A Trial of Quantitative Evaluation on the Difference in Estimated Seismic Ground Motions using Microtremor Measurements

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SUMMARY
Prediction of possible strong ground motions at the site for a construction of a structure is important in the seismic design of the structure. For this purpose, the on-site observations of the seismic motions in medium-size earthquake prior to the seismic design can be an effective methodology. However, the distances between the observation sites and the target site for seismic design can cause errors in the estimated results. It is important to estimate the similarities between seismic motions at the target site and the sites of the observations.
In this study, we studied a method to evaluate the differences between estimated ground motions at two sites. The method is based on the differences in H/V spectrums obtained by microtremor measurements. First, in order to capture the differences between two seismic motions, the ratio of response spectrum was proposed as 'the evaluation index for similarity'. The relationship between the differences in estimated seismic ground motions and differences of peak frequencies in the H/V spectra was also investigated from a former research result. And, with the obtained relationship, a method was proposed to evaluate the differences in seismic ground motions from the differences in peaks of H/V spectra.

Keywords: Seismic motions, microtremor, H/V spectrum, response spectrum

1. INTRODUCTION

There are some methods to evaluate the possible strong motion waveform in future at a site. In these methods, the seismic motion observation of small to medium size earthquake at the target site is often utilized to evaluate the site response characteristics at the site[1)]. However, it is not always easy to install the seismometer at the just point of the site. In many cases, the locations of the observation site and the construction site are slightly different, and the difference of the location could cause an error on the estimated results. Therefore, it is expected to have a method to evaluate the possible differences of the estimated strong motions due to the difference of the locations. Here, the differences of the estimated strong motions are the difference in peak value, Fourier amplitude and phase characteristics, etc.

In this research, we focused on the strong motion evaluation method by the correction of site amplification factor by the difference of the peak frequencies in microtremor H/V spectrum[2)]. Assuming the method is appropriate, a method to evaluate the differences in the estimated strong motions from the difference in microtremor H/V spectrum is proposed. In addition, the applicability of the proposed method is examined by the observed distribution of seismic intensity within Kure city in 2001 Geiyo earthquake, Japan.

2. A PROPOSAL TO EVALUATE THE POSSIBLE DIFFERENCE IN ESTIMATED GROUND MOTION

2.1. An index to evaluate the possible difference in estimated ground motions

In this research, as the index to evaluate the quantitative difference in strong motions, an index based on the shape of response spectrum is proposed. From the response spectrum for strong motion A and B, the ratio of spectrum value in each frequency (B/A) shall be calculated. In other word, the response spectrum of strong motion B shall be divided by the response spectrum of strong motion A. If the strong motion A and B are identical, the ratio shall be 1.0 for whole frequency range. However, in reality, the strong motions are never identical. We define a reference value for the ratio, and the difference between the calculated ratio and the reference ratio shall be integrated. This integration gives the area between the calculated ratio line and the reference ratio line in the figure of response spectrum ratio. We propose the integrated value as the index, as shown in Figure 1. The area of the response spectrum is often used as indexes of the power of strong motion such as the SI value, and the proposed index consider the both power and frequency characteristics of the motions.

The reference ratio should be 1.0 in the case when the observed motion and the estimated motion at a same site are compared. In the case when two motions at different sites are compared, the fact that the attenuation effect depends on frequency should be considered, and the reference ratio varies shall be different in each frequency. However, in this paper, the difference of the reference ratio in frequency was ignored for simplicity.

There are several possible procedures to integrate the area between the calculated ratio line and the reference ratio line. In this paper, the area was calculated in logarithmic axis for both vertical axis (response acceleration) and horizontal axis (frequency). The frequency range for integration was 0.5 to 2.0 Hz, in in which the shaking have much influence on the damage level of earth works.

