

Underground Structures Under Earthquake Loading

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Outline

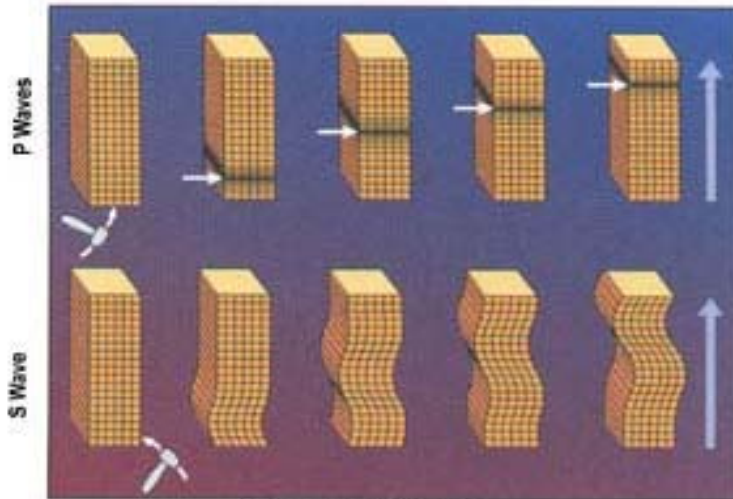
- Earthquake wave characteristics.
- Site condition of Bangkok soil layer
- The respond of site condition due to Earthquake wave.(Site effect)
- Building and Tunnel design code(Thailand,2007)
- Effect of under ground structure due to earthquake wave
- Summary

Earthquake wave characteristics

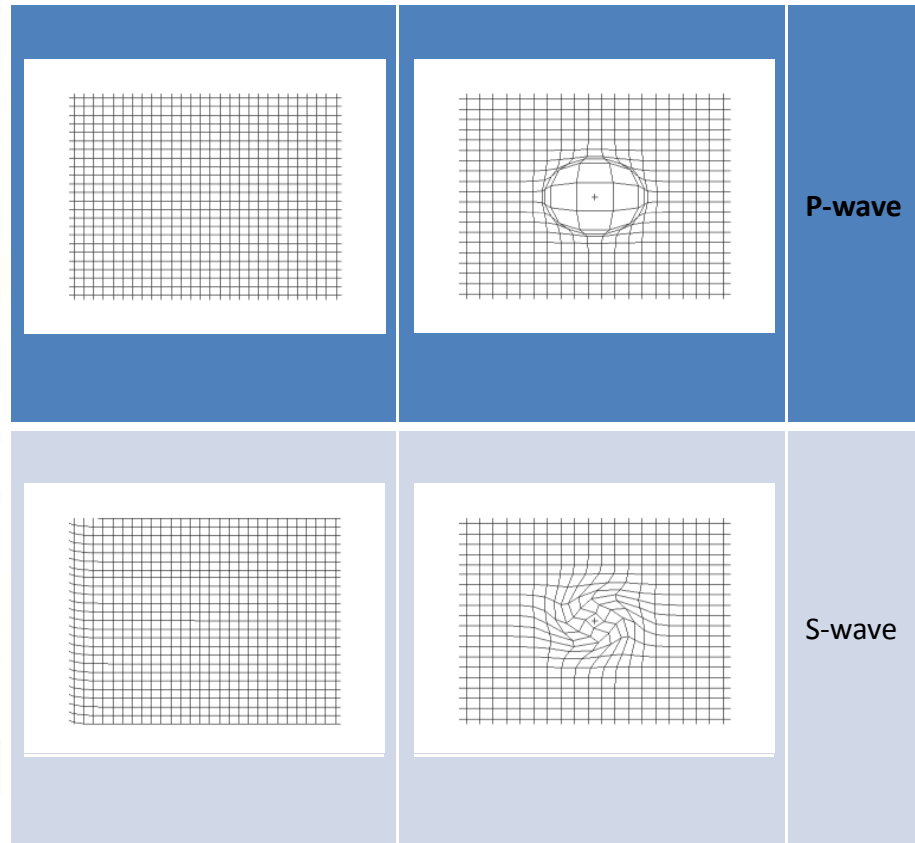
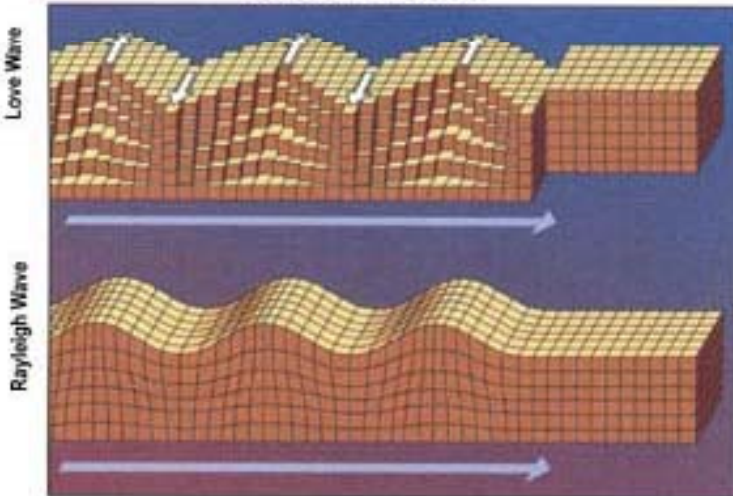
- Body wave
 - 1) P-wave : Primary waves , longitudinal waves or Compression waves
 - 2) S-wave : Shear or secondary waves, transverse waves
- Surface wave
 - 1) Rayleigh wave : ground roll
 - 2) Love wave : circular shearing of the ground

