Earthquake Vulnerability Assessment of High-Rise Buildings in Surabaya using RViSITS Android Application

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Abstract. This article presents about vulnerability assessment of high-rise building in Surabaya, the second largest city in Indonesia. In 2007, the Earthquake National Research Center -Indonesia's Ministry of Public Works released the latest earthquake fault map. Include the discovery of Surabaya fault and Waru fault that across Surabaya. According to that new discovered fault, it is possible that there is a higher potential earthquake hazard for buildings structures in Surabaya. Therefore, the efforts to assess the vulnerability of buildings towards the earthquake need to be conducted, especially for the high-rise buildings. An android based RViSITS (Rapid Visual Survey by Institut Teknologi Sepuluh Nopember) is an application that has been developed based on FEMA 154. That application helps the vulnerability assessments of buildings can be conducted quickly and efficiently. Since, it does not require a lot of personnel, quite short research time and cheaper cost than having to use a manual form that is considered less effective for a large number of buildings. This research itself is conducted to assess the vulnerability of high-rise buildings (8-15 floors) throughout Surabaya city using the RViSITS android application. Based on the results of this study on 98 high rise buildings, it is found that 21 buildings (21.43%) are in the prone category since they had an index value < 2, while 77 buildings (78.57%) are in the safe category with an index ≥ 2. The result obtained in this research can be used as a database of local government institution for mapping the vulnerability of high rise buildings and initial input for mitigation plan toward the higher possibility of an earthquake hazard in Surabaya.

1. Introduction

Geologically, the Indonesian archipelago is at the confluence of two major earthquake pathways. It is Pacific Circum and Alpide Transasiatic earthquake path. Whereas geographically, the Indonesian archipelago is at 6° N-11° South and 95° East-141° East. In addition, Indonesia is located at the confluence of three crustal plates that is the Eurasian plate, Pacific plate and Australian Indian plate. Therefore, the Indonesian archipelago is in an area that has high tectonic and volcanic earthquake activities.

Indonesian government has stipulated several regulations relating to earthquakes such as SNI 1726-2012 concerning earthquake loads on building structures and SNI 2874-2013 regarding on planning of concrete building structures that are resistant to earthquake loads. However, in Indonesia there are many buildings that are still built without regard to these regulations. The more buildings are built without considering the existing regulations; the number of buildings that are vulnerable to damage will increase. It is added by the absence of data related to the vulnerability of each building that has been built, therefore the risk of building damage due to the earthquake is greater [1].

In fact, nowadays, earthquake is still become a threat of disasters for Indonesian people. The impact caused by earthquake is very diverse. It can cause harm to death for humans and the damage of buildings [2]. An earthquake is a disaster that cannot be predicted and prevented by humans, but the impact caused by an earthquake can be minimized by choosing appropriate steps and methods [3].

Earthquake National Research Center -Indonesia's Ministry of Public Works has released the latest earthquake fault map update in 2017. It causes the emergence of sources and potential new earthquake hazards in Indonesia. One of them is the emergence of Surabaya fault and Waru fault across Surabaya city [4]. Thus, some efforts should be made as early as possible for the assessment of vulnerability, especially for buildings which is still functioning to minimize seismic damage due to earthquakes [5].

Building vulnerability assessment is distinguished by a thorough check and quick check called rapid visual screening (RVS). On a thorough check requires a team of structural and earthquake experts, besides this method requires an expensive cost and takes a long time to conduct. Moreover, examination using the RVS method does not require a team of experts and many personnel. It can be completed in a short time and cheaper cost [1,6]. The application of RVS method is used to ensure the condition of building whether it is vulnerable or safe and as a basis for providing follow-up recommendations on the vulnerability of buildings for mitigation plans [7]. Therefore, the RVS method is quite effective to be applied to evaluate building vulnerability in large numbers [8].

In recent digitalization era, the RVS team of Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia, has successfully developed an android-based application called RViSITS. This application is the development of manual form on FEMA 154. Building vulnerability assessment using manual forms is not effective for a large number of buildings [9]. Then, by the existence of RViSITS android application, building vulnerability assessments can be conducted simpler and faster. The surveyor only needs a smartphone in practice without using the manual form for large numbers of building being examined. This application is equipped with features that are connected to the camera, so that during the survey, it can document the object examined. This application is also connected to Global Positioning System (GPS) to determine the coordinates of the building location and the results can be accessed easily by various government sectors as well as the public sectors [1,9]. Therefore, the main purpose of this study is to map the vulnerability value of buildings (8-15 floors) in Surabaya due to the 2017 earthquake map update and the Surabaya fault and the Waru fault crossing Surabaya using the RViSITS android application. Furthermore, conclusions and recommendations based on the research can be accessed by all sectors, both local governments and the public.

