OPINION

What Is the Nakamura Method?

INTRODUCTION

The "Nakamura method" is a technique for estimating the resonance frequency and amplification of ground motions influenced by a surface layer. These influences are calculated by dividing the spectrum of the horizontal component by the spectrum of the vertical component (i.e., horizontal-to-vertical [H/V] spectral ratio [HVSR]) of microtremors or earthquake motions. Each element of the method had originated in Japanese publications (e.g., Nakamura and Saito, 1983), and then summarized in English articles (Nakamura, 1989, 2000, 2008, 2009). Although the applicably of the Nakamura method has been widely cited, there still exists a fundamental misconception that it is based on the characteristics of Rayleigh waves. In this opinion, I outline the background and development of the Nakamura method to clarify what is the Nakamura method, and to avoid further confusion.

BACKGROUND OF THE NAKAMURA METHOD

In late 1978, as a researcher at the Railway Technical Research Institute, I began research to improve the seismic safety of structures of the Shinkansen railway lines. My first task was the development of an earthquake early warning system, which was eventually implemented for the Shinkansen system (Nakamura, 1995). During the development, I pursued the goal of constructing not only an alert system but also a completely new and comprehensive earthquake disaster prevention system. The Nakamura method was one of the key technologies in this disaster prevention system.

CHARACTERISTICS OF EARTHQUAKE MOTION AND IDENTIFICATION OF *P* AND *S* WAVES

Because the earthquake *P*-wave initial motion is utilized for early warning, it is important to identify and distinguish the onset of the *P*-wave within the detected motions. I therefore focused on the ratio of the horizontal component to the vertical component to discern wave types. The vertical component of motion should predominately consist of *P* waves, and the horizontal component of motion should be of *S* waves, if the waves are incident waves from below. Thus, the V/H is expected to be large during *P*-wave arrivals and small during *S*-wave arrivals. *P*- and *S*-wave arrivals can be recognized simply and reliably in this way (e.g., Nakamura, 1995).

I also found a difference in the characteristics of horizontal- and vertical-wave components recorded on soft sites versus hard ground sites after *S*-wave arrivals at various sites. The horizontal component is consistently larger than the vertical component at soft ground sites, whereas the horizontal and vertical components are almost equal and show similar waveforms at hard ground sites (e.g., Nakamura and Saito, 1983).

Because it was difficult to manually analyze the analog earthquake accelerogram on photographic paper at that time, we began by reading the maximum value. We compared the maximum value of the horizontal and vertical earthquake motions, both on hard ground sites and on soft deposits overlying hard ground (e.g., Nakamura and Saito, 1983, in Japanese; or Nakamura, 2000). Notably, the H/V ratio of the maximum value at soft ground sites (fill site, or "f"), $H_{f\,max}/V_{f\,max}$, is similar to the ratio of the horizontal maximum value of soft ground to the horizontal maximum value of hard ground sites (bedrock, or "b"), $H_{f\,max}/H_{b\,max}$, which is the amplification factor. The horizontal and vertical maximum values measured on hard ground are almost the same, $H_{b\,max}/V_{b\,max} \simeq 1$, meaning there is little amplification at hard ground sites. This was the origin of the Nakamura method, which was initially based on recordings of earthquake ground motions.

APPLICATION OF MICROTREMOR ANALYSIS

Microtremors were measured early on in Japan to estimate the characteristics of surface materials. Because of the unknown sources and wave types within microtremors, applications were limited to classification of the surface ground (Kanai and Tanaka, 1961). Even this application was limited because frequency analyses of microtremors yield peaks of unknown origins, and it was difficult to determine the predominant frequency of the measurement site objectively. Furthermore, recommendations were for microtremor measurements to be conducted around 3–4 a.m. to minimize noise from human activities, severely compromising convenience. Therefore, I tested the validity of results from microtremor measurements made over time periods of more than 30 hr. Because of these tests, microtremor is considered to be predominantly caused by human activities from the amplitude change of the entire record, and the types and sources of waves depend on the time of the day and the site location. Finally, I decided the Nakamura method was fully established as an assessment method not only

doi: 10.1785/0220180376

for resonance frequency but also for an amplification factor when it was confirmed the H/V characteristics of the maximum value of earthquake motion are similar to results from lengthy measurements of microtremors (Nakamura and Ueno, 1986, in Japanese; or Nakamura, 1989).

