I. Outline of Seismic Design & Determination of Design Ground Motion

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1. Introduction

Development of Aseismic Design Guidelines in Korea

- ~1995 : Aseismic design was performed for some important structures such as nuclear power plants, tall buildings, bridges et al.
- 1995 : A necessity of aseismic design in Korea arose from severe damages during Kobe earthquake in Japan.
- 1996 : Earthquake Engineering Society of Korea was founded.
- 1997 : Earthquake Engineering Research Center of Korea was founded.
- 1997 : Aseismic Design Guideline in Korea (II) was prepared.
  - ⇒ Determination procedures of design earthquake motion in Korea was developed by referring to Uniform Building Code of US.
  - ⇒ Need to develop design motions suitable for Korean characteristics of earthquake and ground
- 1999 : Seismic Design Guidelines of Port and Harbor Structures in Korea was prepared.
  - ⇒ Evaluation procedures for liquefaction susceptibility
  - ⇒ Design guidelines for quay walls, foundations, earth structures and so on were prepared by referring to design guidelines of US(ASCE), Europe(Eurocode), Japan.
- 1999~ : Preparation of design guidelines of Korea National Housing Corporation, Korea Land Development Corporation and so on

2. Design Earthquake Motions

2.1 Definition of terms

① earthquake wave : amplitude, frequency, duration

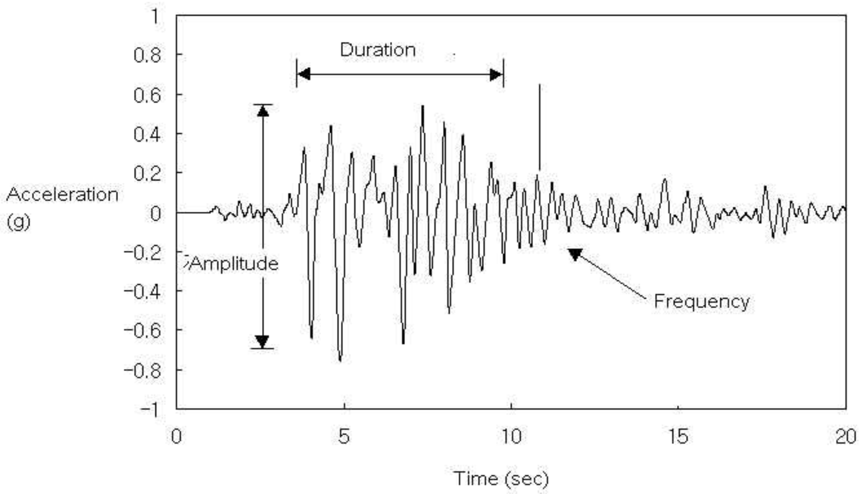


Fig 2.1 Characteristics of earthquake wave

② pseudo-static analysis :

Earthquake load is converted as an additional equivalent static load in the static design

③ seismic coefficient :

Coefficients, which used to evaluate equivalent static load In the pseudo-static analysis. The earthquake characteristics is reflected only by seismic coefficients, so it is important to determine proper values of seismic coefficients. Usually, it is determined from the maximum ground acceleration at surface (a_{max}).

- Horizontal seismic coefficient (k_h) : used to evaluate horizontal earthquake loads
- Vertical seismic coefficient(k_v) : used to evaluate vertical earthquake loads

④ Design level :

consists of Special level, Level I, Level 2 according to importance of structures

⑤ OLE, Operation Level of Earthquake :

Original function of structures has to be maintained during small magnitude of earthquake.

⑥ CLE, Contingency Level of Earthquake :

The collapse of structures has to be prevented although the structures lose the function during large magnitude of earthquake.

⑦ design earthquake :

earthquake wave, which used for aseismic design

⑧ response spectrum :

maximum response (acceleration, velocity, or displacement) of single degree of freedom system to a particular base motion against natural period (natural frequency)

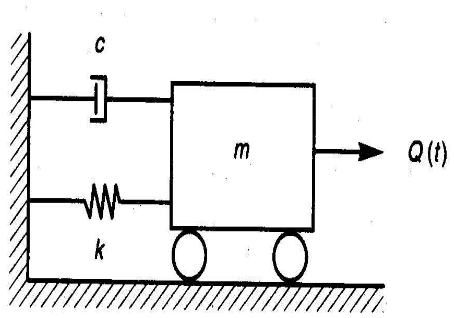


Fig 2.2 Single degree of freedom system for load of Q(t)

Equation of motions of single degree of freedom system under a particular dynamic load Q(t) is solved by time-integration.

$$mu + cu + ku = Q(t)$$

where, m : mass, c : damping coefficient, k : spring coefficient

The time-history of the structure response for Q(t) is calculated by the time-integration, and the maximum response in the time-history of system response is determined by varying the natural period of structures. The maximum response with natural period is the response spectrum.

