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Seismic Vulnerability Evaluation of Existing Structures Using the Rapid Visual Screening Method in Malang City

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Abstract. Indonesia is characterized by its volcanic mountain ranges and bordered by several tectonic plates. This geographical setup makes Indonesia susceptible to both tectonic and volcanic earthquakes. The Indonesian National Standardization Body issued the latest earthquake regulations in 2019, leading to changes in the seismic hazard values used as reference in seismic design. As a result of these regulation changes, seismic load designs have been updated. While these regulations are applicable to the planning of new buildings, it's equally important to assess existing structures to determine if they can withstand the updated seismic loads. This research focuses on evaluating the vulnerability of older buildings constructed before the implementation of the new earthquake regulations. The assessment method employed is Rapid Visual Screening (RVS). This study was conducted in Malang City, as it falls within an area of moderate to high seismicity. After conducting the RVS method, a numerical analysis was performed on a sample of buildings for comparison. The research findings indicate that the examined buildings are still capable of withstanding the updated seismic loads.

1. Introduction

Several tectonic plates encircle Indonesia's territory. Among the plates present are the Pacific Plate, Indian-Australian Plate, Eurasian Plate, and Indian Plate. The boundaries of these tectonic plates can be calculated using active earthquake zones, mountain mass movement zones, volcanic zones, magmatic zones, and hydrocarbon-rich zones[1]. The active earthquake zones have been classified by Indonesia through the earthquake recording agency, the Meteorology, Climatology, and Geophysics Agency, and have been presented on their website. Consequently, Indonesia's regions are susceptible to both tectonic and volcanic earthquakes[2,3].

The Indonesian National Standardization Body issued the latest earthquake regulations in 2019, replacing the 2012 regulations. In this update, there was an increase in the values of PGA (Peak Ground Acceleration), Ss, and S1 on the seismic map compared to the 2010 map. With these increased values, the regions in Indonesia have become more susceptible to earthquakes. In the 2017 seismic map, Malang City had a spectral acceleration response value

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of 0.4 g for long periods (S1) and 0.9 g for short periods (Ss) [3]. According to FEMA P-154, Malang City is classified as a Moderate High Seismicity Region[4].

Table 1. Change of parameters in SNI 1726-2012 and SNI 1726-2019 for Malang City.

Regulation	PGA	Ss	S1
SNI 1726 2012	0,3 – 0,4 g	0,7 – 0,8 g	0,3 – 0,4 g
SNI 1726 2019	0,4 – 0,5 g	0.8 – 0.9 g	0,4 – 0,5 g

Meanwhile, recent active faults have been detected at the border of Surabaya and Sidoarjo, not far from Malang [1]. According to Meteorology, Climatology, and Geophysics Agency data, Malang City has suffered several large earthquakes. As a result, the sensitivity to earthquake hazards of buildings developed in Malang City must be assessed using seismic standards from 2012 and 2002.

Table 2. Earthquake Near Malang Meteorology, Climatology, and Geophysics Agency Data

No.	Date	Location	Magnitude (SR)
1	21 December 2022	Malang Regency	4,8
2	6 December 2022	Jember	6
3	10 April 2021	East Malang	6,1
4	15 April 2020	Malang Regency	4,3
5	19 February 2019	Malang Regency	5,6
6	10 March 2019	Malang Regency	5,2
7	8 August 2018	Malang Regency	5,1
8	8 April 2017	Malang City	3,7
9	16 November 2016	Malang Regency	6,1
10	26 July 2016	Malang Regency	6,3

Existing building vulnerability assessment is divided into two methods: thorough assessment and quick evaluation utilizing Rapid Visual Screening (RVS). Rapid Visual Screening (RVS) is a technique for identifying, collecting, and filtering structures that may be seismically hazardous[4]. The RVS procedure employs direct survey methods and data collection with forms. Surveyors collect data by making visual inspections of the building's outside and its interior. Building information, images, sketches, and earthquake-related data are all collected on data collection forms. A final score is produced based on the data acquired during the study to evaluate the seismic vulnerability state. A full building vulnerability evaluation requires structural civil engineering professionals, expensive, and a large amount of time. On the other hand, using RVS allows for a faster assessment and is less expensive resources [5,6].

