PEAK GROUND MOTION CHARACTERISTICS OF 1995 KOBE EARTHQUAKE AND AN EXTRACTED SIMPLE EVALUATION METHOD

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SUMMARY

It was pointed out that the peak horizontal ground accelerations(PHGA) during the 1995 Hyogo-ken Nanbu (Kobe) Earthquake had been strongly affected not only by the strong nonlinear effect with regard to subsurface ground conditions but also by the rupture directivity effect due to right-lateral strike slip fault based on the overview of more than 100 PHGA records and then a simple evaluation method for PHGA and PHGV(peak horizontal ground velocity) on surface was proposed.

After showing that the PHGA attenuation relationship proposed by Joyner and Boore (1981) based on the records from the western U.S.A. inland events can explain the PHGA records on "rock" or "stiff soil" sites during this event, a simple evaluation method for PHGA and PHGV on surface was constructed based on the attenuation relationship proposed by Joyner and Boore (1981) considering the nonlinear site amplification effect due to the subsurface ground conditions and the rupture directivity effect for the seismic hazard map and calibrated through the comparison with the records. The site amplification effect was modeled as a function of shear wave velocity ratio between subsurface soils and engineering oriented base and the rupture directivity effect coefficient was defined as a function of azimuth angles based on the heterogeneous source model proposed by Koyama(1987).

Conclusions are (1)S wave radiation from strike slip fault can explain the regional distribution of PHGA during the 1995 Kobe Earthquake.(2)High PHGA records in the strike direction area have been strongly affected by the rupture directivity effect.(3)Evaluated PHGA values during 1995 Kobe Earthquake by the proposed method conformed well with the PHGA records.

So, it is important to take the rupture directivity effect into account for evaluating peak ground motions of inland events.

INTRODUCTION

Figure 1 presents the comparison between the PHGA records on rock and stiff soil sites during the Kobe Earthquake and the empirical PHGA attenuation relationship proposed by Joyner and Boore (1981).

The closest distance(D) is a measure of distance from the Earth's surface projection of the fault rupture to the recording site. In this event, the projection is simplified to be a straight-line(fault line) over a length of approximately 40 km based on the fault mechanism solution by Kikuchi(1995). The assumed positions of the fault line edges are (34.52N,134.90E) and (34.73N,135.25E), respectively. The solid and dashed lines in Figure 1 denote the mean and mean ± one standard deviation attenuation relationships as follows.

$$\log PHGA = -1.02 + 0.249 Mw - \log r - 0.00255 r \qquad (1)$$

where $r = (D^2 + 7.3^2)^{1/2}$

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$$\log PHGV=-0.67+0.489Mw-\log r-0.00256r \qquad (2)$$

where $r=(D^2+4.0^2)^{1/2}$

PHGA: peak horizontal ground acceleration(g), PHGV: peak horizontal ground velocity(cm/s),
Mw: moment magnitude, D: closest distance (km)

Subsurface ground conditions for PHGA records follow the classification proposed by Design Code for Bridges in Japan(1990).