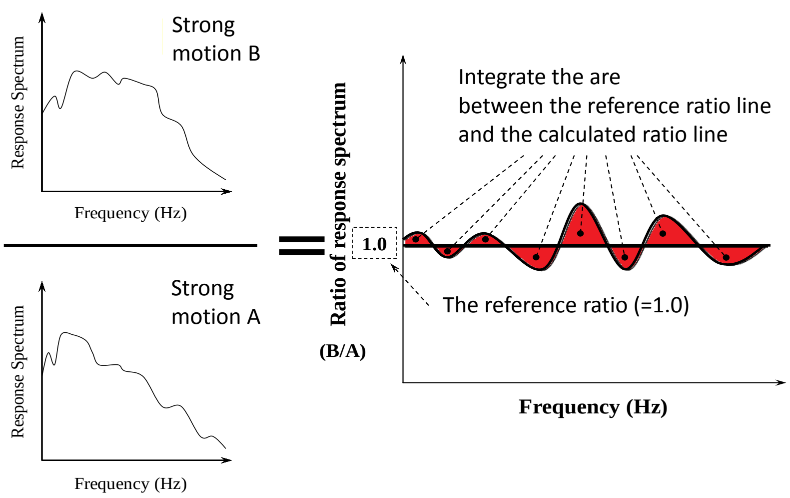


Figure 1. The proposal of the index for the difference of two motions

2.2. An example of the strong motion estimation based on microtremor measurement

Hata et al. estimated the strong motions for the sites along Noto toll road, where slope failures were observed in 2007 Noto Hanto Earthquake, based on microtremor measurement results[3)]. They divided the target area into 4 zones based on the microtremor measurement results. And short term seismic observation was conducted in each zone to estimate the site amplification characteristics. Then, the evaluated site amplification characteristics were applied to each site aling the road with corrections based on the microtremor measurement results.

Figure 2 shows the location of the microtremor measurements along the road, and Figure 3 shows the short-term seismic observation station (the sites where the site amplification factors were evaluated by seismic observation) and the other sites (the site where the site amplification factors were given by the correction to the that of seismic observation station based on the mictororemor measurements). In each zone where the site amplification characteristics might be similar since the characteristics of the microtremor were similar, a seismometer was installed (in detail, T-9, M-10, T-10, and T-38). Then, the site amplification characteristics at these sites were evaluated by the small to medium size seismic motion observation. The evaluated site amplification characteristics were also used for other sites where no seismic observation was conducted. In this application, corrections for the site amplification characteristics were applied based on the microtremor measurements (H/V spectrum) at the target site and the short-term seismic motion observation site (in detail, T-9, M-10, T-10, and T-38). This correction was introduced in the current design standard for Japanese port structures as the second best method. The schematic illustration of the correction was shown in Figure 4. The background of the correction is that the shape of the site amplification characteristics corresponds to the shape of H/V spectrum of microtremors, quantitatively at least to the peak frequency, and qualitatively to the overall shape including the amplitude level.

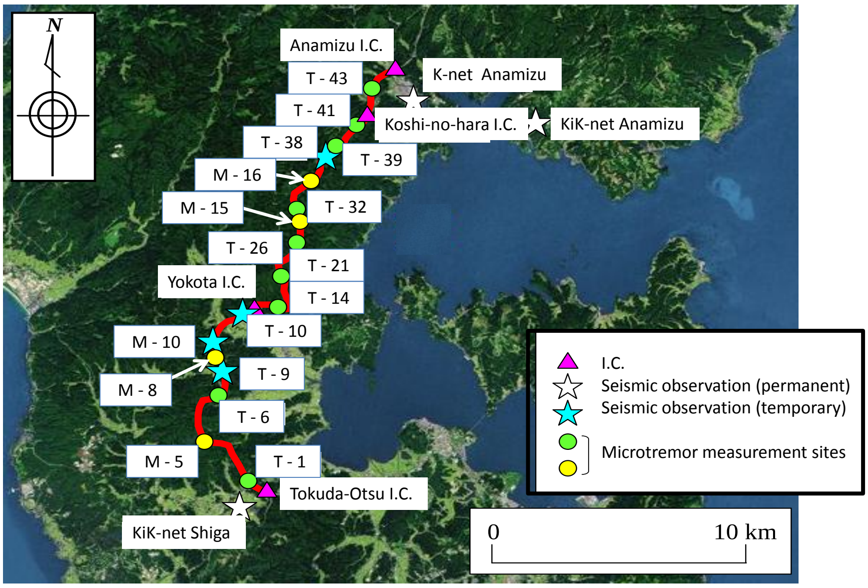


Figure 2. The target sites along the Noto toll road[3)]

