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Seismic Hazard Potential in Yogyakarta Based on HVSR Curve Estimation

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Abstract. In 2006, the Special Region of Yogyakarta was shaken by a destructive earthquake. The United States Geological Survey (USGS) recorded that the earthquake had a magnitude of 6.3 M_w at a depth of 12.5 km below the surface that was triggered by strike slip fault activity. The severe damage occurred in Bantul district and Klaten district, where the Klaten area location were far from the earthquake epicenter. This proves that the magnitude and the earthquake source distance are not the only parameters for seismic hazard potential, but rather the presence of local site effects and building conditions. The present study aims to determine the characteristics of the soil and estimate the seismic hazard potential by using HVSR method. Horizontal to Vertical Spectral Ratio (HVSR) is one method that can be used to obtain the subsurface information from single station measurements. Furthermore, the inversion of Rayleigh wave ellipticity curve is used to obtain 1-D of shear wave velocity (Vs). The parameters from HVSR calculation and Rayleigh wave inversion were mapped to understand the subsurface structure beneath the Yogyakarta area. Based on the soil classification to Vs, Yogyakarta area is categorized to SD (Stiff soil/soft soil) and SC (Very dense soil and soft rock). The results of the mapping analysis indicated that Bantul district is an area with the highest potential of seismic hazard.

1. Introduction

The tectonics of Indonesia is located between several tectonic plates, that is Eurasia, Australia, Pacific, and Philippine Sea plates [1]. Consequently, these conditions cause Indonesia to get activity from earthquakes and volcanism frequently, and also has a rough topography. [2]. In the last two decades, several destructive earthquakes have been recorded with significant magnitudes, one of them is the Yogyakarta earthquake in 2006. The earthquake causes 4,772 fatalities, 17,772 injured, and 204,831 buildings destroyed [3].

Damage of a building from seismic waves propagation can be influenced by the soil properties and the building conditions [4]. Microtremor is one method that can be used to find out the soil properties and identify the potential effect caused by earthquake waves propagation [5]. The microtremor data can be analyzed by Horizontal to Vertical Spectral Ratio (HVSR) method to provide several parameters as a reference in earthquake hazard level in an area [6]. Several parameters obtained from the calculation of the HVSR curveare frequency dominant, amplification factor, and Vs^{30}. This research was conducted to analyze the microtremor data of the 15 GeoForschungsZentrum (GFZ) stations network that includes almost all areas of Yogyakarta by using the HVSR method.

2. Geological Setting

As shown in Figure 1, the Yogyakarta area is located of the southern coast of Java and close to the Australian plate boundary which was affected by the uplift of the Southern Mountain and the Kulon Progo mountains during the early Pleistocene [2,7]. As a consequence, there are a series of volcanoes along the island of Java including Mount Merapi, and became an area affected by tectonic activity.

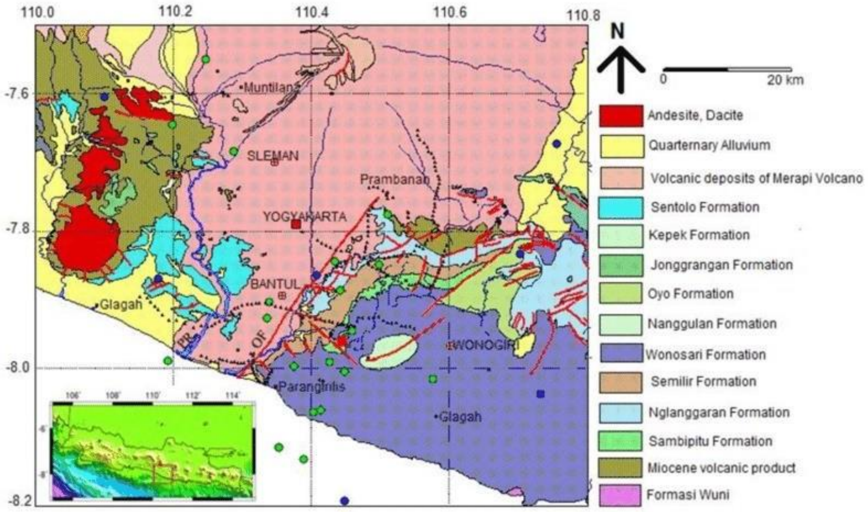

Figure 1. Geological Map of Yogyakarta area. The red line represents the Opak fault line [5] and the blue and green dots represent the location of epicenter [8].

