Assessment to the Soil-Structure Resonance Using Microtremor Analysis on Pare - East Java, Indonesia

Dwa Desa Warnana, Triwulan, Sungkono, Widya Utama

Abstract— **The determination of seismic hazard, oriented to seismic risk management in urban areas, particularly on Pare – East java, force us to know the resonance range between the dynamic behavior of ground and the one of building structures. Since no major damaging earthquake has occurred in site in recent times, the presence of soil–structure interaction effects from observed damage pattern are not available. In order to assess the soil-structure resonance for this site study, the microtremor measurements was applied. Microtremor measurements were performed 6 free-field and inside 6 buildings of various heights. We focused on important public buildings (i.e. schools and mosque). The Horizontal-to-Vertical Spectral ratio (HVSR) analysis was applied in order to access the fundamental frequencies of the sediments, beside the longitudinal (EW) and transverse (NS) fundamental frequencies of each building determined from amplitude spectra and the Floor Spectral Ratio (FSR). When one of these frequencies is close to a nearby free-field fundamental frequency, a potential soil-structure resonance is present. Among 6 buildings with established frequencies we found two buildings with low, one with medium to high and three building with high danger of soil-structure resonance. This study shows that the microtremor method could be used to make preliminary assessment of soil-structure resonance.**

Index Terms—**Microtremor, HVSR, Spectral and FSR, Soil-building resonance, Pare –East Java.**

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I. Introduction

Significant structure damage and loss of human live have been directly attributed to the effect local conditions in almost all major earthquakes, included the 1985 Mexico City, the 1989 Loma Prieta, the 1995 Kobe City, the 1999 Chi-Chi, and the 2006 Jogjakarta earthquakes. In additional the effect local, the structural damage is also dependent on the characteristic building, i.e. frequency natural and damping of building, soil-building interaction, and vulnerability of building.

An importance factor in predicting earthquake damage is relationship between the fundamental frequency of a building and the fundamental frequency of the ground on which building is constructed. If the building's frequencies are close to a nearby the fundamental frequencies of the material on which it is built, or if it equals some whole-number multiple of the material's fundamental frequencies, then seismic motion will create a resonance with building that can greatly increase the stresses in the structure [1].

In order to assess the site effect (the geological conditions that influence site response to strong ground motion) and the characteristics building could be done by measurement of microtremor on the free-fields and in the buildings, respectively.

The microtremor HVSR technique is widely used for microzonation and site effect studies. Reviews on this method can be found as in [2] and [3].The main advantages of HVSR method are simple and low cost measurements which can be performed at any time and any place, and direct estimate of sediments resonance frequency without knowing geological and S-velocity structure of the underground. Any knowledge of thickness or/and velocity of sediments and comparison with other methods and earthquake damage can significantly improve the reliability of the results [2,3].

The use of microtremor was later extended to identify the fundamental frequencies of buildings [4], their vulnerability and soil-structure resonance [2,5,6]. Soil-structure response and effects of damage was recently studied using microtremors for Slovenia earthquake [4], Molise earthquake [5], Mountain earthquake in Bovec basin [7] and the Ljubljana basin [4]. Although the theory and interpretation of ambient vibration measurements in buildings are not elaborated as they are for the free-field measurements, several studies mentioned above showed that the microtremor method is useful for the identification of soil-structure resonance [4-7].

The HVSR method of microtremor was therefore applied to six free-fields and to six buildings measurement of Pare area, Kediri district, East Java, Indonesia in order to assess the fundamental frequencies of the sediments and the buildings, respectively. The measurement distance between free-fields and buildings are near and the geological conditions are same.

We focused on important public building (schools and mosque). That was longitudinal (East-West / EW) and transverse (North-South / NS) fundamental frequencies determined from the amplitude spectra and the spectral ratio between upper floor and the basement were analyzed for both directions [8,9]. Furthermore, the potential of soil-structure resonance was assessed by comparing frequencies of the sediments with the frequencies of buildings; a venture was made to assessing the potential areas soil-structure resonance. That interpretation's soil-building resonances using criteria's that it was proposed as in [7].