Earthquake wave characteristics

Body Waves



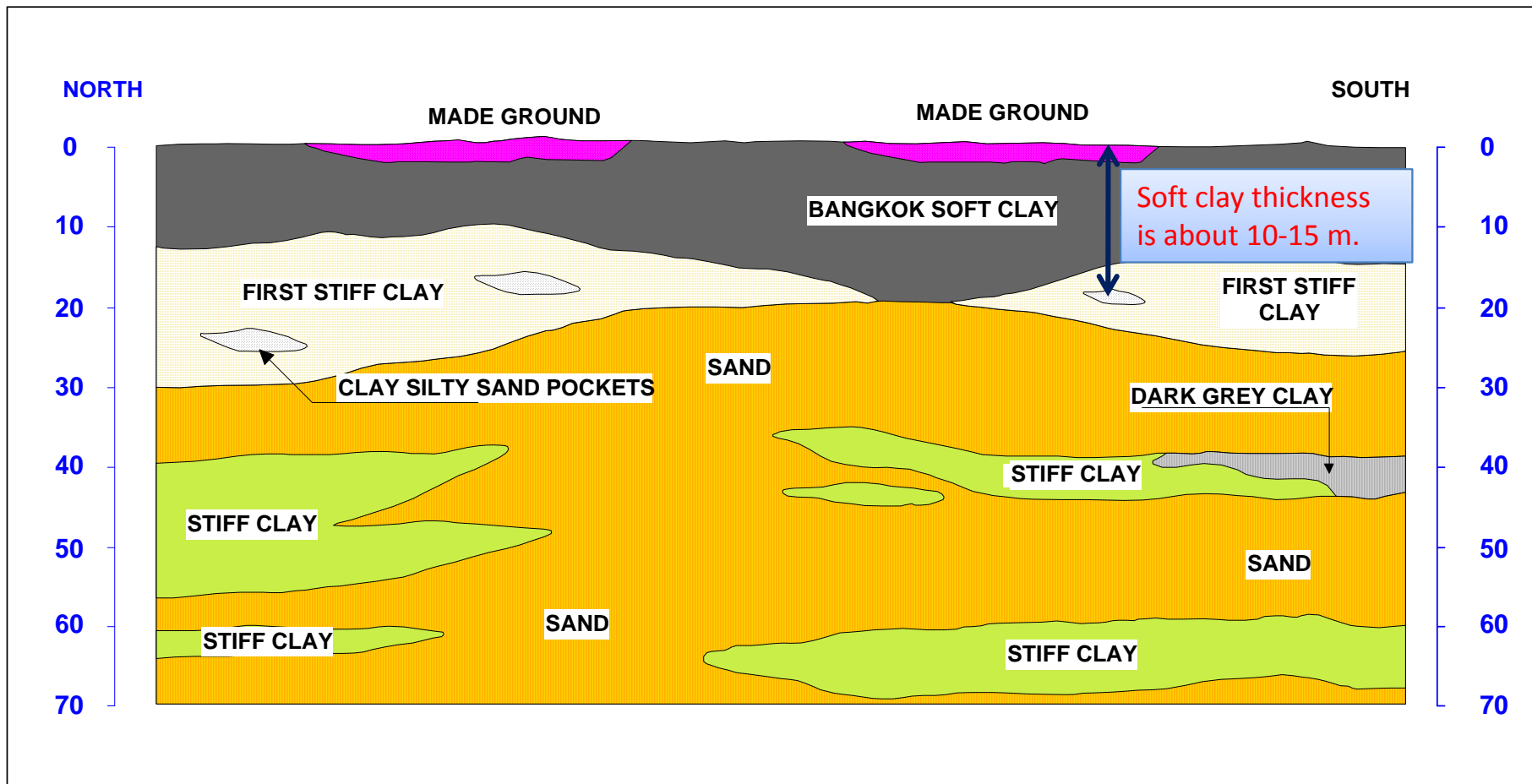
Surface Waves



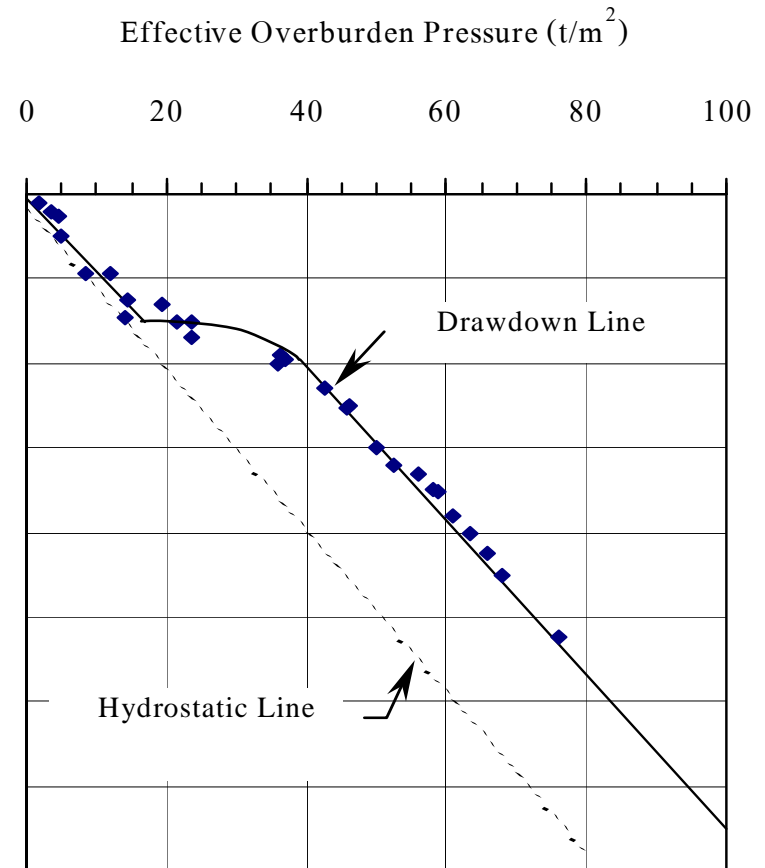
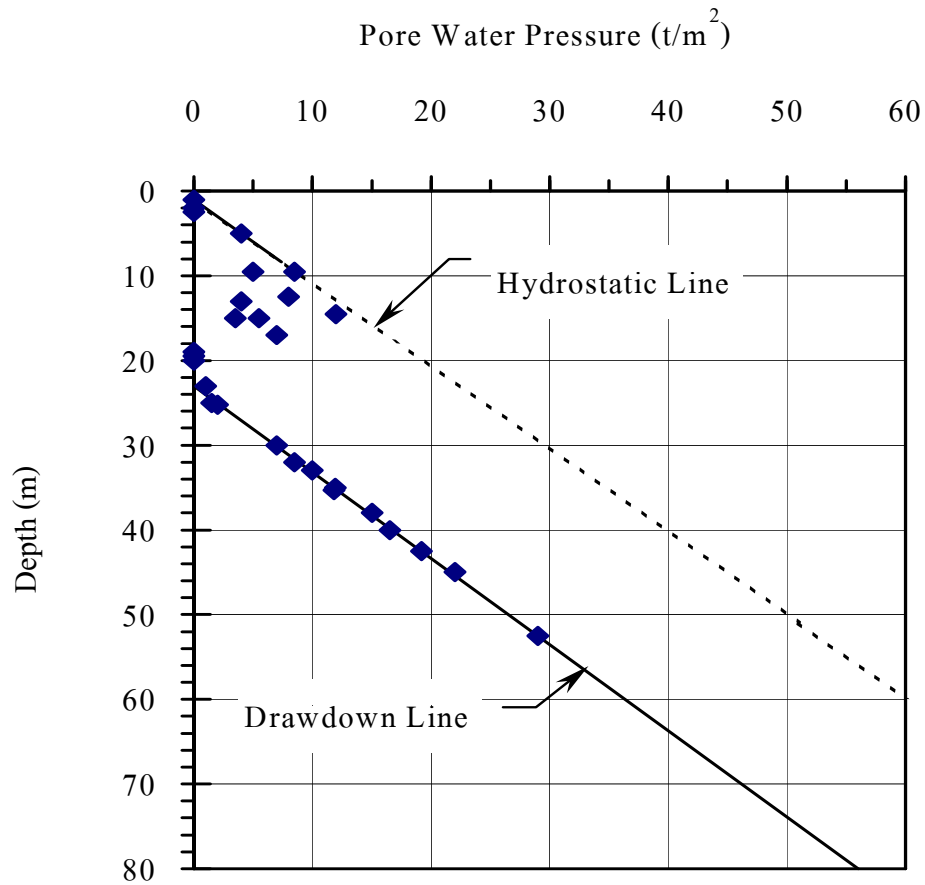
Site condition of Bangkok soil layer

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

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

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

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

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

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

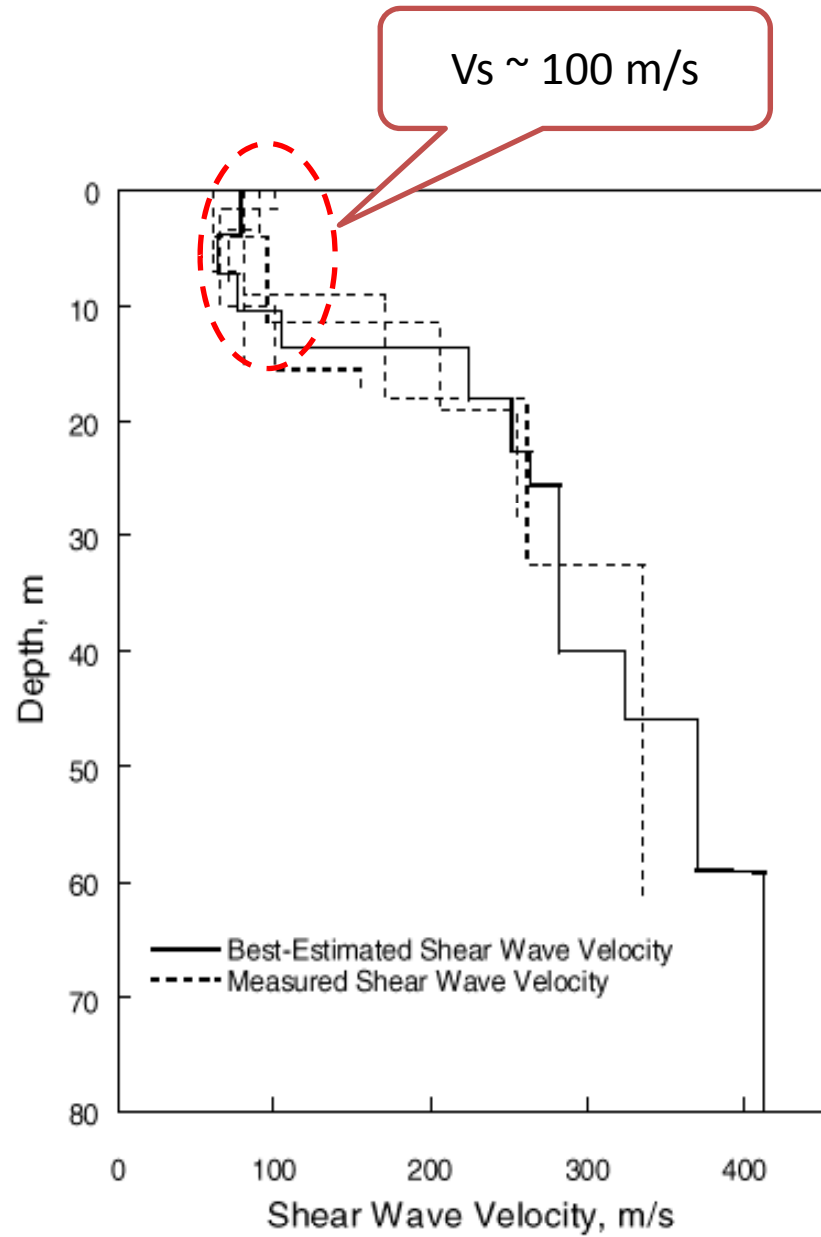
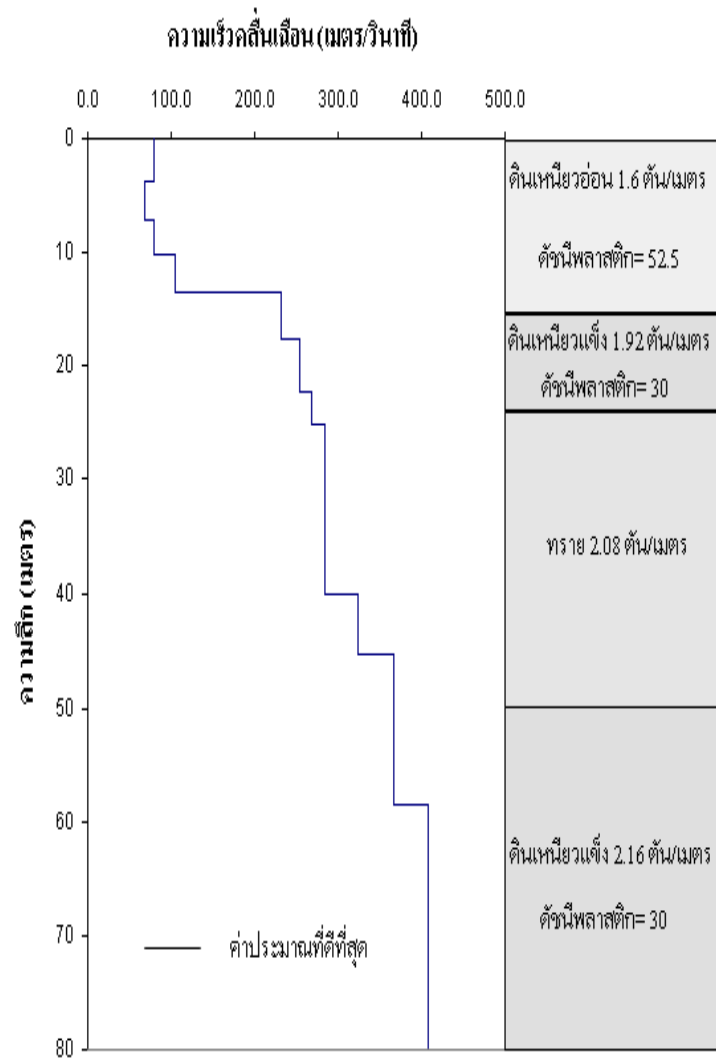