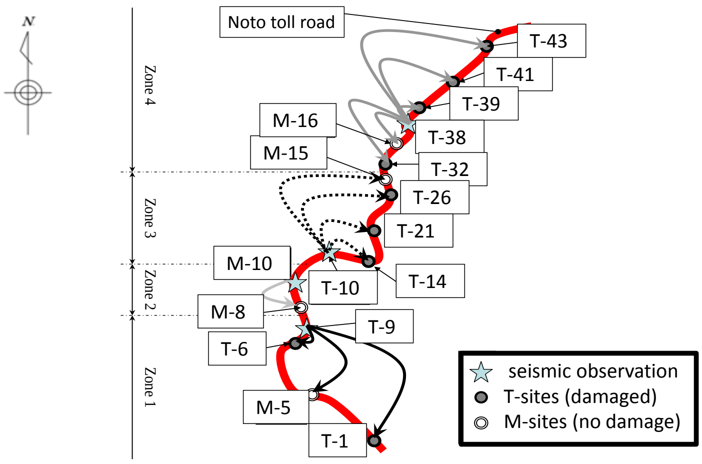


Figure 3. The pair of the sites for the correction of site amplification characteristics[3)]

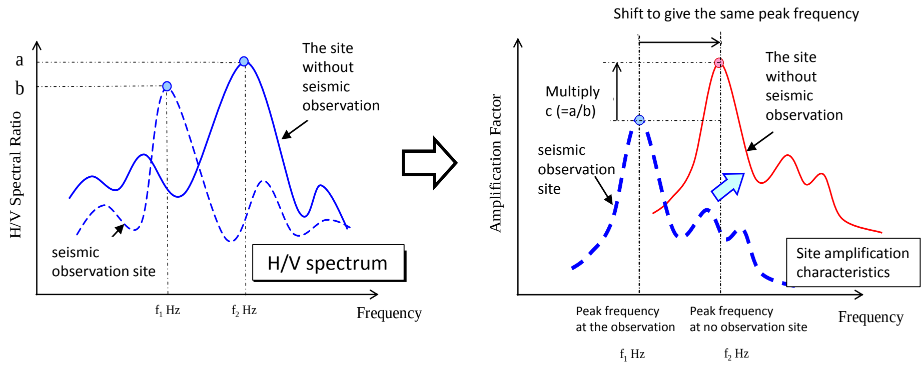


Figure 4. Schematic illustration of the applied correction procedure

2.3. Differences in estimated strong motions and microtremor measurement results

The ratio of response spectrum for the each pair of the sites (the short-term seismic observation site and the site where the corrected site amplification characteristics were calculated) was considered to give the difference index of estimated strong motions. Thus, the relationship between the difference index of estimated motions and the difference in microtremor measurement results can be discussed. Here, the difference in microtremor measurement results is evaluated just by the difference in peak frequency for simplicity. Furthermore, only the absolute value of the difference is focused ignoring the difference in positive or negative. In zone 1, 3 pairs of the sites (T-1/T-9, T-6/T-9, M-5/T-9) were considered. In zone 2, only 1 pair of the site (M-8/M-10) can be considered. 4 pairs (T-14/T-10, T-21/T-10, T-26/T-10, M-15/T-10), and 5 pairs (T-32/T-38, M-16/T-38, T-39/T-38, T-41/T-38, T-43/T-38) were considered in zone 3 and zone 4, respectively. Although the vertical component was ignored, 2 times of the plots can be obtained considering 2 horizontal directions.

Figure 5 shows the relationship between the difference index of estimated motions and the difference in peak frequencies of microtremor H/V spectrum. The value for the horizontal axis is given as the ratio of the peak frequency at the target (corrected) site to the peak frequency at the short term seismic observation site. Considering the fact that the difference index should be zero in the case when the peak frequency at the target (corrected) site and the short term seismic observation site coincident and no correction was applied, the obtained results were approximated by lines going through the origin. The inclinations of these lines differ depending on zones. This is because the effect of the correction depends on the shape of the site amplification characteristics. If the site amplification factors have a sharp peak, the effect of correction might be significant. Conversely, if the site amplification factors were flat shape, the effect of correction is small. This can be confirmed from the ratio of corrected site amplification factors to the original site amplification factors. Figure 6 shows the calculated ratios of site amplification factors and the difference in peak frequencies used in the correction. Figure 6 shows the same tendency observed in Figure 5, showing the larger difference (larger inclinations) is observed in the order of zone 1 > zone 4 > zone 2 > zone 3.