2. Material and Method

2.1. Rapid Visual Screening/RVS

Rapid visual screening (RVS) method is a procedure to quickly assess the vulnerability of buildings due to earthquake. In the 1980s, the RVS method for buildings is first developed by Applied Technology Council (ATC) [10]. RVS is one of the recommended building vulnerability assessment procedures since it can be done without detailed structural calculations. In practice, RVS is easier than analytical calculations that require many detailed calculations with many scenarios [11]. This method can also be conducted with a simple step; by surrounding the building from the outside and ascertain the level of vulnerability of building whether it requires further check or nor based on the final scores [1].

The RVS method has been used by many researchers to evaluate seismic vulnerability of buildings [1,2,6–8,12–21]. In addition, this method can help the authorities in strengthening buildings that are very vulnerable in anticipation of reducing the risk of damage [11]. Although the RVS method can be conducted quickly with a low cost, but this method has several shortcomings. These shortcomings include the need for a long time during the survey process and the final score calculation for a large number of buildings. It takes a long time to compile survey data into digital data. The results of

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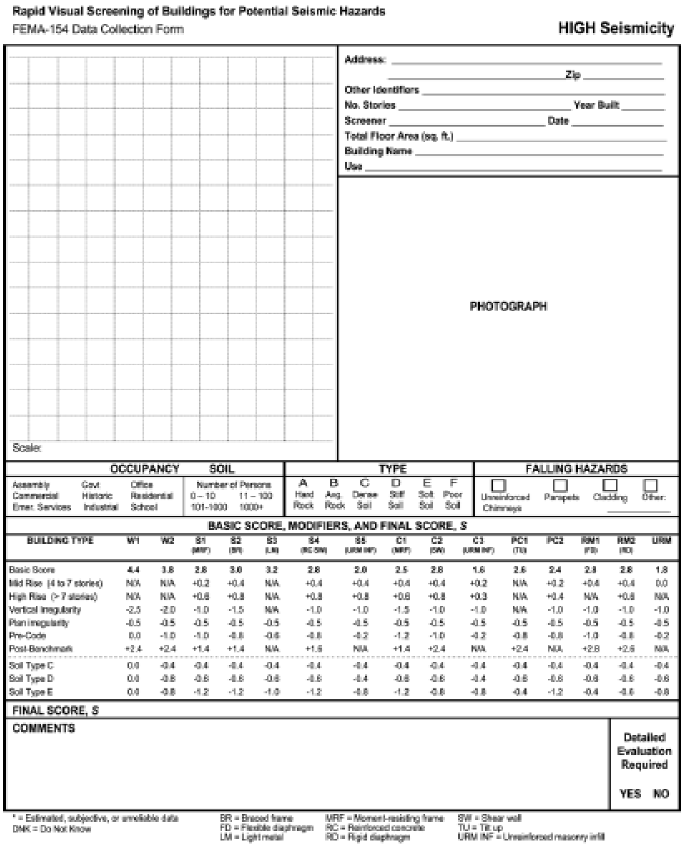
manual calculations are prone to errors, while if there are errors in recording the survey results, it is necessary to change the new form. Thus, this method is considered ineffective and inefficient [1,6,9].

The assessment form in RVS method is divided into three kinds, namely low seismicity, medium seismicity, and high seismicity. On each of the form are having difference value parameters [10,11]. In the figure 1 above shows one of manual form example for high seismicity category commonly used to assess the vulnerability of buildings using the RSV method [10].



Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA-154 Data Collection Form

HIGH Seismicity

Address: ____ Zip ____
Other Identifiers ____
No. Stories ____ Year Built ____
Screener ____ Date ____
Total Floor Area (sq. ft.) ____
Building Name ____
Use ____

Scale:

PHOTOGRAPH

OCCUPANCY			SOIL		TYPE						FALLING HAZARDS			
Assembly	Govt	Office	Number of Persons		A	B	C	D	E	F	Unreinforced Chimneys	Parapets	Cladding	Other:
Commercial	Historic	Residential	0 – 10	11 – 100	Hard Rock	Avg. Rock	Dense Soil	Stiff Soil	Soft Soil	Poor Soil				
Emer. Services	Industrial	School	101-1000	1000+										

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	4.4	3.8	2.8	3.0	3.2	2.8	2.0	2.5	2.8	1.6	2.6	2.4	2.8	2.8	1.8
Mid Rise (4 to 7 stories)	N/A	N/A	+0.2	+0.4	N/A	+0.4	+0.4	+0.4	+0.4	+0.2	N/A	+0.2	+0.4	+0.4	0.0
High Rise (> 7 stories)	N/A	N/A	+0.6	+0.8	N/A	+0.8	+0.8	+0.6	+0.8	+0.3	N/A	+0.4	N/A	+0.6	N/A
Vertical Irregularity	-2.5	-2.0	-1.0	-1.5	N/A	-1.0	-1.0	-1.5	-1.0	-1.0	N/A	-1.0	-1.0	-1.0	-1.0
Plan irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-1.0	-1.0	-0.8	-0.6	-0.8	-0.2	-1.2	-1.0	-0.2	-0.8	-0.8	-1.0	-0.8	-0.2
Post-Benchmark	+2.4	+2.4	+1.4	+1.4	N/A	+1.6	N/A	+1.4	+2.4	N/A	+2.4	N/A	+2.8	+2.6	N/A
Soil Type C	0.0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0.0	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6	-0.6
Soil Type E	0.0	-0.8	-1.2	-1.2	-1.0	-1.2	-0.8	-1.2	-0.8	-0.8	-0.4	-1.2	-0.4	-0.6	-0.8

FINAL SCORE, S

COMMENTS

Detailed Evaluation Required
YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know
BR = Braced frame
FD = Flexible diaphragm
LM = Light metal
MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm
SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Figure 1. Manual Form of RVS Method in accordance with FEMA 145.

2.2. RViSITS Method

RViSITS android application is a form of manual form development based on FEMA 154. It has function to assess the vulnerability of buildings caused by earthquakes in smartphone application. This application is firstly created by RVS Team of Sepuluh Nopember Institute of Technology, Surabaya, Indonesia [1]. The development of this application has purpose to develop information system integrated for efficiency and provide solution from several obstacles face while using building vulnerability inspection system caused by earthquakes conventionally [9]. Afterwards, the development is made by wholly adapting all of the regulation in FEMA 154 with adjustment based on regulation that exists in Indonesia. The RViSITS application has provide simplicity and used to simplify and fasten the process of assessment sent via internet. Further, there will be server as collecting and processing the data. From the data, it can be obtained vulnerability mapping as well as the area that affected by disasters. Thus, it can be accessed by the public, government and private organization [1].

There are 8 steps in the assessment of building vulnerability using RViSITS namely [1,10]: 1) performing update data and information dealing with building that is reviewed based on existing data obtained; 2) walking around the building and take pictures to know the condition of buildings; 3) determining the seismicity level; 4) determining the capacity of peoples who can entering inside the buildings; 5) determining the soil types; 6) identifying the falling hazard; 7) determining the building function; 8) determining the building types on the basic score (BS); 9) identifying and click on the list of choices in M score (as like the amount of floors, building types, determining the pre–code or post benchmark and the soil type); 8) in the final score (S) it can be determined by adjusting the basic score (BS) with the modification score (MS) as mentioned in the step 7, and thus the result score will be emerged automatically in the RViSITS application. If necessary, the detail evaluation about the building can be inputted in the "insert comment."

3. Research Method

The main purpose in this research is to assess the vulnerability of high rise buildings which has eight floor up to fifteen floor in Surabaya which spread along North, South, Center, East and West Surabaya in accordance with the figure 2. The assessment of the building is carried out on 98 buildings which represented five areas in Surabaya City namely 33 buildings in East Surabaya, 7 buildings in West Surabaya, 27 buildings in Central Surabaya, 7 buildings in North Surabaya, and 24 buildings in Surabaya South. The building chosen has eight to fifteen floors. Chosen buildings are including commercial, residential, public service, office, industrial and collage buildings.