II. MIOTREMOR MEASUREMENT AND ANALYSIS

A. Microtremor

Microtremor has based on ambient noise recordings to determine site response parameters. Two methods that have used it are horizontal-to-vertical Fourier amplitude spectral ratio (HVSR), and the more advanced array technique. The ability of the HVSR technique to provide a reliable information related to site response has been repeatedly shown in the past [2].

HVSR method for microtremor data analysis to be derived fundamental frequency of the sediment [2,3]. The use of microtremor was later extended to the identification of the fundamental frequency of buildings and the soil-structure resonance [6,8,9]. Damage enhancement and soil-structure resonance were recently studied using microtremors.

The theory and interpretation of ambient vibration results for buildings are not so structured and straightforward as they are for the free-field case. When measuring inside a given building in a densely populated area, one of the main difficulties is to detect and eliminate the effects of fundamental frequencies of the nearby free-field and of other buildings in the vicinity. In addition, when an instrument is not positioned in the mass centre, the torsion frequencies can mask the results.

In the literature, most often only individual buildings or small samples of buildings have been considered. However, some useful advice and instructions for measurements in buildings and their interpretation were described by Gallipoli et al. [6] and Gosar [4,7]. All measurements at higher floors of the building should represent building characteristics. Their curves should have the same form, their amplitude should increase with height and the peaks should be at the same frequency [6]. Usually Nort-South (longitudinal) fundamental frequency is higher than the East-West (transverse) [4]. When this is not the case, the mass centre may be distinct from the geometrical centre or heterogeneities in construction may exist [4].

In the Pare area, measurements of ambient noise were performed by using one portable seismograph composed of three velocity sensors, GPS receiver, digitizer and recording unit with memory card.

B. Measurement Free-Field

Microtremor measurements were conducted at the Pare area, Kediri district, East Java in Indonesia conducted by 6 locations of near buildings to be analysis of soil-building resonances. The measurement location was chosen carefully to avoid the trees, buildings, traffic and the other human activities influence. The sampling frequency was 100 Hz and the recording length at each point 15 minutes.

The conditions of microtremor measurement were very favorable. Difficulties arise from noise that caused by high winds, traffic and industry noise. In urban areas, free-field space between houses was also very limited. And the measurement also avoided with high winds, because the noise introduced by wind can severely affect the reliability of HVSR analysis [10,11].

The data processing to obtain the HVSR at each site was performed in the following way: recorded times series were visually inspected to identify possible erroneous measurement and stronger transient noise. Each record was then split into 20-40 s-long windows tapered with 5% cosine function. A Fast Fourier Transform (FFT) was calculated for each window in each seismometer component. The Fourier spectra were smoothed using Konno and Ohmachi [10,12] with 40 smoothing constant. HVSR was computed as the geometric average of both horizontal component spectra divided by the vertical spectrum for each window. From the color-coded plot of HVSR functions for minimum 10 windows, the windows no including strong transient noise were identified in order to be excluded from further computed. Although Parolai and Galiana-Merino [13] have shown that transient have little or no effect on HVSR, the effect of transient seismic noise on HVSR analysis in still debated. This analysis was used GEOPSY software.

HVSR analyses of free-field measurements that showed that most of them fulfill the criteria defined as in [10]. Three of these criteria are based on the relation with the peak frequencies to the window length, the number significant cycles, and the standard deviation of the peak amplitude. The next criteria for a clear peak are based on the relation with the peak amplitude to the HVSR curve level, standard deviations of the peaks frequencies and of its amplitude. If all criteria for a reliable, the frequencies of the peaks is considered to be fundamental frequencies of sediments from the first strong impedance contrast.