Morphologically, the Yogyakarta area is divided into several major morphological units. First, the Kulonprogo and Gunungkidul regency from west Yogyakarta are mountains formed in the Tertiary. Second, The Sleman regency from north Yogyakarta was formed by sedimentation from the eruptions of Mount Merapi and the soil profile is mainly composed of coarse sand and gravel. And the last, the Kulonprogo regency from south Yogyakarta is lowland area where the soils structure were formed during the Quaternary period. The soil consists of several young and thick deposits and is crossed by an opaque fault line, which have a high seismic hazard potential [9].

3. Data and Method

3.1 Data

The data is used from the GeoForcshungsZentrum (GFZ) network by using 15 single station broad-band seismometers (Figure 2) distributed in the Yogyakarta area after the 2006 earthquake occurred. The stations are recorded full day from June to August 2006. The digital recorder of the seismometer was connected to Global Positioning System (GPS) antenna, making it possible to receive daily coordinates and time. Data recording results in the form of the time series waveform in miniSEED format (Standard Exchange of Earthquake Data). The data from GFZ network in the form of a waveform in the time domain that consist of three main components, such as: vertical components, North-South (NS) horizontal components, and East-Weast (EW) horizontal components with a measurement duration of 1 hour (Figure 3A).

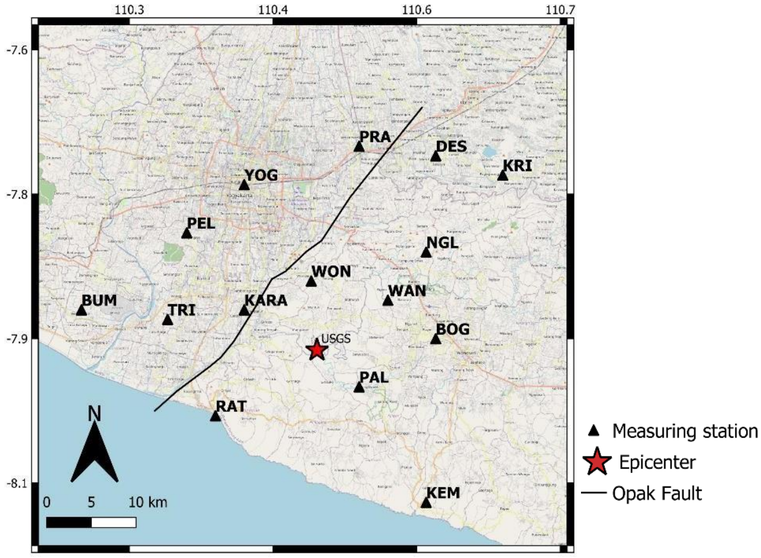

Figure 2. Measuring station distribution in the Yogyakarta area.

3.2 Method

3.2.1 Horizontal to Vertical Spectral Ratio (HVSR)

The fundamental concept of this method is to make a comparison between the spectrum of the horizontal component and the vertical component of a wave [5]. In this study, we used Geopsy software to calculate the spectrum of the measuring station components. Furthermore, filtering of non-stationary signals is carried out by applying the short-time-average through the long-time-average (STA/LTA) algorithm. The filtering needs to be done to reduce noise caused by interference during recording data acquisition. The signal recording from the time domain is converted into frequency domain by the Fast Fourier Transform (FFT) process with a frequency range of 0.5-20 Hz and 60 s timewindow (Figure 3B). The 3 components of the signals can be determined by:

$$A_H = \sqrt{\frac{A_{NS}^2 + A_{EW}^2}{2A_V^2}} \tag{1}$$

where A_{NS}, A_{EW}, and A_V are the components of the Fourier amplitude spectra in the North-South, East-West, and Vertical, respectively.