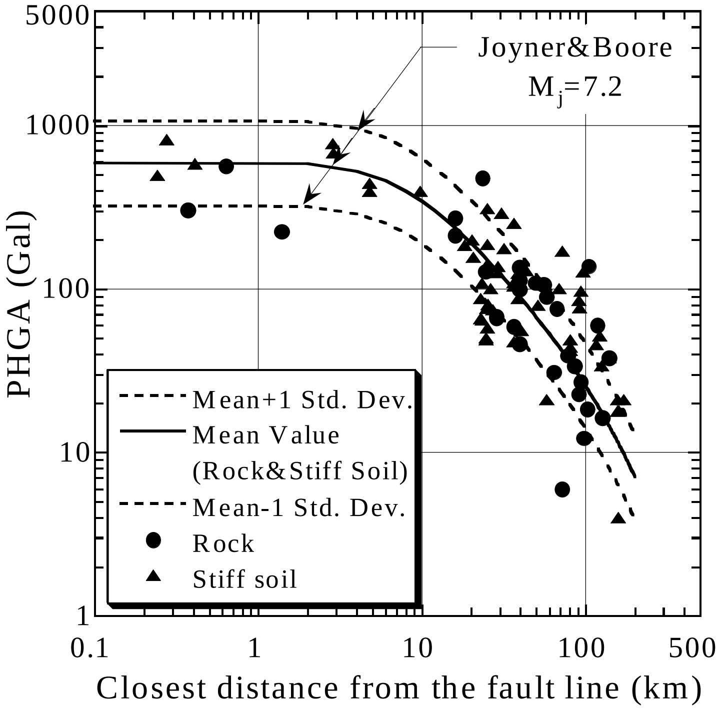


Figure 1: Comparison between the PHGA records and the attenuation relationship

It can be seen that most of the PHGAs recorded at distances shorter than 10 km fall within the ± 1 standard deviation bands and through all distances, the PHGA records on "rock" and "stiff soil" conform well with the mean attenuation relationship for "rock" and "stiff soil" by Joyner and Boore.

So, these attenuation relationships were used for evaluating PHGA or PHGV on "rock" and "stiff soil" sites assuming averaged shear wave velocity of about 500m/s.

Mw can be converted to Mj(JMA magnitude) as following equations proposed by Hanks et al.(1979) and Takemura(1990) respectively, where M_0 is seismic moment(dyne-cm).

$$\log M_0=1.5Mw+16.1 \qquad (3)$$

$$\log M_0=1.17Mj+17.72 \qquad (4)$$

Shimazaki(1995) pointed out that Mj estimated by Takemura's equation had good agreement with the inland fault-length magnitude(ML) proposed by Matsuda(1990).

RUPTURE DIRECTIVITY EFFECT

The rupture directivity effect was examined based on the PHGA records during the Kobe Earthquake in the areas shown in Figure 2 . The PHGA in area A , which is in the fault strike direction, exceed those in another area B by about 50 percent on an average as shown in Figure 3 and this exceedance level is nearly equivalent to those for short-period waves estimated by Koyama(1987) theoretically based on the energy summation method.