C. Measurement Inside Building

Two and one-story residential building prevail in the area. Measurements were performed 6 selected buildings of different height in a range from one to three stories. The building measured is important public buildings, such as: Annur Mosque (H1), Al-Fath junior high school (H2), Dharma Wanita senior high school (H3), Candra Birawa vocational school (H4), Bhakti Mulia (H5) and Karya Husada (H6) high school health science.

Microtremor measurements were performed on all floors of the building using the same instruments as in the free-field measurement. The two horizontal components were oriented one in the NS and one in the EW directions of the building. For measurements inside buildings, shorter spikes mounted at the bottom of the seismograph were used to enable precise leveling, but to avoid vibrations of the unit.

The recording length was 15 min, because frequencies below 1 Hz were not of interest [4,7,10]. Measurements were performed on all floors of the building. Two horizontal components were oriented in the N-S and E-W component directions of the building. The instrument was placed as close as possible to the mass centre of the building and close to the wall. Close to each building, but far enough to avoid its influence, a free-field measurement was also performed.

In determine frequency of building, the use HVSR is not recommended [9], although it may reasonable frequency estimates in some instances. However, there is no theoretical basis for its application as we can't assume that horizontal and vertical spectra don't differ at the ground level. This is especially dangerous if soil amplification is significant strong, in which case the free-field HVSR may contaminate building response, finally to false possible resonance identified [9]. All subsequent analyses were done using spectra (EW and NS) of ambient noise in the building and spectral ratio between the upper floor and basement (free-field near building) were analyzed for both components [8, 9]. This method proposed by Gosar [9] which it is named floor spectral ratio (FSR) that is standard method [9].

In the spectral analysis, each record was split into 20-40 s-long non-overlapping windows for which amplitude spectra were computed using a cosine tapper with 5% smoothing. A Fast Fourier Transform (FFT) was calculated for each window in each seismometer component. The Fourier spectra were smoothed using Konno and Ohmachi [10,12] with 40 smoothing constant. Average amplitude spectra for each component were computed from selected windows.

Then, to derive frequencies natural of building using FSR can be occurred as the spectral analysis to upper floor and free-field measurement. Furthermore, divided between upper floor and free-field measurement are occur.

To check the reliability of FSR and spectral methods from horizontal component to estimate the frequencies of buildings take on different floors in the same building. The good of methods shown from result of analyses, there are good correspondence in the frequency (frequency each floor is the same) and there are amplification or amplitude of peaks fundamental frequencies is increase with increase of high [4,6,7,9]. Moreover, the good method is can determine frequency of building a exact and clear.

Figure 1 and 2 present typical spectral and SFR methods from NS and EW vibration on different of floor, respectively. It was seen that the SFR method was a clear peak about frequency 3 Hz whereas the spectral result was a wide peak (2.85-3.58 Hz) from floor 1st and (3.18-3.73 Hz) from floor 2nd. Thus, SFR method was more focused than spectral method in the amplitude of peaks frequency.