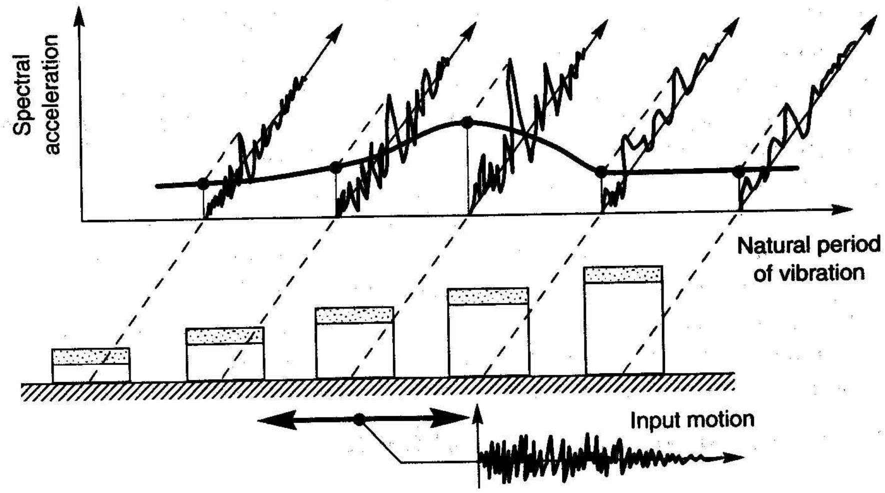


Fig 2.3 Response spectrum

⑨ design response spectrum : response spectrum, which used for aseismic design

⑩ Base rock motion and Rock outcrop motion : As shown in Fig 2.4, base rock motion is the motion of base rock in soil layers / rock outcrop motion is the motion of rock exposed to air.

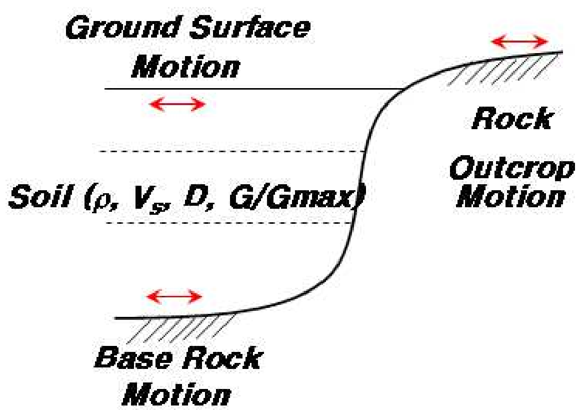


Fig 2.4 Base rock motion and Rock outcrop motion

2.2 Determination of design ground motion (Aseismic Design Guideline in Korea II, 1997)

The maximum surface acceleration a_{max} is determined by two methods. The a_{max} is used to determine the seismic coefficient for pseudo-static analysis.

① Design charts :

a_{max} is determined from design charts, which consider seismic zone, importance and performance level of structures, site classification et al. The assumption is that the soil condition of top 30m governs ground responses. Dynamic characteristics of earthquake waves and particular sites are not considered.

② Ground response analysis :

a_{max} is determined by performing ground response analysis. Earthquake motion at bedrock and dynamic characteristics of grounds (Vs profile, Shear modulus curve, damping curve) are used as input data.

1) Design charts of aseismic design guideline in Korea (1997)

① Determination of seismic zone(Table 2.1, Table 2.2) - Zone I, Zone II
② Importance of structures - Special level, Level 1, Level 2
③ Seismic performance of structure - CLE(Contingency Level of Earthquake)
- OLE(Operation Level of Earthquake)
④ Return period of earthquake is determined according to importance and seismic performance of structures (Table 2.3)
⑤ Importance factor corresponding to return period of earthquake (Table 2.4).
⑥ Site classification (Table 2.5)
⑦ Design response spectrum according to seismic zone, site classification (Fig. 2.5, Table 2.6, Table 2.7)

C_a value of design response spectrum : The natural period of structure of zero means that the rigidity of structure is infinite and the structure moves with grounds. Therefore, C_a value is the maximum ground acceleration at surface.

⑧ C_a value of step ⑦ corresponds to return period of 500 years. C_a values of different return period is obtained by multiplying the importance factor of step ⑤ by C_a.

Table 2.1 Seismic zone

Seismic zone	districts	
I	city	Seoul, Inchun, Daejun, Pusan, Daegu, Ulsan, Kwangju
	province	Kyungki, South of Kangwon, Chungcheong, Kyungsang, Jeolla-Bukdo, North-east of Jeolla-Namdo
II	province	North of Kangwon, South-west of Jeolla-Namdo, Jeju

※ 강원도 북부(군, 시): 홍천, 철원, 화천, 평창, 양구, 인제, 고성, 양양, 춘천시, 속초시

강원도 남부(군, 시): 영월, 정선, 삼척시, 강릉시, 동해시, 원주시, 태백시

전라남도 북부(군, 시): 장성, 담양, 곡성, 구례, 장흥, 보성, 여천, 화순, 광양시, 나주시, 여천시, 여수시, 순천시

전라남도 남부(군, 시): 무안, 신안, 완도, 영광, 진도, 해남, 영암, 강진, 고흥, 함평, 목포시

Table 2.2 Seismic zone factor (return period of 500 years, maximum acceleration at bedrock outcrop)