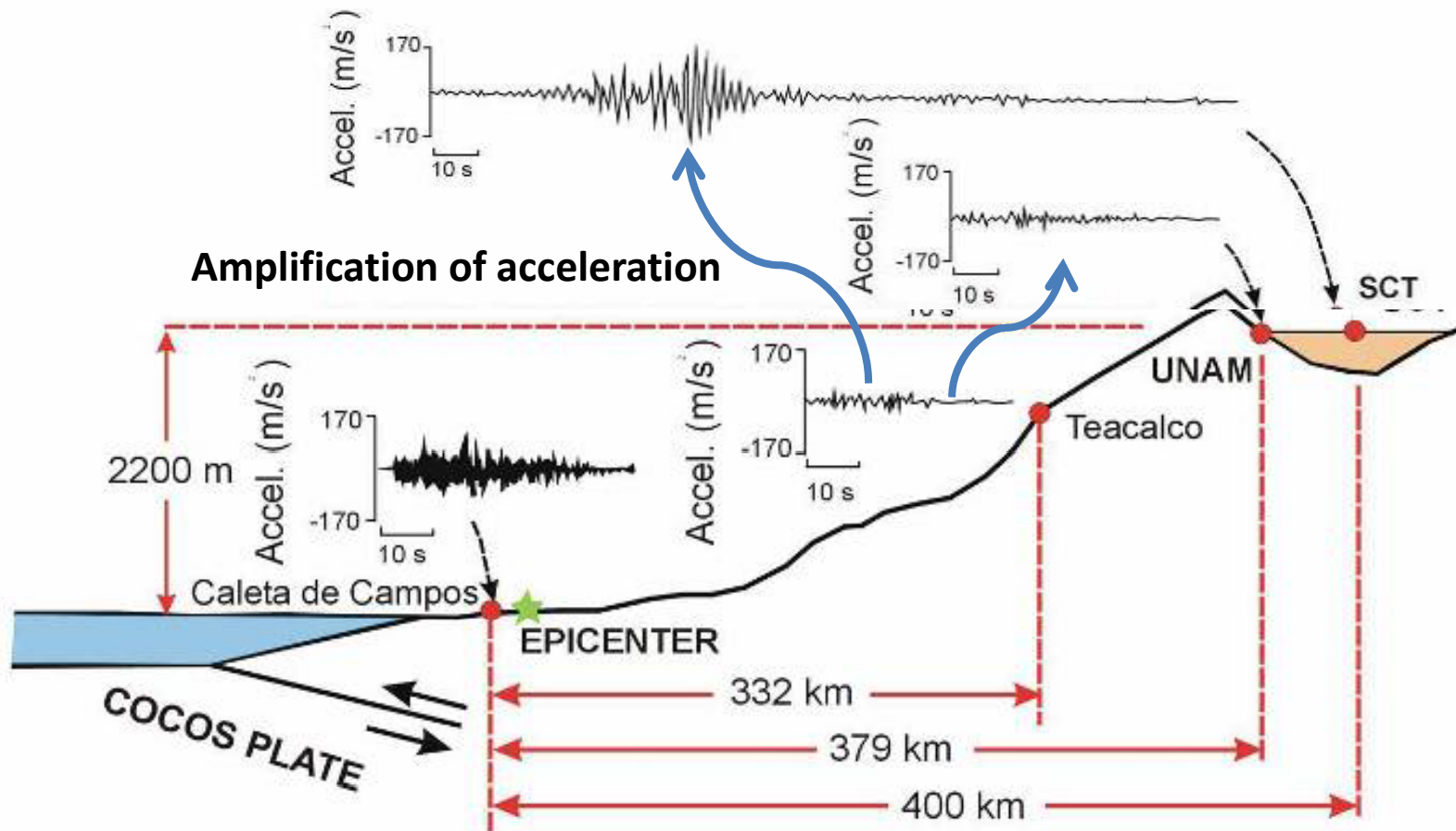
Figure 1: Comparison of measured shear wave velocity profile to best-estimate profile for Bangkok based on empirical correlations.

The response of site condition due to Earthquake wave

- Peak rock-like acceleration
- Amplification factor, A_m
- Predominant period, T_d
- Design response spectrum