Various researchers have used RVS evaluations for building vulnerability checks [7–10]. RVS can be used to assess a building's seismic resilience without the requirement for expertise or specialized software[11]. The RVS results provide an early insight of whether the building is still earthquake-resistant or if structural reinforcement is required[12].

However, because the use of RVS for building assessments is relatively uncommon in Indonesia, more research on the use of RVS in buildings is required. As a result, the focus of this research is on assessing existing buildings using RVS. The study will provide information about the seismic resiliency of these structures. If a building does not fulfill the RVS standards, more action, such as numerical analysis with the assistance of experts, may be required.

2. Method

This research will utilize the Rapid Visual Screening building assessment method based on FEMA 154. Figure 1 illustrates the workflow of this study.

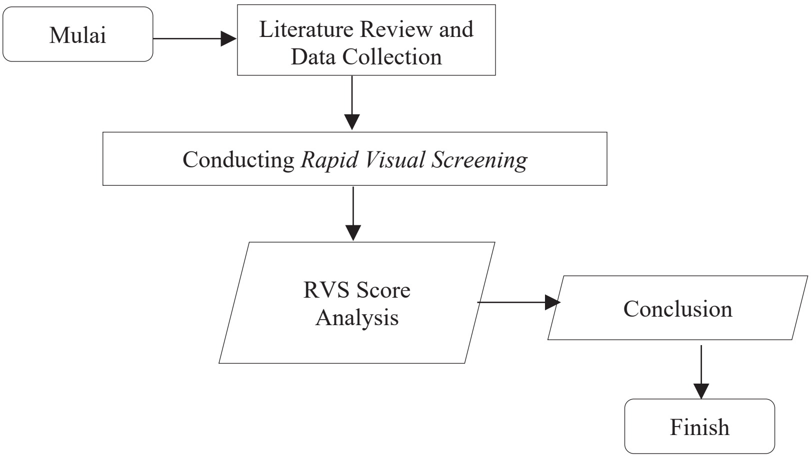


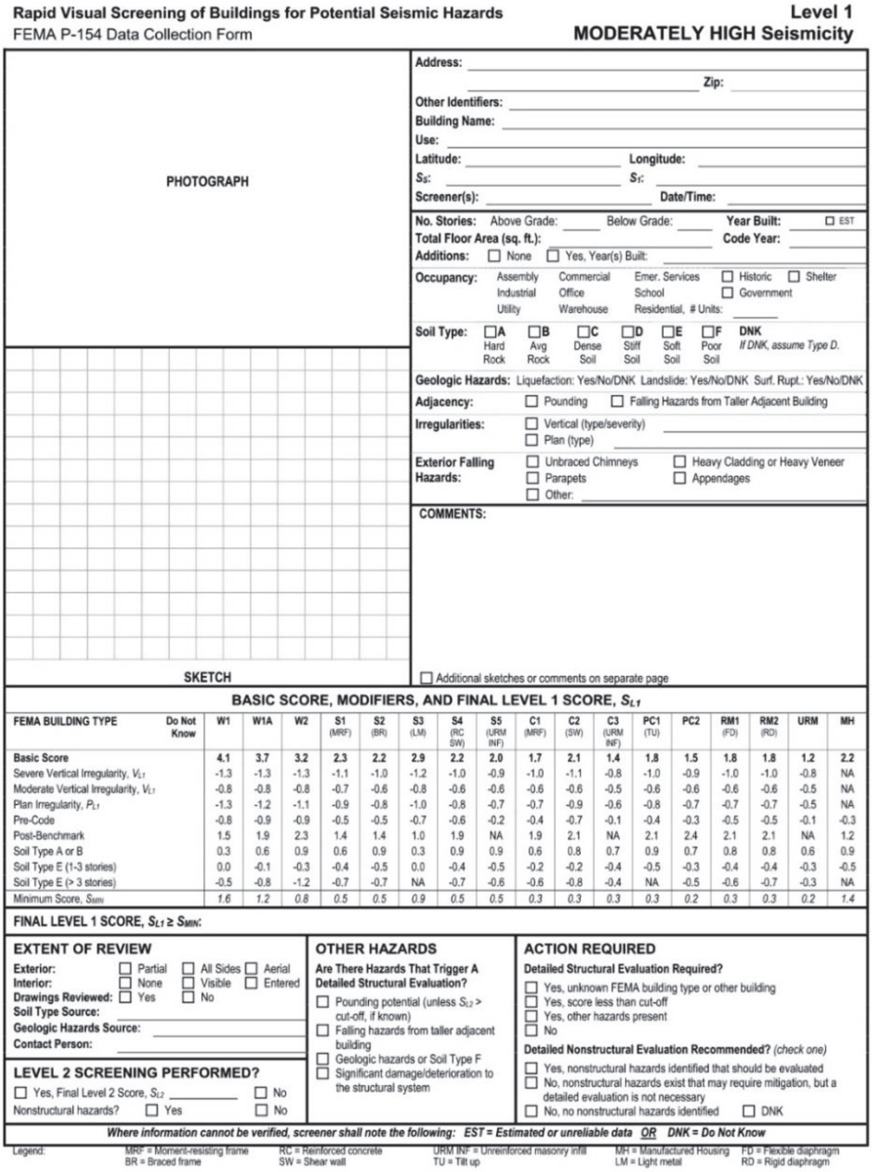
Fig. 1. Study Workflow

This study started with literature reviews and data collection. This process begins with reviewing the earthquake parameters in Malang city, gathering building data, and referencing previous RVS research. RVS is conducted based on FEMA – 154 regulations.

In the RVS analysis, there are several steps as follows[9]:

1. Verify building information.
2. Conduct a construction survey to determine the building's shape, number of floors, and floor plan sketch.
3. Capture photos of the building.
4. Identify the building's function.
5. Review soil data.
6. Identify the surrounding conditions of the building, irregularities in the building, and potential hazards from exterior elements.
7. Make notes if there are conditions that may affect the survey.