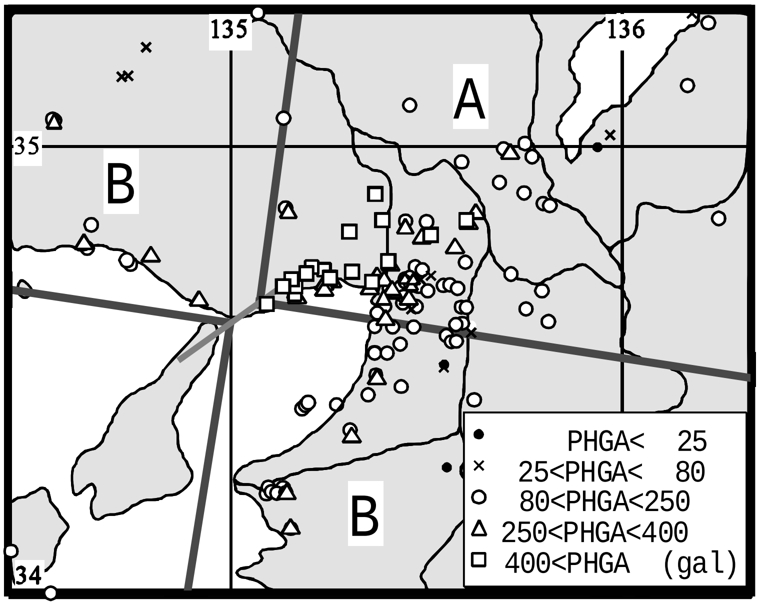


Figure 2: Regional distribution of PHGA records

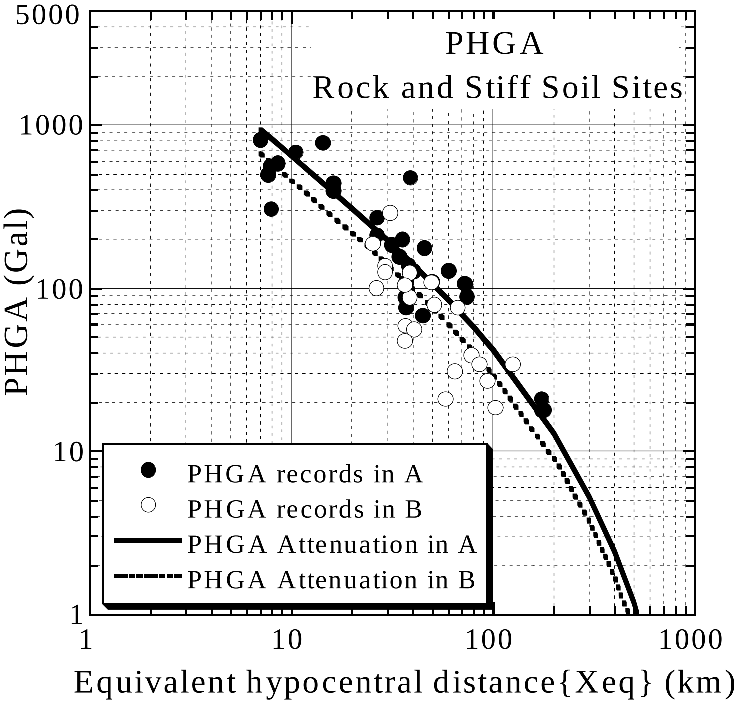


Figure 3: Comparison of PHGA between area A and B

For this reason, the rupture directivity effect has been introduced based on the results by Koyama, and the directivity factors for short-period (T<5.0s) waves on the bilateral rupture from the center of fault(BDF) and the unilatelal rupture from the end of fault(UDF) are determined respectively as follows.

$$BDF = \left[1 - \left(\frac{v}{c}\cos\theta\right)^2\right]^{-\frac{1}{2}} \tag{5}$$

$$UDF = \left[\left(\frac{2v}{c} \right) \left(\frac{c}{v} - \cos\theta \right) \right]^{-\frac{1}{2}} \tag{6}$$

where

θ:azimuth angle, c: shear wave velocity, v: rupture propagating velocity

The PHGA or PHGV values including the rupture directivity effect can be estimated explicitly by multiplying the directivity factors by the values from Equation (1) or (2). Figure 4 shows the directivity factors as a function of azimuth angle. When azimuth angle is equal to 90 degree, BDF is 1.0. It means that the values directly predicted by Equation(1) or (2) are considered not to be affected by the rupture directivity effect.

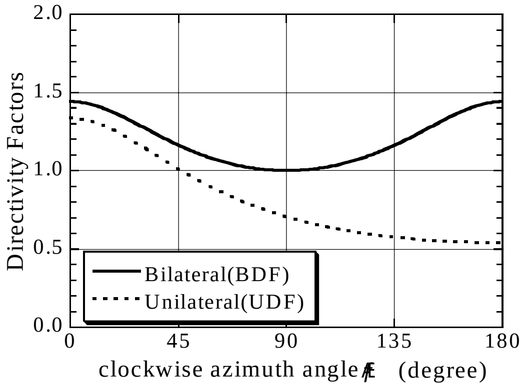


Figure 4: Directivity factors for short-period waves

The attenuation relationships proposed by Joyner and Boore includes the rupture directivity effect originally because they were based on the actual records. In the engineering sense, however, it will lead to safe judgement. The "v/c" value is used to be an average value of 0.72 proposed by Geller(1976).

