Rapid visual assessment of building vulnerability due to earthquake potential hazard in Surabaya

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Abstract. This article studies about Rapid Visual Assessment using android application RViSITS. The Institut Teknologi Sepuluh Nopember team has developed this application, and the purpose is to conduct a more accessible assessment survey in the digital version instead of using the standard form, applying the same standard called FEMA 154. This building vulnerability research was carried out using the application, due to data requirement for mitigation action needed by Surabaya government, due to two newly discovered faults passing the city, namely Surabaya and Waru faults. These two new faults concealed by the National Earthquake Research Centre (PuSGeN) lead to higher earthquake potential hazards in Surabaya, as stated in the SNI 1726. In this research, a two-phase survey was conducted to a total of 366 buildings. From the development of the result mapping of the application, it is discovered that the buildings built after SNI 1726 regulation issued have a higher level of resistance toward earthquake loads, especially the buildings in Surabaya, where gradual seismic risks keep increasing. Therefore, it is necessary to develop mitigation strategies due to the earthquake potential hazard in Surabaya.

1. Introduction
Indonesian territory is surrounded by complicated tectonic plates. The archipelago of Indonesia represents the meeting of Pacific Plate and Indian-Australian Plate (in Eastern Indonesia), Eurasia Plate, and Indian-Australia Plate (in Western Indonesia), and a smaller plate (Caroline Plate and Philippine Sea Plate). Those surrounding plate boundaries can be estimated by the zone of the active earthquake, the zone of mass movement in the mountain region, the zone of volcanism, zone of magmatism, and zone of hydrocarbon [1]. The zone of active earthquakes has already been verified by the Indonesian Meteorological, Climatological, and Geophysics Agency (BMKG) recorded repository regarding the recent earthquake in its website [2]. Another research about this theme in Sulawesi [3] and Lampung [4] is another support to the evidence of Indonesia’s great potential of earthquake hazard.

Earthquake potential hazards have to be standardized by the Indonesian government. Many cities in Indonesia have regulations to deal with earthquake possibilities, which can occur at any time in the future. Surabaya, as the second-largest city in Indonesia, and as the home for approximately 2.9 million people in 2015 [5], faces its own problem regarding earthquake possibilities.
Based on the National Earthquake Research Centre (PuSGeN) released Maps of Earthquake Source and Hazard of Indonesia 2017 [6], it is acknowledged that Surabaya is passed by Baribis-Kendeng Fold-thrust zone, which has 0.05 mm/years slip rate [7]. The Baribis-Kendeng Fold-thrust zone that passes Surabaya consists of two newly discovered faults, as listed as Surabaya fault and Waru Fault [6]. Both of these faults can be seen in Figure 1 [8]. And, a recent earthquake that happened around Surabaya city, which is presented in table 1, confirms that Baribis-Kendeng is potentially posed as an active Fold-thrust zone.

Based on three available Indonesia National Standard (SNI) of Earthquake Resisting Building Design starting from SNI 1726-2002 [9]; SNI 1726:2012 [10] and SNI 1726:2019 [11], there has been gradual seismic increasing risks in Surabaya. And this started from The First Indonesian National Earthquake Standard (SNI 1726-2002). In this regulation, it was stated that Surabaya was categorized to a low-risk hazard zone, with PGA value was 0.1g. It can be seen in table 2. In SNI 1726:2012, it was stated that PGA value was 0.3g - 0.4g and categorized as a middle-risk hazard zone. The newest standard SNI 1726:2019, changed the value to higher number of Surabaya’s PGA to around 0.4g – 0.5g. However, from table 2, the $S_S$ value in the RSNI2 1726:2018 was still categorized as middle zone, despite the fact that it was close to high risk hazard zone. Therefore, every construction needs special design requirement. And further, it is also necessary to develop mitigation strategies due to the earthquake potential hazard in Surabaya.

