A modified estimation method for amplification factor of ground and structures using the H/V spectral ratio

Yutaka Nakamura[1]

Abstract

There is a consensus that the predominant frequency of surface ground can be estimated from the H/V spectral ratio of microtremor or strong motion. However, on amplification factor estimated by the H/V spectral ratio, there are still various discussions without any agreements. The author has claimed that the H/V spectral ratio method stands on phenomenon of multi-refraction of SH wave in surface ground. This paper explains a new technique on amplification factor estimation of surface ground based on the H/V spectral ratio. Then this proposed technique is confirmed by the verification with actual measured microtremor and earthquake motion at Mexico City and actual measured microtremor and the damage situation caused by the 2011 Off the Pacific Coast of Tohoku Earthquake at Urayasu.

1. Introduction

The H/V spectral ratio is called QTS, Quasi Transfer Function, according to its function. QTS is useful tool for characteristics investigation of surface ground and buildings. In general the predominant frequency derived from QTS gives extremely good result, but there is an objection against that the peak of QTS is corresponding to the amplification factor. In this paper, a new modification technique for the amplification factor investigation of QTS will be described.

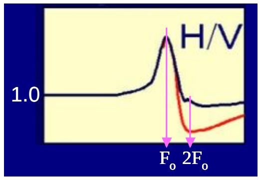
At first the characteristics of QTS are summarized as below;

i) The first peak near F_0 consists of S-wave mainly.
ii) The first trough near $2F_0$ caused by Rayleigh wave.

---

1 System and Data Research Co., Ltd., Japan.

Around F_0 there is almost no energy of Rayleigh waves, so the dispersion curves are unstable near F_0. Rayleigh wave are growing from F_0, and reaches the first peak near the $2F_0$. QTS of both microtremor and strong motion are useful for estimation of at least fundamental frequency F_0 and its amplification factor.



Tipical Shape of QTS

Figure 1 shows the result of comparing QTS of both strong motion and microtremor. These strong motion records were observed at some stations in Mexico City. QTS is supposed to approximate the dynamic characteristics of surface ground. The shape of the ratio as the peak value or predominant frequency can be well in agreement both strong motion and microtremor. It shows that it is possible to estimate the dynamic characteristics from microtremor. However, QTS of microtremor is sometimes shifted to downward. This shift may be caused by spike noise from walkers or Rayleigh waves related to deeper structure.

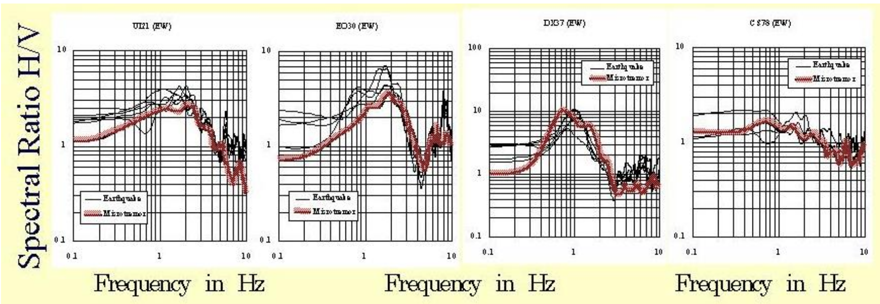


Figure1. *Comparison between Microtremor and Strong Motion on Spectral Ratio H/V, QTS, in Mexico City*

So this paper describes a new technique to estimate the amplification factor of ground and structures using QTS.

2. Fundamental idea

Because vibration at hard and uniform ground has no reason to cause particular bias, it is considered that the vibration is specially and temporally uniform. A boundary of layers or ground surface with high impedance ratio leads a phenomena as reflect or refraction and then causes uneven distribution of wave motion energy. Soft surface layer tends to trap and accumulate the wave motion energy, so the amplitude of the wave motion becomes large. This is the amplification phenomenon of soft surface layer, and at this time the amplified frequency of vertical component V is higher than that of horizontal component H. So it is concerned that the vertical motion is not amplified at the frequency range that the horizontal motion amplified. In case of hard ground, because the vibration characteristics is similar to each other between horizontal motion and vertical motion, it is considered that the vertical motion holds the vibration characteristics of the horizontal motion of the hard base ground at lower frequency range than that horizontal motion amplified at the surface ground. Thus in case of focusing the horizontal motion, it is possible to estimate the amplification characteristics of the surface layer from QTS. This is the basic idea of QTS.