ON THE NAKAMURA METHOD TO ESTIMATE THE EARTHQUAKE-MOTION AMPLIFICATION CHARACTERISTICS OF THE SURFACE LAYER

The amplification characteristics of horizontal motions by surface layers can be estimated from the ratio of horizontal-motion spectra measured at soft fill sites and bedrock sites, H_f/H_b. However, obviously by actual result of calculation, with microtremors it is sometimes difficult to determine the resonance frequency corresponding to the surface layer because the spectral ratio can have several peaks. This phenomenon was recognized to be caused mainly by Rayleigh waves (Nakamura, 1988, 1989). I therefore considered how to distinguish in microtremors the amplification caused by multiple reflections of *SH* waves, which is important for earthquake disaster prevention, from the amplification of other wave types.

I decided to use the ratio of vertical motion at soft fill and bedrock sites V_f/V_b, to reduce the influence of Rayleigh waves, because the vertical component of motion is expected to be large for Rayleigh waves. I emphasized the effects of multiple reflections of horizontally polarizing shear waves (*SH*) and reduced peaks caused by Rayleigh waves by dividing the horizontal transfer spectrum H_f/H_b, by the ratio of the vertical motions V_f/V_b.

There is almost no amplification caused by multiple reflections of *P* waves at the resonant frequency of the *SH* waves because the travel time of a *P*-wave propagating through the surface layer is generally less than one-third of an *SH*-wave. It is thus expected the ratio of vertical motions between a soft fill site and a bedrock site is about 1 in the frequency range containing the primary *SH*-wave peak. Because the predominant peak of the vertical motion is at about twice the frequency of the *SH*-wave, if Rayleigh waves predominate, the division procedure by V_f/V_b can reduce peaks caused by Rayleigh waves without affecting significantly the amplification measurement of *SH* waves.

I confirmed this procedure can estimate properly the resonance frequency and amplification factor caused by multiple reflections of *SH* waves using either earthquake-motion records or microtremors (Nakamura, 1988, 1989). Also, the spectral amplitude ratio derived from this procedure is the ratio between the horizontal-motion spectral ratio at the site and at bedrock H_f/H_b, and the vertical-motion spectral ratio V_f/V_b. In other words, this spectral amplitude ratio becomes the ratio between the spectral ratio of the ground surface H_f/V_f, and the spectral ratio of the base (bedrock) ground H_b/V_b. The horizontal-to-vertical-motion spectral ratio of hard ground H_b/V_b, is almost 1 for a wide frequency range based on observations (e.g., Nakamura, 1989, 1996). Therefore, the amplification characteristics derived from the procedure mentioned earlier can be approximated from the HVSR of the ground surface H_f/V_f, and thus the amplification characteristics of the surface layer can be largely estimated from the measurement only at the ground surface. This is what is commonly called the Nakamura method. In addition, if the shape of H_b/V_b at the site considering base ground is not a widely 1 and flat but has peaks, it means the observed site is not at base ground. Therefore, obviously from the definition of the Nakamura method, in case of the estimation of the amplification factor at a target site based on the site considering base ground, it is necessary to divide H_f/V_f of the target site by H_b/V_b of the site considering base ground.

This resulted in an objective method to determine the resonance frequency and the amplification factor without depending on personal technique or the experience of an analyst. In addition, it was confirmed, from the aforementioned measurement data mentioned earlier, the HVSR gives almost similar results regardless of the measured time of a microtremor despite the frequency characteristics changing by time of day. These characteristics of the HVSR make it possible to make measurements at a large number of sites, and an inventory survey of ground conditions became feasible.

