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AN EXAMINATION OF NON-LINEARITY EFFECTS USING OBSERVED RECORDS BY THE WARNING INFORMATION SYSTEM OF EARTHQUKAKE (WISE) IN HOKKAIDO, JAPAN

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SUMMARY

Site effects on peak ground motion, especially non-linearity behaviors on amplification at subsurface layers using the strong motion records observed at the Warning Information System of Earthquake (WISE) in Hokkaido, Japan. First the attenuation relation for peak ground velocity (PGV) of the surface ground of Tertiary deposit and in the engineering bedrocks are developed from records at 146 sites of WISE observatories. The site amplification factors were derived from the ratio of the maximum observed values of PGV to the values from the attenuation relation for the surface ground of the Tertiary deposit. The correlation between the site amplification and the average shear wave velocity in the subsurface layers shows almost coincidence with the existing relationship derived from Midorikawa et al. [1] at another sites of Japan. The amplification factors of the 2003 Tokachi-Oki earthquake records are smaller than of the observation records from small earthquakes before the 2003 Tokachi-Oki earthquake. Then the average shear strain levels of the records are evaluated by the ratio between the PGV at ground surface and the average shear wave velocity within the subsurface layers. The shear strain level analysis show the effect of the nonlinearity on the amplification factors of the peak ground velocity does not become significant within the shear strain level equals to 1×10^{-3}.

INTRODUCTION

Warning Information System of Earthquake (WISE) began to work at the 1993 Kushiro-Oki earthquake under the control of the Civil Engineering Research Institute of Hokkaido, Japan. This WISE system was intended to estimate the peak ground acceleration (PGA) at the roads, river banks, dams and bridges in the Hokkaido Regional Development Bureau using the observation strong ground motion records

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immediately after the earthquake. This system is an on-line system and are connected the 146 strong motion seismographs in Hokkaido area.

The attenuation relationship and the site amplification factors were investigated by the strong motion records in WISE system because of the improvement of the accuracy of the estimating seismic ground motions. The site amplification factors were discussed by many researchers. Midorikawa et al. [1] presented the relationship between amplification factors for peak acceleration and peak velocity with the time-weighted average of shear wave velocity from surface to a depth of 30m. Furthermore nonlinearity of site amplification is examined by using the ground motion records of the 2001 Geiyo earthquake and subsequent smaller events by Fujimoto and Midorikawa [2].

We developed site amplification factors in the non-linear behaviors of the ground using the strong motion records in WISE system of the 2003 Tokachi-Oki earthquake on the magnitude 8.0 of the JMA scale.

STRONG MOTION DATA

The strong motion records have been observed from 1996 in WISE system. More than 1500 records have been recovered from earthquakes. The data used in the analysis consists of 25 earthquakes that observed more than 10 seismological stations. The occurrence time, the location of the epicenter, the depth of the hypocenter and JMA magnitude of earthquakes used in this analysis are summarized in Table 1. Fig. 1 shows the location of epicenters used in the analysis.

Table 1. List of Earthquakes using the analysis.

No.	Occurrence		Epicenter		Depth (km)	JMA Mag.
	Date	Time	Lat.	Long.		
a	1993/01/15	20:06	42.917	144.357	101	7.8
b	1993/07/12	22:17	42.780	139.183	35	7.8
c	1994/08/31	18:07	43.490	146.068	84	6.5
d	1994/10/04	22:22	43.372	147.678	28	8.1
1	1997/02/27	23:22	41.552	142.073	71	4.6
2	1997/03/13	10:12	42.800	142.997	129	4.6
3	1997/07/01	12:40	42.642	144.655	73	5.1
4	1997/07/15	1:09	43.115	146.292	37	5.9
5	1997/10/03	13:46	42.507	144.822	50	4.9
6	1997/11/15	16:05	43.647	145.088	153	6.1
7	1997/12/23	4:08	42.978	143.488	113	5.1
8	1998/01/03	3:19	42.938	145.415	50	4.8
9	1998/01/31	0:50	41.468	142.067	60	5.1
10	1998/04/09	14:29	42.803	144.977	48	4.8
11	1998/09/03	16:58	39.795	140.910	10	6.1
12	1998/10/14	5:41	40.077	143.497	0	5.4
13	1998/12/10	0:56	42.303	143.137	57	4.6
14	1999/01/09	12:05	44.102	147.395	121	5.6
15	1999/02/09	9:19	42.333	143.113	57	4.7
16	1999/03/19	2:55	41.030	143.242	44	5.7
17	1999/05/13	2:59	42.943	143.908	104	6.4
18	1999/05/31	12:22	43.047	144.588	75	4.6
19	1999/06/15	16:47	42.982	146.168	43	5.1
20	2000/01/28	23:31	42.980	146.715	56	6.8
21	2003/09/26	4:50	41.767	144.067	42	8.0