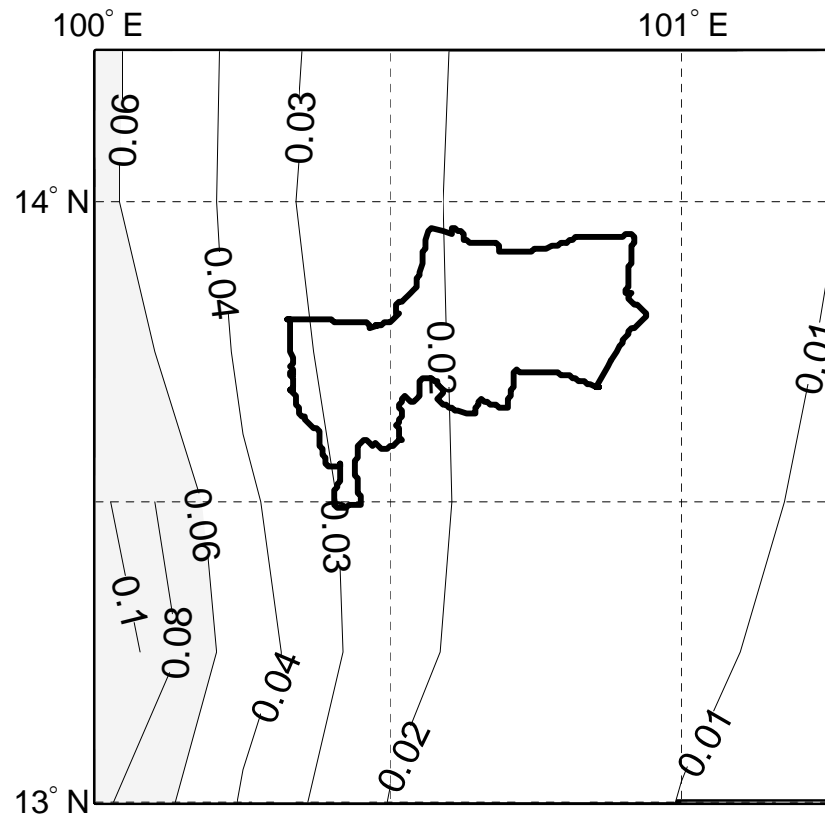
Example Site effect of Mexico city

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

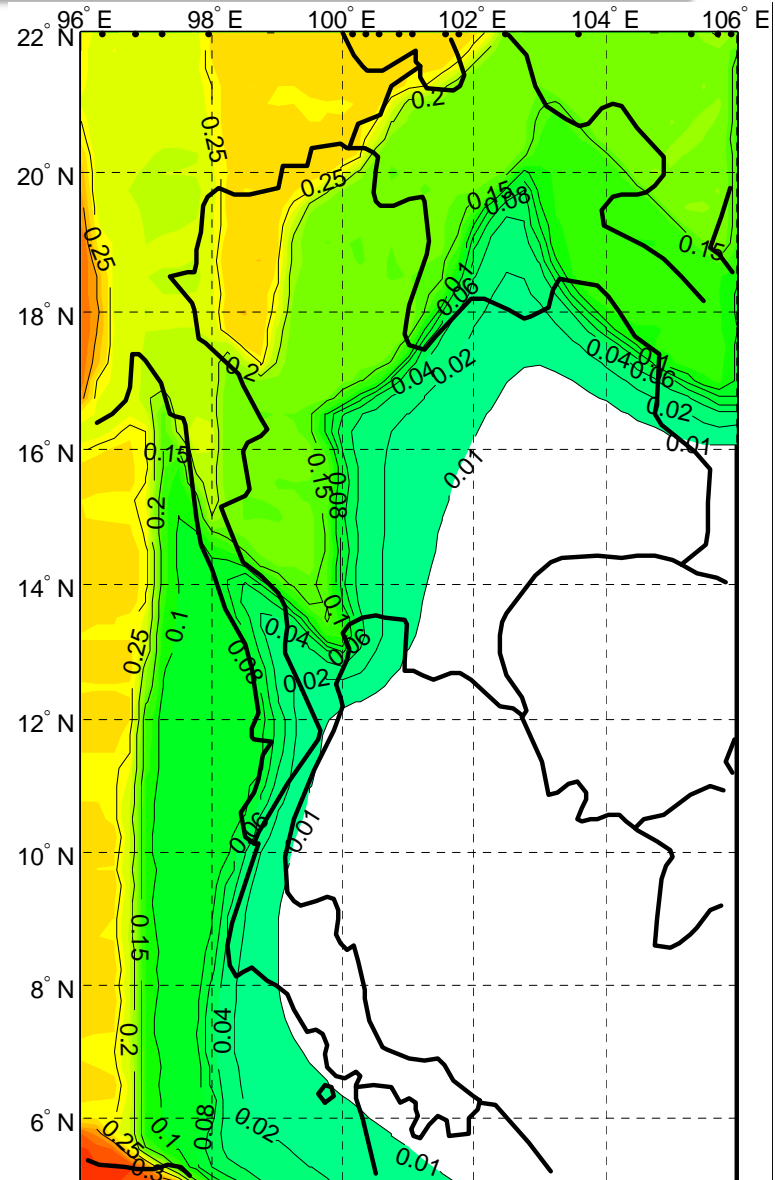


Peak rock-like acceleration

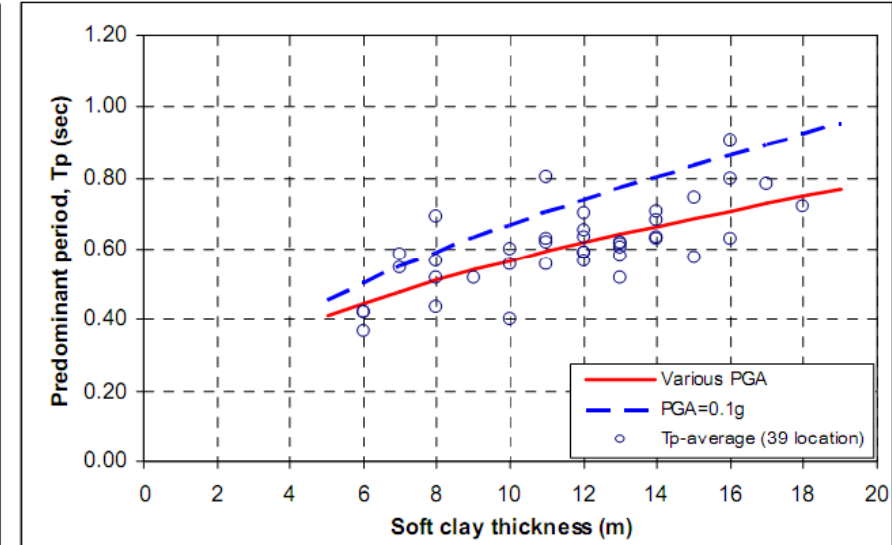
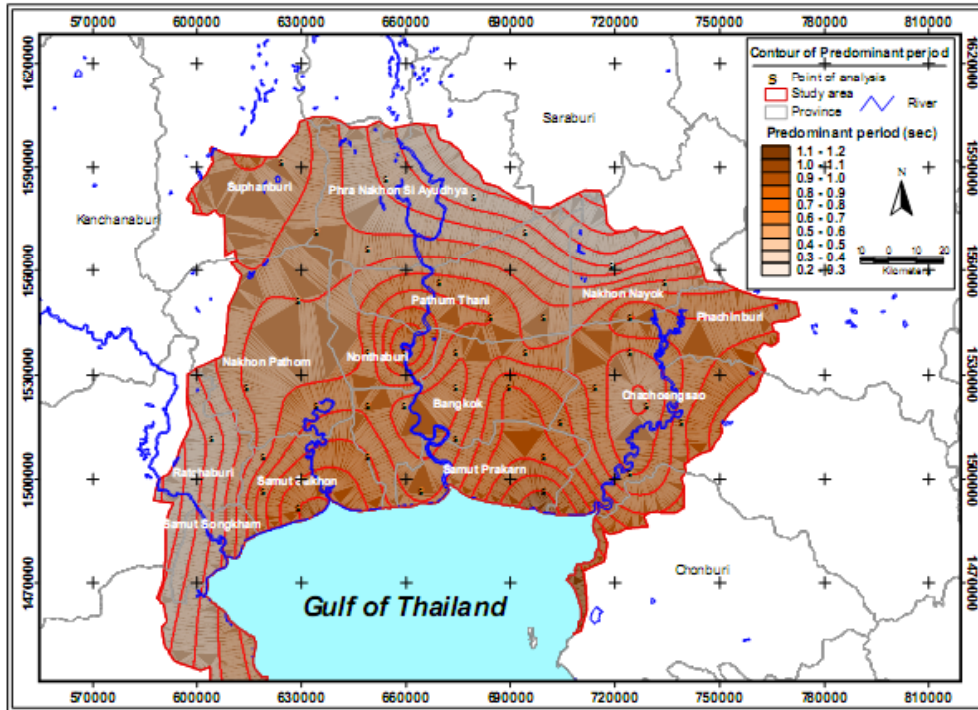
PHA Map for 10% probability of exceedance in 50 years



Maximum ~ 0.03g



Predominant period, Td

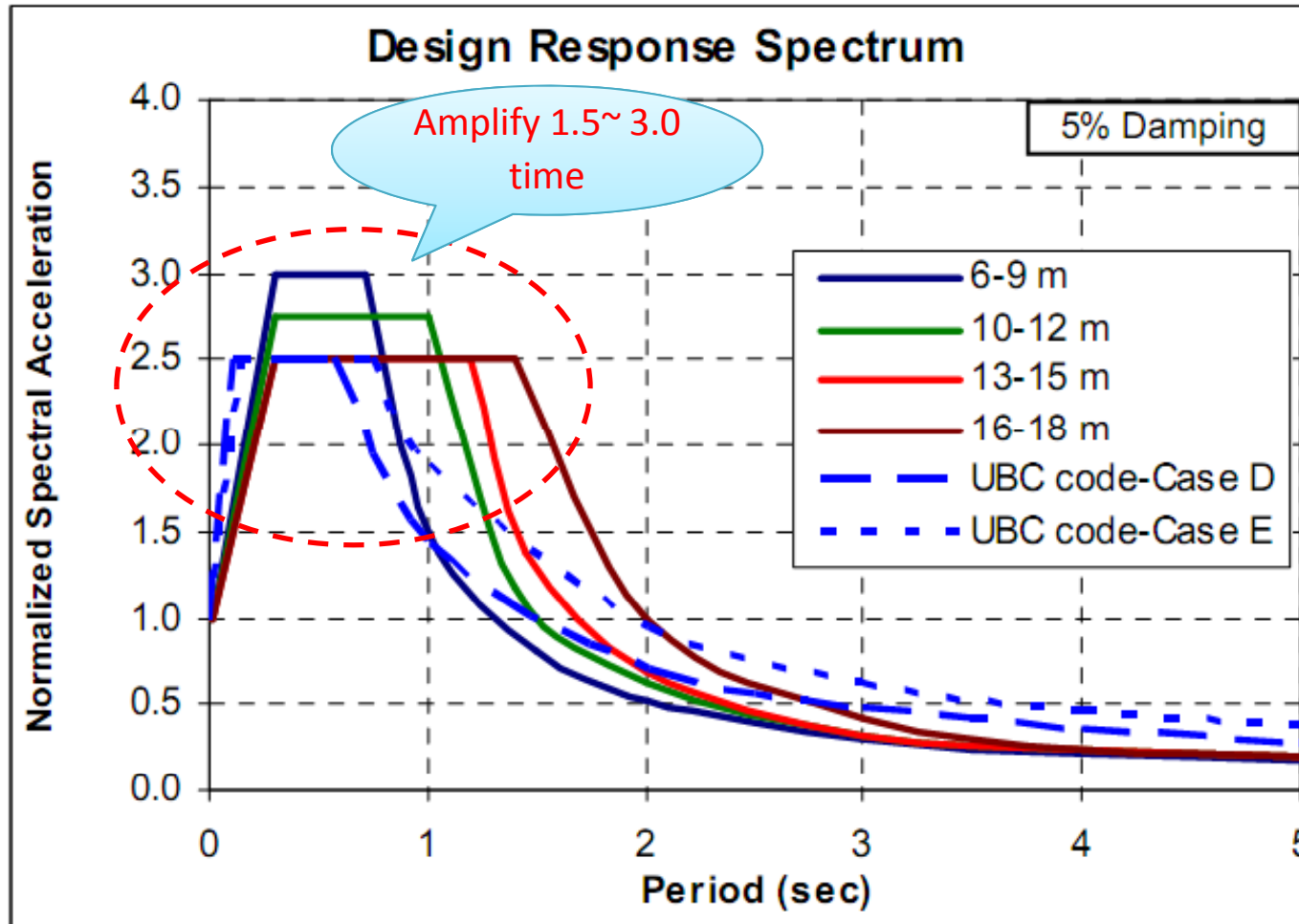


The variation of Predominant period with Thickness of soft clay layer (varied from 0-20m.)

