Valuation of Building strength against earthquake Vibrations using Microtremor Analysis (case study: the city of Surabaya)

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Abstract. The potential damage due to earthquakes is not only identified by the magnitude and the epicenter distance to a particular region, but also by the topography and it's near surface geological condition. In the inhabited area, such as the urban locations, it is necessary to assess buildings against the earthquake vibration. For this purpose the microtremor vibration analysis was conducted in the city of Surabaya, in order to determine the earthquake-prone buildings and their vulnerability against the vibrations induced by earthquake. The possibility of resonance structure-soil in this specific area was also studied. The microtremor on grounds was analyzed using the Horizontal to Vertical Spectral Ratio (HVSR) and the microtremor inside the buildings was analyzed using the spectrum analysis method, the Floor Spectral Ratio (FSR) and the Random Decrement Method (RDM). This study was performed on ten-borne buildings throughout the region, which represent the one-story buildings, governmental buildings, historic buildings and public buildings. We found that from these buildings, seven of them have low-level, two have low- to medium-level of resonance, and one has a high-level of resonance. The minimum building vulnerability index in the horizontal direction EW (East-West) is 4.55 and in the NS direction (North-South) is 4.14. The maximum vulnerability index was found in the horizontal direction EW (East-West) and the NS directions, which amounts to 143.47 and 171.233.

1. Introduction
Topographically, Surabaya is located in the northern part of the Java Island, which is dominated by lowlands. The majority (80\%) of the region is alluvial deposit that spreads along the Porong and Surabaya River. The rest is low rolling hills formed by weathering of tertiary rocks [1]. According to [2], regions formed by alluvial sediments, sandstone, tuff and clay are having a great potential to ground vibration, due to the amplification mechanism induced by the ground and its interaction with the soil-structure during the earthquake. The soft sedimentary rocks are able to strengthen the vibration [3]. Therefore, the average earthquakes damage is more severe compared to the areas with the near surface formed by hard rocks. This phenomenon is proven, for example, in the devastating earthquake of Mexico, in 1985. Although the distance to the epicenter of Mexico City is no less than 390 Km, the induced damage was very severe due to the amplification of horizontal wave acceleration

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of Mexico City, due to the fact that the city was formed by soft soil-deposits from compacted bogs having a shear wave velocity of 40 - 90 m/s [1, 3].

This fact clarify that the geophysical micro-zonation acts is required and need to be conducted in to estimate the strength of buildings, using the microtremor analysis. We concentrate our study in Surabaya, in order to classify the earthquake-prone buildings by determining the natural frequency, specifying the vulnerability index of buildings against earthquake vibrations and identifying the possible soil-structures resonance.

2. Theory

2.1 The geology and Seismicity of Surabaya

![Figure 1. Geological map of Surabaya taken with permission from [4] with the physiography of mid-Kendeng hills, mid Rembang-Madura hills, north Java alluvium, mid East Java and east of Randublatung curve. The stratigraphic order exposed consists of alluvium deposits (Qa) Kabuh formation (Qpk), Pucangan Formation (Qtp) and the Lidah formation (Tpl).](image)

Judging from the condition of its seismicity, Surabaya is crossed by two active faults that can trigger the occurrence of earthquakes in Surabaya and its surrounding area, namely the fault in the subduction zones along the South of Java with a distance of about 300 Km South of Surabaya and Lasem strike slip fault which is located about 75 Km Northwest of Surabaya. In addition, there is a passive fault located around Surabaya, Watukosek fault that extends from Mount Penanggungan through Sidoarjo Mud Volcano to Gunung Anyar to Madura [5]. Surabaya is located in the class 5 seismicity zone with the PGA values (Peak Ground Acceleration) of 0.15 - 0.2 g, so that Surabaya has is potentially vulnerable to earthquake hazard [6].