The output from this processing is an H/V curve that provides the value of dominant frequency and amplification factor. The dominant frequency is estimate as follow:

$$f_0 = \frac{v_s}{4h} \tag{2}$$

and amplification factor is:

$$A_0 = \frac{v_b}{v_s} \tag{3}$$

where the f_0, v_s, h, and v_b are the frequency dominant, shear wave velocity on the surface layer, thickness, and shear wave velocity of basement, respectively [10]

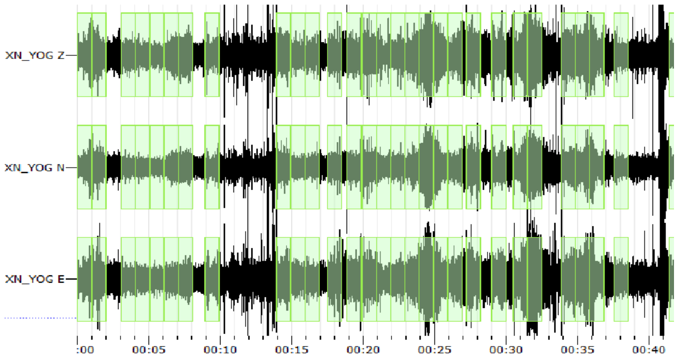

Figure 3. Waveform of YOG station with 3 components that are selected by time window for 1 hour.

3.2.2 Inversion Process

The inversion process is used to transform the measurement data into model parameters. This method assumes that the microtremor data and the H/V curve are dominated by surface waves called the elliptical Rayleigh waves [11]. The ellipticity of Rayleigh waves is inversed to investigate shallow subsurface structure by using DinverPackage from Geopsy in dinver format to obtain the minimal misfit equation. The misfit equation is estimated based on Neighbourhood algorithm as follow:

$$misfit = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Di-Mi}{\sigma_i}\right)^2} \tag{4}$$

where the N, Di, Mi, and σi are the number of data, inversion data result, observation data result, and standard deviation [12].

According to Herak (2008) there are six parameters that affecting the HVSR curve, such as: compression wave velocity (v_p), shear wave velocity (v_s), thickness (h), density (ρ), and attenuation factors (*Qp*, *Qs* [13]. Therefore, to find out the level of influence of the six parameters, an inversion process was performed on HVSR curve. In this study, we define the model parameters initial trial and error by correlating parameters to conditions geology of the research area. This is concluded in order to obtain a comparison between the observation data and the calculated data as small as possible.

Table 1. Model parameters used in the inversion process.

Layers	v_p(m/s)	v_s(m/s)	Depth (m)	Poisson's Ratio	ρ (kg/m^3)
1	100-500	150-500	100		
2	300-1000	150-750	20-100 (Thickness)		
3	600-1500	500-1000	20-100 (Thickness)	0,2-0,5	2000
4	900-2000	500-1250	30-100 (Thickness)		
5	1200-2500	500-1500	30-200 (Thickness)		
6	1500-3000	1000-1750	400 (half space)		

4. Results and Discussion

4.1 H/V Curve

The results of the H/V calculation from all measuring stations obtained three types of H/V curves which are characterized based on the number of the peaks. The three types of curves are: clear peak curve, multiplepeaks curve, and flat curve. These three types of curves are interpreted based on [14]. As shown in Figure 5, the shape of the peak on the H/V curve indicates presence or absence of impedance contrast in the subsurface layer. The clear peak curve (a) indicates the presence of impedance contrast, the multiple peaks curve (b) indicates the presence of impedance contrast with the boundary between new layer and old layer, and the flat curve (c) indicates the absence of impedance contrast in the subsurface layer.