This idea is applicable to not only ground but also buildings. At this time there are two peaks which are corresponding to each, ground and buildings, respectively.

While if pulse noise is mixed in the vertical motion, the spectrum must be superposed uniform spectrum for wide frequency range. In such case, the shape of the spectrum is similar but shifted lowly in all frequency range. This phenomenon is caused by pulsed vibration excited by passing walker or vehicles close to the measurement point. As a result, it is sometimes impossible to estimate the amplification factor correctly by QTS. However even in such case, it is often possible to estimate the predominant frequency.

If it is possible to assume that the surface layer consists of one layer, the vibration at the base ground boundary *B* can be estimated from the vibration at ground surface *S* following the equation below.

$$B(t) = \{S(t + h/Vs) + S(t - h/Vs)\}/2$$

Here, *h* and *Vs* are depth and velocity of shear wave propagation for surface ground. And *F* is predominant frequency of QTS. Then, *h/Vs* can be derived from next equation.

$$h/Vs = 1/4F$$

Transfer spectrum can be calculated as a spectrum ratio between ground surface and basement as follows, and then it becomes to be possible to estimate the amplification factor at predominant frequency.

$$T(f) = F[S(t)](f)/F[B(t)](f)$$

Here, *F[*]* is Fourier transform.

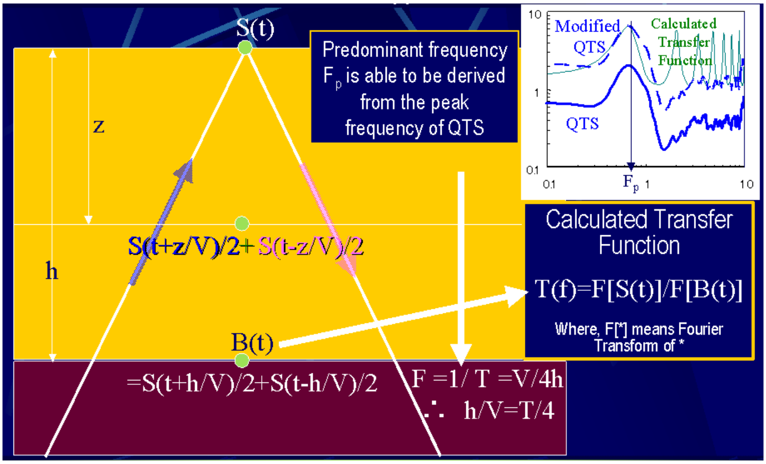


Figure 2. *Illustration of Proposed Method for Amplification Factor Estimation*

Discussion with strong motion records [1] says that the shape of QTS is similar to that of standardized spectrum based on the hard ground even in case of under estimation of QTS amplification. So, here a correction technique for amplification factor of QTS is proposed using estimated peak amplitude of spectrum ratio to estimated base ground above mentioned.

Below are validation and application of this technique.

3. Validation

3.1. Measurement at Mexico City

The analysis of microtremor and strong motion observation in Mexico City gave results below;

i) QTS derived from strong motion at surface ground is almost similar to amplification characteristics corresponding to a reference site with hard surface layer.

ii) QTS of earthquake motion is almost similar to that of microtremor.

Then it is confirmed that QTS of microtremor can appropriate the amplification characteristics of earthquake motion. However there were some cases that QTS of microtremor shifted below even the shape is similar. This is caused by enlargement of vertical component of microtremor in wide frequency range. The factor is seems to be influenced by a spike noise as caused by walkers passing by the sensor unit or other vibration source to excite soft surface ground largely up-to-down. Here is the examples of the correction applied the proposed technique for these sites.