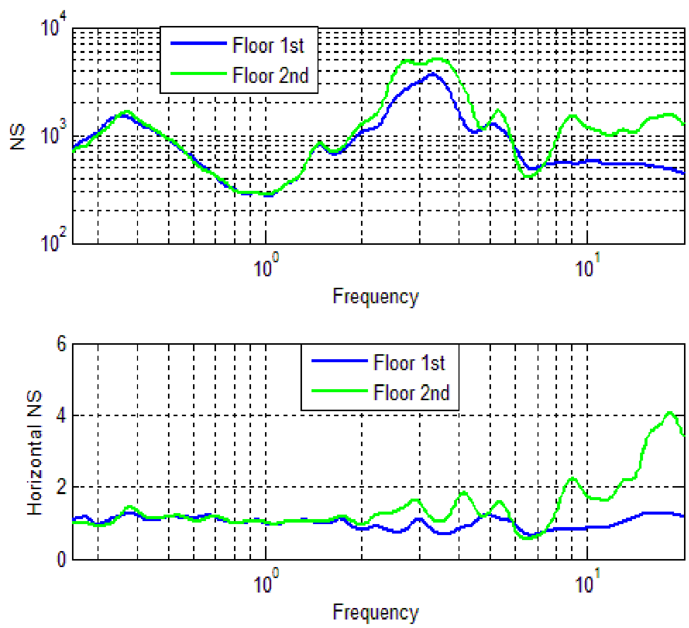

Fig. 1. Top: Spectra of NS vibration on floors 1st and 2nd in the H1 building, the frequency identified from spectra method is wide peak (3.18−3.73Hz) centered around 3.6 Hz to floor 1st and is wide peak (2.85−3.58 Hz) centered 3.44 Hz to floor 2nd. Bottom: FSR of NS vibration on floors 1st and 2nd in the H1 building, the frequency identified from SFR method is 2.97 Hz to floor 1st and 2.93 Hz to floor 2nd. Mainly, the peaks result of FSR methods more share peak than spectral method. The peaks frequencies after fundamental frequencies are usual frequencies of higher modes.

In the Figure 1, frequency of building derived by SFR method is 2.97 Hz to floor 1st and 2.93 Hz to floor 2nd while the spectral method is a wide peak centered around 3.6 Hz to floor 1st and 3.44 Hz to floor 2nd. In the Figure 2 is the spectral method a clear peak at frequency 3.60 Hz to floor 1st and 3.29

Hz to floor 2nd while in the SFR method a clear peak at frequency 2.97 Hz to floor 1st and to floor 2nd. So, in base on these analyses was the SFR method more stable than spectral method. Therefore, in the furthermore analyses of buildings frequency will be used both methods. The SFR method used to determine building frequencies (fundamental and higher modes), while spectral method used to detect in determine of fundamental frequency of building. Since the frequency result of SFR method is more one peak, i.e. fundamental mode and higher modes [9].

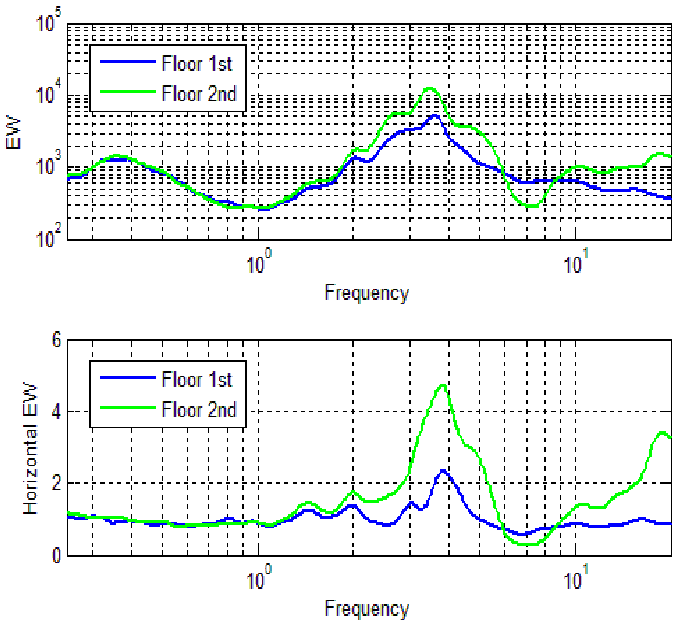

Fig. 2. Top: Spectra of EW vibration on floors 1st and 2nd in the H1 building, the frequency identified from spectra method is 3.60 Hz to floor 1st and 3.29 Hz to floor 2nd. Bottom: FSR of NS vibration on floors 1st and 2nd in the H1 building, the frequency identified from SFR method is 3.82 Hz to floor 1st and to floor 2nd.

III. SOIL-STRUCTURE RESONANCE

Measurement performed in buildings confirmed that microtremors are an effective tool for identification of the main building frequencies. For all measurement buildings, it was possible to identify the longitudinal and transverse frequencies. We used amplitude spectra of horizontal and standard spectral ratio (building spectral divided by free-field spectral) as proposed by Gosar [4,7,8] and Herak [9]. The soil-structure resonance identify can be compared between frequencies of sediment and building. The amplitude of HVSR ranges are mainly in the range.