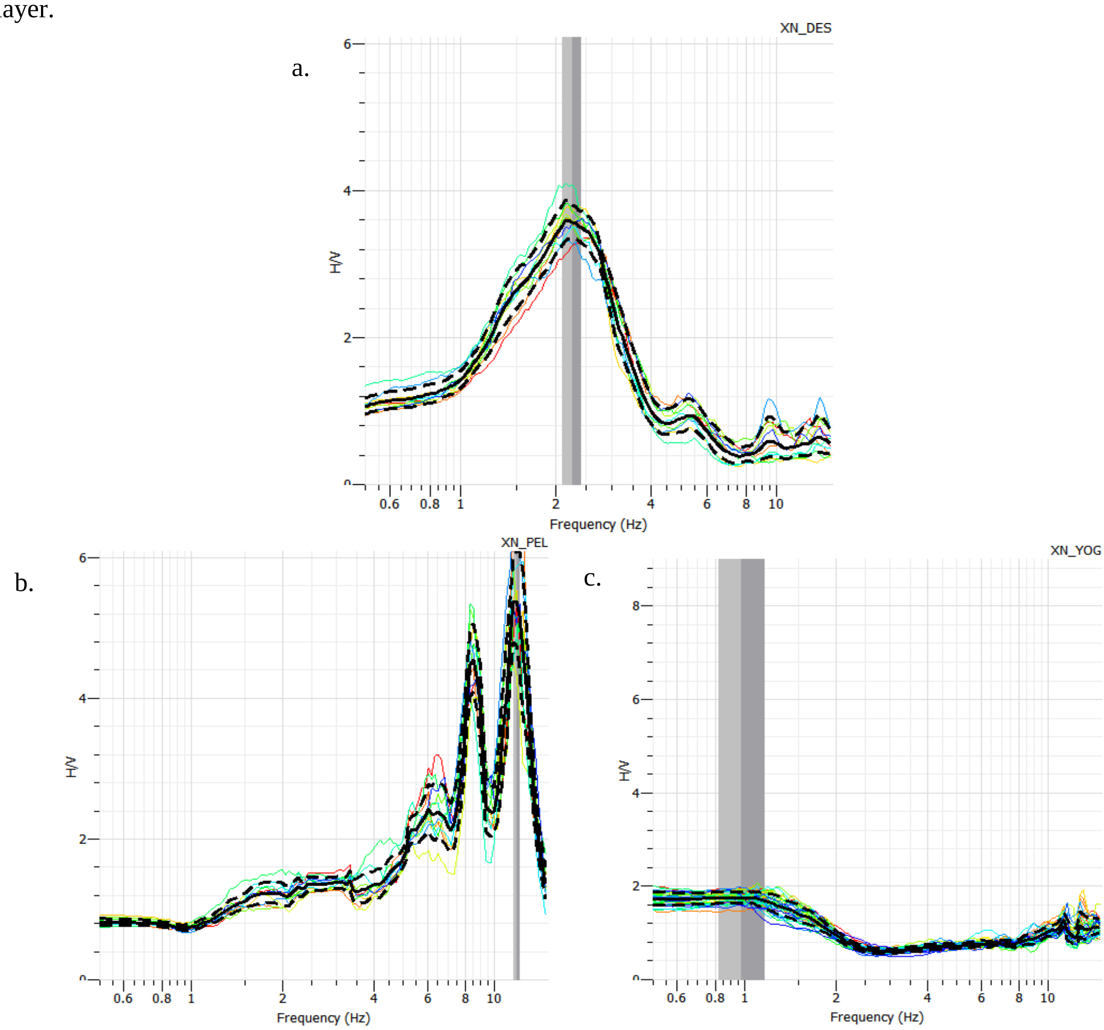

Figure 4. Three types of H/V curves, a. Clear peak curve, b. Multiple peaks curve, c. Flat curve. Every spectrum color shows window selection result, black line shows the mean of the HVSR value, and the black dotted line shows the lower and upper standard deviations.

4.2 Frequency Dominant and Amplification Factor

The result of the H/V calculation have a dominant frequency ranges from 1.05 – 13.7 Hz and amplification factor ranges from 1.17 – 7. Figure 5,6 show the distribution of dominant frequency and amplification factor for 15 measuring station. The dominant frequency is associated with the thickness of the sediment [10]. The areas with low dominant frequency indicate that has relatively deep bedrock depths, on the other hand, the areas that have a high dominant frequency indicate that has relatively thin bedrock depths.

Amplification factor is the ratio of the surface to subsurface layer amplitude [14]. Inother words, the amplification factor value depends on the geometry of the sediment structure. The Yogyakarta area is dominated by amplification factor ranges from 1 – 3.3, but around the PEL station, the value of the amplification factor is more than 6.3. The highest value of the amplification factor is due to PEL station located at Sentolo Formation (Bantul district), which is composed of several different layers [16]. The values of dominant frequency and amplification factor indicate Bantul is a vulnerable area of seismic hazard.