![Figure 1. Surabaya fault (top line) and Waru fault (bottom line) through Surabaya.](image)

**Table 1. Recent earthquake recorded around Surabaya.**

| No. | Date            | Depth (km) | Location                     | Magnitude |
|-----|-----------------|------------|------------------------------|-----------|
| 1   | July 24th, 1984 | 33         | Bojonegoro                   | 4.7       |
| 2   | May 14th, 1992  | 33         | Java Sea (South of Madura)   | 4.7       |
| 3   | July 28th, 2006 | 10         | Grobokan                     | 4.5       |
| 4   | January 24th, 2007 | 35     | Bojonegoro                   | 4.3       |
| 5   | February 28th, 2015 | 45.06   | Java Sea (South of Madura)   | 4.1       |
| 6   | June 25th, 2015 | 9.77       | Bojonegoro                   | 4.3       |
| 7   | November 4th, 2016 | 17.87   | Ngawi                        | 4.7       |
| 8   | February 20th, 2017 | 10      | Madura                       | 3.7       |

**Table 2. Earthquake variable value in Indonesia national standard of earthquake resistant building.**

| Name of standard | Value of PGA (g) | Value of SS (g) | Value of $S_1$ (g) |
|------------------|------------------|-----------------|--------------------|
| SNI 1726-2002    | 0.1              | 0.38            | 0.24               |
| SNI 1726:2012    | 0.3 – 0.4        | 0.6 – 0.7       | 0.2 – 0.3          |
| SNI 1726:2019    | 0.4 – 0.5        | 0.7 – 0.8       | 0.4 – 0.5          |
All the newly discovered faults, which are newly published on earthquake hazard maps, or new standards, become the reasons why mitigation strategies have to be accelerated in Surabaya. To propose the mitigation techniques, the database of building assessment will be needed as one of the compulsory requirements. The conventional method of building assessment needs to involve several building and structure experts, and other related fields involved. Therefore, it requires more time and more expenses. Due to the assessment problem, Federal Emergency Management Agency (FEMA) suggests an application of a technique called Rapid Visual Screening (RVS) presented in FEMA 154 [12].

The RVS is a quick and low-cost method that has been selected to evaluate building vulnerability subjected to seismic loading. This method can also be applied to buildings with minimum access as it can be carried out through an observation conducted from the outside surroundings of the buildings. RVS technique has been widely used by several researchers to evaluate building vulnerability due to earthquake potential hazards [13], [14], [15].

In this research, the RVS android based application, which has been developed by Institut Teknologi Sepuluh Nopember, is called RViSITS (Rapid Visual Survey by Institut Teknologi Sepuluh Nopember). The application of RViSITS has been verified by numerical analysis, which shows the same results as the results of previous studies [13]. Moreover, since RVS method by FEMA 154 still applies several manual paper forms, the proposed RViSITS application can be selected and used as a faster and simple method. The manual paper forms of the RVS method by FEMA 154 can be omitted using RViSITS application, which is based on android systems, as shown in figure 2.

2. The Material and Method

2.1. Research Methodology
Since the earthquake potential hazards in Surabaya have increased, as presented in [9], [10], [11], it is necessary to perform building vulnerability assessment using RVS method. The main purpose of this research is to collect and build database of buildings’ vulnerability in Surabaya. Therefore, several steps must be carried out to achieve the purpose of the research. The first step is literature study related to the earthquake potential hazard, building assessment and vulnerability, and hazard mitigation and response in Surabaya. Then, the second step is field survey, which is very crucial in this research as to gather building data from several types of buildings in Surabaya. Along with the data collecting process, the software development toward the mapping of the assessment results must be conducted simultaneously. Result from mapping and data processing are needed as well, before this paper comes to a discussion and draws a conclusion. The Illustration of the research methodology is shown in figure 3.

2.2. Field Survey
The field survey of this research started with the sequence of permission processing. This field survey obtained two official permission letters from Surabaya Government, the first letter was from Surabaya Planning Board (Bappeko), and the second letter was from the National Unity, Politics and Society Protection Board of Surabaya Government (Bakesbangpol dan Linmas). The field survey was conducted by several numbers of registered surveyors. These registered surveyors had been trained to use the application in advance before carrying out the field survey as the method in FEMA 154 [12] and RViSITS’s user guide [16]. Meanwhile, the copyright of the application had already been registered in Indonesia’s Ministry of Law and Human Rights, Republic of Indonesia, with registration number 000154073. The phase of the field survey is illustrated in figure 4.

The first field survey phase was conducted on several buildings that belonged to the Government of Surabaya. The duration of this field survey was one month. These government buildings were chosen due to the fact that apart from the function of these buildings, like public buildings, the Surabaya government has the authority to rebuild or renovate the buildings. Therefore, if the results of the survey showed unqualified scores and did not meet the requirements. Surabaya government could take necessary action toward these buildings. In this phase, there were 110 buildings surveyed using RViSITS. And the buildings were separated to several government building categories such as: schools, health facilities, mosques, churches and district offices.