This research is divided into five steps such as 1) collecting the reference and regulation which supports the research; 2) conducting introduction survey to get the information about the buildings reviewed; 3) conducting assessment of building vulnerability using RViSITS application; 4) processing the results data; 5) serving the observation result in form of conclusion and recommendation.

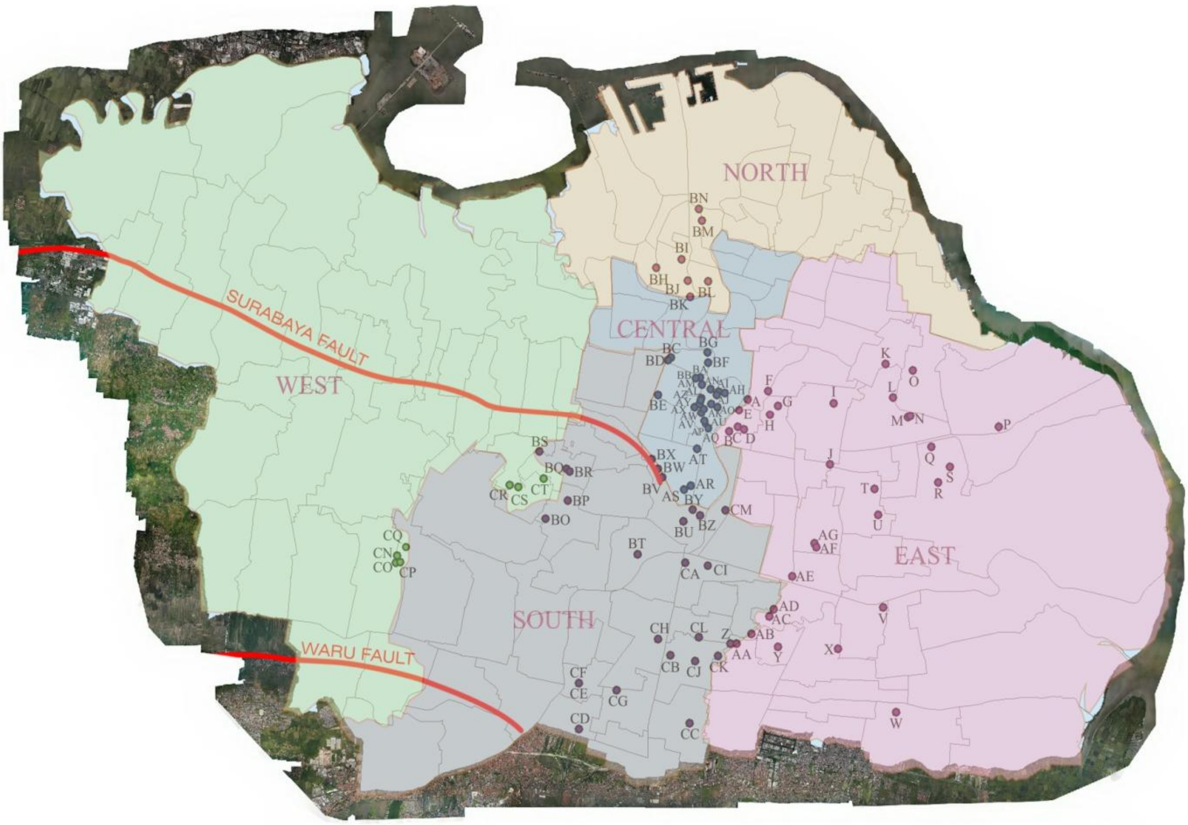


Figure 2. Buildings Points Reviewed.

The research steps using RViSITS can be seen in the Figure 3 (a) to (n) [9,22].