However, because the HVSR method has become popular, I have feelings of resistance toward it being called by my name as the Nakamura method. Also to avoid misunderstanding of the Nakamura method, I proposed a name Quasi Transfer Spectrum (QTS) to make clear the meaning of the method (e.g., Nakamura, 1996, 2009). This QTS has not been widely accepted. Although it is acceptable to be called HVSR, it creates confusion with the HVSR of Rayleigh waves that have different characteristics as described later.

ON THE ARTICLES BY NOGOSHI AND IGARASHI

Next, I discuss the articles by Nogoshi and Igarashi that are often cited as the roots of the Nakamura method. Nogoshi and Igarashi investigated what a microtremor is at in an early stage in a series of articles (Nogoshi and Igarashi, 1970a,b, 1971). This series of studies investigated stationarity and transmissibility of microtremors to determine whether a microtremor is composed of body waves or surface waves. These studies showed, although microtremor could be caused by either body waves or surface waves, the HVSRs of microtremors match the theoretical HVSRs of Rayleigh waves found by Suzuki (1933). Also on the theoretical HVSR of a Rayleigh wave at the site with surface layer, Ohta (1963) examined detailed numerical parametric analysis for various impedance ratios and Poisson's ratios. Thus, Nogoshi and Igarashi (1971) concluded a microtremor is caused by Rayleigh waves, especially on the lower frequency range, but more detailed investigations were required because of differences at higher frequencies. However, there is little Rayleigh-wave energy in the lower frequency range, and Rayleigh waves predominate at higher frequencies. Although, the main topic of the Nogoshi and Igarashi articles is what is a microtremor; they did not describe the HVSR of microtremors approximating the amplification characteristics of the surface layer. Thus, the origin of the Nakamura method does not come from these studies despite some researchers citing them (e.g., Bard, 1999; Bonnefoy-Claudet *et al.*, 2006; Molnar *et al.*, 2018; Napolitano *et al.*, 2018; or the HVSR URL in Data and Resources).

ON RAYLEIGH WAVE PROPAGATING THROUGH A TWO-LAYERED GROUND

Nogoshi and Igarashi (1971) showed various spectral amplitude diagrams of horizontal and vertical components of Rayleigh waves. These figures show the amplitudes of Rayleigh waves are about zero below the predominant frequency of *SH* waves (F_0) and increase gradually to reach a maximum value at around $2F_0$, and then keep the value after that. It shows a surface site with resonance frequency F_0 behaves as a high-pass filter with cutoff frequency $2F_0$ against Rayleigh waves. On the HVSR of Rayleigh waves, the peak around F_0 is an apparent peak because the amplitude of the vertical motion is almost zero despite the small amplitude of the horizontal motion, and there is little Rayleigh-wave energy at that frequency. However, in the observed microtremor spectra, there often are significant amplitudes around F_0 in both the horizontal and vertical components. Therefore, the multiple reflection of *SH* waves clearly causes the peak of the HVSR around F_0. Nogoshi and Igarashi (1971) missed these important points, and misinterpreted the entire HVSR of a microtremor, including around F_0, it is based on Rayleigh waves. This is a point later researchers also have misinterpreted. Of course, it is natural a trough around $2F_0$ on the HVSR is affected by Rayleigh waves. Various results identifying the dispersion curve of Rayleigh waves showed the phase velocities were calculated at a higher frequency range than F_0 (e.g., Bonnefoy-Claudet *et al.*, 2006). These studies also showed large scattering error at a frequency range around F_0, although it was calculated stably at greater than $2F_0$. This fact also suggests Rayleigh waves exist primarily in the frequency range higher than F_0.