![Figure 3. Research methodology](image)

![Figure 4. Field survey phase classification.](image)

The initial survey was carried out to all the surveyed buildings located in the areas of where the faults passed. Some of the districts that Surabaya fault passed are: Asemrowo, Sambikerep, Sawahan, Sukomanunggal, Tandes, Benowo and Pakal. The districts near Waru fault are fewer than the districts near Surabaya fault. Waru fault only covers two districts, the two districts are Karangpilang and Wiyung. The results of the first phase survey project were reported to the Government of Surabaya [17]. To compare any actions that the Government of Surabaya performs regarding this case, the report of the results is illustrated and discussed in this article.

The second extension survey was carried out to another 256 different buildings. The field survey duration was just 35 days. It focused on residential buildings, which were built only in a radius of 1 km from the fault estimated locations revealed by the National Earthquake Research Centre (PuSGeN). The residential building survey was carried out to collect information about the housing around the city near to the faults. The results from the survey are expected to be able to be applied and used as consideration for Surabaya Government to plan its urban regional planning, especially the one that is related to building construction regulation.
However, there were several boundary conditions used as input in the application operated in this study. Each of them is listed below:

1. Surveyors were only for trained people who have the capability or knowledge regarding building, structures, and earthquakes.
2. The names of the buildings were written by the official name or the owner’s name.
3. The Addresses and GPS locations were entered as clearly as possible.
4. The construction date entered was the time of the initial construction.
5. The seismic level that is used as the default is set as “High” to perceive the building score well, especially when faced with the current level of potential earthquake hazard. As an example of data comparison, the building constructed before 2012 was set as “Low”. While another building constructed in the middle of 2012 and 2019 was set to “Middle”.
6. The soil condition in this fault area is categorized as “Soft Soil”. Nonetheless, any data needed for East part of Surabaya City, the input then was categorized as “Poor Soil”.
7. Other categories, that were not limited to the list, are adjusted due to the real condition in the field, when the survey activities were being conducted by the surveyors.

![Java fault (.kmz) line in Goggle Earth.](image1)

**Figure 5.** Java fault (.kmz) line in Goggle Earth.

![Java fault (.kmz) line in RViSITS website](image2)

**Figure 6.** Java fault (.kmz) line in RViSITS website.

### 2.3. Development of Website Mapping

There are many features available besides data-based collection in RViSITS website. The added features of the website in this research phase are the results of the mapping and uploading google earth line data (.kmz). The mapping results will be discussed later, however kmz extension data that is used in this focused article is Java fault. The comparison of Java fault line opened in Google Earth and in this website
can be seen in the figure 5 and figure 6. It is expected that the progress of the development of this website will be able to accommodate google earth line data, thus the results can satisfy and meet the result mapping needed by public use in the future. In addition to this development, the result mapping has a change as well in this research phase. In the previous project, the website can only show the building location captured by GPS. However, in this current research project, both qualified and unqualified results of the survey are properly illustrated on the result map according to the GPS location.

3. Results and Discussion

3.1. Survey Results
Survey result in this section will be separated as a graph that defined numbers of building categories in each surveyed phase. Another result in this article shows the result mapping of the two phases of survey. As seen in the previous figure 4, there are 110 buildings surveyed in the first phase. These 110 buildings are divided in two different fault areas, Surabaya fault and Waru fault. Numbers of different building categories and the survey results are illustrated in figure 7. The bar chart in figure 7 illustrates numbers of building on the first phase survey result that are divided in 4 building categories: 19 buildings of public services (mosques and churches), 30 buildings of government buildings (district offices), 57 school buildings, and 4 buildings of health services.

From the illustrated graph, it is shown that all the health services show a great result as these buildings are categorized to qualified classification. Unfortunately, this result is gained from very limited survey data taken just from 4 surveyed buildings. This is due to the regulation applied in Indonesia, that every health service building that requires a survey must have an official permit from the Ministry of Health. Due to the difficulties of obtaining the official permit from the Minister of Health for health service buildings, this study only managed to survey four health service buildings, even though it had attained an official permission from Bappeko Surabaya. The most number of surveyed buildings are schools. There are 24 buildings, categorised as qualified. Unfortunately, there are more number of buildings categorised as not qualified, these are 33 buildings. The government buildings show similar case as half of the surveyed buildings gain qualified result. Whereas, the other half of the buildings are not qualified. The results obtained from the public services building, including mosques and churches show that 6 buildings are categorised as qualified buildings, meanwhile 13 of them are categorised as not qualified buildings.