Seismic zone	I	II
Zone factor, z(g)	0.11	0.07

Table 2.3 Return period of design earthquake

Performance level	Special level	Level 1	Level 2
OLE	200 years	100 years	50 years
CLE	2400 years	1000 years	500 years

Table 2.4 Importance factor

Return period (years)	50 years	100 years	200 years	500 years	1000 years	2400 years
I	0.4	0.57	0.73	1.00	1.40	2.0

Table 2.5 Site classification

Site class	Soil Profile	Average properties in top 30m		
		Shear wave velocity(m/s), $\overline{v_s}$	$\overline{N}$ ($\overline{N}_{CH}$) (blow/foot)	Undrained shear strength, $\overline{S}_u$
S_A	hard rock	> 1500	-	-
S_B	rock	760-1500		
S_C	very dense soil or soft rock	360-760	> 50	> 100
S_D	stiff soil	180-360	15-50	50-100
S_E	soft soil	<180	< 15	< 50
S_F	site specific evaluation required			

note : $\overline{v}_s = \dfrac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \dfrac{d_i}{v_{si}}}$ $\quad \overline{N} = \dfrac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \dfrac{d_i}{N_i}}$ $\quad \overline{s}_u = \dfrac{d_c}{\sum_{i=1}^{n} \dfrac{d_i}{s_{ui}}}$

d_i = thickness of i-th layer, d_c=total clay thickness

v_{si}, N_i, s_{ui} = shear wave velocity, N value, undrained shear strength of i-th layer

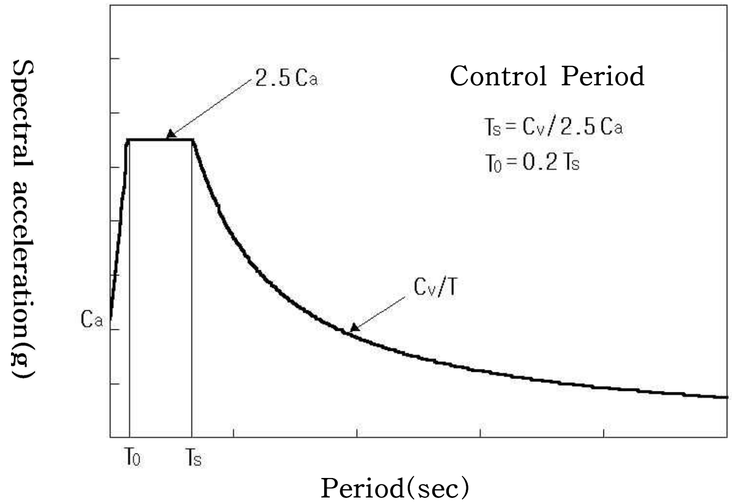


Fig. 2.5 Design response spectrum (5% damping ratio)

Table 2.6 C_a value(return period of 500 years) : maximum surface acceleration

Site class	Seismic zone	
	I	II
S_A	0.09	0.05
S_B	0.11	0.07
S_C	0.13	0.08
S_D	0.16	0.11
S_E	0.22	0.17

Table 2.7 C_v(return period of 500 years) : medium-long period characteristics of response spectrum

Site class	Seismic zone	
	I	II
S_A	0.09	0.05
S_B	0.11	0.07
S_C	0.18	0.11
S_D	0.23	0.16
S_E	0.37	0.23

2) Ground response analysis

(a) Determination of design earthquake motion at bedrock

Ground response analysis is usually performed by using one dimensional programs such as SHAKE 91. Design earthquake motions are determined as follows.

① Usually, only horizontal motion is used as input motion and vertical motion is ignored.