2.4. A proposal of the method to evaluate the difference of estimated motions

The lines shown in Figure 5 enable the evaluation of the difference of estimated motions by measuring the difference in peak frequencies of microtremor H/V spectrum. Although there are 4 different lines in Figure 5, the choice of the line for the evaluation can be done as follows. Considering the fact that Figure 6 is similar to Figure 5, Figure 7 is obtained as the relationship between the inclination of the lines in Figure 6 and the inclination of the lines in Figure 5.

a) The site amplification factors at the target area should be obtained.

b) Apply the correction of the peak frequency of the site amplification factors to the obtained factors to give slightly different peak frequencies. Then the ratios of the corrected factors and original factors are calculated for these corrections as indexes of the difference.

c) The variation of peak frequency applied in the above step and the calculated indexes of difference are compared as same as the Figure 6. Thus, the inclination of the lines for Figure 6 in this case is obtained.

d) Figure 7 should be used to calibrate the inclination of the line in Figure 5, from the inclination of the line in Figure 6 obtained above step.

e) Based on the inclination of the line in Figure 5 (given from the Figure 7), the difference of estimated strong motions can be evaluated from the difference in peak frequencies of microtremor H/V spectrum using the scheme of Figure 5.

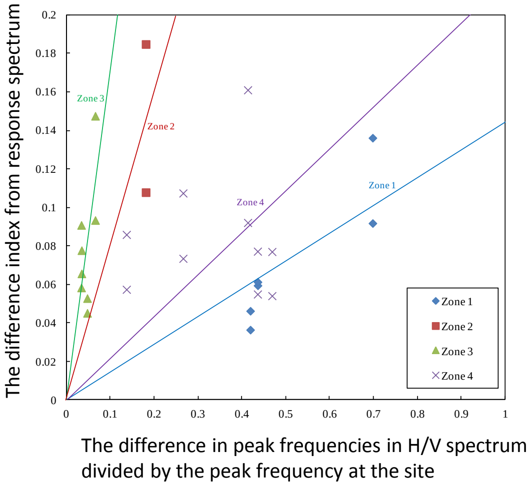


Figure 5. The relationship between the difference index of estimated motions and the difference in peak frequencies of microtremor H/V spectrum

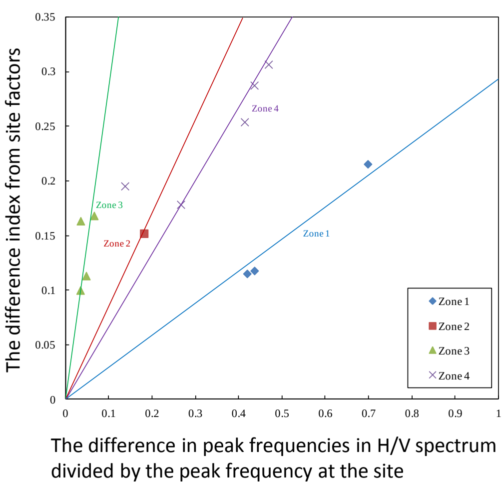


Figure 6. The relationship between the difference in corrected site factors and the difference in peak frequencies of microtremor H/V spectrum

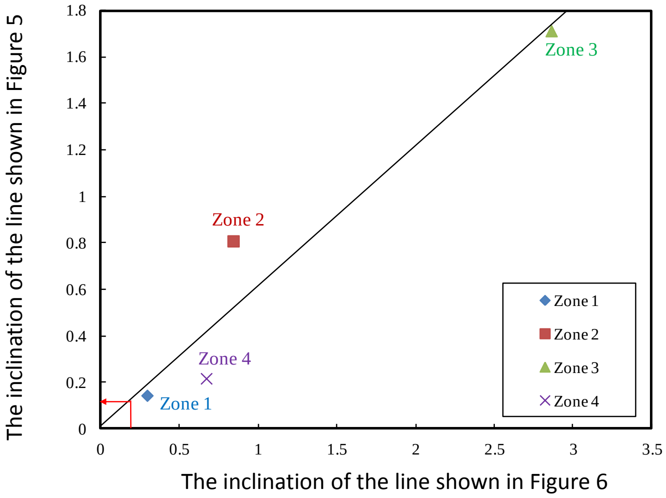


Figure 7. The relationship between the lines in Figure 5 and the lines in Figure 6