*: a-d Earthquakes occurred former WISE system.

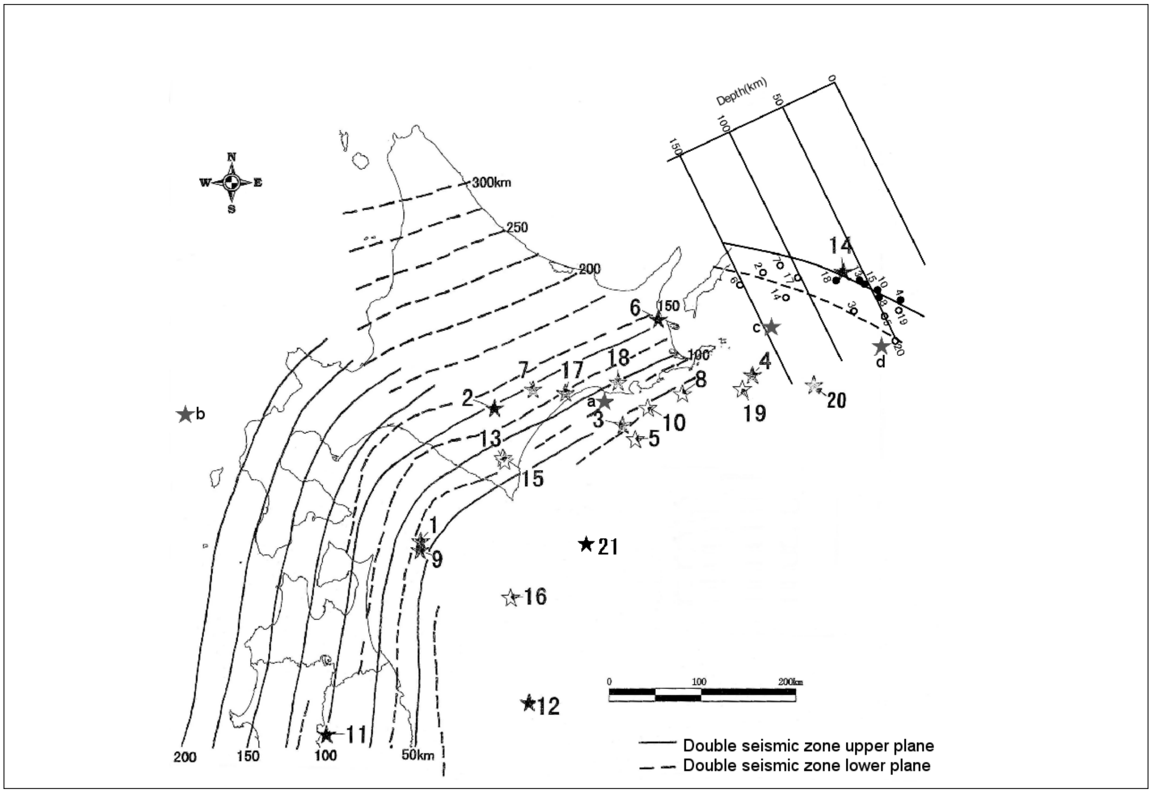

Fig. 1. Epicentral map for the analysis.

AVERAGE SHEAR WAVE VELOCITY

For the evaluation of the site amplification factors, the time-weighted average of shear wave velocities ($AVS(30)$) from surface to a depth of 30m is computed by the following formula:

$$AVS(30) = D_{30} / (\sum \frac{Di}{Vs_i}) \quad \text{--------------------------------------} \quad (1)$$

where D_{30} is the thickness of the ground layers that equals to 30m, D_i is the thickness of the each ground layers (m) and Vs_i is the shear wave velocity of the each ground layers (m/sec). For 105 observation sites out of 146 seismological stations where shear wave velocity profiles have been obtained. These shear wave velocities data is derived from the geological and PS logging data from WISE seismological station and K-NET and KiK-net by National Research Institute for Earth Science and Disaster Prevention. Fig. 2 shows the 105 observation sites where shear wave velocities profiles were identified.