8. Determine the construction material, load-bearing system, and seismic force-resisting system to determine the FEMA construction type and circle the basic score from the survey form.
9. Calculate the final score for the building to determine its vulnerability.

The overall building score goes from 0 to 7, with higher ratings indicating superior seismic performance and a lower risk of collapse. The proposed final score criterion is S_{min}. Smin criteria based on FEMA-154 forms. Buildings with a final score of S_{min} or less should be explored further with extensive study by seismic structural design experts.



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

Level 1
MODERATELY HIGH Seismicity

PHOTOGRAPH

Address: ____________________
____________________ **Zip:** ____________
Other Identifiers: ____________________
Building Name: ____________________
Use: ____________________
Latitude: ____________ **Longitude:** ____________
S_S: ____________ **S_1:** ____________
Screener(s): ____________ **Date/Time:** ____________

No. Stories: Above Grade: ____ Below Grade: ____ **Year Built:** ____ ☐ EST
Total Floor Area (sq. ft.): ____________ **Code Year:** ____________
Additions: ☐ None ☐ Yes, Year(s) Built: ____________

Occupancy: Assembly, Commercial, Emer. Services, ☐ Historic, ☐ Shelter
Industrial, Office, School, ☐ Government
Utility, Warehouse, Residential, # Units: ____

Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil **DNK** *If DNK, assume Type D.*

Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK

Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building

Irregularities: ☐ Vertical (type/severity) ____________
☐ Plan (type) ____________

Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer
☐ Parapets ☐ Appendages
☐ Other: ____________

COMMENTS:

SKETCH

☐ Additional sketches or comments on separate page

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	Do Not Know	W1	W1A	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	MH
Basic Score		**4.1**	**3.7**	**3.2**	**2.3**	**2.2**	**2.9**	**2.2**	**2.0**	**1.7**	**2.1**	**1.4**	**1.8**	**1.5**	**1.8**	**1.8**	**1.2**	**2.2**
Severe Vertical Irregularity, V_{L1}		-1.3	-1.3	-1.3	-1.1	-1.0	-1.2	-1.0	-0.9	-1.0	-1.1	-0.8	-1.0	-0.9	-1.0	-1.0	-0.8	NA
Moderate Vertical Irregularity, V_{L1}		-0.8	-0.8	-0.8	-0.7	-0.6	-0.8	-0.6	-0.6	-0.6	-0.6	-0.5	-0.6	-0.6	-0.6	-0.6	-0.5	NA
Plan Irregularity, P_{L1}		-1.3	-1.2	-1.1	-0.9	-0.8	-1.0	-0.8	-0.7	-0.7	-0.9	-0.6	-0.8	-0.7	-0.7	-0.7	-0.5	NA
Pre-Code		-0.8	-0.9	-0.9	-0.5	-0.5	-0.7	-0.6	-0.2	-0.4	-0.7	-0.1	-0.4	-0.3	-0.5	-0.5	-0.1	-0.3
Post-Benchmark		1.5	1.9	2.3	1.4	1.4	1.0	1.9	NA	1.9	2.1	NA	2.1	2.4	2.1	2.1	NA	1.2
Soil Type A or B		0.3	0.6	0.9	0.6	0.9	0.3	0.9	0.9	0.6	0.8	0.7	0.9	0.7	0.8	0.8	0.6	0.9
Soil Type E (1-3 stories)		0.0	-0.1	-0.3	-0.4	-0.5	0.0	-0.4	-0.5	-0.2	-0.2	-0.4	-0.5	-0.3	-0.4	-0.4	-0.3	-0.5
Soil Type E (> 3 stories)		-0.5	-0.8	-1.2	-0.7	-0.7	NA	-0.7	-0.6	-0.6	-0.8	-0.4	NA	-0.5	-0.6	-0.7	-0.3	NA
Minimum Score, S_{MIN}		*1.6*	*1.2*	*0.8*	*0.5*	*0.5*	*0.9*	*0.5*	*0.5*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.3*	*0.3*	*0.2*	*1.4*

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$:

EXTENT OF REVIEW
Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source: ____________
Geologic Hazards Source: ____________
Contact Person: ____________

LEVEL 2 SCREENING PERFORMED?
☐ Yes, Final Level 2 Score, S_{L2} ________ ☐ No
Nonstructural hazards? ☐ Yes ☐ No

OTHER HAZARDS
Are There Hazards That Trigger A Detailed Structural Evaluation?
- ☐ Pounding potential (unless S_{L2} > cut-off, if known)
- ☐ Falling hazards from taller adjacent building
- ☐ Geologic hazards or Soil Type F
- ☐ Significant damage/deterioration to the structural system

ACTION REQUIRED
Detailed Structural Evaluation Required?
- ☐ Yes, unknown FEMA building type or other building
- ☐ Yes, score less than cut-off
- ☐ Yes, other hazards present
- ☐ No

Detailed Nonstructural Evaluation Recommended? *(check one)*
- ☐ Yes, nonstructural hazards identified that should be evaluated
- ☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
- ☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data OR DNK = Do Not Know

Legend:
MRF = Moment-resisting frame
BR = Braced frame
RC = Reinforced concrete
SW = Shear wall
URM INF = Unreinforced masonry infill
TU = Tilt up
MH = Manufactured Housing
LM = Light metal
FD = Flexible diaphragm
RD = Rigid diaphragm

Fig. 2. FEMA-154 RVS Example Form (Moderate High Seismicity)

There are several forms in FEMA-154 based on seismicity region. Determining seismicity region based on spectral acceleration response. Every form has final score. The equation of the final score in RVS method is,

$$\text{Final Score } (S_{L1}) = \text{Basic Score} + \text{Modifiers Score} \quad (1)$$

Basic Score : Basic score from building type
Modifiers Score : Building Condition (irregularity, Pre-Code, Soil Type)

Determining building capability of withstanding the updated seismic loads with equation (2),

$$S_{L1} \geq S_{min} \geq S_{cutoff} \quad (2)$$

S_{L1} : Final Score
S_{min} : Minimum Score
S_{cutoff} : Cutoff Score (about 2.0)

The final score obtained from RVS Form basic score and modified score. The Minimum Score was calculated by considering the worst conceivable combination of soil type, vertical and plan abnormalities, and building age. Cutoff score is the acceptable probability of collapse in existing buildings, which is again roughly equivalent to a value of S of about 2.0. The existing buildings to be inspected are structures located in Malang City. These buildings are the Civil Engineering Department Laboratory, the Faculty of Economics Building 1, the Faculty of Economics Building 2, the Faculty of Mathematics and Natural Sciences Building, and the Laboratory Elementary School of Malang State University. Table 3 and Table 4 for determine the seismicity region and building type for determine FEMA RVS form.