2.2 Local site effect from Earthquake

The local site effect, i.e. the local geological and topographic conditions, is one of the causes of destructive earthquakes [7, 8, and 9]. In [1] explain that relationship of the intensity of the earthquake damage to a region are affected by the quake epicenter, distance scale, the size of the earthquake fault zone, the energy released rocks, geological type between the source and the local geological conditions. Differences in local conditions in a region with other regions due to the variation of geological formations, the thickness and physical properties of rocks and soils, surface water and depths of bedrocks, and also underground structures above the region [10].
2.3 Microtremor

Microtremor is a quake vibrations that propagate with the amplitude of the order of micrometers brought about by natural events (e.g. wind and ocean waves) or artificial (e.g., industrial machinery and vehicles) [11]. This method was introduced by [12] and is applied by [2] with the proposed method HVSR (Horizontal to Vertical Spectral Ratio) to estimate natural frequencies and amplification of the local geology of the microtremor data. Later this evolved in the way that the method is able to estimate ground and building vulnerability indices, interaction of soil-structure, and damping ratio of building. In this study, the HVSR method is used to data analysis of microtremor measured in ground and spectral methods, RDM, and FSR for the microtremor data measured in the building. According to [13], in a microtremor analysis of a building, HVSR method is not recommended to despite the natural frequency of its estimation result is logical. This is caused by there is no basic theory in its application so that it cannot be assumed that vertical and horizontal spectrum on the underground level is the same.

3. Method

3.1. Analysis of microtremor data measured in Ground

This research uses a set of portable microtremor instrument consists of three component digital seismograph station with short period manufactured by Taurus (Canada) with short-period seismograph feedback sensor type DS-4A and equipped digitizer (Data Logger). Microtremor measurement of the soil conducted on 10 point location, adjacent to the building that will be analyzed. Geopsy software is used for the data processing. Each vertical and horizontal components of the spectrum is divided into 20-40 S long window tapper with 5% cosine function. Furthermore, the analysis of Fourier spectral of each window will change the initial microtremor data from time domain into the frequency domain. Smoothing process of FFT results implement [9] filter, with bandwidth coefficient of 40.

Smoothed data is analyzed to use amplitude spectrum ratio (H/V spectrum ratio) method of the two amplitude of horizontal and one vertical Fourier spectral being estimated using Equation (1) [14]:

\[ R(T) = \frac{\sqrt{F_{NS}(T)^2 + F_{EW}(T)^2}}{F_Z(T)} \]  

where \( R(T) = \) horizontal to vertical (H/V) ratio spectral, \( F_{NS}, F_{EW} \) and \( F_Z \) are Fourier spectral in NS, EW and Z (vertical), respectively.

Furthermore, spectrum is plotted as the H/V spectral for each measurement point. Typically, the frequency of peak of H/V spectrum is the natural frequency of the local site effect. Therefore, estimation of vulnerability index of ground can be determined from natural frequency and amplification.

3.2. Analysis of Microtremor measured in building

Microtremor Data taken on 10 buildings spread on the whole area of Surabaya (table 1) with the criteria of public buildings, Government buildings and historic buildings. Parallel with the above activities, also taken soil data that represents the subsurface Geologic conditions of each building.

Microtremor measured in building recorded along 15 minutes each floor of the building, and 20 minutes for the ground using the same process of measurements. Analysis of microtremor data measured on building used three methods, namely; spectral analysis, RDM and FSR. Spectral analysis is done by dividing the window spectrum and continued with FFT (Fast Fourier Transform) analysis. Because the result of the FFT analysis is random, smoothing technique [7] is used with a bandwidth of 40. Calculation of average spectrum of the entire window is then applied. The natural frequency is identified as the frequency with largest peak amplitude.
To find out the possible soil-structures resonance underneath when the earthquake occurred, the calculation is done based on the following equation:

\[ R = \left| \frac{f_b - f_t}{f_t} \right| \times 100\% \]  

(2)

According [13] classify the vulnerability level of soil-structures resonances against earthquake in three criteria, i.e. high vulnerability to the difference frequency ±15%, medium vulnerability for 15-25% values and low vulnerability for higher than 25%.

4. Results and Discussion

The natural frequency in the ground shows geological structure in the local area. The magnitude of natural frequency is inversely proportional to the depth of bedrocks and is directly proportional to the velocity or the average density of the subsurface structure of the local.

