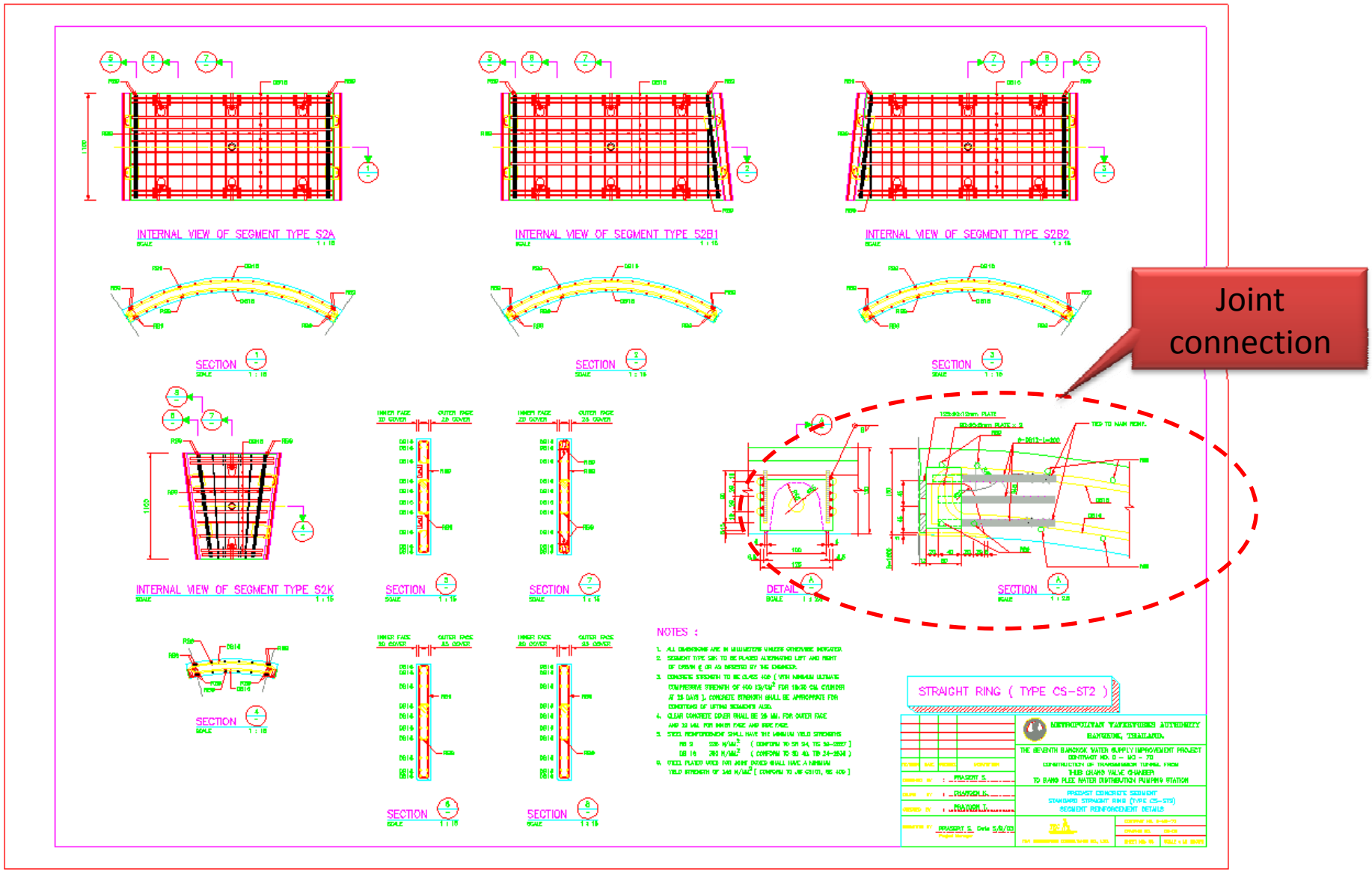
The behavior at segment joint become hinge under earthquake wave and increase the ductile behavior of overall structure