THE NAKAMURA METHOD AND HVSR OF RAYLEIGH WAVES

The Nakamura method uses the HVSR of microtremors or earthquake-motion records around the resonance frequency F_0, in which the peak value appears. The H/V ratio at the peak value is considered as the amplification factor of surface layers caused by the multiple reflection of *SH* wave at the frequency F_0. However, the Nakamura method is often confused with the behavior of HVSRs of Rayleigh waves. As mentioned earlier, the energy of Rayleigh waves is small around the frequency F_0. Moreover, if only Rayleigh waves are recorded, the HVSR approaches 0.7 at both lower and higher frequency ranges (Suzuki, 1933; Ohta, 1963). However in the actual observations, the HVSR by microtremors or earthquake-motion records fluctuates around 1 broadly except near F_0, and shows a trough around $2F_0$ in case of rich Rayleigh waves (e.g., Saita *et al.*, 1998; Nakamura, 2000). These observations show the influence of Rayleigh waves at the trough that appears around $2F_0$, and we can conclude the peak value exists at F_0. When the influence of Rayleigh waves is limited, higher-order resonance frequencies caused by the multiple reflections of *SH* waves also can be observed without observing the trough at $2F_0$. When earthquake motions are analyzed, this trend is often observed because the influence of Rayleigh waves is relatively small (e.g., Sato *et al.*, 2004). As mentioned earlier, the Nakamura method was applicable for grasping the site characteristics of the multiple reflections of *SH* waves while reducing the influence of Rayleigh waves.

In other words, because the earthquake motion or a microtremor consists of various kinds of wave motion, it is natural to consider HVSR derived from actually observed waveforms can contain many kinds of characteristics of not only Rayleigh waves but also surface waves and body waves, as *SH* waves, *SV* waves, or *P* waves. In contrast, although the HVSR of a Rayleigh wave reflects only the wave-motion characteristics of Rayleigh waves, Rayleigh waves in the ground with a surface layer does not exist evenly in the entire frequency range. It seems a Rayleigh wave in the ground with a surface layer starts existing around the resonance frequency F_0 by the *SH*-wave multiple reflection, then reaches the maximum value at $2F_0$, which is twice the resonance frequency, and keeps the value over $2F_0$. Thus, the peak on the HVSR of a Rayleigh wave has only a mathematical meaning and is almost not actually observed. In case of analysis using the characteristics of a Rayleigh wave, it is considered to be applied at the frequency range over $2F_0$. On the other hand, it is expected the HVSR of earthquake motion or a microtremor predominates at the peak caused by the multiple reflection of *SH*-wave at the surface ground, and the resonance frequency F_0 and its amplification factor can be estimated properly. So, it is necessary for applying HVSR to notice the difference of frequency range for the kind of wave motion.

INTERNATIONAL RECOGNITION

On 27 March 1991, I received a letter from W. D. Liam Finn of Columbia University asking about the analysis of microtremors. The question was motivated by a report (Ohmachi *et al.*, 1991) that compiled the results of microtremor measurements during the damage investigation after the Loma Prieta earthquake using HVSRs. In reply to his inquiry, I sent an article (Nakamura, 1989). That article is an English version of an article (Nakamura, 1988) comprehensively summarizing ideas of HVSRs. After the article was introduced at the Fourth International Conference on Seismic Zonation by Finn (I did not attend), the HVSR or so-called Nakamura method has been widely used around the world. About the same time, Pierre-Yves Bard of Université de Grenoble visited CEntro NAtional de PREvencion de Desastres (CENAPRED) of Mexico and heard about the HVSR from Kojiro Irikura who was also visiting CENAPRED from Kyoto University. Bard then started testing the method with numerical analyses. Although that research is based on similar misunderstandings such as by Nogoshi and Igarashi, it promoted the use of the HVSR.