The danger levels soil-structure resonance was chosen by applying the following criteria. First we select the building frequency that is closer to the free-field frequency and then we compute the ratio between them. Reference [4] explained that the difference is within ±15%, the danger of soil-structure resonance is high, if it is within 15–25%, it is medium, and if it is higher than ±25%, then it is low.

Annur Mosque (Fig. 3) is located in the Pahlawan streets, where a clear peak at frequency 3.39 Hz with amplitude 5.21 was obtained in free-field measurement. From microtremor measurements in this building, it was possible to identify the main building EW is a wide peak (3.18−3.73Hz) centered around 3.6 Hz using spectral method and a clear peak at frequency 3.87 Hz for SFR method and NS is 3.29 Hz for spectral method and 2.97 Hz for SFR method were identified. Soil-structure resonance is therefore very likely. This building is in high danger due to soil-structure resonance during earthquake.

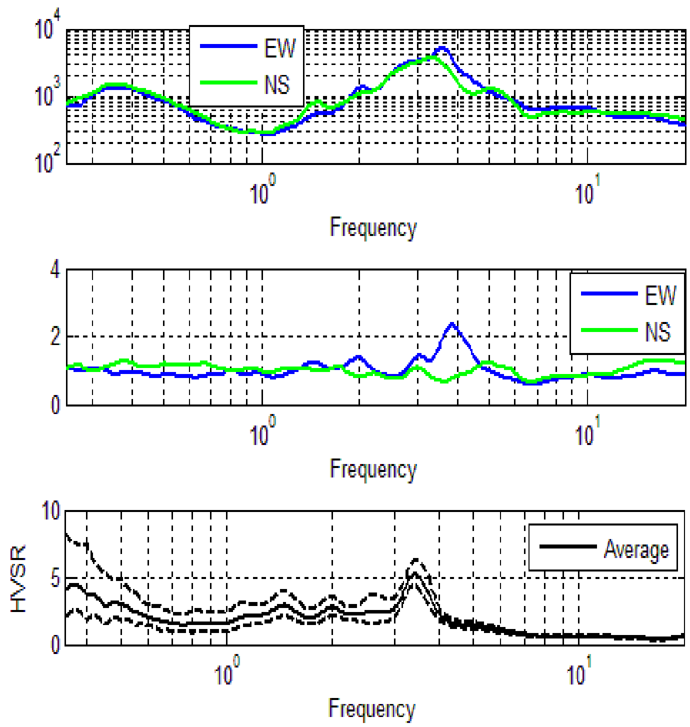

Fig. 3. Building H1 where is the level of soil-structure resonance low-medium. Top: 2nd floor of the mosque −spectral method of each horizontal component. Center: 2nd floor of the mosque−Standard spectral ratio (building/free-field) of vibration of each horizontal component. Bottom: free-field HVSR.

The building H2 (Fig. 4) is Al-Fath Senior High Scool in Pare city. A clear peak at frequency 4.89 Hz with amplitude of 2.54 was obtained in free-field measurement. The main building EW (5.35 Hz) and NS (5.93 Hz) frequencies were identified. Soil-structure resonance is therefore very likely. This building can be medium-high damage cause of resonance free-field and building during earthquake motion. This result of possible soil-structure resonance is difference in [15]. Differencing of result was caused by difference method analysis. In [15] used each horizontal to vertical spectral ratio while this paper used each horizontal spectral and FSR method. According to [9] was method used [15] usually false identification of resonance frequency of building. So, this was result more accurate than [15].