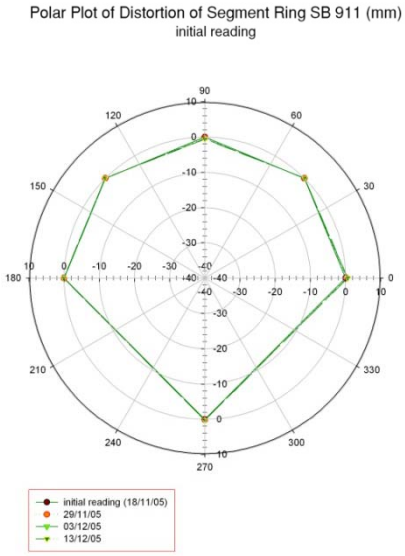
RC Segment design



Joint connection

RC Segment

Tunnel of MRT

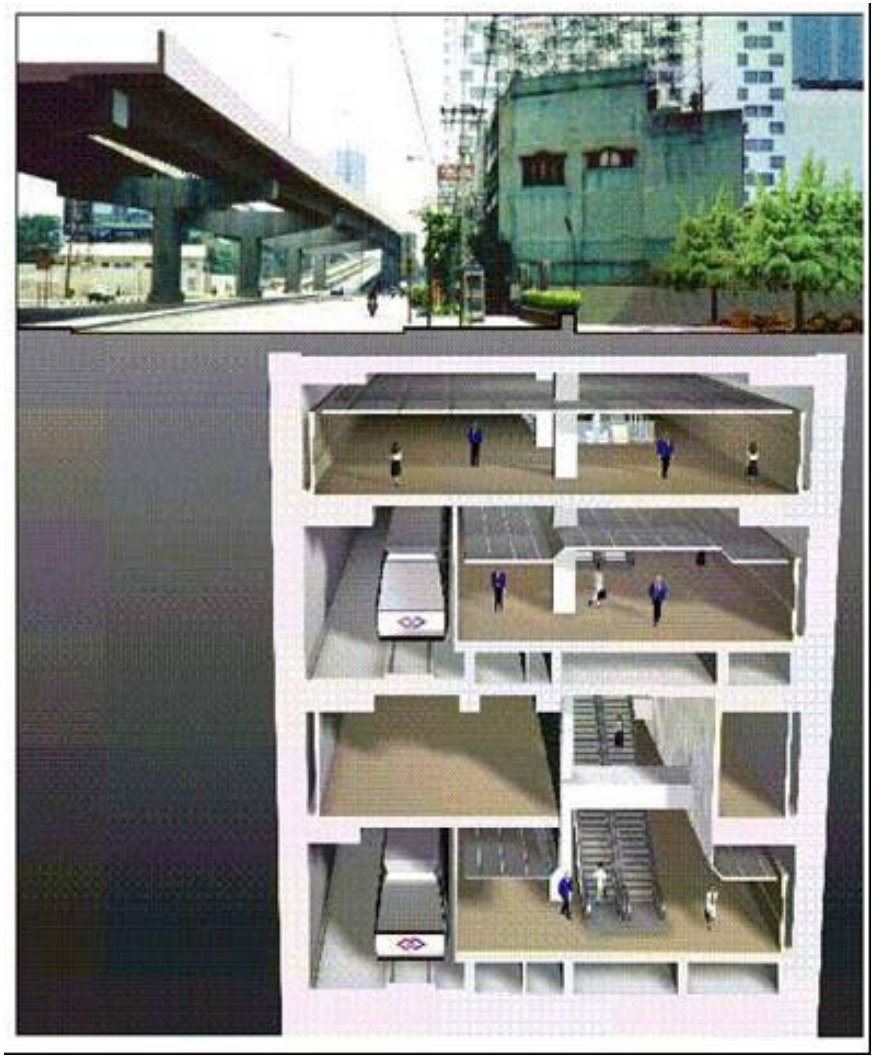


Pile Wall,Excellent Medical Center, Siriraj Hospital

Head Office, Bank of Thailand

MRT Underground station

Horizontal Dual Tunnel



Vertical Stack Tunnel

Siam Paragon

Center of art gallery, BMA

Summary

Underground structure such as basement, subway station and tunnel are safe during and after earthquake