Strong motion observatories in Mexico City CI05 and CJ03 are chosen as examples of sites with lower shifted QTS of microtremor

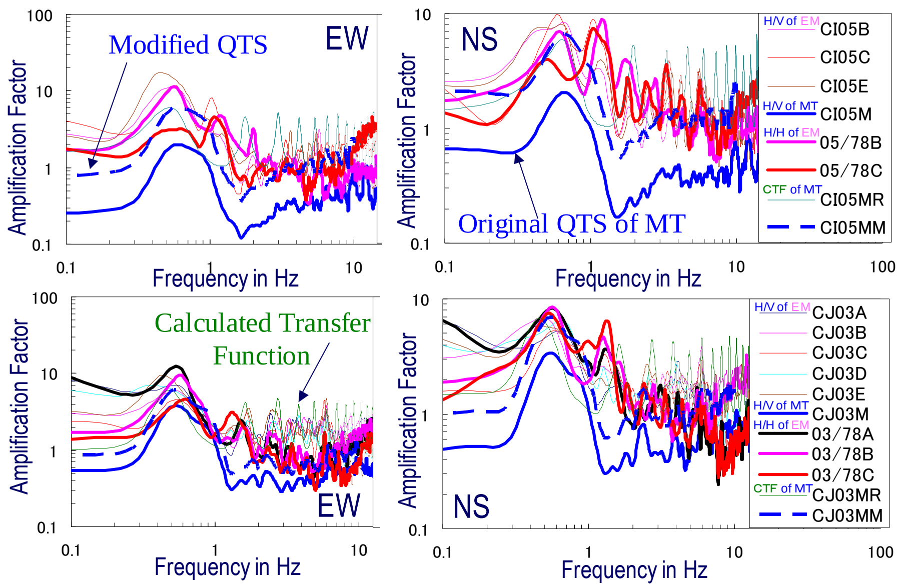


Figure 3. *Verification of Proposed Method for sites in Mexico City*

measurement. Figure 3 shows QTS of earthquake motion layered with H/H spectrum ratio, horizontal component of the site to that of hard ground, for some earthquakes. These spectrums are almost similar to each other even with scattering. QTS of microtremor showed in the same figure shifts beneath largely, although the amplification characteristics curve and its shape agree with the amplification characteristics of strong motion.
On the other hand, Figure 3 also shows the result of calculation of spectrum ratio from estimated base ground waveform derived from the proposed technique in green line and the adjusted QTS of microtremor to fit the first peak in blue dot line. Because corrected QTS can almost agree with targeted spectrum, it shows that the proposed technique is appropriate.

3.2. Result of measurement at Urayasu

Although Urayasu locates more than several hundred kilometers from the focal region of the 2011 Off the Pacific Coast of Tohoku Earthquake (hereafter the 3.11 earthquake), there was one of the severe damaged areas of liquefaction. Here the result of microtremor measurement after the 3.11 earthquake is described.

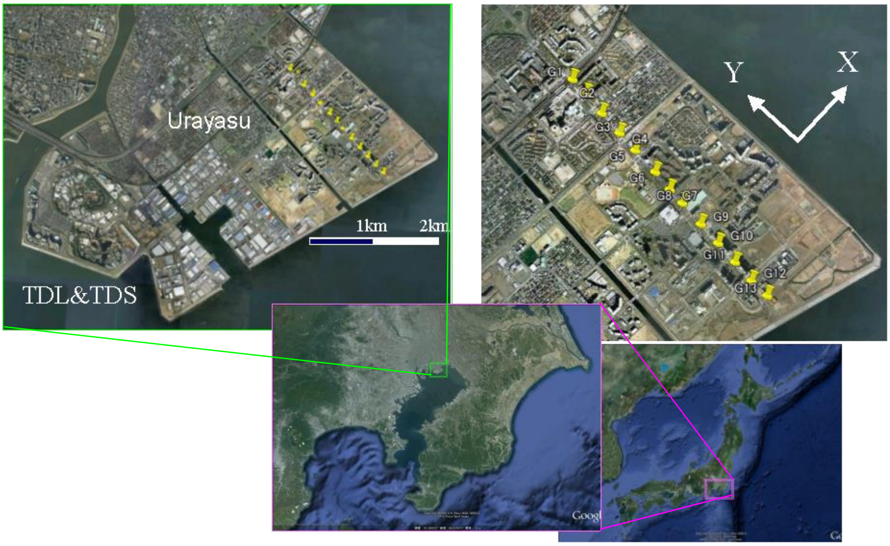


Figure 4. *The Site for Application of Proposed Method*

Figure 4 shows the distribution map of measured sites G1-G13 from a railway station to coast line. This area is rather new reclaimed land filled up till 1980's with pumped sediment from under the sea. Severe liquefaction attacked this area at the time of the 3.11 earthquake and the situation of liquefaction can be seen on YouTube for example recorded between G8 and G9. There was significant liquefaction between G8 and G10 along this measurement line, several photos are shown on Google Earth. And ground subsidence about 40cm was caused by the blow off of sand at G9 shown in Photo 1.