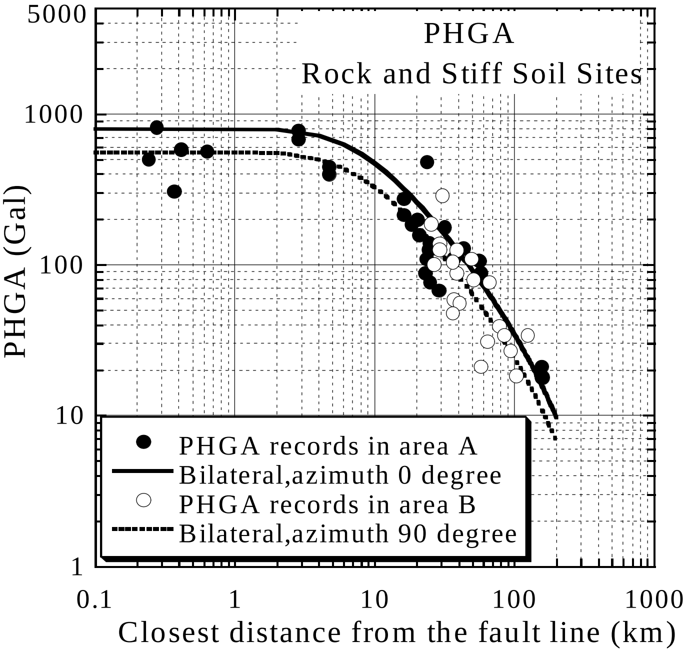


Figure 5: PHGA including bilateral directivity effect

Figure 5 shows the comparison between the PHGA records on rock and stiff soil sites during the Kobe Earthquake and the estimated values including the bilateral rupture directivity effect. It can be seen that the estimated values conform well with the records.

NONLINEAR SITE AMPLIFICATION EFFECT

Midorikawa et al.(1980) and Midorikawa(1980) proposed the linear site amplification factors for peak ground motions to bedrock outcroppings having shear wave velocity of 3000m/s as a function of the time averaged shear wave velocities of subsurface soils as follows.

$$ALA=40Vss^{-0.374} \qquad (7)$$

$$ALV=170V_{30}^{-0.6} \qquad (8)$$

where

ALA: linear site amplification factor for PHGA, Vss: averaged shear wave velocity of subsurface soils shallower than soil layer having shear wave velocity of over 300m/s, ALV: linear site amplification factor for PHGV

V_{30}:averaged shear wave velocity in the top 30m subsurface soils

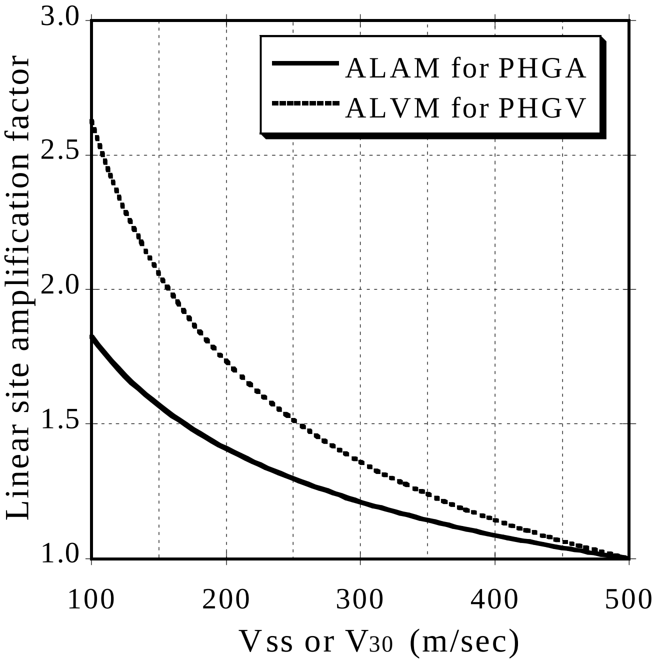


Figure 6: Linear site amplification factors versus Vss,V30

Figure 6 and Equation (9),(10) shows the modified linear site amplification factors ALAM, ALVM to "rock" and "stiff soil" having shear wave velocity of 500m/s defined in previous section.

$$ALAM=\left(\frac{Vss}{500}\right)^{-0.374} \qquad (9)$$

$$ALVM=\left(\frac{V30}{500}\right)^{-0.6} \qquad (10)$$

Consequently, the PHGA linear values (PHGAL) and PHGV linear values at the soft ground surface can be estimated by multiplying the modified linear site amplification factors by the values on rock and stiff soil sites including the rupture directivity effects.

In general, it is well known that the reduction in site amplification factors with increased intensity of bedrock shaking occurs due to the nonlinear stress-strain response of the soft soil deposits. Borcherdt (1994) proposed the nonlinear site amplification factors for the averaged Fourie spectral ratios depending on not only V_{30} but also the levels of bedrock shaking. Their relationships were derived from the records obtained during the 1989 Loma Prieta earthquake and the results of nonlinear site response analyses for higher accelerations.