3. EXAMINATION OF THE APPLICABILITY OF THE PROPOSED METHOD

3.1. Microtremor measurements in Kure City, Japan

A questionary survey to investigate the distribution of the seismic intensity was conducted in Kure City, Hiroshima, Japan, after the 2001 Geiyo Earthquake[4]. Figure 8 is the distribution of seismic intensity in Kure City given from the survey. Figure 9 is the site amplification factors at K-NET Kure site[5]. Figure 10 is the summary of obtained microtremor H/V spectrum. Figure 11 show the contour of the difference of peal frequency from that of the K-NET Kure site. The microtremor measurements were conducted as 100 Hz sampling for 660 sec, and 3 sections of 163.84 sec. were analysed. Parzen window of 0.05 Hz was applied to each spectrum, and the average of 3 sections was shown in Figure 10. Figure 10 indicates that the peak frequency is relatively high in Kure City, except for the Yakeyama site where no clear peak was observed. In the following analysis and Figure 10, Yakeyama site was excluded.

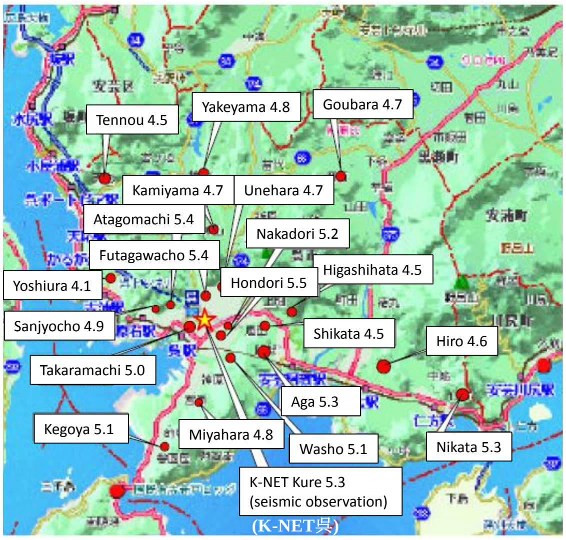


Figure 8. Estimated seismic intensities in Kure City[4]