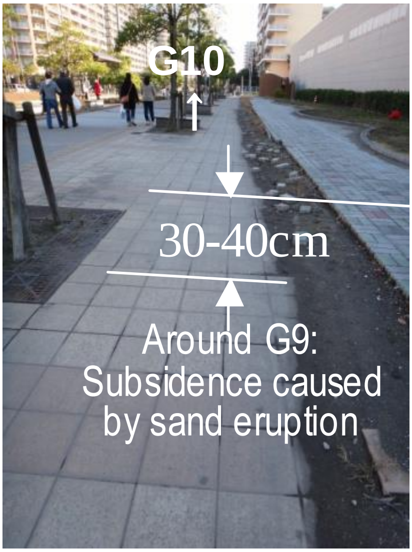


Photo 1. *Situation of around G9: 9 month after the 3.11 Eartquake*

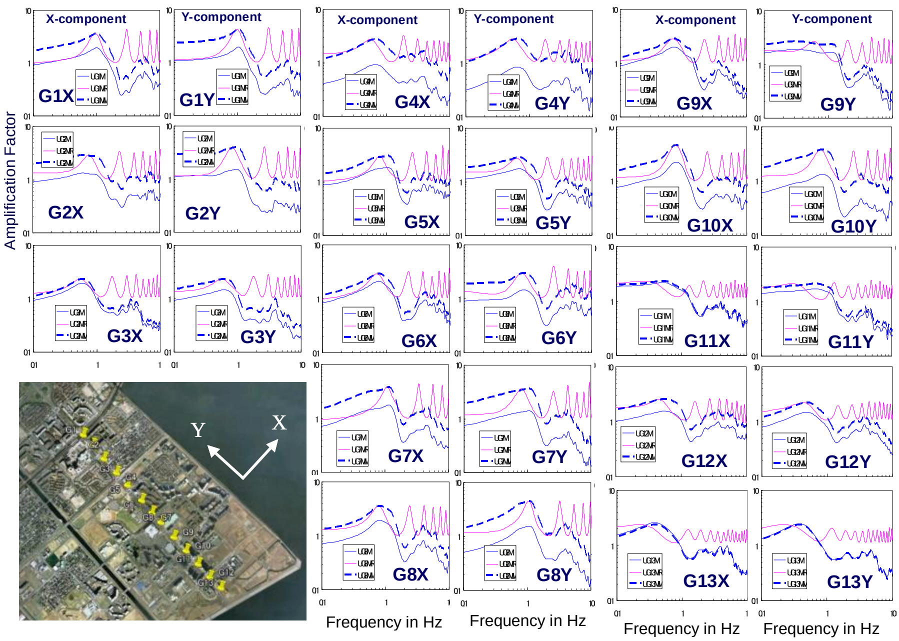


Figure 5. *Original and Modified QTS for G1 to G13 at Urayasu*

Table 1.*Results: Predominat Frequency, Amplification Facotrs, Kg-value, Basement Ground Depth h and Shear Velocity Vs in Surface Layer for each Sites*

Urayasu Site	X-comp. F (Hz)	X-comp. A	X-comp. MA	X-comp. Kg (μ/Gal)	X-comp. h (m)	X-comp. Vs (m/s)	Y-comp. F (Hz)	Y-comp. A	Y-comp. MA	Y-comp. Kg (μ/Gal)	Y-comp. h (m)	Y-comp. Vs (m/s)
G1	1.00	1.94	3.63	13	21	83	1.05	1.95	4.23	17	17	71
G2	0.61	1.33	2.90	14	42	104	1.00	1.53	3.94	16	19	76
G3	0.59	1.95	2.33	9	55	129	0.61	1.47	2.34	9	52	128
G4	0.68	0.94	2.77	11	40	108	0.66	0.86	2.89	13	39	104
G5	1.05	1.85	3.02	9	24	99	0.71	1.76	2.84	11	37	105
G6	0.76	2.11	2.91	11	34	103	0.88	1.47	2.99	10	29	100
G7	1.15	1.78	3.82	13	17	79	1.05	1.41	3.60	12	20	83
G8	0.81	1.94	3.58	16	26	84	1.07	1.55	4.47	19	16	67
G9	0.71	2.01	2.84	11	37	106	0.29	1.91	2.67	24	96	112
G10	0.83	2.25	4.59	25	20	65	0.85	1.32	3.77	17	23	80
G11	0.51	2.18	2.33	11	63	129	0.68	1.72	2.13	7	52	141
G12	0.56	1.55	2.55	12	52	118	0.49	1.49	2.22	10	69	135
G13	0.39	2.59	2.40	15	80	125	0.39	2.48	2.39	15	80	126