Tabel 1. Analysis result of ground and building microtremor and resulted ground natural frequency, building natural frequency and building resonance to the ground (R: Low and T: High)

| Code | Building                      | Ground F (Hz) | Damping Ratio | Building Spectrum | Building RDM | Building FSR | Resonance |
|------|-------------------------------|---------------|---------------|-------------------|--------------|--------------|-----------|
| M97  | Lt.1 Gedung Kawasan Negara   | T22           | 1.1756        | 7.79 5.96        | 1.1538       | 1.2038       | 1.32 1.19 1.21549 1.18566  T |
| M92  | Lt.2 Gedung Kawasan Negara   | T22           | 1.1756        | 7.03 6.1         | 1.23038      | 1.12876      | 1.2 1.22 1.27698 1.10125  T |
| M114 | Lt.4 PDAM Surabaya           | T32           | 1.2894        | 6.73 7.85        | 2.95482      | 2.95482      | 2.95 2.88 2.95482 2.91859  R |
| M123 | Lt.3 Intiland Tower          | T33           | 2.3151        | 4.29 1.37        | 1.95357      | 1.15696      | 1.07 1.15 1.05337 1.12876  R |
| M202 | Lt.2 Golose Bung Tomo        | T15           | 0.7072        | 4.6 6.34         | 1.44465      | 1.32512      | 1.5 1.33 1.37509 1.35823  R |

Tabel 2. Estimation of building and ground vulnerability indices and building maximum acceleration

| Code | Ground | Building Acrel | Building F | Building A | H | Average Kb | Max Acceleration |
|------|--------|---------------|------------|------------|---|------------|------------------|
| M97  | T22    | 3.56          | 1.24 1.19 2.58 3.87 | 21 | 20.18 32.86 | 347.70 213.49 |
| M92  | T22    | 3.56          | 1.24 1.15 1.40 1.77 | 6  | 38.79 56.47 | 180.85 124.22 |
| M114 | T32    | 3.08          | 2.95 2.92 2.55 2.269 | 16 | 4.62 4.22 1760.29 1928.22 |
| M123 | T33    | 2.57          | 1.05 1.15 5.55 9.32 | 12 | 106.89 149.84 | 91.06 64.96 |
| M202 | T15    | 5.76          | 1.44 1.34 0.29 0.23 | 8  | 4.55 4.14 954.77 1049.63 |

The application of HVSR method in the Surabaya area shows the natural frequency of 15 point of measurement in Surabaya which were used to estimate the possibility soil-structures resonances, vulnerability index of ground and vulnerability index of building. The value of soil frequency ranges between 0.7072 - 2.3511 Hz. The research results showed that the natural frequency of local site in Surabaya is small (table 1), which means that the soft layer is thick enough in Surabaya. This was confirmed by [4], that Surabaya is generally dominated by lowlands, 80% of the area is alluvial deposits and the rest is low rolling hills formed by soil weathering results of tertiary rocks/old.
Table 1 shows the value of building frequency using the spectral analysis, RDM and FSR approaches. The analysis of each building resulting horizontal natural frequency value (NS and EW). The natural frequency values obtained at the Graha Pena is varied. Research on the building was conducted on several floors to prove whether the natural frequencies of each floor in a building are the same. Therefore, it requires only a single measurement at one floor.

To support the result of natural frequency data, damping ratio analysis, vulnerability index and maximum acceleration can be held down the building needs to be calculated. The vulnerability index and the maximum acceleration of the building can withstand is estimated from FSR results analysis. Also in the case of natural frequency analysis results, the parameter index of the vulnerability of buildings and the maximum acceleration that the buildings can withstand also pointed out that the strongest building is PDAM Surabaya, while the weakest is Intiland Tower building.

Estimation of damping ratio is different with natural frequency, vulnerability index and the maximum acceleration that is capable of being held by buildings. Damping ratio estimation results show that Intiland Tower has the lowest strength while STIKOM Surabaya has the weakest buildings strength. But the strength difference is not noticeable. This is possible because the method used is based on the single degree of freedom (SDOF) whereas in practice building naturally has multi degree of freedom (MDOF). Next in the classification of strength building determination, this parameter can be ignored.

5. Conclusion

The potential damage to buildings as a result of the vibrations of an earthquake can be estimated using natural frequency parameter, the possibility soil-structures resonance, and the maximum acceleration of the vulnerability index which the building can withstand. From the analysis results can be shown that Rusun Penjaringan Sari, Antariksa Hotel, Tjuh Belas Agustus University, Sukolilo Dian Regency, East-Java Police Department, Ciputra Apartment, EAST JAVA Senate, PDAM Surabaya, Intiland Tower, Siola Tunjungan City, Bhayangkara University, UNESA Physics Department, Firehouse Department, Bung Karno Stadium has the potential resonance between the structure and soils. The Intiland Tower and the STIKOM building has the weakest strength, while the most powerful buildings are Surabaya Firehouse Department, National Finance building and Surabaya PDAM building and the others have medium strength.
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