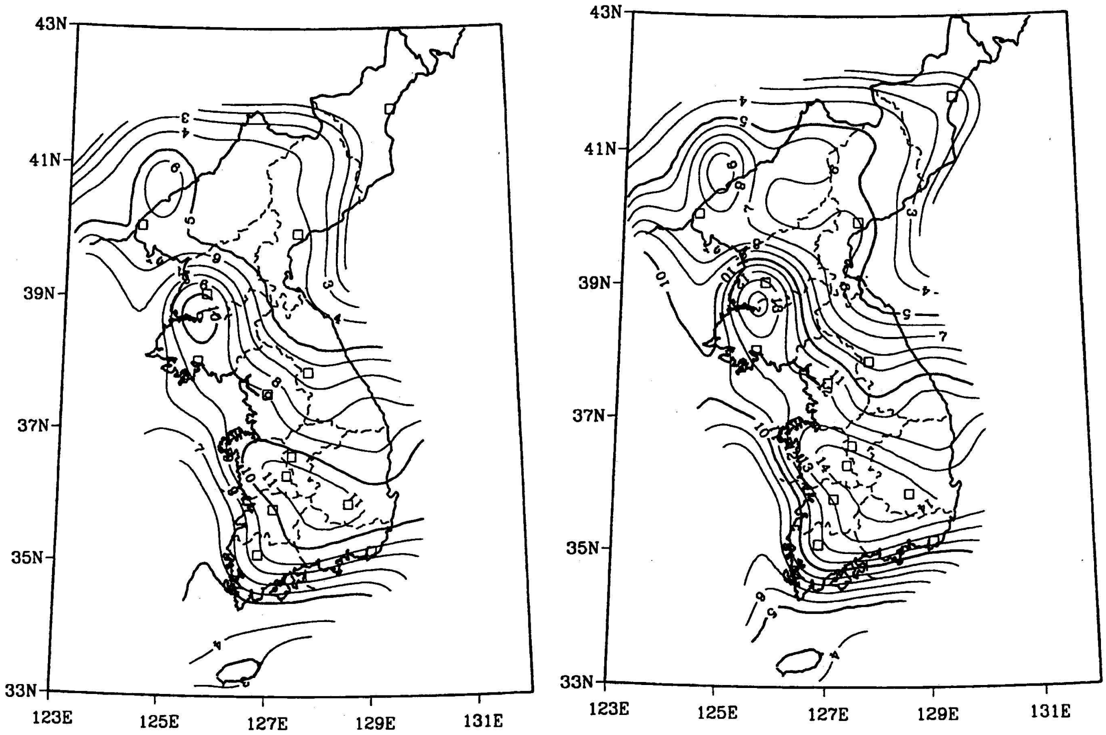
② Design earthquake motion should include at least 3 motions, which consist of real earthquake motion of long period, real earthquake motion of short period, and artificial earthquake motion, which satisfies design response spectrum (Seismic Design Guidelines of Port and Harbor Structures in Korea, 1999)

③ Usually, for the seismic design of port and harbor structures, Hachinohe motion of Tokachi-oki earthquake(1968) and Ofunato motion of Miyagi-ken-oke earthquake (1978) are used as long period and short period earthquake motions, respectively. The artificial earthquake motion is made to satisfy the design response spectrum of Fig. 2.5. Fig. 2.8 shows the artificial earthquake motion(Fig. 2.8(a)) and the comparison between the design response spectrum and the response spectrum of artificial motion (Fig. 2.8(b)).

④ The amplitude scale of design earthquake motion is modified to satisfy that the maximum amplitude of real earthquake motions (Hachinohe earthquake, Ofunato earthquake) is equal to a_{max} at bedrock outcrop.

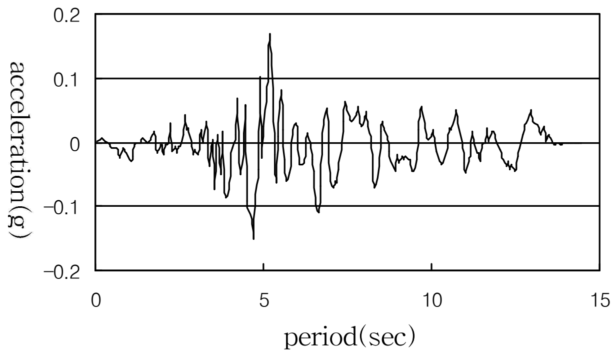
⑤ At step ④, bedrock is defined as the rock stiffer than S_B in Table 2.5. So, Vs of bedrock should be larger than 760 m/sec. a_{max} of bedrock outcrop is found in Table 2.6 as 0.11 g for zone I and 0.07 g for zone II. a_{max} of the different return period is determined by multiplying the importance factor I and a_{max} value.

⑥ In order to obtain a_{max} value at a particular location, the seismic zonation map of Fig. 2.6 can be used to determine a_{max} value at bedrock outcrop.

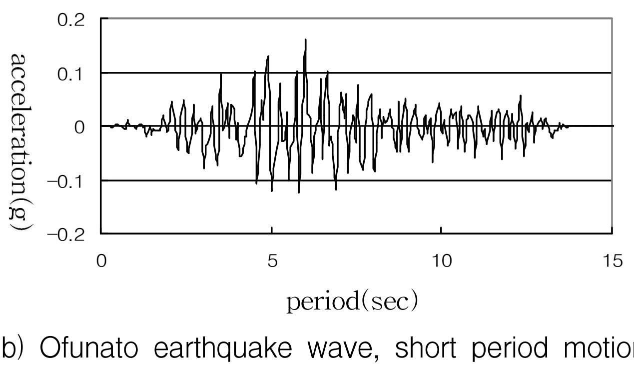


(a) return period of 500 years (b) return period of 1000 years

Fig. 2.6 maximum acceleration of bedrock outcrop motion (unit : gal)