ATTENUATION RELATION

Two kinds of Attenuation relation are developed by the observation records of WISE system. The data sets were used by a) to d) and No. 1 to No. 20 in Table 1. One of the attenuation relations is derived from the observation records of the surface ground that the geological condition of the observation sites is Tertiary deposit or former Tertiary deposit.

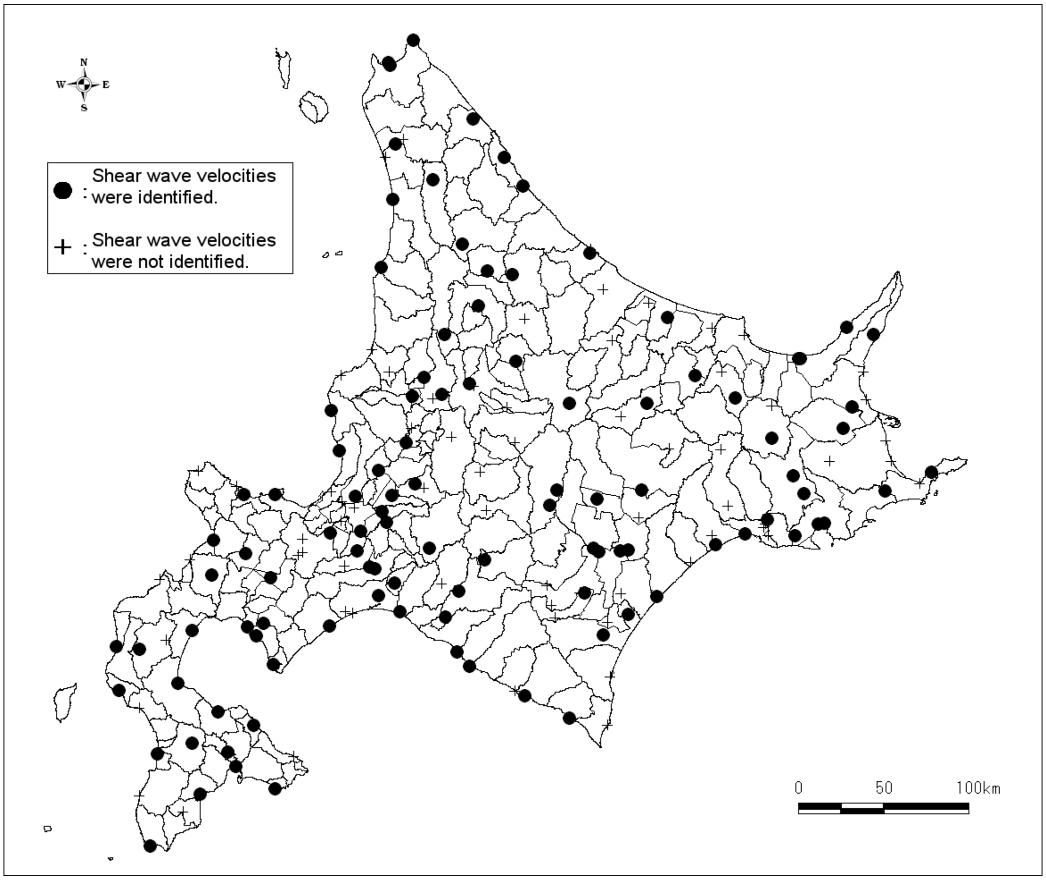

Fig. 2. Distribution of the observation sites.

The other attenuation relation are used the calculated records at the engineering bedrock of the shear wave velocity equals 300m/sec using the equivalent linear response analysis. A model is used to develop the attenuation relations of the data:

$$\log(V_{\max}) = aM - \log R + bR + c \qquad \text{----------------------------------} \qquad (2)$$

where $V_{\max}$ is peak ground velocity (PGV) (cm/sec), M is JMA magnitude and R is the hypocentral distance in km. This type of the attenuation relation was proposed by Fukushima and Tanaka [3]. The regression analysis are adopted the two-step stratified regression method developed by Joyner and Boore [4].