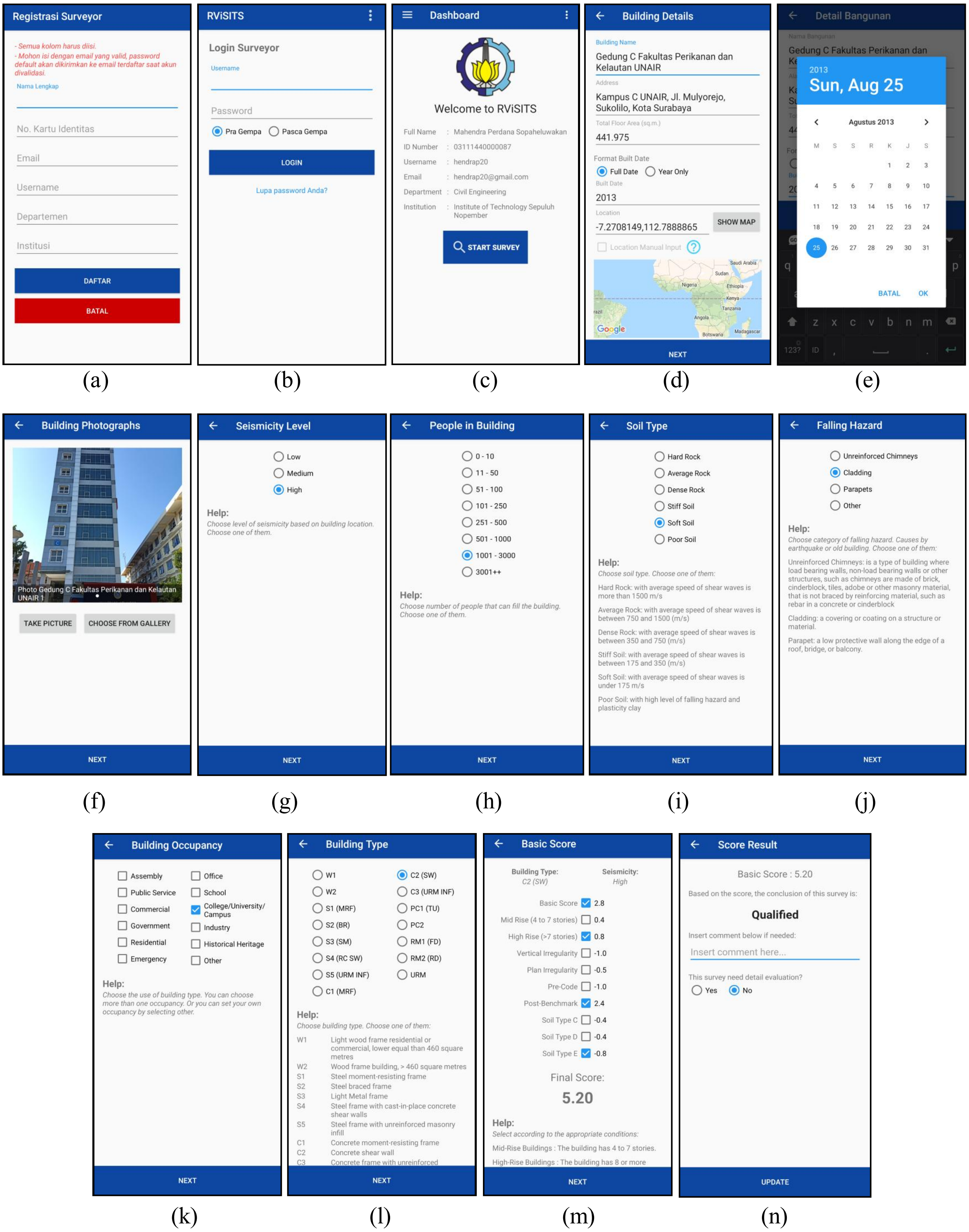


Figure 3. The Steps in Using RViSITS Andrid Program (a) to (n).

The score in RVS is divided into three kinds. Basic score (BS) is determined based on the building structure reviewed. In the Modifiers Score (MS) is influenced by several factors including the building type (mid-rise building and high rise building), the shape of building (vertical and plan irregularity), pre-code, post-benchmarks, and the soil type (C, D, and E type). Meanwhile, in the last score (S) is obtained based on the addition of basic score (BS) and modifiers score (MS) chosen. The final score is amounted in range from 0 to 7. The higher the score shows that the performance structure is better. Based on the current design seismic criteria, the final score (S) is permitted not less than 2 score. The buildings with S score is less than 2 should be assess more by the professional structure expert in the earthquake planning field [1,10]. Here is the pattern to obtain the final score as like equation (1).

$$Final\ Score\ (S) = Basic\ Score\ (BS) + \ Modifiers\ Score\ (MS) \tag{1}$$

The potential of building damage is categorized into five grades in accordance with the final score (S) as mentioned in the table 1.