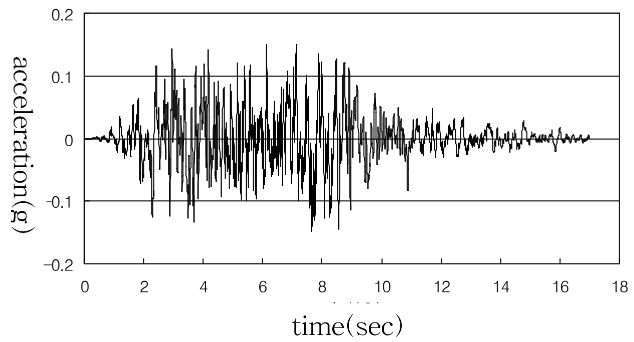


(a) Hachinohe earthquake wave, long period motion

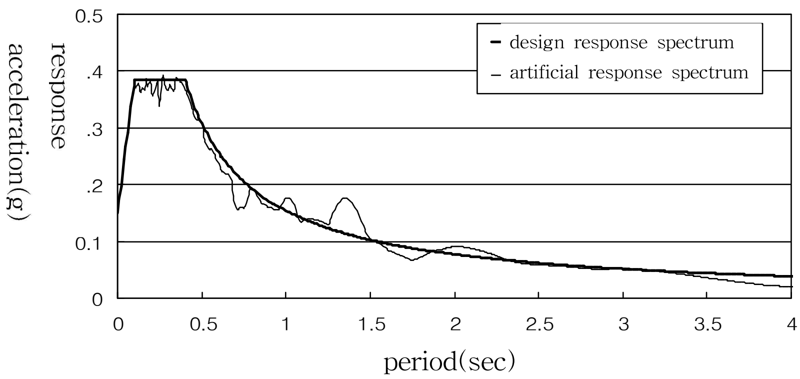


(b) Ofunato earthquake wave, short period motion

Fig. 2.7 Real earthquake motions



(a) artificial earthquake motion - example



(b) comparison with design response spectrum

Fig. 2.8 Manufacturing of artificial earthquake motion

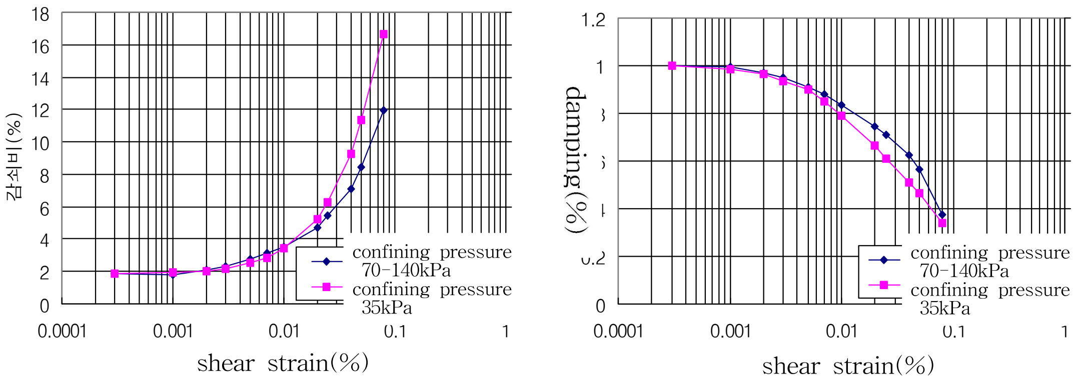
(b) Ground response analysis

One-dimensional ground response analysis is performed to obtain shear stress, ground acceleration with depth, and maximum surface acceleration. The design earthquake motion obtained from section (a) is a bedrock outcrop motion, so it is converted as in-layer motion by using 'Outcrop' option in the program. The following information is usually necessary for one-dimensional ground response analysis.

① bedrock or bedrock outcrop motions

② Maximum shear modulus with depth (G_{max}) : obtained from crosshole, downhole, SASW tests, resonant column tests, or empirical equations

③ normalized shear modulus(G/G_{max}) curve, damping curve : from resonant column tests, empirical equations. Fig. 2.9 shows G/G_{max} curve (Fig. 2.9(a)) and damping curve(Fig. 2.9(b)) obtained from the resonant column test.



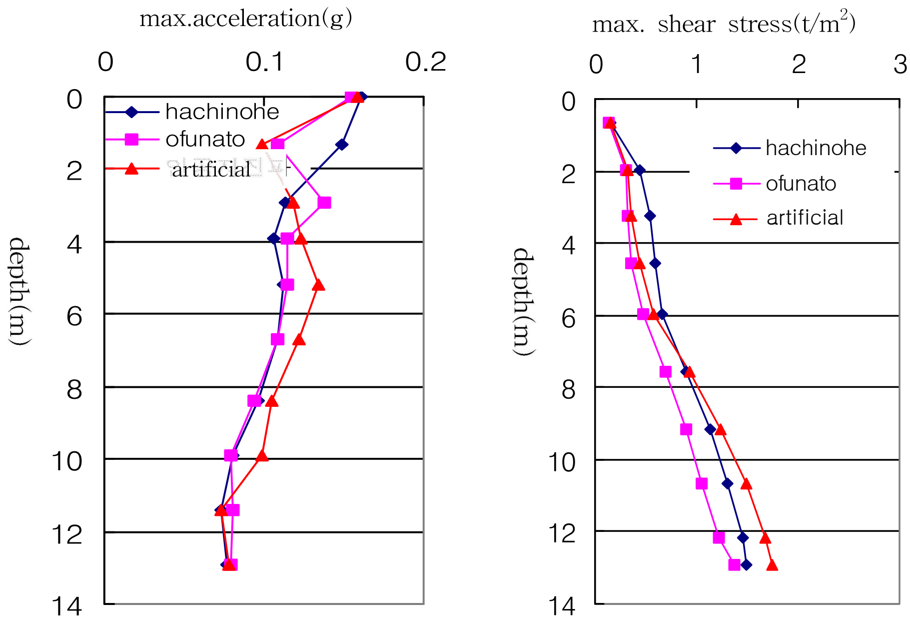
(a) G/G_{max} curve (b) damping curve

Fig. 2.9 Variation of G/G_{max} and damping with shear strain

The following results can be obtained from the analysis.