In the second phase survey, different results are gained. Figure 8 illustrates the residential house survey results in that phase. The graph shows that 76% of the residential building near to new discovered fault are classified in not qualified category. And, only 24% of them are qualified.
3.2. Comparison of Seismic Category

Our developed website can map the result in two categories: qualified (represented by green dots) and not qualified (represented by red dots), as depicted in Figure 9 to Figure 12. The development of the increased capability of this application shows better result in the survey. In this research project, two different seismic categories are compared. The first one is seismic category based on Indonesian National Standard used when the building are constructed. For an example, if a building was built in 2003, and considered using the Indonesian National Standard (SNI 1726-2002) [9], in which the seismic category of Surabaya was classified as “low”, it is then entered into the “Low” zone. Another example if a building was built around 2013, and considered using the Indonesian National Standard (SNI 1726-2012) [10], in which the seismic category of Surabaya was categorized as “Middle”, it is then entered in the application into “Middle” zone. Since the potential seismic risks in Surabaya keeps increasing, due to the finding of the existence of the two newly found faults, in this research the seismic category of the area, where the two faults pass are categorized as “High”. This modification in seismicity criteria definitely changes the final result scores of the buildings as written in FEMA 154 that used in the RViSITS application. If the result is “qualified”, the maps will show green dots. In the opposite, if the result is “not qualified” it will show red dots.

Figure 9. Surabaya fault – RViSITS’s maps for seismic criteria follow the standard when the building was built.

Figure 10. Surabaya fault - RViSITS’s maps for high seismic criteria.
Figure 11. Waru fault – RViSITS’s maps for seismic criteria follow the standard when the building was built.

Figure 12. Waru fault - RViSITS’s maps for high seismic criteria.

The mapping result are shown in figure 9 to Figure 12. Each of the mapping result illustrates the condition of the building assessment result based on different seismic criteria written above. Figure 9 and Figure 10 show the assessment results of the buildings near Surabaya fault, whereas figure 11 and figure 12 show the assessment results of the buildings near Waru fault. The different results in the maps are shown in figure 9 and figure 10 of Surabaya fault, and figure 11 and figure 12 of Waru fault. All the pictures show that there are changes of the vulnerability score of the buildings, and these lead to different colours in the maps. The vulnerability score using RViSITS of some buildings, which were built from 2003 until 2012 increase, and the building colours in the maps will change from green dots (means: qualified) into red dots (means: not qualified). Hence, Bappeko Surabaya should perform the hazard mitigation policies due to the assessment results using RViSITS based on the increasing seismic hazard in Surabaya.

3.3. Surabaya’s Mitigation Strategies

In term of responding to earthquake potential hazard, Surabaya still has low resilience performance index [18]. Hence, it is necessary to develop mitigation strategies due to the earthquake potential hazards in Surabaya. Since the building vulnerability assessment results have been obtained and collected as the database system using RViSITS, the following steps which consist of mitigation strategies in Surabaya should be developed and supported by Bappeko Surabaya. A general procedure of developing mitigation strategies is presented in figure 13. Meanwhile, the buildings which have ‘not qualified’ result from field survey should be further analysed compared to the other buildings with ‘qualified’ results. The conceptual design and method of retrofitting solution should be proposed to the ‘not qualified’ buildings. The retrofitting solution should be evaluated for both short-term and long-term benefits using cost-benefit analysis. The proposed solution should involve some experts in structural building engineering, and Surabaya Government representatives. After the proposed solutions has been approved, the Government representatives, which is Bappeko Surabaya, must issue the practical acting code and regulations regarding the building assessment results as well as the retrofit design and method. This code
and regulations must cover the construction of all buildings in Surabaya. Further, a successful strategies of earthquake hazard mitigations requires high public risk awareness and public trust in risk reduction policies. And, this can be best performed by developing risk awareness campaigns, including training programs.

![Diagram of General procedure of developing mitigation strategies]

**Figure 13.** General procedure of developing mitigation strategies.

### 4. Conclusions

The obtained results of the field surveys using RViSITS show that it requires 65 days to conduct a survey of 366 buildings. That means the use of RViSITS to help rapid visual survey for building assessment are relatively quick in time duration. A building built in accordance with the Indonesian National Standard Criteria (SNI) applied at the time of the construction, will have higher damaged risks when it is faced with increased earthquake potential hazard, especially in Surabaya, which has gradual increasing seismicity risks. In the future, it is expected that the development of other capabilities to generate reliable rapid visual survey results on this RViSITS application can be carried out, including the use of the latest standard and codes in the application. And, it is also expected that other types of categories and number of buildings can be collected and observed for the development of this kind of research in the future.
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