Table 1. Damage Potential based on Structural Score [11].

RVS Score	Damage Potensial
$S \leq 0.3$	High probability of grade 5 damage; very high probability of grade 4 damage
$0.3 < S \leq 0.7$	High probability of grade 4 damage; very high probability of grade 3 damage
$0.7 < S \leq 2.0$	High probability of grade 3 damage; very high probability of grade 2 damage
$2.0 < S \leq 2.5$	High probability of grade 2 damage; very high probability of grade 1 damage
$S > 2.5$	Probability of grade 1 damage

In the grade 1, there is little bit damage on the building, thus it can be ignored. In the grade 2, there is medium damage in which the damage looks like cracks in the wall. In the grade 3, the building is predicted will heavily damage with the cracks in the column and shell column. In the grade 4, the damage categorize as very heavy in which the several column or upper floor will collapse, meanwhile in the grade 5, the ground floors collapsed [11,14].

4. Result and Discussion

In the analysis process using RViSITS application, the basic score is influenced by several parameters, namely: 1) Seismicity level: based on earthquake map 2017, the acceleration of the period of 0.2 second of Surabaya City is 0.9 g, and the acceleration of the 1 second period is 0.3 g. It means that the Surabaya City in High Seismicity zone according on FEMA 154, so this paper used the RVS High Seismicity level.; 2) Buildings type: 97 buildings are C2 (concrete shear wall), and 1 building is S2 (steel bracing frame).

On modifiers score, all buildings reviewed are included in the high rise building category. Type of soil being soft soil (Type E). Other factors are influenced by shape of building (18 buildings including vertical irregularity, 7 buildings including plan irregularity, 20 buildings including both, and 53 other buildings including typical buildings vertically and horizontally). In terms of the year of construction, 21 buildings were built before 2002 where earthquake regulations have not been implemented in Indonesia. So the score modifier is selected post code, and 77 buildings are selected post benchmark.

Based on the result analysis using RViSITS application is described in the figure 4.

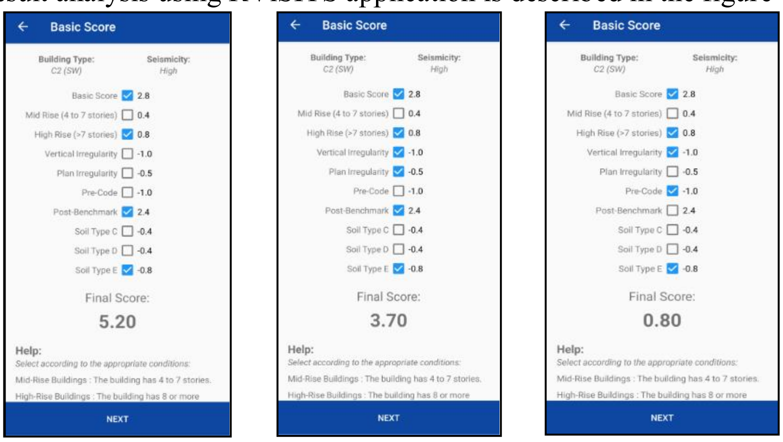
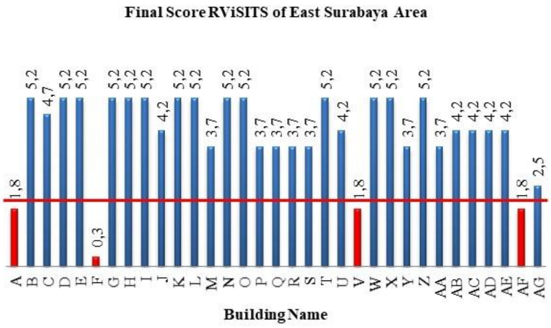
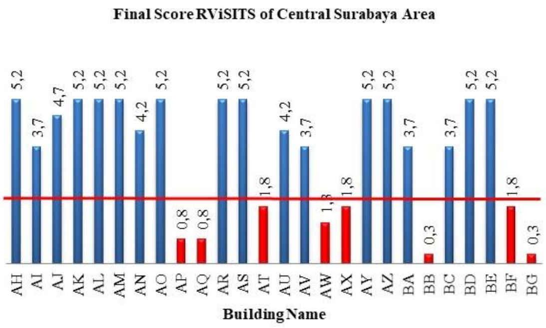


Figure 4. Three example of Output Final Score of RViSITS Android Program.