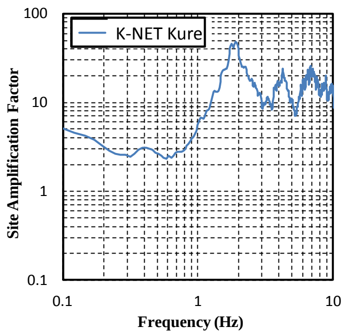
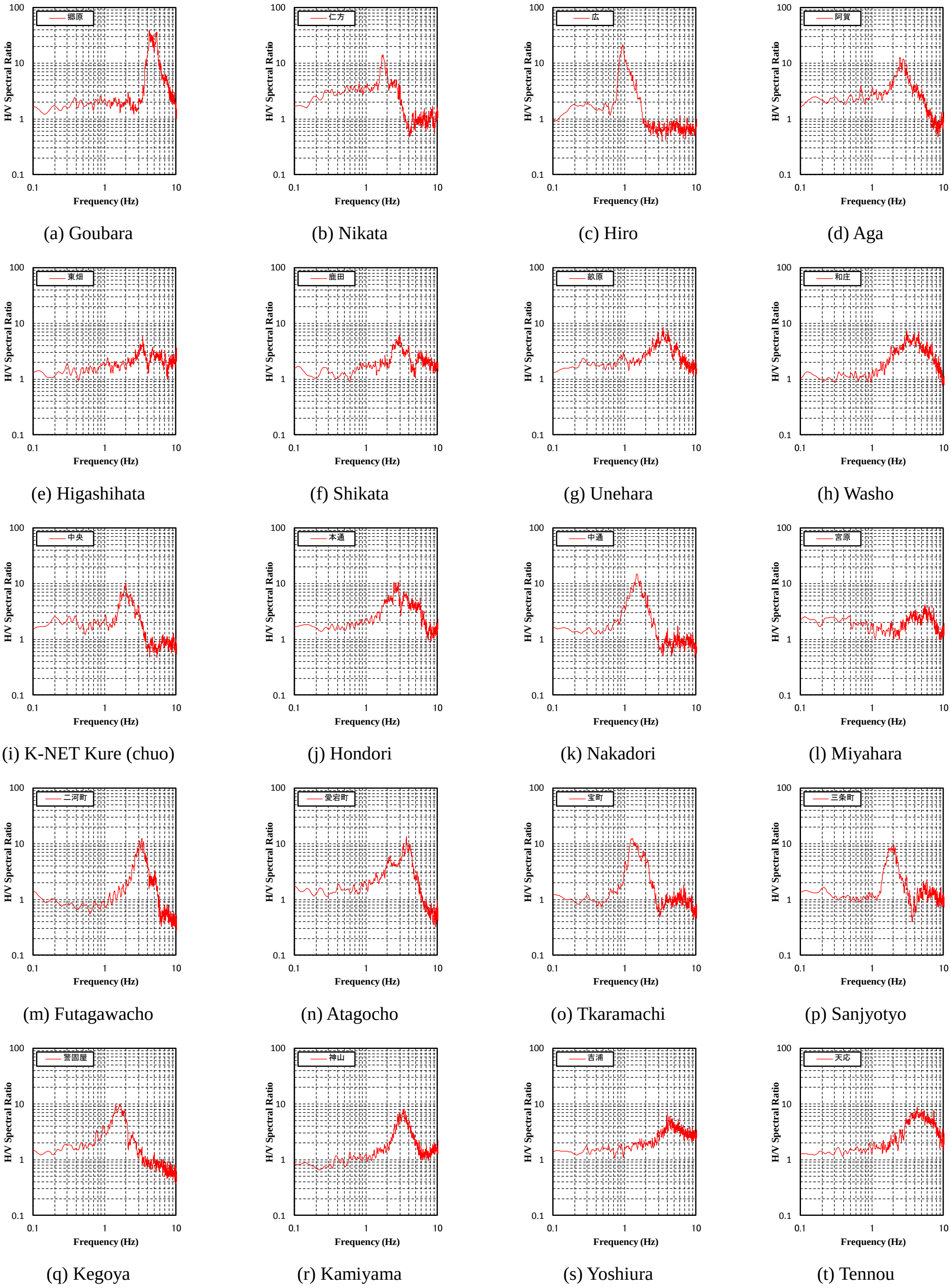


Figure 9. Site amplification factor at K-NET Kure site[5]

3.2. The result of the application of the proposed method to Kure City, Japan

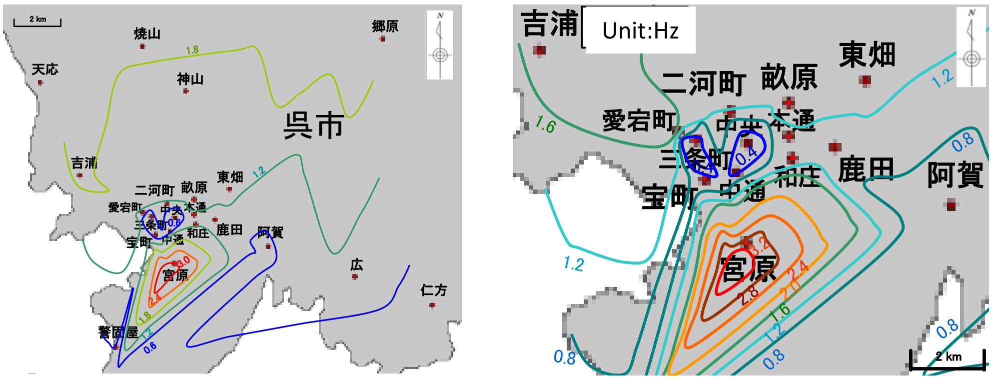
The proposed method was applied to the microtremor measurement results in Kure City. Figure 12 shows the difference of corrected site amplification factors to the correction of peak frequency, which was obtained in the step (b) of the proposed method. The inclination of the line for the site amplification factor at K-NET Kure site is 0.23. Then, from Figure 6 (shown in magnification at Figure 13), the inclination for the evaluation of the difference in estimated seismic motions (the inclination of the line in Figure 5) is 0.16.