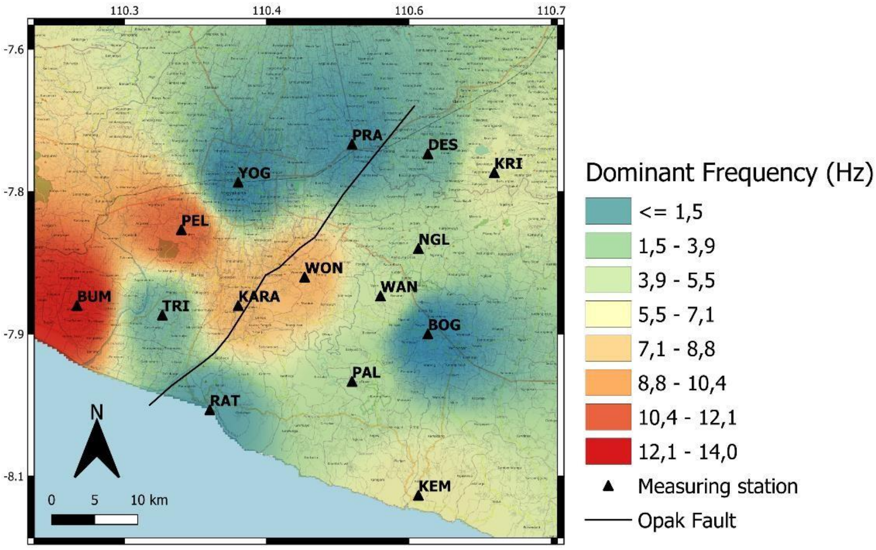

Figure 5. Dominant frequency distribution map of Yogyakarta area

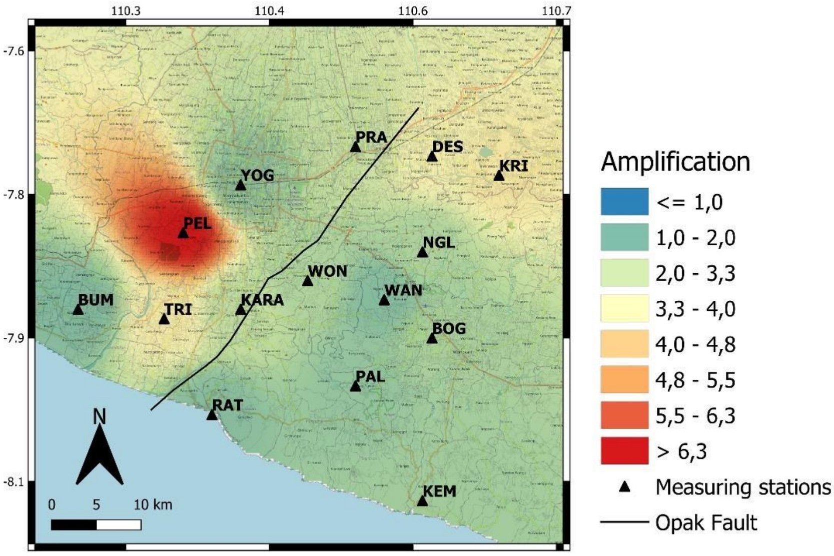

Figure 6. Amplification distribution map of Yogyakarta area

4.3 Ground Profile and Vs^{30}

After the specific parameter model is set, the ellipticity curve and ground profile can be displayed to approach the shear wave velocity in each layer. According to Table 1, the inversion process obtained the estimation model of the ground profile and the ellipticity curve in 1D. The color spectrum of the curve is the result of the estimation model of inversion process for each value of misfit. The red line is the inversion model that has the minimum misfit value. As an inversion concept, the inversion process is worked by iterating the initial model to the best model obtained with the smallest misfit. This result produces a minimum misfit value of 0.38 and maximum misfit value of 0.5 shown by Figure 7.

After the Vs value is obtained from inversion process, then the average value of Vs is calculated at a depth of 30 meters below the ground surface as in equation (2). This result provides the average of Vs^{30} value between 240 – 600 m/s as shown in Figure 8. Based on the value, the Yogyakarta area can be classified according to the type of soil as shown in table 2. Yogyakarta area is categorized into soil profile types SC and SD. However, the value of Vs^{30} is not enough to classify the soil profile types in an area, it is caused the structure of the sediment is also influenced by the value of dominant frequency [10].