Predominant period of soft clay soil layer

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; มยพ.1301-50

**Use for above ground structure
and regularity**

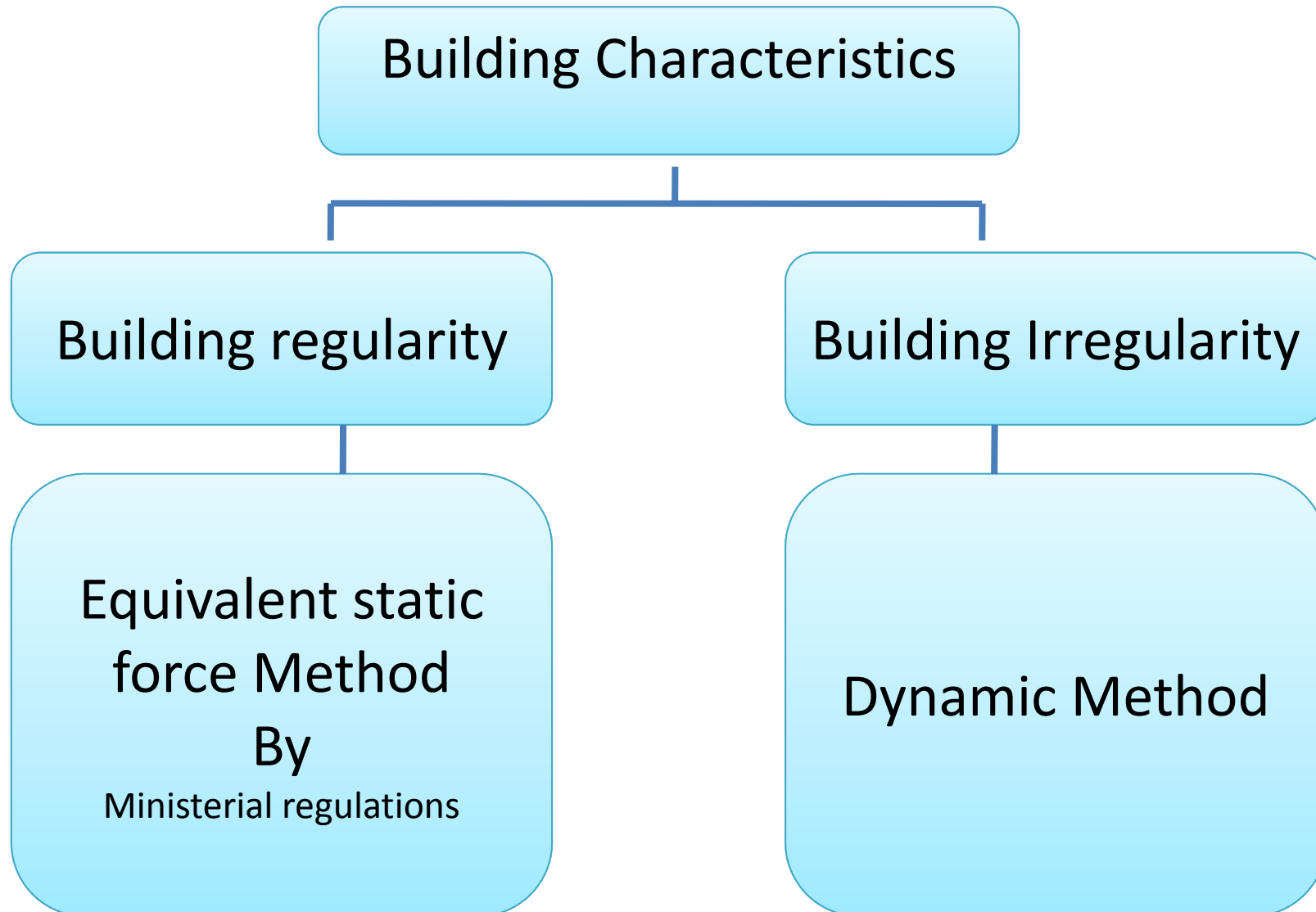
Addition of control area

- 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: $V = ma$

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

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

Seismic Zone Coefficient

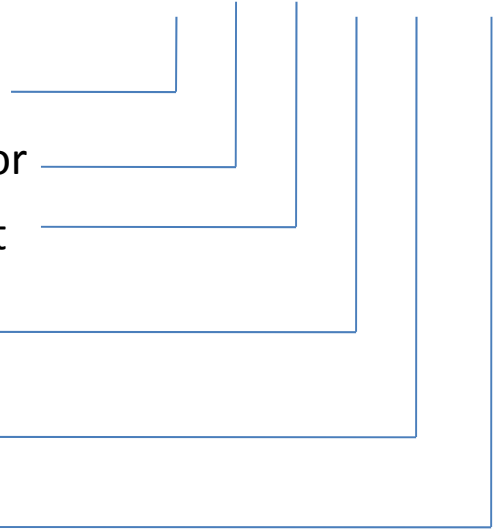
Occupancy Importance Factor

Structural System Coefficient

Nature period of building
Coefficient

Soil profile Coefficient

Weight of building



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

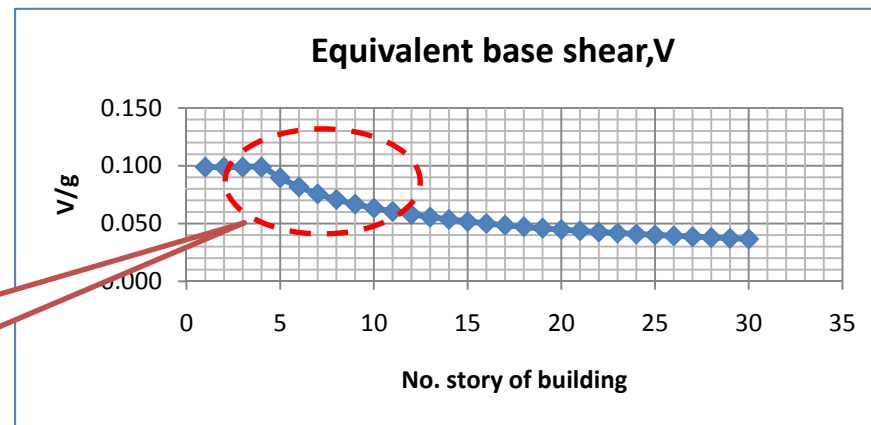
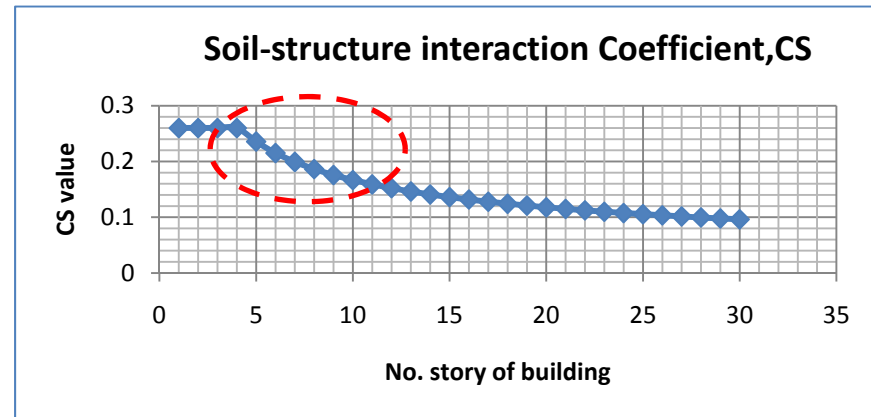
- Nature period of building Coefficient, C
- Soil profile Coefficient, S
- Code use - $C*S = 0.14$ when $C*S < 0.14$
 - $C*S = 0.26$ when $C*S > 0.26$ (Soft soil)