For now, this approach is the best way to evaluate the nonlinear site amplification effects conveniently.
But there is not yet same approach in accordance with complicated subsurface soils in Japan especially for peak ground motions.

So, a simple method proposed by Kobayashi(1995) was used to take the nonlinear effect into account and adapted to only PHGA on soft soil deposits having Vss of less than 300m/s. If the PHGA linear values(PHGAL) at the soft ground surface is over 520Gal, the reduced PHGA(PHGANL) was calculated by following equation.

$$PHGANL = 0.3(PHGAL-520)+520 \qquad (11)$$

Where

PHGANL: PHGA values affected by nonlinear effect at the soft ground surface,

PHGAL:PHGA linear values at the soft ground surface

Figure 7 shows the comparison between the PHGA records on soft soil sites during the Kobe Earthquake and the estimated PHGA values including both the bilateral rupture directivity effects and nonlinear site amplification effect (PHGANL).

It was assumed that the subsurface soft soil deposits on the underlying base layer having shear wave velocity of over 300m/s were characterized by a thickness H=15m and Vss=150m/s. It can be seen that the PHGA attenuation in the present study can explain the mean attenuation characteristics of the PHGA records on soft soil sites.

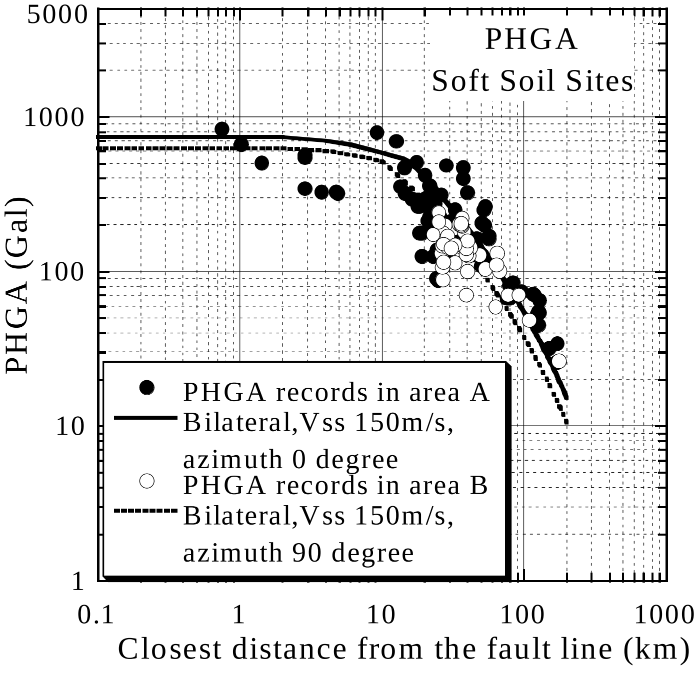


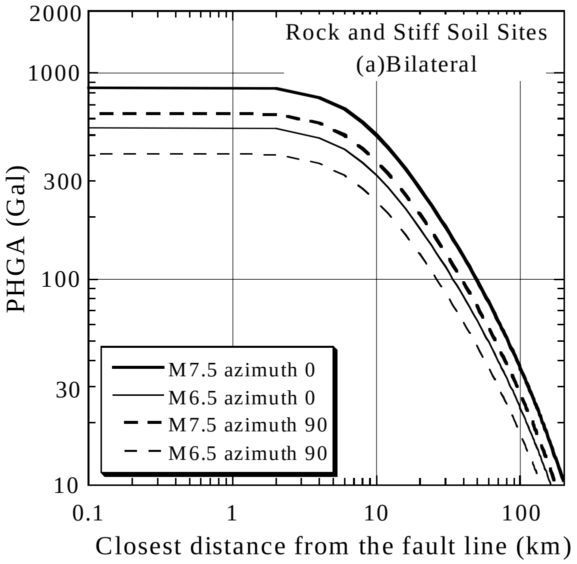
Figure 7: PHGA including nonlinear site amplification and bilateral directivity effects