(a) Goubara (b) Nikata (c) Hiro (d) Aga
(e) Higashihata (f) Shikata (g) Unehara (h) Washo
(i) K-NET Kure (chuo) (j) Hondori (k) Nakadori (l) Miyahara
(m) Futagawacho (n) Atagocho (o) Tkaramachi (p) Sanjyotyo
(q) Kegoya (r) Kamiyama (s) Yoshiura (t) Tennou

Figure 10. The observed H/V spectrum at each site

From the Figure 11, the estimated difference in evaluated seismic motion can be calculated easily. The contour line for the evaluated difference from the K-NET Kure site is shown in Figure 14. It was given just by the multiplication of 0.16 to Figure 11.



(a) Overview (b) Magnified view of the central city area

Figure 11. The contour of the difference in peak frequency of H/V spectrum of each site from that of the K-NET Kure site

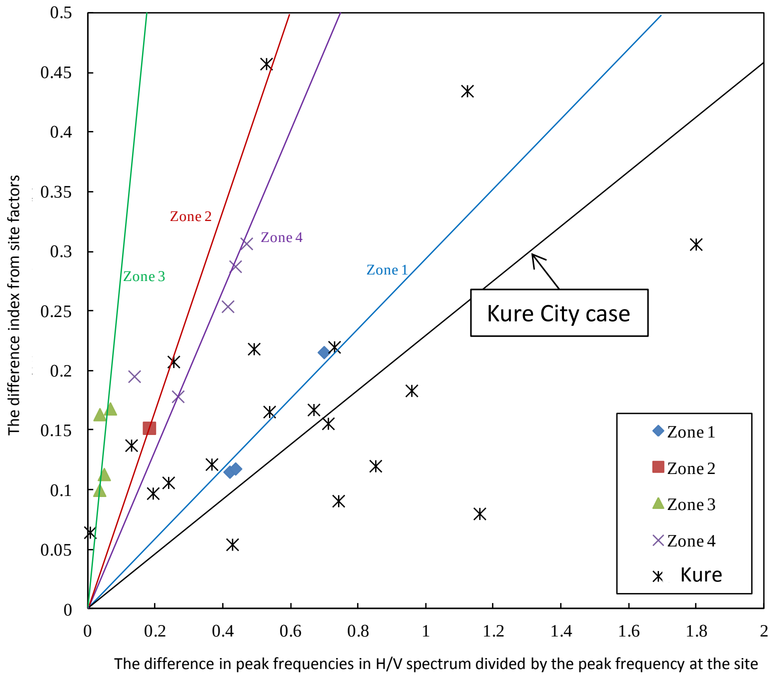


Figure 12. The relationship between the difference indexes of corrected site amplification factors and the difference in peak frequencies of microtremor H/V spectrum for Kure City case

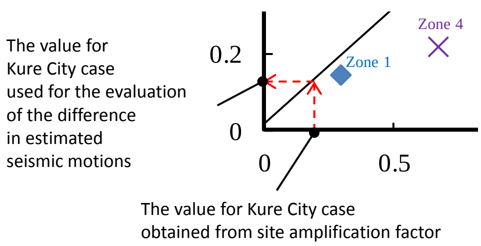
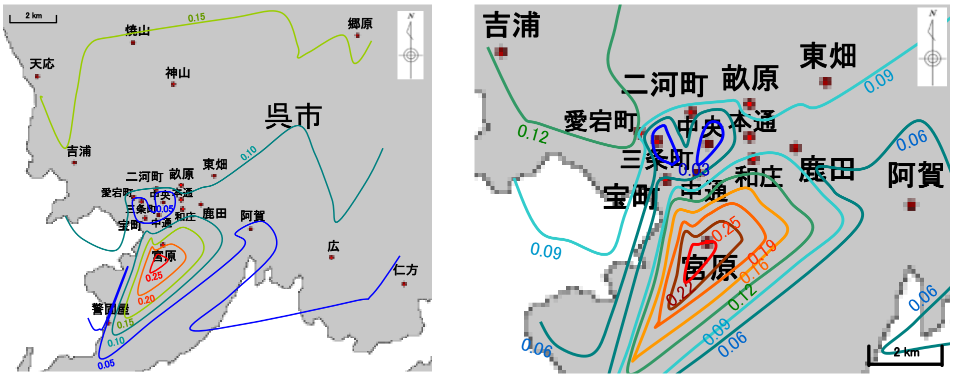