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

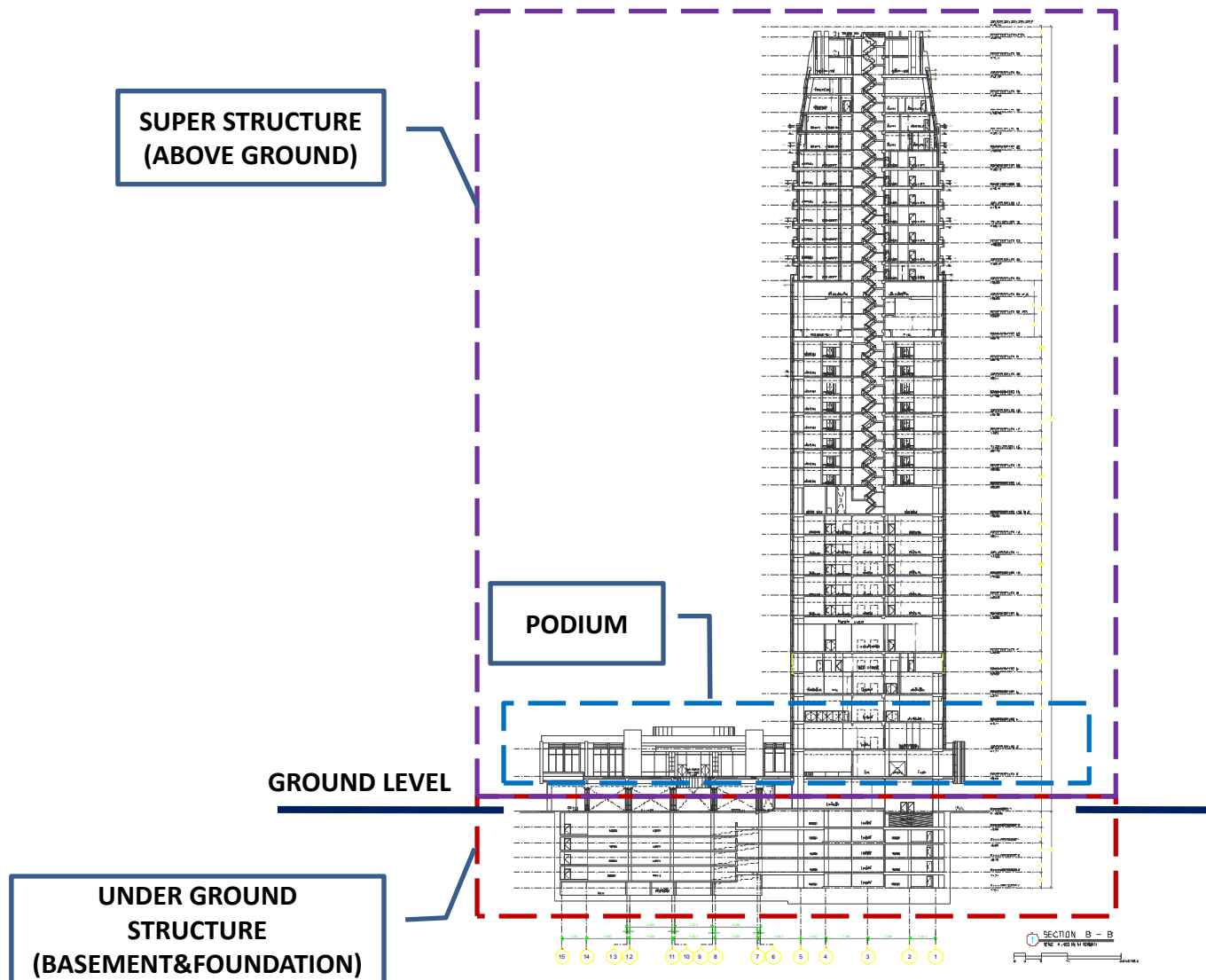
Effect of under ground structure due to earthquake wave