The maximum PGV component of the two horizontal observation records is used in the regression analysis. Fig. 3 shows the attenuation curves for the surface ground of the Tertiary deposit. Fig. 4 shows the attenuation curved for the engineering bedrock.

The regression coefficients obtained for two types of formula are summarized in Table 2. The results indicate that the regression coefficient for the surface ground of the Tertiary deposit is lager than for the engineering bedrock.

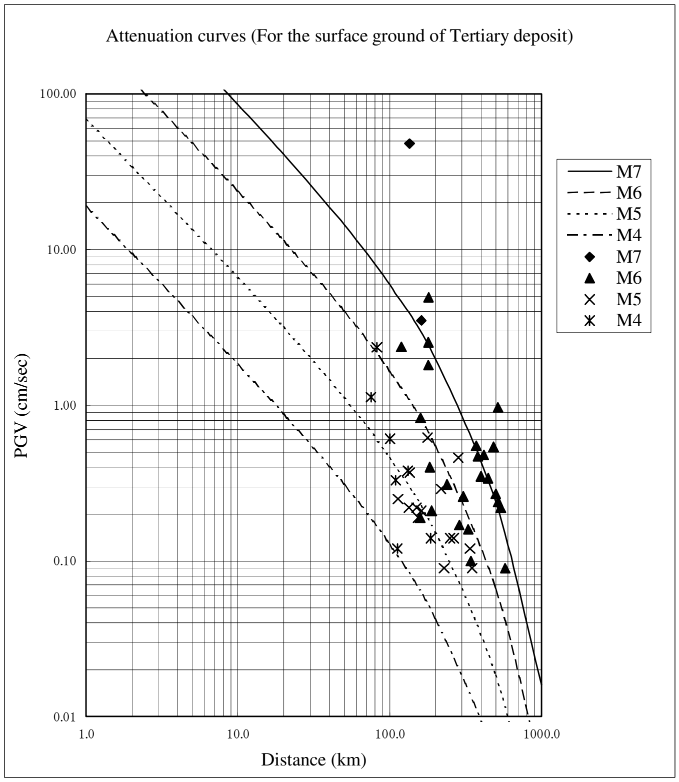

Fig. 3. Attenuation curves of the peak ground velocity (PGV) for the surface ground in the Tertiary deposit.

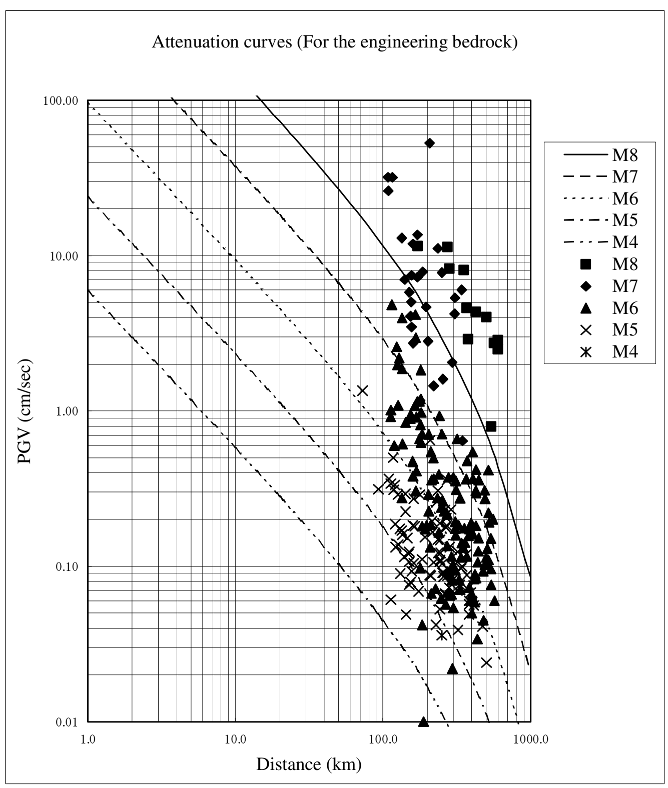

Fig. 4. Attenuation curves of the peak ground velocity (PGV) for the engineering bedrock.