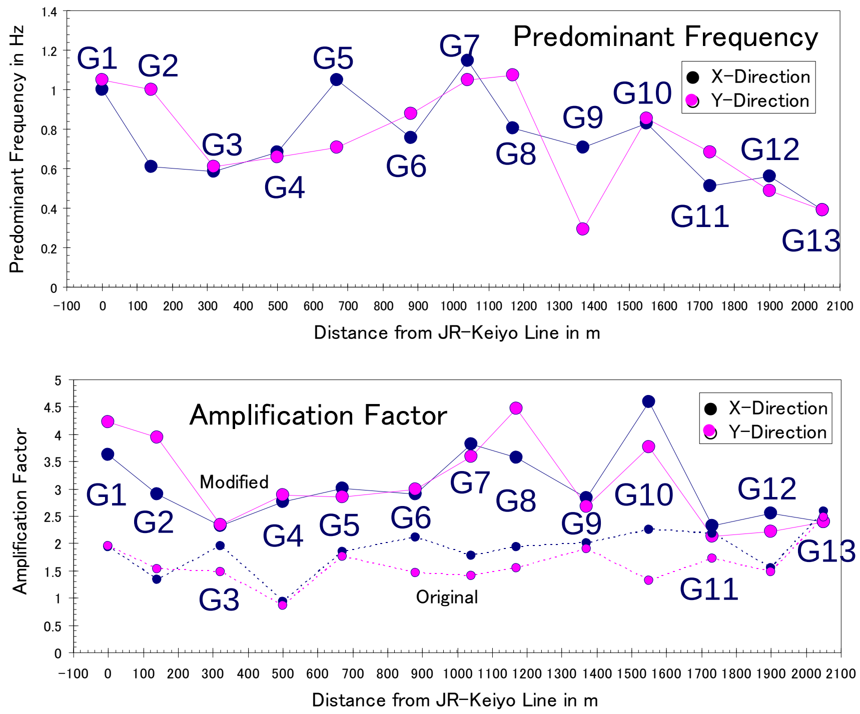


Figure 6*. Estimated Predominant Frequencies and its Amplification Factors*

Figures 5 to 10 show the result of microtremor measurement. Figure 5 shows the result of comparison of amplification factor between before and after applying the proposed technique. Figure 6 show the distribution of estimated predominant frequency and its amplification factor with modified amplification factor. There seems to be pulsed waveform in many portions on the microtremor waveform in Figure 7. The amplification factor does not differ from before and after the correction at G13, and there is almost no pulse noise on the microtremor waveform shown in Figure 7.