MISUNDERSTANDINGS AND A REQUEST

There are two misunderstandings I would like to clarify. The first is Rayleigh waves cause the peak of the HVSR of microtremors or strong motions. The second is the origin of the Nakamura method as derived from Nogoshi and Igarashi (1971). These misunderstandings may come from the fact that the article by Nogoshi and Igarashi (1971) was written in Japanese and has been connected with Nakamura (1989), without understanding the original contents of the articles because it is difficult for non-Japanese researchers to read these articles. In fact, I asked some researchers who cited Nogoshi and Igarashi (1971) whether they had read the original article, and the answer was none had read it but instead understood the contents through explanation by Japanese researchers. This process misrepresented the contents of Nogoshi and Igarashi (1971), leading to incorrect citations in English articles. Moreover, the contents of Nogoshi and Igarashi (1971) have been incorrectly quoted repeatedly, thus spreading the incorrect interpretation widely in the world without checking the original contents. Based on this experience, I emphasize authors need to review the original contents of cited articles when referring to them in their manuscripts, even if summaries of the cited article were published in peer-reviewed journals. When there are both English and non-English versions (e.g., Japanese) of the article with similar topics, it is proper to cite both articles. If the original article is written only in non-English language, citing it should point to the original article for accessing a reference.

DEVELOPMENT OF THE FRAGILITY INDEX K_g-VALUE TO ESTIMATE EARTHQUAKE DAMAGE

The motivation of the Nakamura method is not to understand the shallow ground in detail, but to assess the potential damage by earthquakes. To prevent earthquake damage, it is important to investigate many sites to screen out problematic sites. Therefore, it is required that the site investigation method must be simple and the results must be consistent without depending on subjective interpretation by researchers. Based on this motivation, the fragility index for ground (K_g)-value was proposed to evaluate the risk of soil liquefaction using the results from the HVSR of microtremors (Nakamura and Takizawa, 1990b):

$$K_g = A^2/F,$$

in which A and F are peak amplification factor and its resonance frequency, respectively, assessed by the Nakamura method. Because the damage potential is related to the induced shear strain, the K_g-value was designed to estimate the shear strain of the shallow subsurface by multiplication with the base-ground maximum acceleration amplitude. Nakamura (1996, 1997) further confirmed the K_g-value is correlated not only with soil liquefaction but also with damage to small buildings.

With the Nakamura method, I was interested in determining the characteristics of a surface layer, the averaged shear-wave velocity of the shallow subsurface layer (V_S) and its thickness (h), so I compared the results to boring surveys and other data. Through this study, the following relationships were obtained between V_S or h and the averaged shear-wave velocity of bedrock or base-ground (V_{Sb})

$$V_S = V_{Sb}/A,$$
$$h = V_{Sb}/4AF.$$

Amplification factor A at the resonance frequency of surface ground relates to the impedance ratio between the surface ground and the bedrock, and it is coincident with the velocity ratio between each ground V_{Sb}/V_S if the density of both grounds is same. So, the *SH*-wave propagation velocity V_S of surface ground can be given approximately as V_{Sb}/A. From this, the thickness of surface layer h can be roughly estimated with $V_{Sb}/4AF$ using the law of quarter-wavelength giving the fundamental frequency of the surface ground. Because the *SH*-wave propagation velocity of the base-ground V_{Sb} is expected to be stable spatially in a wider range than the surface layer, only measuring a microtremor can realize to estimate V_S and h of the surface layer at the site if V_{Sb} is known.

For example, based on the survey along the Shinkansen railway in Japan, an average $V_{Sb} = 600$ m/s was obtained (Nakamura and Takizawa, 1990a, in Japanese; or Nakamura, 1996). Therefore, the h and V_S can be estimated from the previous equations using the Nakamura method.

