Seismic micro-zonation framework for earthquake risk in Medan-North Sumatera Indonesia using geotechnical engineering survey

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Abstract. The micro zonation is very essential to identify the tectonic and geological formation in the study area, and still fundamental for determining the seismic source and establishing a realistic earthquake hazard model. Indonesia is located in the Pacific Ring of Fires, it is constantly at risk of earthquakes, tsunamis, and the eruption of volcanic. In this case, we focused to review the previous study of micro zonation in Indonesia and making the framework of micro-zonation for earthquake risk in Medan-North Sumatra, Indonesia. The goal of this study to illustrate the diversity of methodologies presently in use for the preparation of seismic hazard maps and to evaluate basic principles of zonation for different purposes and at different scales in new planning in Medan, North Sumatera. We select the micro zonation methods and looking for the opportunity for planning the micro zonation based on the literature review. The result of this review, the plan and framework of micro zonation in Medan, North Sumatera will be important and needed for mapping the seismic hazards. The output of seismic micro-zonation map based on the geotechnical engineering survey with the Multichannel Analysis of Surface Waves (MASW), Spatial Auto Correlation (SPAC) and Horizontal to Vertical Ratio (HVSR) for dominant period.

1. Introduction

Seismic micro-zonation is very important not only in other countries but also in Indonesia. The potential of the earthquake and geothermal activity, making Indonesia mitigate seismic risk. Indonesia is located between the Ring of Fire. This location making why Indonesia has so many earthquakes and potential of geothermal and volcanic activity. In general, the Indonesia archipelago has the unique geological condition [1], [2]. It is located between two big plates, Indo-Australia Plate in the south and Eurasia Plate in the north [3], [4].
Seismic micro-zonation is one of the steps in earthquake risk mitigation study and needs a multidisciplinary approach with major influences from the field of geology, seismology, geophysics, and geotechnical engineering. The seismic micro-zonation is very imperative to identify the tectonic and geological formation in the study area and also for beginning a realistic earthquake hazard models and for investigation [5]. The micro-zonation studied attempts to identify geologic zones of an area of interest with similar seismic hazards at the local scale.

Seismic micro-zonation is the most current tool for earthquake risk assessment and creates a database for planning pre-earthquake disaster management [6]–[8]. It includes delineation of the homogenous zones is seismological and geological characteristics and description of zone characteristics by dynamic parameter [9]. The seismic micro-zonation had been studied and developed in two decades, [10] initiated a model of seismic micro-zonation of the Skim Himalaya by integrating the geological and strong motion feature using geographic information system. These output of maps, generally a better spatial representation of seismic hazard including the site-specific analysis. Based on [11] present the deterministic seismic micro-zonation of Kolakat city by the computing of spectral ground motion amplification. One of the natural disaster that have expressively impacted on risk and damage is an earthquake, [12] investigating the seismic zone and earthquake hazard micro-zonation by using Neo-Deterministic seismic hazard analysis.

In this case, we review some literature about micro-zonation in other countries to compare the micro-zonation which had been done in Indonesia, and a potential plan of micro-zonation in Medan, North Sumatera. The aim of this study to evaluate micro-zonation in some areas in Indonesia and how seismic micro-zonation is very important in a new location of micro-zonation in Medan, North Sumatera, Indonesia.

2. Literature Review
It has long been known that the location of Indonesia in the ring of fire can greatly influence the activity of earthquake and impact effect and risk. In micro-zonation in some areas in Indonesia had been done. Figure 1 shows the micro-zonation in some areas in Indonesia, started from Padang, Jakarta, Bandung, Semarang, Yogyakarta, Banjarnegara, Singaraja and Palu.

![Figure 1](image-url)

**Figure 1** A brief of history micro-zonation in some city in Indonesia

The micro-zonation in some areas in Indonesia had been done. The micro-zonation using some methods or models for plotting the map. In Table 1, show the methods of micro-zonation based on input data and be contingent on the scale of mapping in the level of zonation. The micro-zonation in Indonesia is very urgent based on the location of Indonesia at the Pacific in Ring of Fire. Generally, the histories of micro-
zonation in Indonesia consisted of three grade show in the Table 1, grade I based on the historical earthquake and current information of geological and geomorphological maps. Grade 2, the micro-zonation according to the micro-tremor studies, and simplified geotechnical studies. Grade 3, based on the complete geotechnical investigations and ground response analysis.