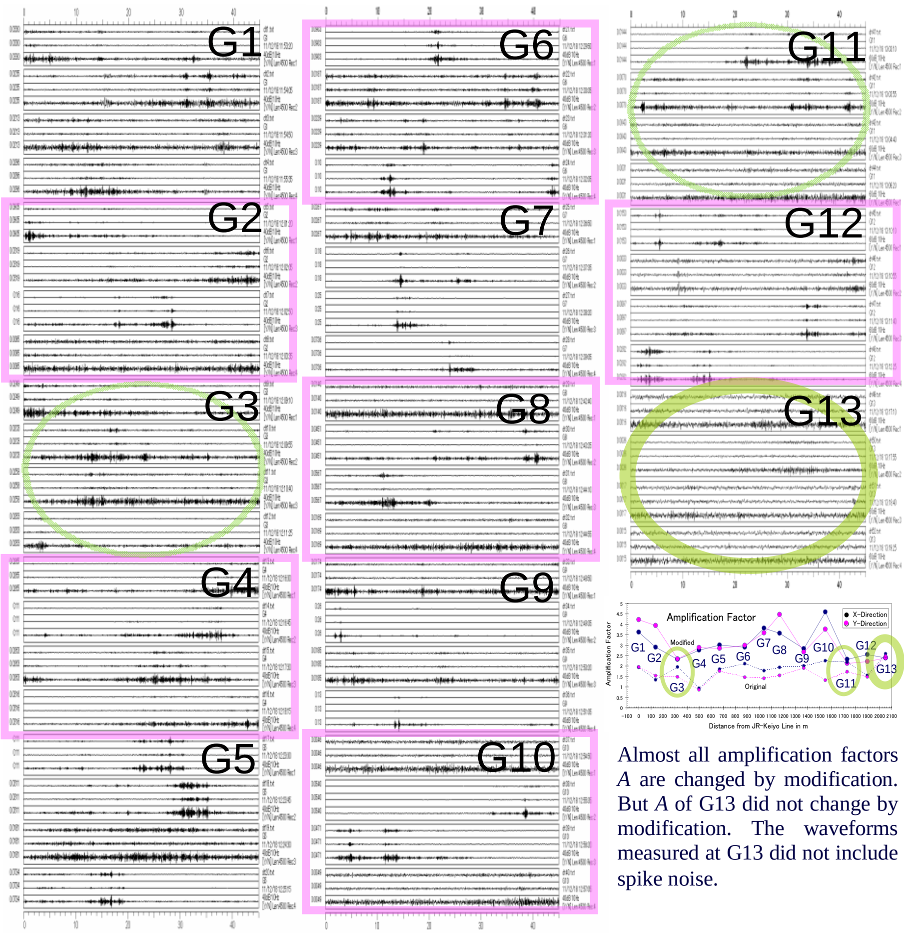


***Figure 7**. Waveforms of Microtremor at Urayasu*

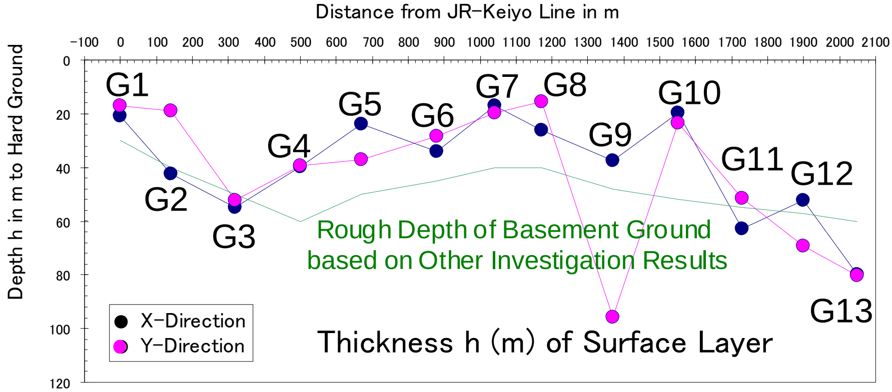


Figure 8. *Distribution of Depth h of Basement Ground along the measuring line of Urayasu*

Table 1 shows the calculated Kg-value, depth of base ground and shear wave velocity of surface ground derived from the predominant frequency of QTS and corrected amplification factor. Table 1 also shows the used equations (see detail [2]). Here, the shear wave velocity of base ground is assumed 300m/sec, instead of 600m/sec in common, from the result of boring investigations in this area.

Figures 8 to 10 are distribution of these indices corresponding to each measured site. Figure 8 for estimated depth of base ground also shows outline of the interpreted depth of base ground from a map in public, and these depth agrees with each other. Figure 9 shows distribution of Kg-value, location of large Kg-value corresponds to severe damaged