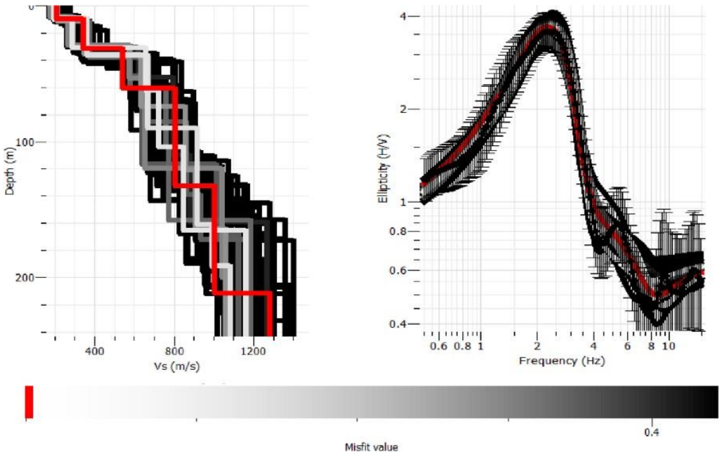

Figure 7. 1D ground profile (left) and ellipticity curve (right)

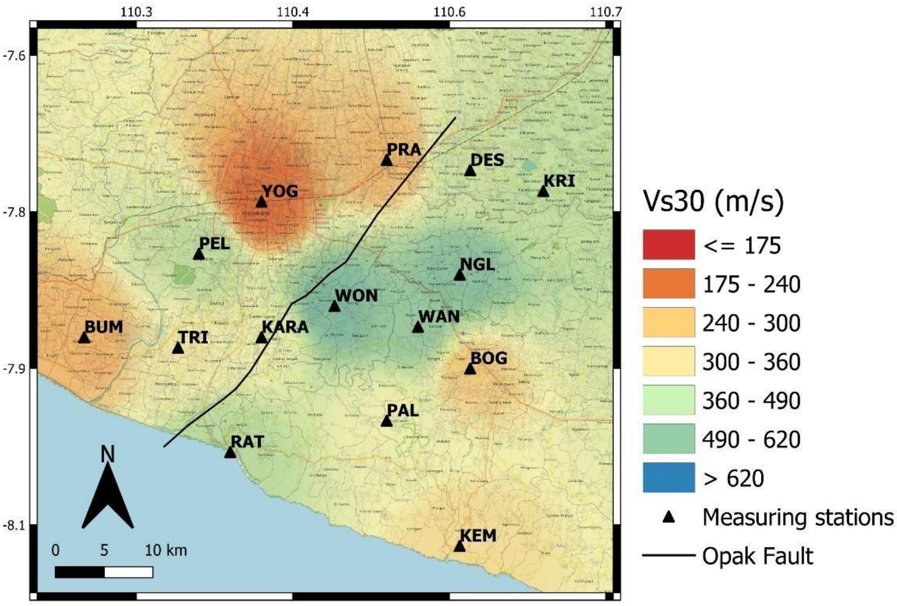

Figure 8. Vs^{30} distribution map of Yogyakarta area

Table 2. Site classification based on Vs^{30} according to SNI 1726:2012

Soil profile type	Description	Vs^{30}	Station
SA	Hard rock	> 1.500 m/s	
SB	Rock	750 – 1.500 m/s	
SC	Very dense soil and soft rock	350 – 750 m/s	DES, KEM, KRI, NGL, PAL, PRA, WAN, BUM, WON
SD	Stiff soil	175 – 350 m/s	BOG, YOG, TRI, RAT PEL, KARA
SE	Soil	< 175 m/s	

5. Conclusion

The result of calculating 3 signal components in each station produced the 3 types of H/V curves based on number of the peaks. The H/V curves obtained the value of dominant frequency and amplification factor. The inversion process from the ellipticity curve of Rayleigh waves produced the value of Vs^{30} that categorized the Yogyakarta area to SD or Stiff soil, and SC or Very dense soil and Soft rock. Those values can indicate the seismic hazard potential in Yogyakarta area. Bantul is an area with a high potential of seismic hazard. This is because the Bantul area is dominated by clear peak and multiple peaks H/V curves and high dominant frequency with the highest amplification factor.

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