VALIDATION STUDY THROUGH PRACTICAL APPLICATION ON MANY SITES

These techniques were developed for practical applications such as inventory surveys, so their validity and practicality must be confirmed at a large number of sites. By the late 1980s and the early 1990s, detailed boring surveys and large amounts of built structural information were collected along the railways in the Tokyo and Osaka metropolitan areas and along the Shinkansen lines in Japan. I verified the validation of the Nakamura method and K_g-values by conducting microtremor measurements along these railways, in addition to gathering the information from the boring surveys, the dimensions of built structures, and topographic maps. Microtremor measurements were conducted on built structures and at ground level for every 100 m, along local lines in the Tokyo metropolitan area (total length about 1500 km), some local lines in the Osaka area (about 100 km), and along the Tokaido and Sanyo Shinkansen lines (total length about 1000 km), to understand the amplification characteristics of the built structures and ground at more than 20,000 sites (e.g., Nakamura, 1989). Geologic columns by boring data were gathered along the railway lines and put on the longitudinal section. Then soil profiles were estimated with connecting the same geological layer at each geologic column and presented as a geological section diagram. All the figures were compiled for every 2 km as "Earthquake disaster prevention diagrams" with the other measured results such as HVSR, the transfer spectrum, resonance frequency and amplification factor of ground and structures, and structure type along the railway line of each point. Based on these results, a system for supporting recovery, the Hazard Estimation Restoration Aid System (HERAS), was produced experimentally for the Tokyo metropolitan area to accurately estimate the damage situation after an earthquake occurrence (Nakamura, 1995), and this system was installed on a trial along the Tokaido Shinkansen line in 1992.

Earthquake reconnaissance was also performed by studies after many damaging earthquakes such as the 1989 M_w 6.9 Loma Prieta, the 1990 M_w 7.7, Luzon, Philippines, 1993 M_w 7.6 Kushiro-Oki, 1994 M_w 6.7 Northridge, 1995 M_w 6.9 Kobe, 1997 M_w 6.0 Assisi, 1999 M_w 7.5 Kocaeli, and 2009 M_w 6.3 L'Aquila earthquakes (e.g., Ohmachi *et al.*, 1991; Saita *et al.*, 1998; Sato *et al.*, 2004). Microtremors were recorded in and around damaged areas after earthquakes, and sometimes both before and after the events (e.g., Nakamura *et al.*, 2009). Microtremors were also recorded at some cities or monuments where there is concern for earthquake damage such as Grenoble, Mexico City, Manila, Pisa, Rome, Istanbul, Berkeley, and Pasadena (e.g., Nakamura, 2011).

Through these applications, the applicability and validity of the Nakamura method have been confirmed for estimating ground and structural damage. For example, K_g-values by microtremor measurement in the 1980s distinguished liquefaction and nonliquefaction sites within the Tokyo metropolitan area during the 2011 Tohoku-Oki earthquake (Nakamura *et al.*, 2014).

During studies and investigations mentioned earlier, we found cases that the entire HVSR shape seems to shift downward although the peak frequency of HVSR is reasonable. For example, as a result of calculating the amplification characteristics curve of earthquake-motion records of the observation sites on soft ground in Mexico City standardized by the earthquake-motion records on hard ground, they agree well with the HVSR of earthquake-motion records but the HVSR of microtremors at some observation stations shifted downward with similar shape against the spectral shape of the amplification characteristics curve.

This phenomenon seems to be caused by the influence of Rayleigh waves due to deeper soil structure and/or the influence of spike noise by people walking around during microtremor measurement (Sato *et al.*, 2004). Therefore, I proposed a technique to correct measured HVSR as modified QTS (Nakamura, 2014). This technique estimates waveform at base or bedrock ground from measured microtremors at the ground surface based on the multiple reflection of *SH* waves using an estimated resonance frequency, and then estimates of the amplification characteristics from the spectrum ratio of the measured and estimated waveforms. Finally, the modified QTS is derived with shifting upward the measured HVSR using the estimated amplification characteristics. The validity of this method is confirmed by comparing the microtremor records around the liquefaction area of the 2011 Tohoku-Oki earthquake to the actual damage situation. It is also confirmed by comparing modified QTS derived from measured microtremors to the QTS or horizontal-motion spectral ratio between at the site and at hard ground just below or close to the site (HHSR) of earthquake-motion records in Mexico City.