① maximum ground acceleration with depth (Fig. 2.10(a))

② shear strain or shear stress with depth (Fig. 2.10(b))



(a) maximum ground acc. (b) maximum shear stress

Fig. 2.10 maximum ground acceleration and shear stress with depth

3. Design Example

3.1 Analysis section of gravity type quay wall

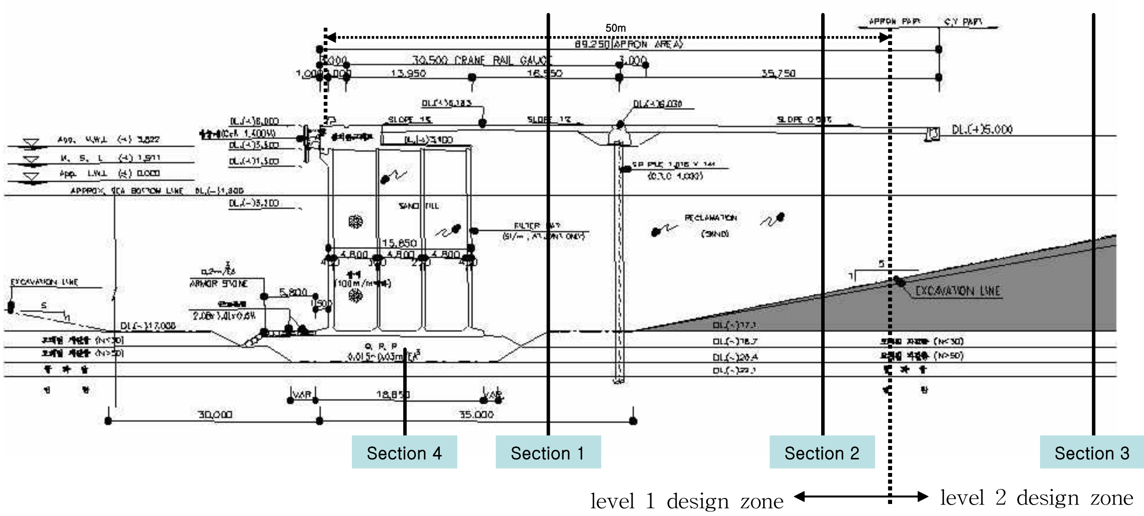


Fig. 3.1 Gravity type quay wall (location : Jeolla-Namdo, KwangYang)

3.2 Design earthquake motion

1) Determination of maximum ground acceleration at bedrock outcrop

- Backfill : Level 2, CLE level - return period of 500 years
- Gravity quay wall : Level 1, CLE level - return period of 1000 years
- bedrock is defined as site class of S_B.

Table 3.1 Maximum ground acceleration at bedrock outcrop

<table>
<tr><th>Performance level</th><th>return period</th><th colspan="3">Design chart</th><th>Zonation map</th></tr>
<tr><td rowspan="2">Level 2
/ CLE</td><td rowspan="2">500 years</td><td>Zone factor
(1)</td><td>Importance
factor
(2)</td><td>a_{max} at
bedrock
outcrop
(1)×(2)</td><td rowspan="2">0.08g</td></tr>
<tr><td>0.11g</td><td>1.0</td><td>0.11g</td></tr>
<tr><td rowspan="2">Level 1
/ CEL</td><td rowspan="2">1000 years</td><td>Zone factor
(1)</td><td>Importance
factor
(2)</td><td>a_{max} at
bedrock
outcrop
(1)×(2)</td><td rowspan="2">0.11g</td></tr>
<tr><td>0.11g</td><td>1.4</td><td>0.154g</td></tr>
</table>