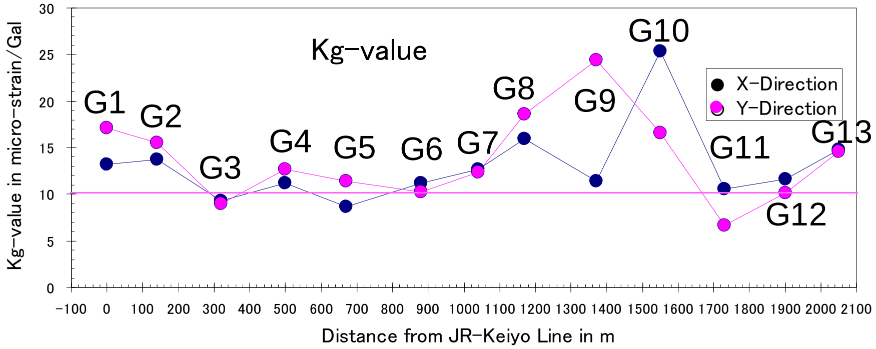


Figure 9. *Ditribution of Kg-value along the measuring line of Urayasu*

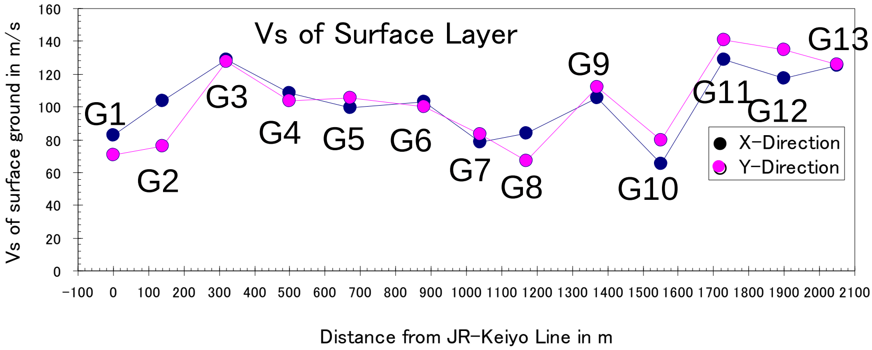


Figure 10. *Distribution of Vs along the measuring line of Urayasu*

area and to damage situation clearly. However, the result of analysis on G9, in the area with blowing up heavily of liquefaction sand, shows quite different result depending on the direction. It suggests that Kg value is possibly changed by the liquefaction during earthquake motion. There is no wonder if Kg value is changed by land deformation. For example, repeated liquefaction was observed during 2010 to 2011 in New Zealand and there is a possibility that it is able to grasp the change of Kg value if microtremor was measured in each case of liquefaction occurrences. Figure 10 is distribution of *Vs* of surface ground. According this figure, *Vs* are distributed between 70m/s and 140m/s around 100m/s, and low velocity corresponds to large Kg-value. The result of analysis of microtremor at Urayasu shows propriety of the amplification factor correction with the proposed technique.

4. Conclusions

This paper proposed a technique to solve phenomenon not to be able to estimate the amplification properly with pulse noise, one of the problems on estimation of surface ground characteristics from QTS. This technique is simple technique that estimating a waveform at base ground from observed waveform based on the wave theory, estimating amplification factor of noticed frequency from each spectrum, and then correcting the amplification factor estimated from QTS. This paper confirmed that this technique can correct the amplification factor properly and estimate the surface ground characteristics more effectively with applying to the actual measured records. The author believes that this technique improves the reliability of QTS method and extends its application range.

Acknowledgement

The author appreciates cooperation of CIRES, *Centro de Instrumentación y Registro Sísmico*, for arranging microtremor measurements and provision of strong motion records in Mexico City. The author had a lot of helping from Mr. Saita of the senior research engineer of SDR, System and Data Research. I would like to express my gratitude to him.

References

[1] Nakamura, Y.: A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface, *Quarterly Report of RTRI*, Vol.30, No.1, pp.25-33, 1989.1.

[2] Nakamura, Y.: Real-Time Information Systems for Hazards Mitigation, *Proceedings of 11th World Conference on Earthquake Engineering*, Acapulco, Mexico, 1996.6.

[3] Nakamura, Y,: Clear Identification of Fundamental Technique and its Applications, *Proceedings of 12th World Conference on Earthquake Engineering*, paper #2656, Auckland, New Zealand, 2000.7.

[4] Gurler, D. G., Nakamura, Y., Saita, J. and Sato, T.: Local Site Effect of Mexico City Based on Microtremor Measurement, *Proceedings of 6th International Conference on Seismic Zonation*, 2000.11.