Table 2. Results of the two-step stratified regression analysis.

	Data set	
Coefficient of attenuation relation	PGV for the surface ground of the Tertiary deposit	PGV for the engineering bedrock
a	0.5562	0.5499
b	-0.0017	-0.0013
c	-0.9449	-1.3318
Regression Coefficients	0.7573	0.7321

RESULTS

Calculation of the site amplification factors

The site amplification factors are calculated by the ratio of the peak ground velocity (PGV) of the observation records to the PGV from the attenuation curves for the surface ground of Tertiary deposit.

The relation between the site amplification factors and the average shear wave velocity

The site amplification factors from above definition are calculated to the observation records of WISE system from the peak ground velocities more than 2 cm/sec. The average shear wave velocity ($AVS(30)$) is derived from equation (1). Fig. 5 shows the correlations of the amplification factors for the peak ground velocity (AFV) with the average shear wave velocity ($AVS(30)$).

The open symbols in the Fig.5 are plotted from the earthquake records before the 2003 Tokachi-Oki earthquake in WISE system. The closed symbols in the Fig.5 indicate the amplification factors of PGV in the 2003 Tokachi-Oki earthquake. The regression curves of the both symbols are shown in Fig.5. The regression curve of the open symbols is higher than of the closed symbols about the amplification factors of PGV. This corresponds to the peak ground velocities of the 2003 Tokachi-Oki earthquake are largest among the observation records before this earthquake. The results of this study are consistent with the general tendency of the nonlinearity of the site amplification factors.

Similar relationships were already proposed. Midorikawa et al. [1] proposed the relation between AFV and $AVS(30)$ to the following expression:

$$\begin{aligned} &\log AFV = 1.83 - 0.66 \log AVS(30) \pm 0.16 \\ &[100 m/\sec < AVS(30) < 1500 m/\sec] \end{aligned} \qquad \text{------------------------------ (3)}$$

The one of the relationships is also shown by the broken line in Fig.5. This relationship is derived from the observation records of the 1987 Chiba-Ken-Toho-Oki earthquake. The 1987 Chiba-ken-Toho-Oki earthquake occurred almost 60km east of Tokyo with moment magnitude Mw=6.7. The peak ground accelerations appeared range 30 to 200 cm/sec^2 and the peak ground velocities range 3 to 20cm/sec of this earthquake.

The amplification factors of the peak ground velocity in the results of this study are higher than those from previous studies of formula (3). This suggests that there are regional differences of the amplification factors of the peak ground velocity.