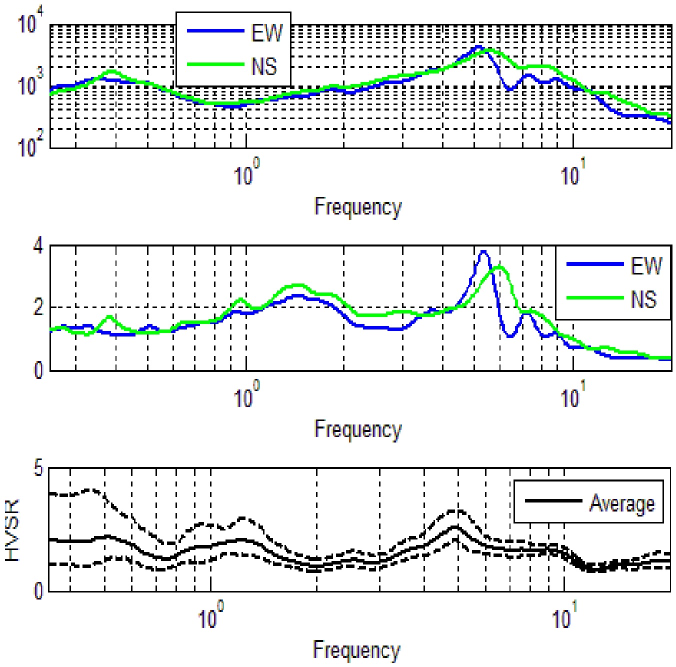

Fig. 4. Building H2 where is the level of soil-structure resonance low-medium. Top: 1st floor of the Al-Fath junior high school −spectral method of each horizontal component. Center: 1st floor of of the Al-Fath junior high school−Standard spectral ratio (building/free-field) of vibration of each horizontal component. Bottom: free-field HVSR

Building H3 (Fig. 5) is located at the Jend. Ahmad Yani streets number 1, Pare City, where a clear peak at frequency 3.64 Hz with amplitude 2.73 was obtained in free-field measurement. The frequency building from derived by microtremor measurement was possible identify the main building EW (a clear peak at frequency 9.06 Hz to spectral method and 9.20 to SFR method) and NS (a clear peak at frequency 9.75 Hz to spectral method and 9.90 Hz to FSR method) frequencies were identified. So, this building is not in danger due to soil-structure resonance during earthquake shaking.

Building H4 (Fig. 6) is located in Pahlawan streets, 500 meter to the East of building H1. A clear peak at frequency 3.59 Hz was obtained in free-measurement. The main building EW (a clear peak 3.55 Hz to spectral method and many clear peaks frequency 3.6 Hz as fundamental mode, 5.59 Hz and 9.90 Hz as higher modes) and NS (a wide peak 3.45−4.89 Hz optimum around 4.86 Hz and clear peak at frequency 8.30 Hz to spectral method and two clear peaks at frequency 4.75 as fundamental mode and 8.42 Hz as higher mode) frequencies were identified. Frequency of building used soil-structure resonance were fundamental mode only. Furthermore, this building is high danger soil-structure resonance during earthquake shaking.

Building H5 (Fig. 7) is located on the Matahari streets, 100 meter to the south of building H1. A clear peak at frequency at 3.60 Hz with amplitude of 2.78 was obtained in free-field measurements. The new building was build at 2008s. From microtremor measurements in this building, it was possible identify the main building EW (a wide peak between 3.41 Hz to 4.30 Hz centered around 3.44 Hz from spectral and a clear peak at frequency 3.39 Hz from FSR analysis) and NS (a clear peak frequency 3.65 Hz from spectral and a wide peak between 3.2−4.90 Hz peak optimum a round 3.60 from FSR analysis) frequencies. This building is in high danger due to soil-structure resonance during earthquake motion.