Table 3. Seismicity Region based on S_s and S_1

Seismicity Region		**Spectral Acceleration Response, S_s (Short-period, or 0,2 seconds)**	**Spectral Acceleration Response, S_1 (long-period, or 1,0 seconds)**
🟩	Low	Less than 0,25 g	Less than 0,1 g
🟨	Moderate	Greater than or equal to 0,25 g but less than 0,5 g	Greater than or equal to 0,1 g but less than 0,2 g
🟧	Moderately High	Greater than or equal to 0,5 g but less than 1,0 g	Greater than or equal to 0,2 g but less than 0,4 g
🟥	High	Greater than or equal to 1,0 g but less than 1,5 g	Greater than or equal to 0,4 g but less than 0,6 g
🟪	Very High	Greater than or equal to 1,5 g	Greater than or equal to 0,6 g

Table 4. FEMA Building Type

FEMA Building Type	
W1	Light wood frame single- or multiple-family dwellings of one or more stories in height
W1A	Light wood frame multi-unit, multi-story residential buildings with plan areas on each floor of greater than 3,000 square feet
W2	Wood frame commercial and industrial buildings with a floor area larger than 5,000 square feet
S1	Steel moment-resisting frame
S2	Braced steel frame
S3	Light metal frame
S4	Steel frame with cast-in-place concrete shear walls
S5	Steel frame with unreinforced masonry infill walls
C1	Concrete moment-resisting frame
C2	Concrete shear wall
C3	Concrete frame with unreinforced masonry infill walls
PC1	Tilt-up construction
PC2	Precast concrete frame
RM1	Reinforced masonry with flexible floor and roof diaphragms
RM2	Reinforced masonry with rigid floor and roof diaphragms
URM	Unreinforced masonry bearing-wall buildings
MH	Manufactured housing

3. Result and Discussion

The readings of the Spectral Acceleration Values $S_s = 0.87$ g and $S_1 = 0.4$ g based on the building's location indicate that the reviewed buildings are situated on type D soil with Moderate High Seismicity classification. Occupation, Soil Type, Building Type, and Seismicity region show at Table 5

Table 5. Building Occupation, Soil Type, FEMA Building Type, and Seismicity Region

No	Building	Occupation	Soil Type	Building Type	Seismicity Region
1	Civil Engineering Department Laboratory	School	SD	C1	Moderate High
2	Faculty of Economics Building 1	School	SD	C1	Moderate High
3	Faculty of Economics Building 2	School	SD	C1	Moderate High
4	Faculty of Mathematics and Natural Science Building	School	SD	C1	Moderate High
5	Laboratory Elementary School of Malang State University	School	SD	C1	Moderate High

Table 6. RVS Final Score for Buildings

No	Building	C1 Final Score (S_{L1})	C1 S_{min}	Final Score Use	Cut Off Score	Result
1	Civil Engineering Department Laboratory	2.9	0.3	2.9	2	OK
2	Faculty of Economics Building 1	2.9	0.3	2.9	2	OK
3	Faculty of Economics Building 2	2.9	0.3	2.9	2	OK
4	Faculty of Mathematics and Natural Science Building	2.9	0.3	2.9	2	OK
5	Laboratory Elementary School of Malang State University	2.9	0.3	2.9	2	OK