- 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

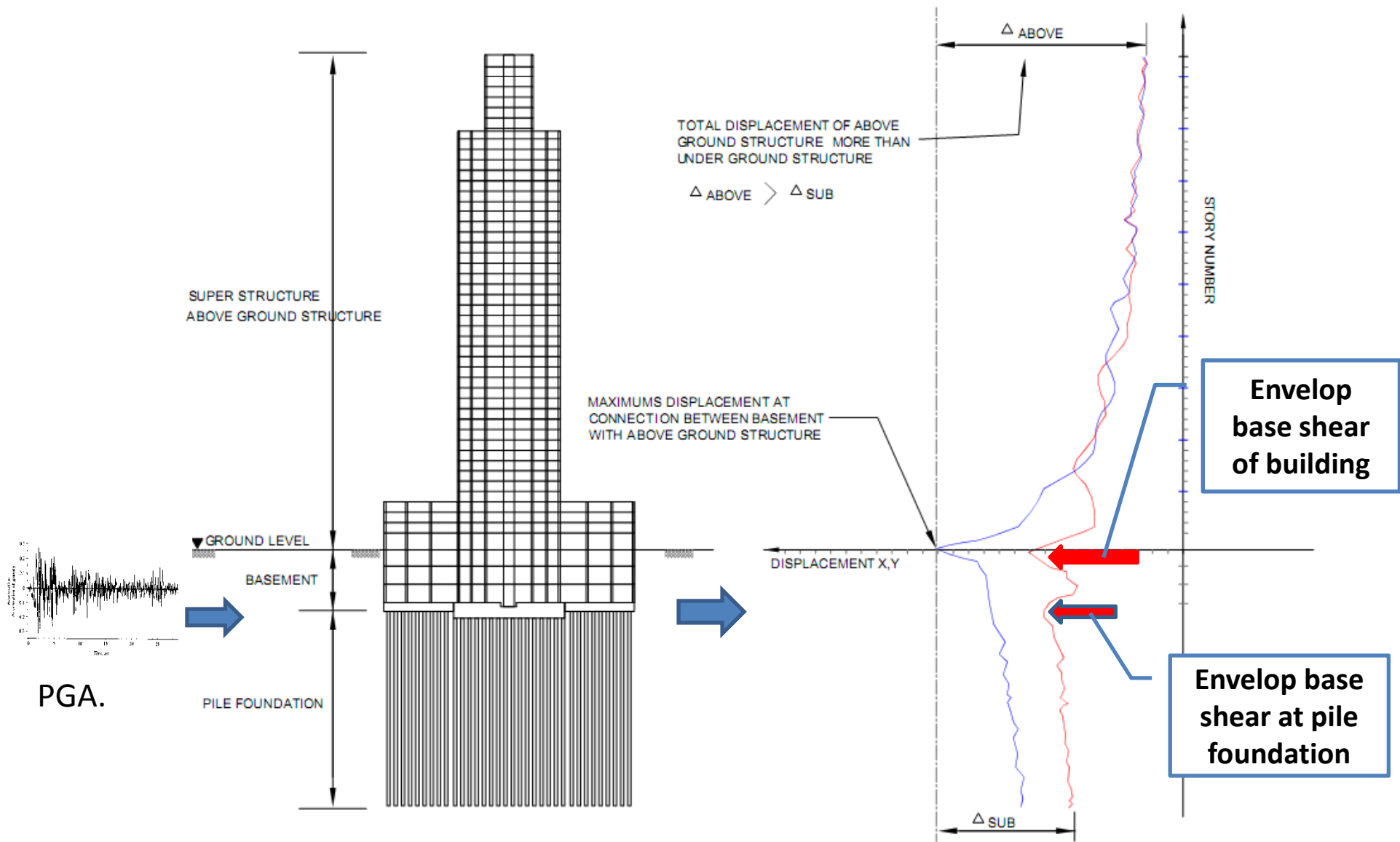
Under ground structure of building

- 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

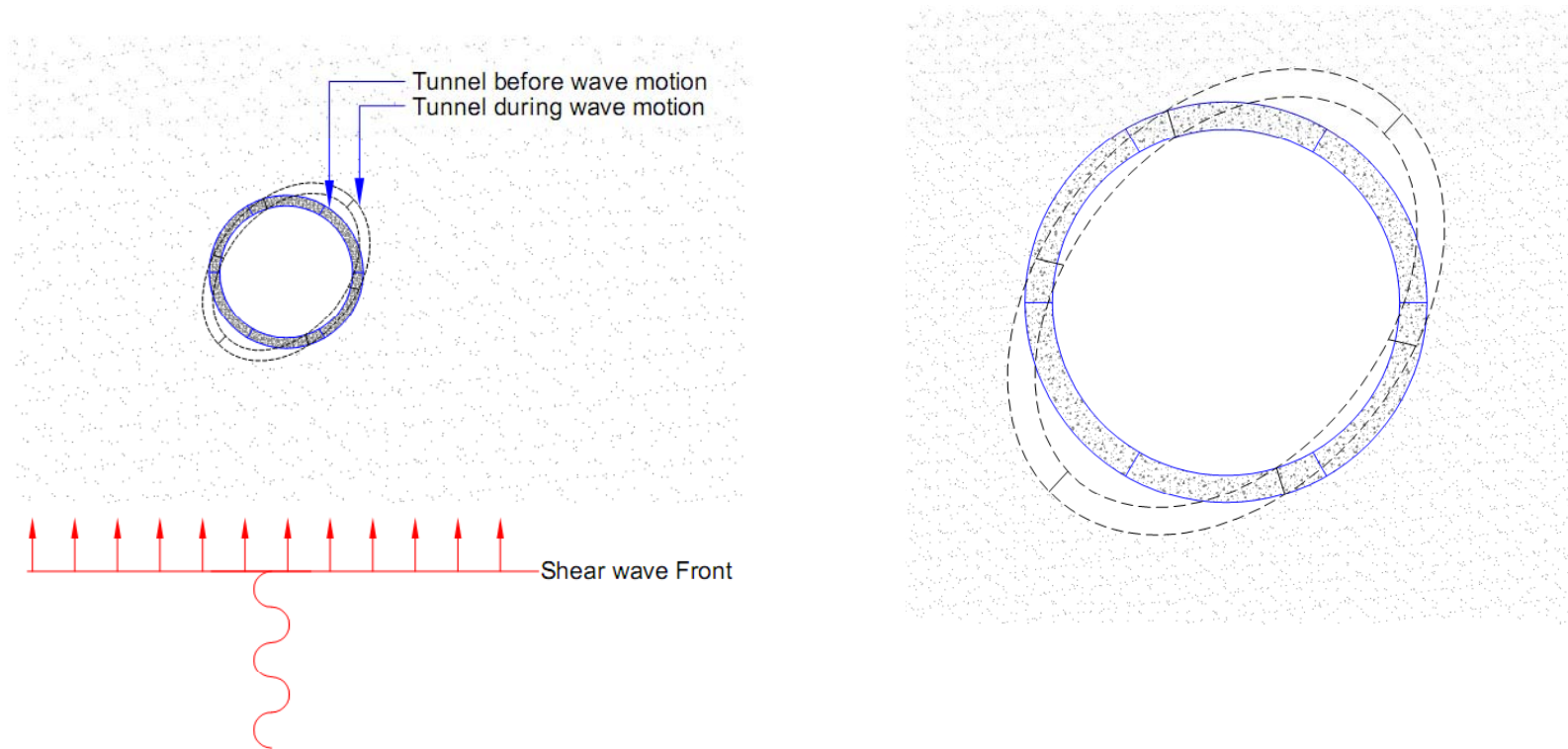


Example responding of building under Earthquake



Effect of Tunnel due to earthquake wave

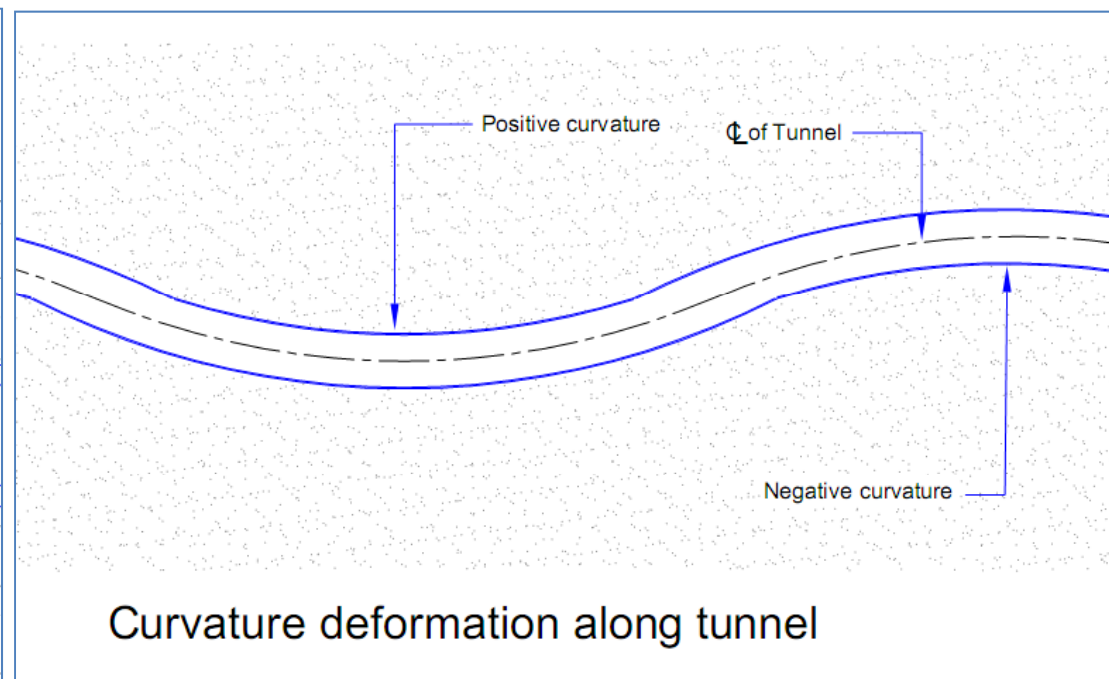
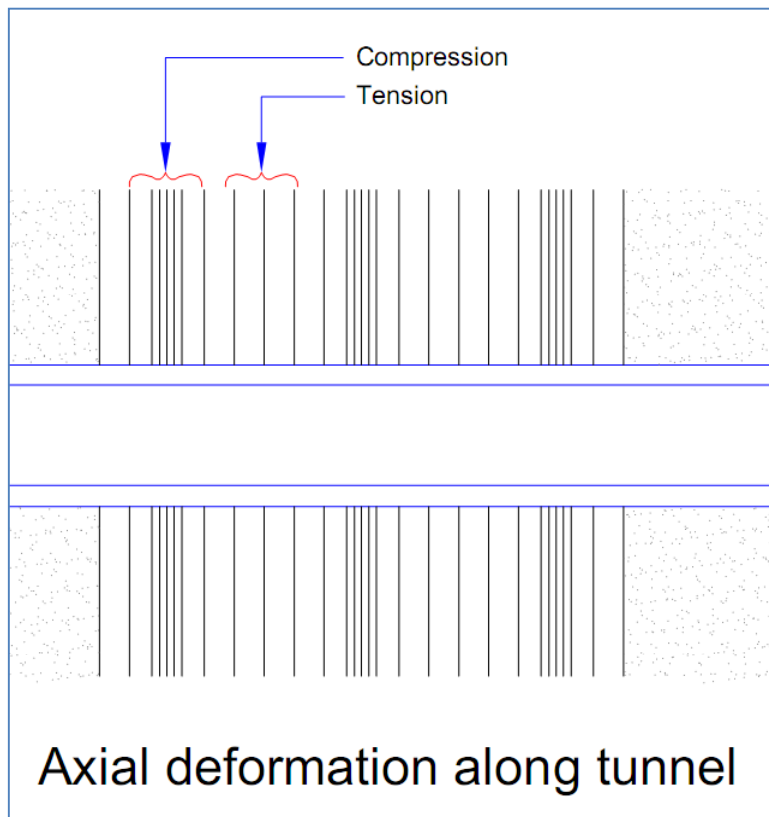
- Segment of structure in cross section.
 - Ovaling and Racking deformation



Ovaling deformation of a circular cross section

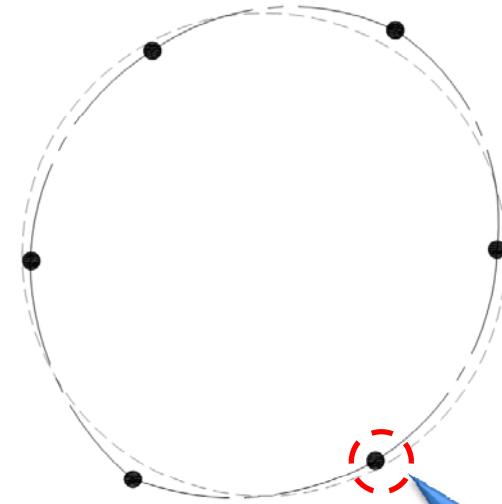
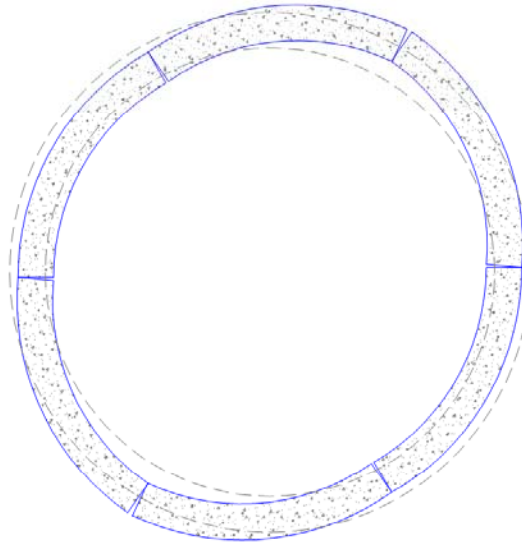
Tunnel