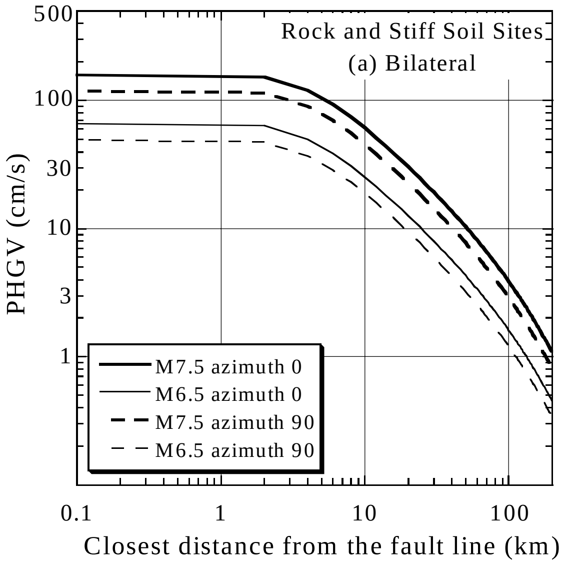
GENERAL TREND OF THE ESTIMATED PEAK GROUND MOTIONSON ROCK AND STIFF SOIL SITES

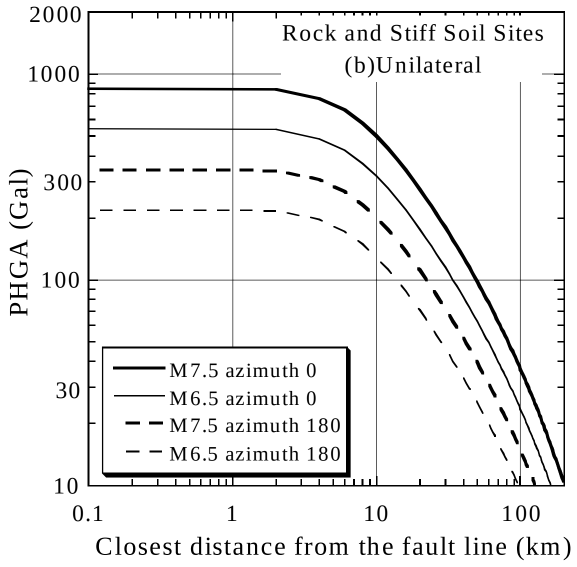
Figure 8 shows the estimated PHGA attenuation on rock and stiff soil sites for each magnitude including the rupture directivity effect. Figure 9 shows the estimated PHGV attenuation in same manner.

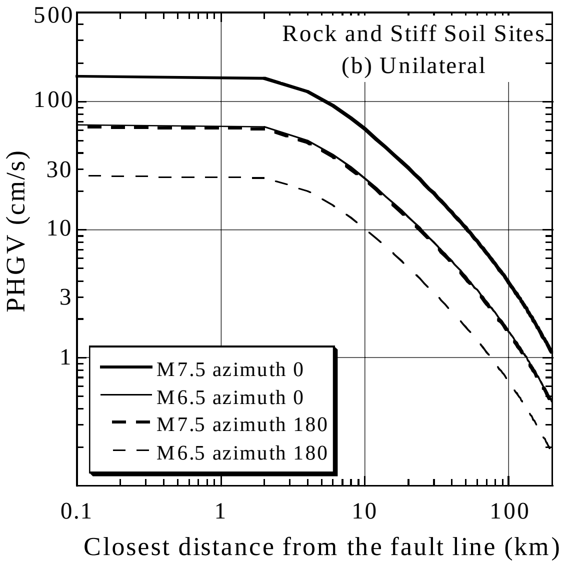
The estimated value from the bilatelal rupture fault with azimuth angle of 0 degree and magnitude of 7.5 is highest value on both PHGA and PHGV. In this case, the PHGA and PHGV values near the fault line seem to reach about 900Gal and 180cm/s respectively.

So, It is known that it is important to take the rupture directivity effects into account for evaluating peak ground motions accurately.









CONCLUSIONS AND REMARKS

An convenient evaluation method for PHGA and PVGA induced by inland earthquake were proposed based on the attenuation relationship proposed by Joyner and Boore and calibrated through the comparison with the records obtained during the 1995 Kobe Earthquake. As there still remains ambiguity especially on nonlinear site amplification, more effort should be made to improve and validate our evaluation method and collect the soil profiles and properties at many recording sites.