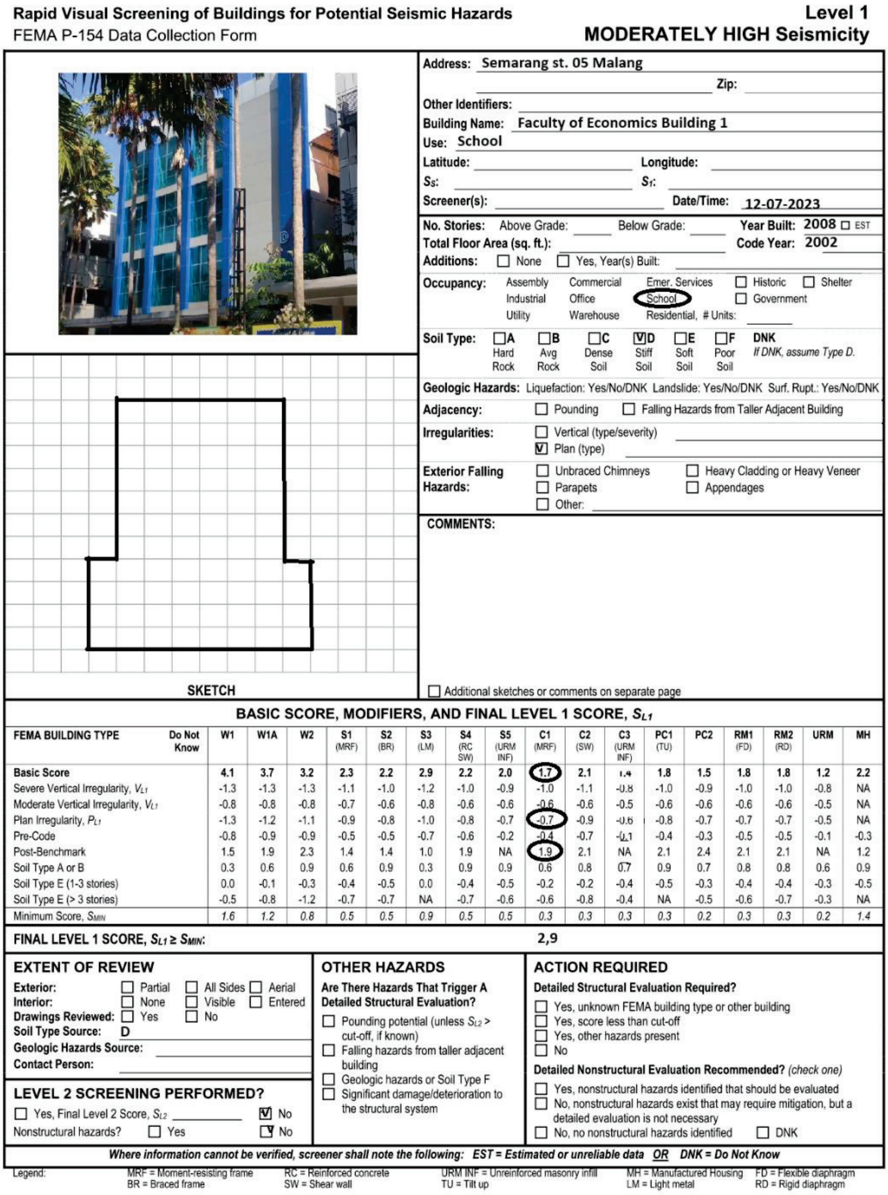
The final score for each building was obtained from basic score C1 building type (1.7), Plan irregularity (-0.7), and Post Benchmark (1.9).

$S_{L1} = 1.7-0.7+1.9 = 2.9$

$S_{min} = 0.3$

Use $S_{L1} = 2.9 \geq 2$ (OK)

All of buildings that assessed has same structure and irregularities. The structure is concrete frame with column and beam structural member.



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

Level 1
MODERATELY HIGH Seismicity

Address: Semarang st. 05 Malang
Zip:
Other Identifiers:
Building Name: Faculty of Economics Building 1
Use: School
Latitude: **Longitude:**
S_S: **S_1:**
Screener(s): **Date/Time:** 12-07-2023

No. Stories: Above Grade: Below Grade: **Year Built:** 2008 ☐ EST
Total Floor Area (sq. ft.): **Code Year:** 2002
Additions: ☐ None ☐ Yes, Year(s) Built:
Occupancy: Assembly Commercial Emer. Services ☐ Historic ☐ Shelter
Industrial Office [✓ School] ☐ Government
Utility Warehouse Residential, # Units:
Soil Type: ☐ A Hard Rock ☐ B Avg Rock ☐ C Dense Soil ☑ D Stiff Soil ☐ E Soft Soil ☐ F Poor Soil **DNK** *If DNK, assume Type D.*
Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK
Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building
Irregularities: ☐ Vertical (type/severity)
☑ Plan (type)
Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer
☐ Parapets ☐ Appendages
☐ Other:

COMMENTS:

☐ Additional sketches or comments on separate page

SKETCH

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	**Do Not Know**	**W1**	**W1A**	**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**	**MH**
Basic Score		**4.1**	**3.7**	**3.2**	**2.3**	**2.2**	**2.9**	**2.2**	**2.0**	[✓ **1.7**]	**2.1**	**1.4**	**1.8**	**1.5**	**1.8**	**1.8**	**1.2**	**2.2**
Severe Vertical Irregularity, V_{L1}		-1.3	-1.3	-1.3	-1.1	-1.0	-1.2	-1.0	-0.9	-1.0	-1.1	-0.8	-1.0	-0.9	-1.0	-1.0	-0.8	NA
Moderate Vertical Irregularity, V_{L1}		-0.8	-0.8	-0.8	-0.7	-0.6	-0.8	-0.6	-0.6	-0.6	-0.6	-0.5	-0.6	-0.6	-0.6	-0.6	-0.5	NA
Plan Irregularity, P_{L1}		-1.3	-1.2	-1.1	-0.9	-0.8	-1.0	-0.8	-0.7	[✓ -0.7]	-0.9	-0.6	-0.8	-0.7	-0.7	-0.7	-0.5	NA
Pre-Code		-0.8	-0.9	-0.9	-0.5	-0.5	-0.7	-0.6	-0.2	-0.4	-0.7	-0.1	-0.4	-0.3	-0.5	-0.5	-0.1	-0.3
Post-Benchmark		1.5	1.9	2.3	1.4	1.4	1.0	1.9	NA	[✓ 1.9]	2.1	NA	2.1	2.4	2.1	2.1	NA	1.2
Soil Type A or B		0.3	0.6	0.9	0.6	0.9	0.3	0.9	0.9	0.6	0.8	0.7	0.9	0.7	0.8	0.8	0.6	0.9
Soil Type E (1-3 stories)		0.0	-0.1	-0.3	-0.4	-0.5	0.0	-0.4	-0.5	-0.2	-0.2	-0.4	-0.5	-0.3	-0.4	-0.4	-0.3	-0.5
Soil Type E (> 3 stories)		-0.5	-0.8	-1.2	-0.7	-0.7	NA	-0.7	-0.6	-0.6	-0.8	-0.4	NA	-0.5	-0.6	-0.7	-0.3	NA
Minimum Score, S_{MIN}		*1.6*	*1.2*	*0.8*	*0.5*	*0.5*	*0.9*	*0.5*	*0.5*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.3*	*0.3*	*0.2*	*1.4*

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$: 2,9

EXTENT OF REVIEW
Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source: D
Geologic Hazards Source:
Contact Person:

LEVEL 2 SCREENING PERFORMED?
☐ Yes, Final Level 2 Score, S_{L2} ☑ No
Nonstructural hazards? ☐ Yes ☑ No

OTHER HAZARDS
Are There Hazards That Trigger A Detailed Structural Evaluation?
☐ Pounding potential (unless S_{L2} > cut-off, if known)
☐ Falling hazards from taller adjacent building
☐ Geologic hazards or Soil Type F
☐ Significant damage/deterioration to the structural system

ACTION REQUIRED
Detailed Structural Evaluation Required?
☐ Yes, unknown FEMA building type or other building
☐ Yes, score less than cut-off
☐ Yes, other hazards present
☐ No
Detailed Nonstructural Evaluation Recommended? *(check one)*
☐ Yes, nonstructural hazards identified that should be evaluated
☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data <u>OR</u> DNK = Do Not Know

Legend:
MRF = Moment-resisting frame
BR = Braced frame
RC = Reinforced concrete
SW = Shear wall
URM INF = Unreinforced masonry infill
TU = Tilt up
MH = Manufactured Housing
LM = Light metal
FD = Flexible diaphragm
RD = Rigid diaphragm

Fig. 3. Faculty of Economics Building 1 FEMA-154 RVS Form (Moderate High Seismicity)

Exterior hazard data from the assessment are shown at table 7 below. There are unbraced chimneys, parapets, heavy cladding, and others for exterior hazard type. Exterior hazards indicate that in the event of an earthquake, the exterior has the potential to pose a collapse.

Table 7. Exterior Hazard

No	Building	Unbraced Chimneys	Parapets	Heavy Clading	Other
1	Civil Engineering Department Laboratory			√	√
2	Faculty of Economics Building 1		√	√	
3	Faculty of Economics Building 2			√	
4	Faculty of Mathematics and Natural Science Building			√	
5	Laboratory Elementary School of Malang State University				

4. Conclusion

a) The buildings under inspection are classified in the Moderate High Seismicity Zone, according to FEMA-154.
b) All assessed buildings have a low risk of collapsing due to earthquakes because the final assessment scores for these buildings are above the minimum threshold.
c) FEMA RVS forms can be used with Ss and S1 data from the latest earthquake regulations from Indonesia National Standard
d) The irregularity factor in buildings, the post-benchmark, and the type of soil affect a building's vulnerability to earthquakes.

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