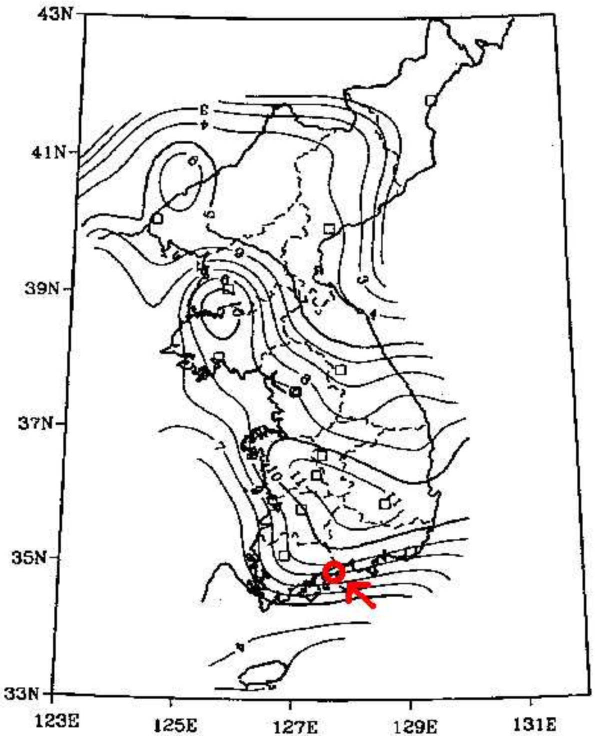


Fig. 3.2 Zonation map of return period of 500 years

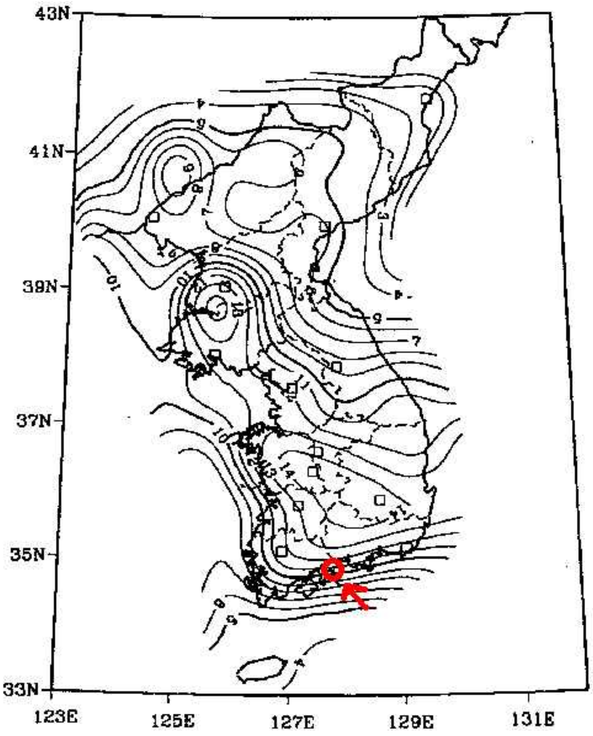
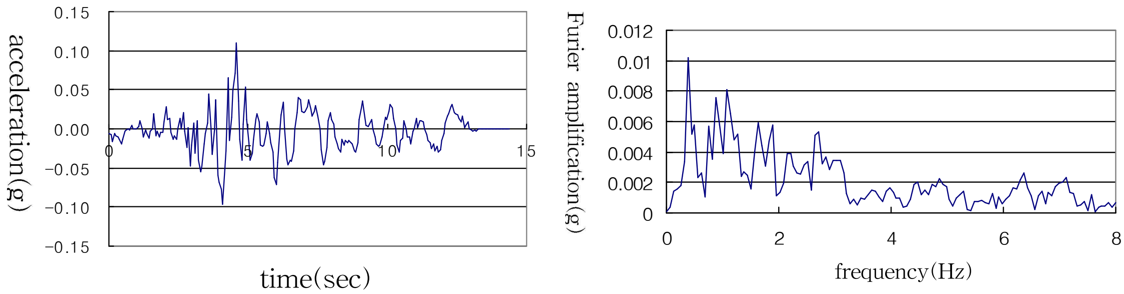


Fig. 3.3 Zonation map of return period of 1000 years

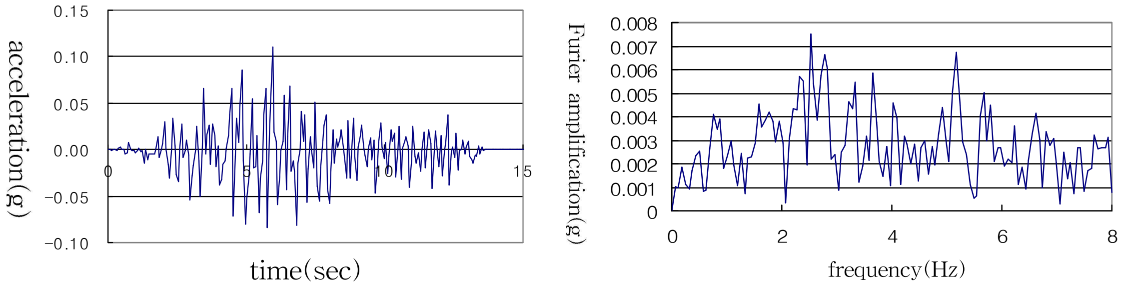
2) Determination of design earthquake motions

- 3 design earthquake motions
  - long period earthquake motion – Hachinohe earthquake motion
  - short period earthquake motion – Ofunato earthquake motion
  - artificial earthquake motion

- The amplitude of real earthquake motion is scaled to match the maximum acceleration at bedrock outcrop as shown in the following figure.