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

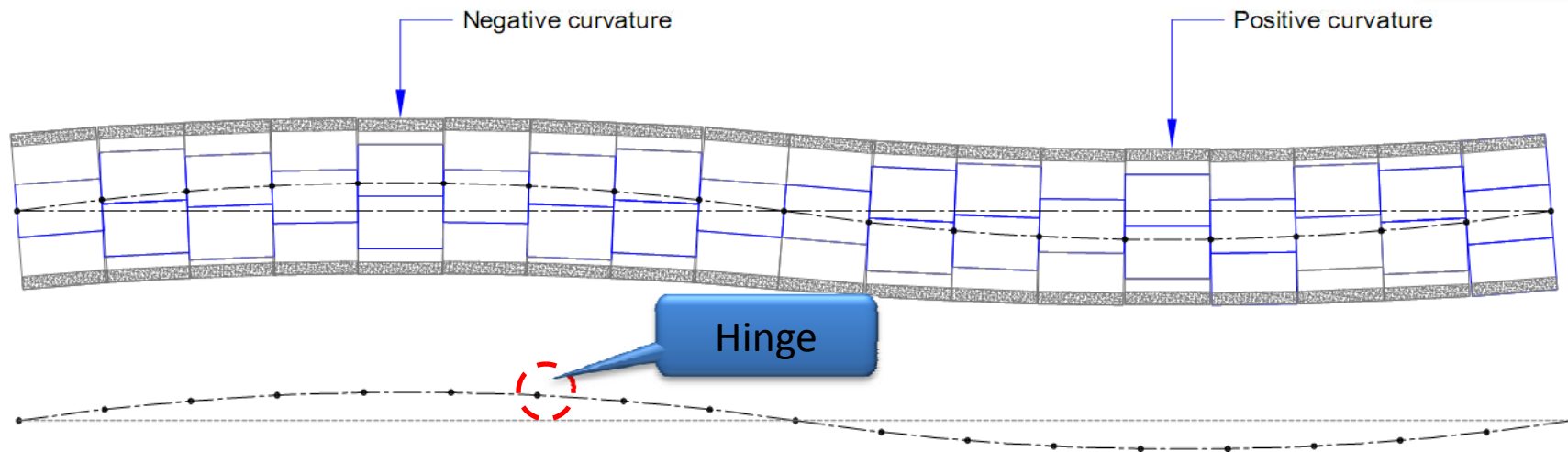


Tunnel Design

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

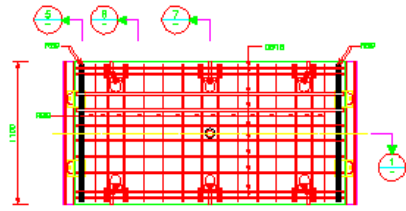


Hinge

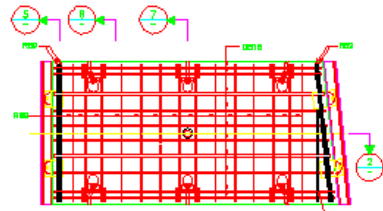


Hinge

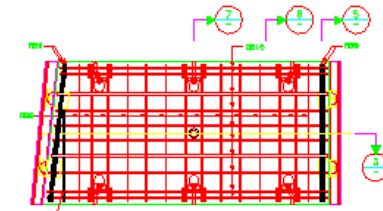
RC Segment design



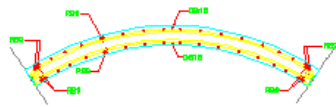
INTERNAL VIEW OF SEGMENT TYPE S2A
SCALE 1:10



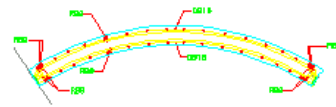
INTERNAL VIEW OF SEGMENT TYPE S2B1
SCALE 1:10



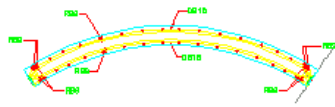
INTERNAL VIEW OF SEGMENT TYPE S2B2
SCALE 1:10



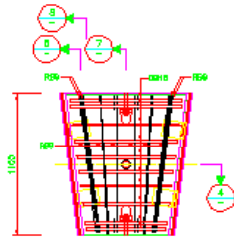
SECTION 1-1
SCALE 1:10



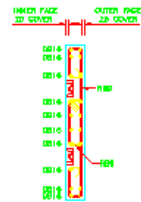
SECTION 2-2
SCALE 1:10



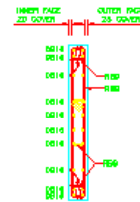
SECTION 3-3
SCALE 1:10



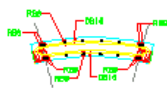
INTERNAL VIEW OF SEGMENT TYPE S2K
SCALE 1:10



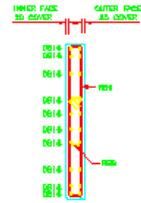
SECTION 4-4
SCALE 1:10



SECTION 5-5
SCALE 1:10



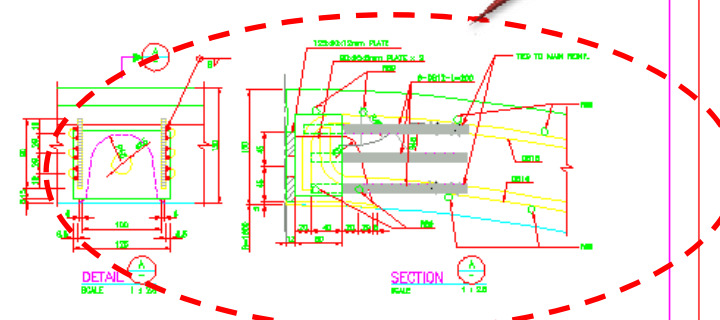
SECTION 6-6
SCALE 1:10



SECTION 7-7
SCALE 1:10



SECTION 8-8
SCALE 1:10



DETAIL A
SCALE 1:10

SECTION A-A
SCALE 1:10

Joint connection

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE INDICATED.
2. SEGMENT TYPE S2K TO BE PLACED ALTERNATING LEFT AND RIGHT OF CHAIN & IS AS INDICATED BY THE CHAINING.
3. CONCRETE STRENGTH TO BE CLASS C40 (WITH MINIMUM ULTIMATE COMPRESSIVE STRENGTH OF 400 IS/CM² FOR 18HR CAL CURING AT 28 DAYS). CONCRETE STRENGTH SHALL BE APPROPRIATE FOR CONDITIONS OF LIFTING SEGMENTS AS IS.
4. CLEAR CONCRETE COVER SHALL BE 25 MM. FOR OUTER FACE AND 20 MM FOR INNER FACE AND SIDE FACE.
5. STEEL PERFORMANCE SHALL HAVE THE MINIMUM YIELD STRENGTH
 RE S 235 N/MM² (CONFORM TO IS 94 TO IS 30-2007)
 RE 16 235 N/MM² (CONFORM TO IS 44 TO IS 34-2004)
6. STEEL PLATED WELDED JOINT ENDS SHALL HAVE A MINIMUM YIELD STRENGTH OF 345 N/MM² (CONFORM TO IS 10101, IS 400)

STRAIGHT RING (TYPE CS-ST2)

DESIGNED BY	PROJECT S
CHECKED BY	PROJECT S
APPROVED BY	PROJECT S
DATE	5/8/20

MUNICIPALITY TANKS/STATION AUTHORITY,
 BANGKOK, THAILAND.
 THE SEVENTH BANGKOK WATER SUPPLY IMPROVEMENT PROJECT
 CONTRACT NO. B - M3 - 70
 CONTRIBUTION OF TRANSPARENT TAPERS FROM
 B&B CHAIN VALVE CHAMBER
 TO RAW PLEE WATER DISTRIBUTION PUMPING STATION
 PROJECT CONCRETE SEGMENT
 STRAIGHT RING (TYPE CS-ST2)
 SEGMENT REINFORCEMENT DETAILS

CONTRACT NO. B-10-70
CHANGING NO. CS-03
REVISION NO. 01
DATE 4/18/20

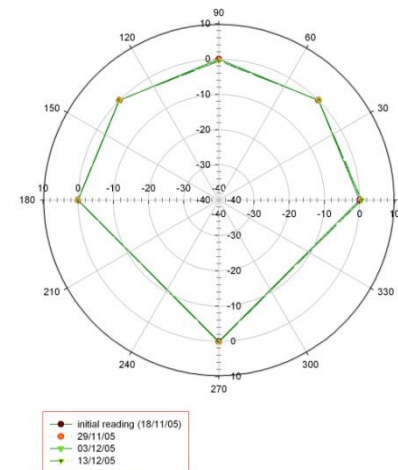
RC Segment



Tunnel of MRT



Polar Plot of Distortion of Segment Ring SB 911 (mm)
initial reading



Pile Wall, Excellent Medical Center, Siriraj Hospital



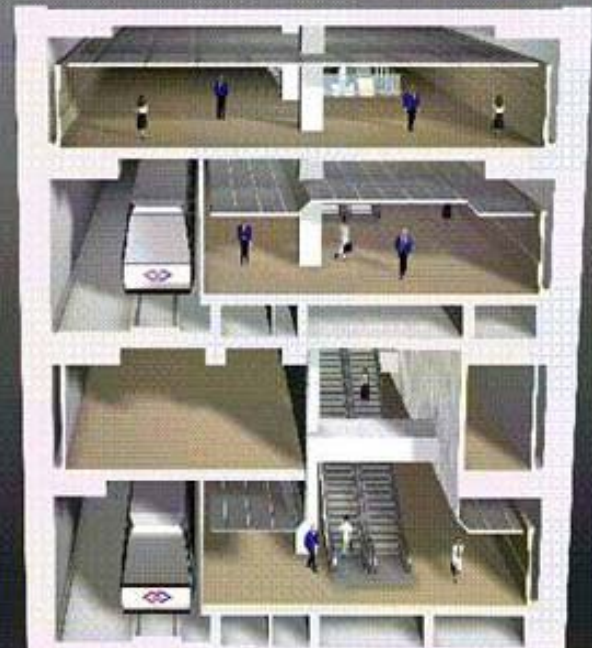
Head Office, Bank of Thailand



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