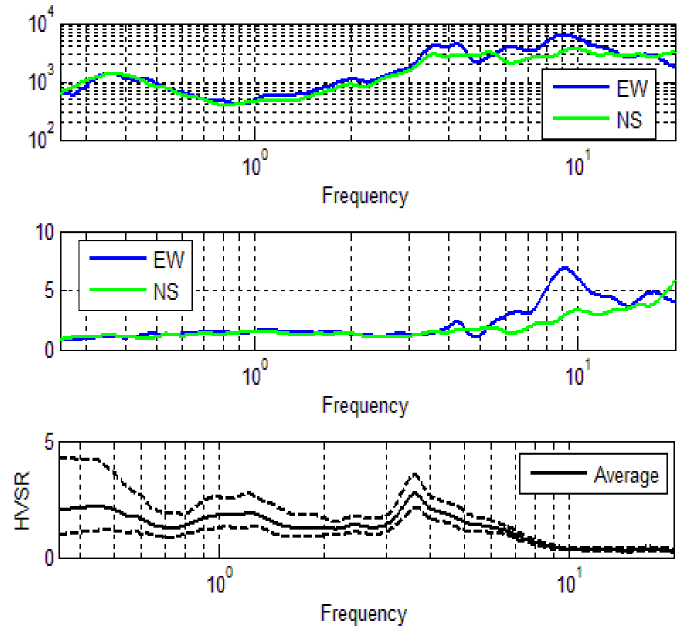

Fig. 5. Building H3 where is the level of soil-structure resonance low-medium. Top: 1st floor of the Dharmawanita senior high school −spectral method of each horizontal component. Center: 1st floor of of the Dharmawanita senior high school−Standard spectral ratio. Buttom: free-field HVSR

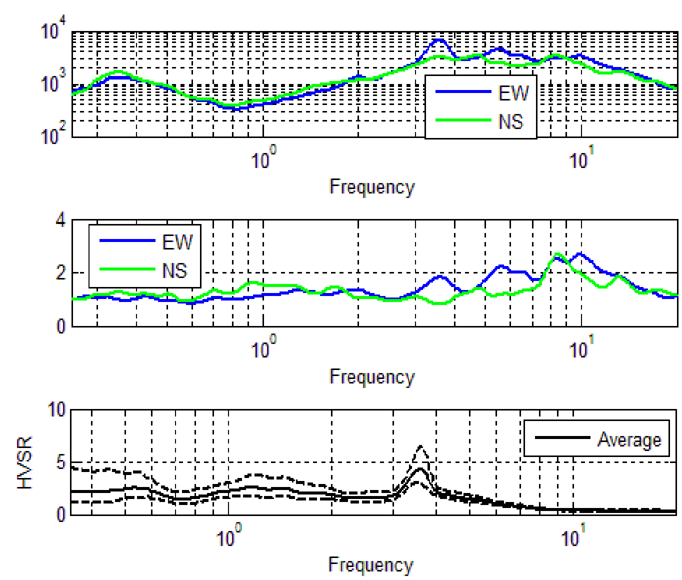

Fig. 6. Building H4 where is the level of soil-structure resonance low-medium. Top: 1st floor of the Candra Birawa vocational school−spectral method of each horizontal component. Center: 1st floor of of the Candra Birawa vocational school −Standard spectral ratio. Buttom: free-field HVSR