(a) Hachinohe motion



(b) Ofunato motion

Fig. 3.4 Amplitude modification of real earthquake motions

- Manufacturing of artificial earthquake motion
  - Seismic zone I / Site class of S_B
  - return period of 500 years : Ca = Cv = 0.08 g
  - return period of 1000 years : Ca = Cv = 0.11 g

Fig. 3.5 Computer program for manufacturing of artificial earthquake motions

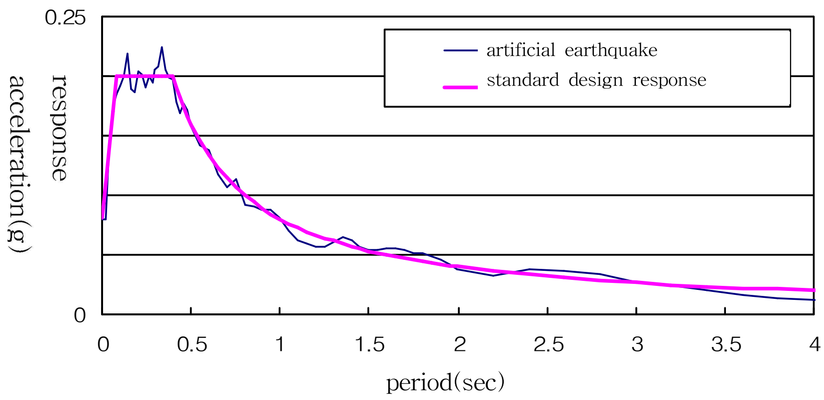


Fig. 3.6 Comparison between design response spectrum and response spectrum of artificial earthquake motion (damping ratio : 5%, a_{max}=0.08g)

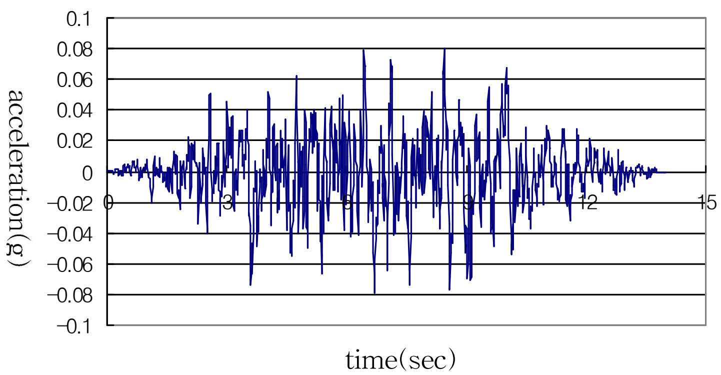


Fig. 3.7 Time history of artificial earthquake motion (damping ratio : 5%, a_{max}=0.08g)

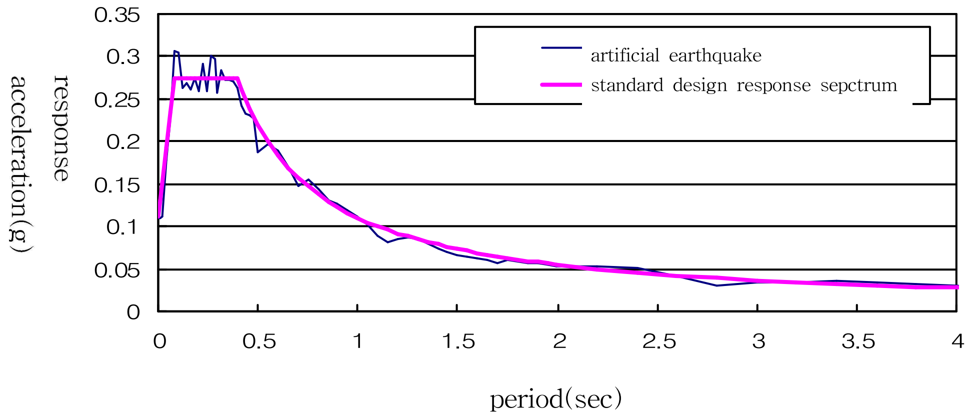


Fig. 3.8 Comparison between design response spectrum and response spectrum of artificial earthquake motion (damping ratio : 5%, a_{max}=0.11g)

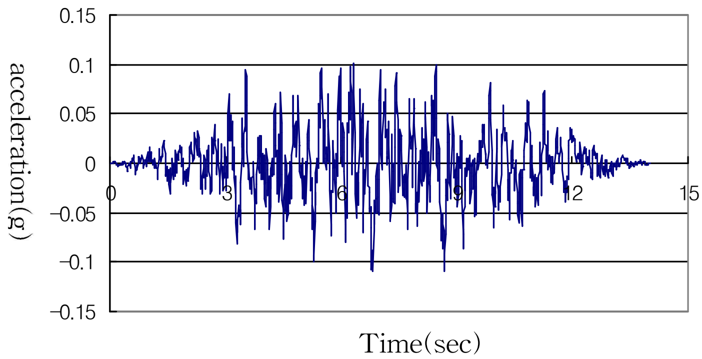


Fig. 3.9 Time history of artificial earthquake motion (damping ratio : 5%, a_{max}=0.11g)

References

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4) Steven L. Kramer(1996), "Geotechnical Earthquake Engineering"