SUMMARY

HVSR, known as the Nakamura method, was developed to reduce the influence of Rayleigh waves for a spectrum HHSR to estimate the seismic response at the ground surface versus that at a reference bedrock site, and is not used to characterize a Rayleigh-wave spectrum. Although misunderstandings and confusion are caused by the similar shape of each HVSR, I reiterate here the Nakamura method differs from methods to determine the characteristics of Rayleigh waves, and the target frequency range is also different. The intended frequency range of the Nakamura method is around F_0, which is the resonance frequency of the multiply reflected *SH* waves in the surface layer. Of course, the frequency range can be extended if the impact of Rayleigh waves is less, as for earthquake signals. On the other hand, the intended frequency range of methods for characterizing Rayleigh waves is greater than F_0 and generally more than $2F_0$. I am conscious the Nakamura method is only one of the tools to estimate the resonance frequency and the amplification factor at the site. Although this is an available tool to estimate roughly the amplification factor with dispersion inherently, and it is possible to pick out a ground with relatively high risk based on the result of estimation, this is absolutely one of the engineering tools. I think this is not considered a scientific tool for theoretical exploration or pursuit of truth. On the other hand, I would like to add a remark that it is possible from the characteristics of the Nakamura method to estimate not only the resonance frequency and amplification factor of a surface layer using HVSR at ground surface but also the resonance frequency and the amplification factor of both buildings and ground using HVSR at the top of a building.

I made a presentation to clear up misunderstandings about the Nakamura method at the 12th World Conference on Earthquake Engineering at Auckland, New Zealand (Nakamura, 2000). I have since tried to correct researchers of their misunderstandings through attendance at symposia and workshops. Although discussions based on these misunderstandings have decreased somewhat, this history of the Nakamura method is written because misunderstandings still persist. I hope this article will contribute to reducing misunderstandings and confusion.

DATA AND RESOURCES

The other relevant information is available at http://www.geopsy.org/wiki/index.php/H/V_spectral_ratio (last accessed April 2019).

ACKNOWLEDGMENTS

This article originated by submitting comment to *BSSA*, because an article describing misunderstanding was published in the first *BSSA* of 2018. In response, Editor-in-Chief Thomas L. Pratt of *BSSA* suggested it is better to explain properly the background, the basic idea, and its application of the Nakamura method than to give a comment to an individual article, and because a similar comment to correct this kind of misunderstanding was already posted in *SRL*. Editor-in-Chief Zhigang Peng of *SRL* also agreed with this idea. The author owes his submitting this article to their suggestions and advisements, and the author would like to express deep gratitude to them. The author appreciates Jun Saita of System and Data Research Co., Ltd. who translated the complicated Japanese to appropriate English. The author greatly appreciates the help of Thomas L. Pratt and Tadahiro Kishida, Ph.D., assistant professor of Khalifa University, on help for readable and orthodox English. Realizing microtremor measurements at quite a lot of sites and confirming the validity or applicability of the developed method are the results of support and collaboration of many people. The author would like to thank them all. The author greatly appreciates Tatsuo Ohmachi and assistant Takumi Toshinawa, professor of Meisei University at present, of Tokyo Institute of Technology at the time, who helped on conducting cooperative surveys with the microtremor measurement at the damaged area just after the Loma Prieta earthquake. The results of this investigation caught the attention of Finn, and he introduced the method across the world. It became a springboard for diffusion of the Nakamura method. The author thanks Finn for this. Bard gave a suggestion that the theoretical background of the Nakamura method is supposed to be the characteristics of the horizontal-to-vertical spectral ratio caused by Rayleigh waves. Because of detailed considerations of a set of articles by Nogoshi and Igarashi were thought to be the basis for the opinion, the author became aware of misunderstandings of them. The author sincerely thanks Bard for helping him deeply understand the characteristics of Rayleigh waves. The author has nice memories of conducting microtremor measurements at Grenoble together with him in 1994. The author thanks Kojiro Irikura, former vice president of Kyoto University, who followed at early times the development of the Nakamura method and introduced this technique for Bard. Comments of reviewers Samuel Bignardi and Alan Yong are useful for obtaining this article's sophistication. The author is very thankful for their detailed reviewing.

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Yutaka Nakamura
System and Data Research Co., Ltd.
3-25-3 Fujimi-dai, Kunitachi-Shi
Tokyo 186-0003, Japan
yutaka@sdr.co.jp

Published Online 1 May 2019