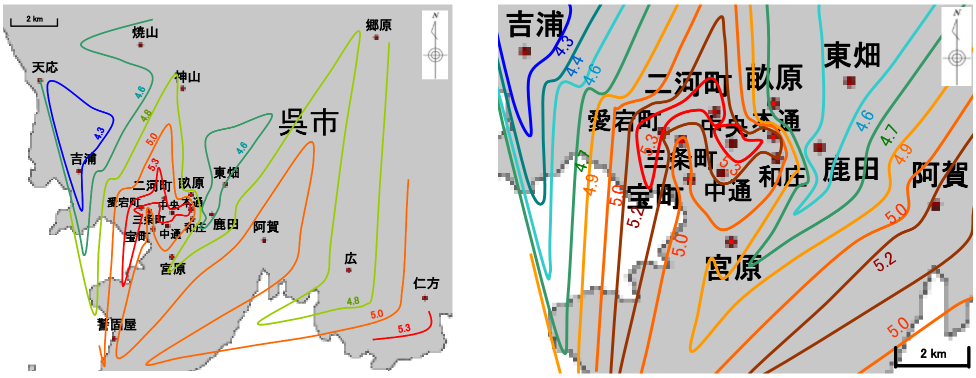
Figure 13. The evaluation of the inclination for the evaluation of the difference in the estimated seismic motions

Figure 15 shows the contour of the difference of the seismic intensities of the sites from that of the K-NET Kure site. Although there are many discrepancies in detail, overall trend is similar. Figure 16 shows the comparison of the estimated difference of seismic motions for each sites and the observed difference of seismic intensity, both of the value are given as the difference from the value of K-NET Kure site. In general, it looks a certain level of agreement.



(a) Overview (b) Magnified view of the central city area

Figure 14. The contour of the estimated difference in the response spectrum of estimated motion from that of the K-NET Kure site



(a) Overview (b) Magnified view of the central city area

Figure 15. The contour of the difference of the seismic intensities of the sites from that of the K-NET Kure site.

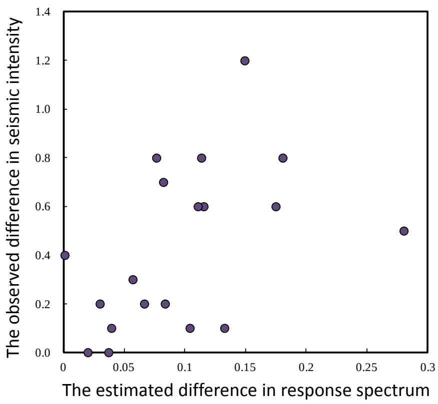


Figure 16. The comparison of the estimated difference (in terms of response spectrum) and observed difference (in terms of seismic intensity)

4. CONCLUSIONS

In this study, we proposed a method to evaluate the differences between estimated ground motions at two sites. The method is based on the differences in H/V spectrums obtained by microtremor measurements. In addition, the applicability of the proposed method is examined by the observed distribution of seismic intensity within Kure city in 2001 Geiyo earthquake, Japan. Following conclusions are obtained.

1) In order to capture the differences between two seismic motions, the ratio of response spectrum was proposed as 'the evaluation index for similarity'.

2) The relationship between the differences in estimated seismic ground motions and differences of peak frequencies in the H/V spectra can be given from the shape of site amplification factor at the sites.

3) With the abovementioned relationship, the difference in estimated seismic ground motions can be evaluated by the difference in the peak frequencies of microtremor H/V spectrum.

4) A certain level of the applicability of the proposed method was confirmed by the comparison of estimated difference in response spectrum and observed difference in seismic intensity, in the Kure City case of 2001 Geiyo Earthquake, Japan.

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