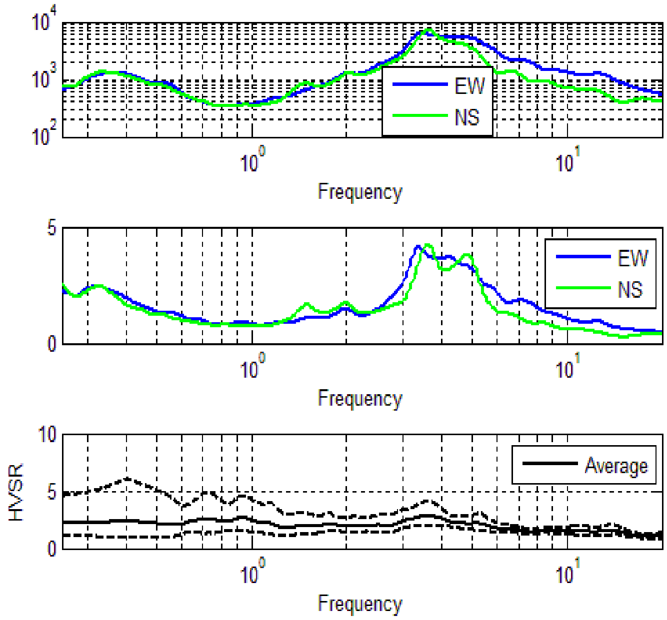

Fig. 7. Building H5 where is the level of soil-structure resonance low-medium. Top: 1st floor of the Bhakti Mulia high school heath science −spectral method of each horizontal component. Center: 1st floor of of the Bhakti Mulia high school heath science−Standard spectral ratio. Buttom: free-field HVSR

Building H6 (Fig. 8) is located on Sukarno-Hatta streets, where a clear peak at frequency 1.22 Hz with amplitude of 3.82 was obtained in free-field measurement on near this building. The main building EW (5.67 Hz from spectral method and 5.83 Hz from FSR method) and NS (5.84 derived by spectral method and 5.92 Hz estimated by FSR method) frequencies were identified. So, the dangers soil-structure level in this building is low level.

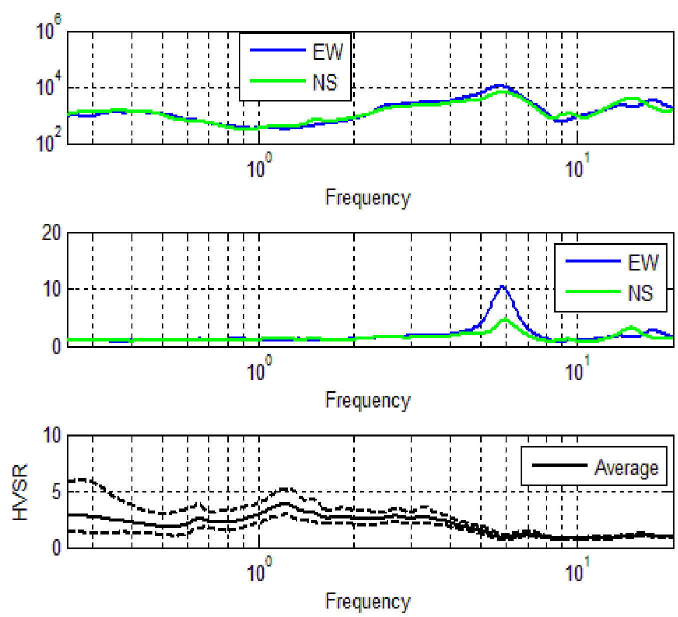

Fig. 8. Building H6 where is the level of soil-structure resonance low-medium. Top: 1st floor of the Karya Husada high school heath science −spectral method of each horizontal component. Center: 1st floor of of the Karya Husada high school heath science− Standard spectral ratio. Buttom: free-field HVSR

All NW and EW frequencies for six investigated buildings are shown in Figure 3−8. Main building frequencies are visible as clear isolated peaks on both measured components. The frequency difference between both directions is usually small, because most buildings have a rather symmetrical shape [4].

IV. Conclusion

The measurements of microtremor inside buildings were shown to be efficient and quick, reliable result, accurate and temporally stable estimates of frequencies of the building vibration modes. Together with the free-field measurements to assess the fundamental frequency of sediments, the first attempt was made to assess the dangers soil-structure resonance in the site study.

The microtremor investigation had been conducted on 6 free-field measurements and inside 6 buildings where the buildings located were close to free-filed, at Pare−East Java. The results of these microtremor analyses were found two building (H3, H6) with low, one building (H2) with medium−high and three building (H1, H4, H5) with high danger of soil-structure resonance.

Although the microtremor investigation have proved to be an effective tool for assessing the soil-structure resonance, microtremor measurements in a larger number of housed should be performed, including analysis of their dynamic behavior and of available information on the construction of individual buildings. In addition investigation should be enhanced to identify the area study of possible soil-structure resonance.

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