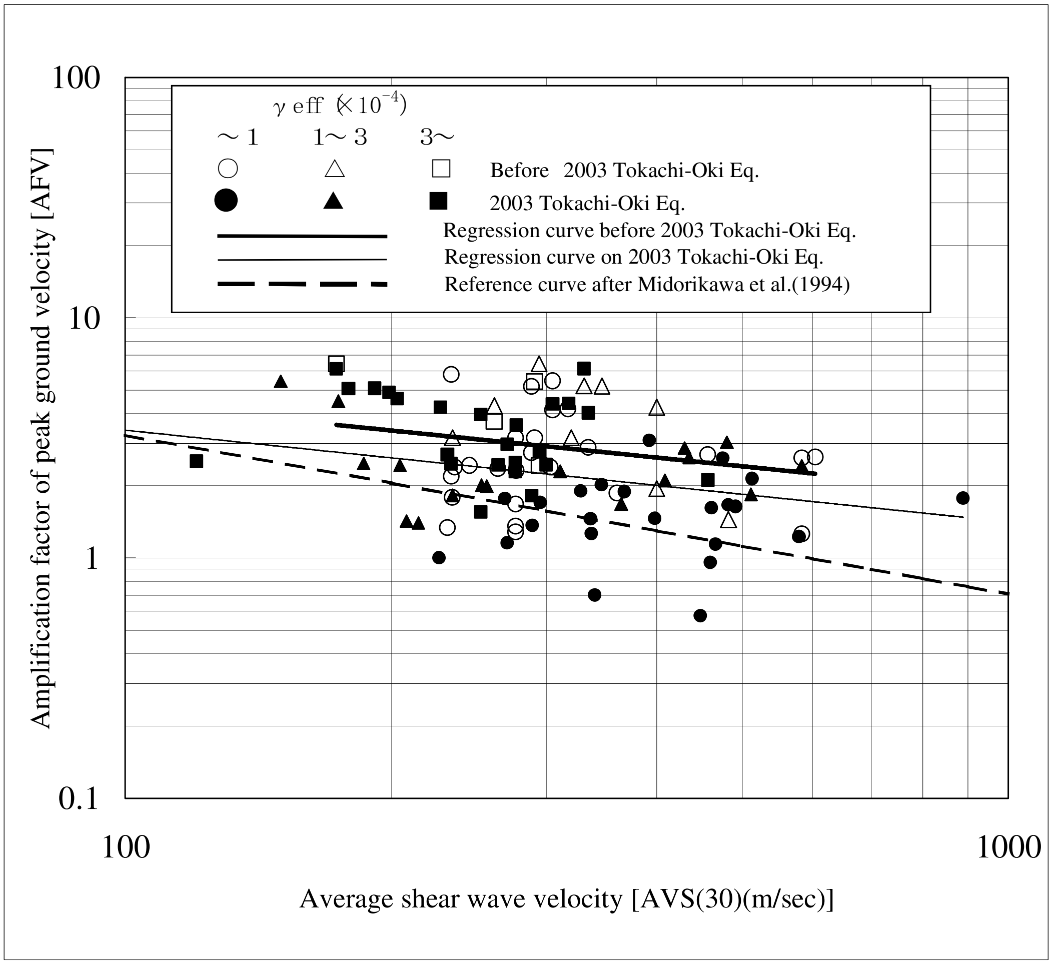

Fig. 5. Relation between the Amplification factors of the peak ground velocity (AFV) and the average shear wave velocity (AVS(30)).

DISCUSSION

The average shear strain levels of the records are evaluated by the ratio between the PGV at ground surface and the average shear wave velocity within the subsurface layers. The effective shear strain is approximately given by

$$\gamma_{eff} = 0.4\left(V_{\max} / AVS(30) \right) \quad \text{--------------------------------------} \quad (4)$$

where γ_{eff} is the effective shear strain, $V_{\max}$ is the peak ground velocity and $AVS(30)$ equals the average shear wave velocity [5]. $AVS(30)$ is substituted the shear wave velocity under the surface of ground from the original paper [5] in the formula (4). So the effective shear strain is lower about ten percent than original formula.

Fig.5 also shows the correlation of the amplification factors of the PGV (AFV) with the average velocity ($AVS(30)$) in the three effective strain levels, as indicated by the level of less than 1×10^{-4} strain,

1×10^{-4} to 3×10^{-4} strain and more than 3×10^{-4} strain. The shear strain level analysis show the effect of the nonlinearity on the amplification factors of the peak ground velocity does not become significant with the shear strain level. These results may be influenced by the using attenuation curves for the surface ground of Tertiary deposit without the correction terms for the attenuation relations corresponding to the anomalous seismic intensity in Hokkaido Japan.

CONCLUSIONS

The site effects from the amplification factors of peak ground velocity are discussed using the records observed at the Warning Information System of Earthquake (WISE) in Hokkaido [6] from 1997 to 2000 earthquakes and 2003 Tokachi-Oki earthquake. The results are as follows.

(1) The correlation of the amplification factors of PGV with the average shear wave velocity is some differences with the previous studies. The amplification factors of PGV in WISE records are higher than those in the Midorikawa (1994) has proposed.

(2) The amplification factors of the peak ground velocity from the 1997 to 2000 WISE data is higher than the data from the 2003 Tokachi-Oki earthquake. This indicates that the peak ground velocities of the 2003 Tokachi-Oki earthquake are largest among the observation records before this earthquake.

(3) The effect of the nonlinearity on the amplification factors of the peak ground velocity does not become significant within the shear strain level equal to 1×10^{-3}. The results of the analysis almost coincide with the previous studies of Midorikawa [2]. However, the results may be influenced by the using attenuation curves for the surface ground of Tertiary deposit without the correction terms for the attenuation relations corresponding to the anomalous seismic intensity in Hokkaido Japan.

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