**Table 1. The reviews methods for micro-zonation in Indonesia**

| City/Year      | Grade I                                                                 | Grade II                                      | Grade III                                      |
|---------------|-------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------|
| Palu, 2015 [13] | Deterministic and probabilistic approach, and                           | Microtremor measurement                      | -                                             |
|                | Historical of earthquakes                                              |                                               |                                               |
|                | Existing information on geological and geomorphological maps           |                                               |                                               |
| Jakarta, 2015 [14] | Deterministic, probabilistic approaches, and                           | Microtremor array measurements, output      | Detailed seismic risk map                      |
|                | seismotectonic map                                                     | parameters: PSA                              |                                               |
| Semarang, 2015 [15], [16] | Deterministic approach, and                                            | Single station feedback seismometer         | -                                             |
|                | geological map                                                         | measurement, output parameters: Spectral     |                                               |
|                |                                                                        | Acceleration                                 |                                               |
| Bojonegoro, 2017 [2], [17] | Deterministic, probabilistic approach, and                            | Microtremor measurement, output              | -                                             |
|                | geological map                                                         | parameters: f₀, Kg                           |                                               |
| Padang, 2017 [18] | Geological map                                                          | Microtremor measurements, output parameter: | -                                             |
|                |                                                                        | type of soil                                 |                                               |
| Singaraja, 2017 [19] | Geological map                                                          | Microtremor measurement, output              | -                                             |
|                |                                                                        | parameters: Am, type of soil                 |                                               |
| Yogyakarta, 2017 [20] | Deterministic and probabilistic approach, soil condition, and          | Borcholes and microtremor measurement,      | -                                             |
|                | geological map                                                         | output parameter: Empirical prediction of PGA|                                               |
| Bandung, 2018 [21], [22] | Geological map                                                          | Microtremor/ambient noise data, output      | -                                             |
|                |                                                                        | parameters: f₀, Am, Kg                       |                                               |
The methods for micro-zonation in Indonesia used the microtremor for the geotechnical engineering survey. And the parameter for micro-zonation produced the type of soil.

3. Methodology
The micro-zonation methods based on the level zonation had been done in some areas in Indonesia. The framework plan of micro-zonation can illustrate in Figure 2. The first step of the micro-zonation by using a geotechnical engineering survey by using MASW, SPAC and the HVSR for dominant period. Figure 2 show the pre-processing of the geotechnical engineering survey produces the shear wave Velocity, Density function, and Lithological information. The second step by analyzing site response, soil properties and spectra acceleration to get the seismic micro-zonation map. The new framework of micro-zonation in Medan, North Sumatera will be done in 2020.

Figure 2. The methods of micro-zonation planning in Medan
The micro-zonation methods in this study, based on the geotechnical engineering survey. The first method is MASW. The MASW is a seismic exploration. The technique first introduced in geophysics by [23], [24]. The MASW evaluates ground stiffness by measurement shear wave velocity (Vs). MASW is useful the micro-zonation methods for exploring shallow geological structure and in particular, the relative shear strength of subsurface materials.

The second methods in geotechnical engineering survey is SPAC method. The SPAC was first proposed by [25] for understanding horizontally propagating waves or the relations between the temporal and spatial spectra of micro-tremors and their phase velocity characteristics [1], [13], [21], [24], [26]–[29].

The last methods for geotechnical engineering survey in this study is HVSR for dominant period (Td). The natural periods of vibration of the soil profile are most significant dynamic parameters involved in response analysis [27], [30], [31].

4. Result and Discussions

The framework of seismic micro-zonation result for the analysis of seismicity of North Sumatera as shown in Figure. 2 indicates the micro-zonation in Medan City as the capital of Prov. North Sumatera is a good investigation to evaluate and identify the seismology and geology structure in the field. There are three approaches for micro-zonation will be computed, the first approach by using geotechnical engineering survey by using MSAW, seconds, geotechnical engineering survey by using the SPAC and the last is using HVSR for dominant period in geotechnical engineering survey. The HVSR is a method for getting subsurface material from single station measurement by comparing the spectrum of horizontal component to the vertical components. HVSR method applied to ambient noise (Nakamura).

The goal of HVSR methods to feature the resonance frequency or fundamental mode of the soil. The deterministic approach is based on grade and level characteristics.

Figure. 3 Seismicity of Regional North Sumatera Period 2009-2019

Figure. 3 is the distribution of earthquakes from 2009 to 2019. The map seismicity had been classified based on the depth and the Magnitude. The depth and classification are divided into three-part, shallow (0-60 km), middle (60-100 km) and deep (> 100 km). The classification of Magnitude in the seismicity maps shows between small Magnitude (< 4 SR), Magnitude (4-5 SR) and Magnitude biggest 5 SR.
The location of Medan City, North Sumatera, Indonesia is close to Sumatera Fault, the earthquake activity in Medan is dominated by horizontal fault.

Figure 4 is a combination of the micro-zonation (yellow circle) that has been done and being done (red circle) in Medan, North Sumatera, Indonesia. The determining of Medan city as the next micro-zonation is crucial, seeing the location and condition of Medan City are disaster-prone areas and impact and risk of earthquake potential. Based on the [32] try to identify the earthquake activity in Deli Serdang on 2017 by analyzing the waveform from broadband station using machine learning approach. Based on Figure 2, the seismicity of Medan City as the capital of North Sumatra or near to the Medan area like Deli Serdang indicated the distribution of earthquake in the field can affect the living condition and these building areas.

5. Conclusions
In this study, we present new micro-zonation in Medan, North Sumatera, Indonesia. The micro-zonation is urgent to identify the structure of geology and the environment of the Medan field. Based on the review methods of micro-zonation in Indonesia, we suggest using the approach from framework micro-zonation in the geotechnical engineering survey based on MASW, SPAC, and HVSR methods. The micro-zonation in Medan City as a potential disaster impact is recommended and a good way to identify the structure and geology in the Medan field based on the history of Medan as a potential impact and risk of earthquake activity. The new framework of micro-zonation in Medan, North Sumatra will be offer urban planners and city to mitigate earthquake risk.

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