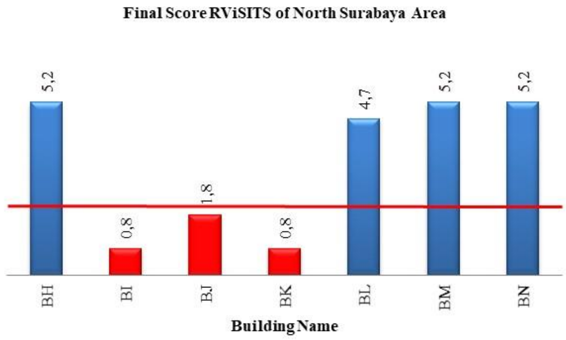
The final score is obtained automatically by the RViSITS android application based on the sum of the values of the basic score and modifiers score as in formula1. From the figure 4 the final scores for all the buildings being reviewed are presented in a diagram like in figure 5 (a) to (e). It shows the result analysis using RViSITS application found that there are 21 buildings which including into vulnerability category since the final score (S) is < 2. Otherwise, 77 other buildings included into save category with the final score (S) is ≥ 2.



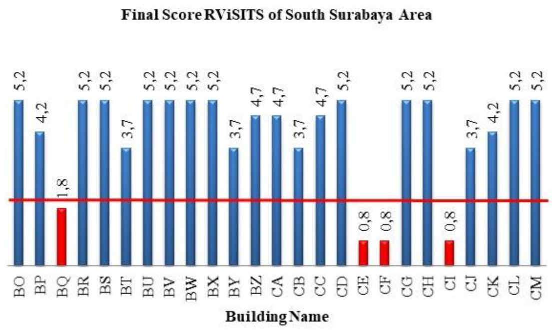
(a)



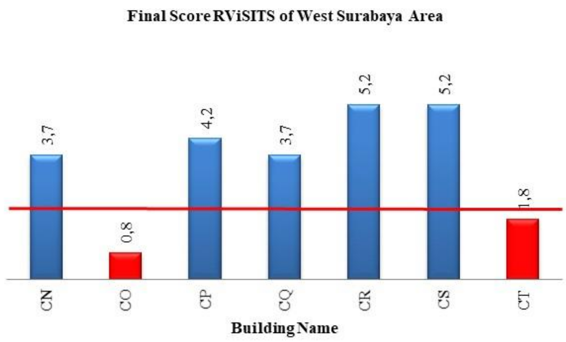
(b)



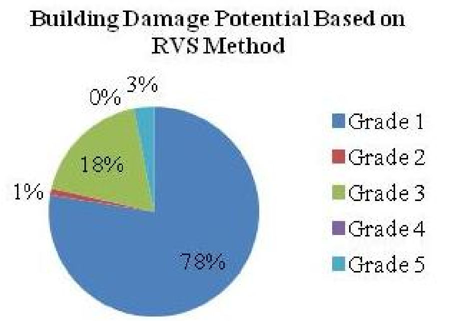
(c)



(d)



(e)



(f)

Figure 5. (a–e) The Final Score Graphic of RViSITS and (f) Percentage of Damage Potential.

In the final step of the study, after obtaining the final score as shown in figure 5 a–e above, the potential damage can be classified. Based on the analysis, it was found that 76 buildings (78 %) included into grade 1, 1 building (1 %) classified as grade 2, 18 buildings (18 %) classified as grade 3, no building (0 %) classified as grade 4, and 3 buildings (3 %) entered as grade 5, as shown in figure 5 (f).

5. Conclusions

The building vulnerability assessment was carried out using the RViSITS application on 98 high rise buildings (8-15 floors) in Surabaya. Based on the assessment it was found 21 buildings have fall into the vulnerable category are caused because all the buildings were built before 2002 in which the earthquake regulations have not been applied in Indonesia [1]. Moreover, the other causes are influenced by irregular shape of buildings both vertical and horizontal. While reviewing the possibility of the potential damage of 21 building (21%) included in grades 3 to 5, where it is possible that heavy damage will occur if an earthquake occurs on a large scale. Furthermore, the proposed recommendation is that there is a need for planning data collection, as well as further inspection of 21 buildings that are included in the vulnerable category.

Acknowledgement

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