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REFERENCES

1. AIJ(1993):*Earthquake Motion and Ground Conditions*, In Commemoration of the 20th Anniversary of the Research Subcommittee on Earthquake Ground Motion,PP35-45
2. Borcherdt,R.D.(1994):*Estimates of Sites-Dependent Response Spectra*, Earthquake Spectra, Vol.10,No.4,PP617-653
3. Ejiri,J.,Goto,Y. and Toki,K.(1995):*Strong Ground Motion Characteristics during the 1995 Hyogoken-Nambu Earthquake*,JSCE Earthquake Engineering Symposium,PP.237-240(in Japanese)
4. Ejiri,J.,Sawada,S.,Goto,Y. and Toki,K.(1996):*Peak Ground Motion Characteristics*, Soils and Foundations Special Issue,JGS
5. Geller,R.J.(1976):*Scaling Relations for Earthquake Source Parameters and Magnitudes*, Bull.Seism.Soc.Am.,65, PP.1073-1093
6. Hanks,T.C. and Kanamori,H.(1979):*A Moment Magnitude Scale*,J.Geophys. Res. 84, PP.2348-2350
7. Japan Road Association(1990):*Design Code for Bridges -Earthquake Resistant Design-*,Vol.V(in Japanese)
8. Joyner,W.B. and Boore,D.M.(1981):*Peak Horizontal Acceleration and Velocity from Strong Motion Records from the 1979 Imperial Valley-California- Earthquake*, BSSA,Vol.71,No.6,PP.2011-2038
9. Kikuchi,M.(1995):*Source mechanism of Hyogoken-Nambu Earthquake*,January 17,1995,GSJ Preliminary Report on the 1995 South Hyogo Prefecture Earthquake,PP.117-122 (in Japanese)
10. Kobayashi,H.(1995):*Comparison between the Ground Motion of Fukui Earthquake of 1948 and Hyogo-ken Nambu Earthquake of 1995*,the 23rd Symposium of Earthquake Ground Motion,AIJ, PP.53-64(in Japanese)
11. Koyama,J.(1987):*Short Period Seismic Directivity*, Zisin,Vol.40,PP.397-404(in Japanese)
12. Matsuda,T.(1975):*Magnitude and Recurrence Interval of Earthquake from a Fault*, Zisin,Vol.28, PP.269-283(in Japanese)
13. Matsuda,T.(1990):*Seismic Zoning Map of Japanese Inlands, with Maximum Magnitude Derived from Active Fault Data*,Bull.Earthq.Res.Inst.,Vol.65,PP.289-319(in Japanese)
14. Midorikawa,S.(1980):*Prediction of Intensity Distribution due to Major Earthquake with regard to Fault Rupture and Site Ground Conditions*, the 8th Symposium on Ground Vibrations, AIJ (in Japanese)
15. Midorikawa,S. and Kobayashi,H.(1980):*Prediction of Peak Ground Acceleration Distribution in and around the Epicentral Region*, Journal of S.C.E, AIJ, No.290, PP.83-92 (in Japanese)
16. Nakamura,Y.,Hidaka,.K,Saita,J. and Sato,S.(1995):*Strong Accelerations and Damage of the 1995 Hyogo-Ken-Nanbu Earthquake*, JR Eartquake Information No.23b
17. Ohno,S.,Ohta,T.,Ikeura,M. and Takemura,M.(1993):*Revision of Attenuation Formula considering theEffect of Fault Size to Evaluate Strong Motion Spectra in near Field*, Tectonophisics,218,PP.69-81
18. Shimazaki,K.(1995):*Long-Term Forecast of A Large Earthquake on the Basis of Active Fault Data*,the 23rd Symposium of Earthquake Ground Motion,AIJ, PP.5-10 (in Japanese)
19. Takemura,M.(1990)*:Magnitude-Seismic Moment Relations for Shallow Earthquake in and around Japan*, Zisin,Vol.43,PP.257-265(in Japanese)
20. Toki,K.,Goto,Y.,Ejiri,J. and Sawada,S.(1995):A Brief Review of Source Effects and Local Site Effectsduring Hyogo-ken Nanbu Earthquake, Journal of JSCE(in Japanese)