DETERMINATION OF SEISMIC VULNERABILITY ASSESSMENT BY USING RAPID SCREENING METHOD THROUGH WEB-BASED APPLICATION

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA

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by

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ABSTRAK

Visual Saringan Pantas adalah pendekatan cepat dan ringkas yang sering digunakan oleh penyelidik untuk menganggarkan kerentanan seismik sejumlah besar bangunan. Walaupun hasilnya kurang tepat, ia akan memberikan maklumat kepada para pemegang tanah kepentingan tentang bahagian mana lokasi kajian yang umumnya lebih rentan dan memerlukan perhatian lebih dalam pelan mitigasi seismik di masa depan. Walaupun Pulau Pinang belum mengalami gempa bumi besar, penyelidikan kerentanan seismik harus dilakukan secepat mungkin untuk memastikan negeri ini bersedia untuk menghadapi kemungkinan pengaruh gempa bumi jarak dekat dan jarak jauh pada masa depan. Dalam kajian ini, penilaian kerentanan seismik awal 500 bangunan yang terletak di George Town utara dan timur, Malaysia dilakukan dengan menggunakan kaedah FEMA-154 (2002) yang diubah suai mengikuti keadaan Malaysia, digabungkan dengan pendekatan pengumpulan data dalam talian penuh melalui Google Maps dan Google Earth. Pendekatan RVS ini akan menghasilkan skor prestasi akhir untuk setiap bangunan berdasarkan beberapa parameter yang penting seperti sistem penahan beban lateral bangunan, ketinggian bangunan, penyelewengan struktur, usia bangunan dan jenis tanah, di mana tahap kerosakan bangunan selepas kejadian gempa bumi dapat diramalkan berdasarkan skor masing-masing. Hasilnya mengungkapkan keperluan segera strategi mitigasi seismik yang berkesan, kerana 90% bangunan yang dikaji dianggap berbahaya seismik dan memerlukan analisis terperinci lebih lanjut untuk menunjukkan prestasi kerentanan seismik yang tepat. Prestasi stok bangunan kajian yang sangat buruk mungkin berkaitan dengan semua parameter yang disebutkan di atas, oleh itu peta GIS, "*RVS Malaysian Form- George Town Area*", telah dihasilkan melalui platform ArcGIS dan dikongsi kepada orang ramai untuk memberikan maklumat penting mengenai parameter tersebut, yang dapat digunakan sebagai asas untuk kerja penyelidikan selanjutnya.

ABSTRACT

Rapid Visual Screening is a quick and simple approach often used by researchers to estimate the seismic vulnerability of large number of buildings. Although the results might not be accurate, it no doubt will provide insight to the stakeholders about which part of a study area is generally more vulnerable and requires more attention in future seismic mitigation plan. Although Penang is yet to experience any major earthquake, seismic vulnerability researches should be done as soon as possible to make sure the state is well prepared to face potential near-field and far-field seismic influence in the future. In this study, preliminary seismic vulnerability assessment of 500 buildings situated at northern and eastern George Town, Malaysia was carried out by utilizing modified FEMA-154 (2002) method that suits Malaysian conditions, combining with full online data collection approach via Google Maps and Google Earth. This RVS approach will generate a final performance score for every building based on several governing parameters such as building lateral load resisting system, building height, structural irregularities, building age and soil type, which their respective damage state post-earthquake event can be predicted. The results revealed the immediate need of effective seismic mitigation strategy, as 90% of the studied buildings were considered seismic hazardous and require further detailed analysis to pinpoint their exact seismic vulnerability performance. The considerably bad performance of building stocks might relates to all those aforementioned parameters, thus a GIS map, "RVS Malaysian Form-George Town Area", was created via ArcGIS platform and shared to the public to provide important information regarding those parameters, which can be used as a foundation for further research work.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION

1.1 Background

RVS is a method to estimate the seismic vulnerability of a large number of structures in a city such as Penang in Malaysia as (FEMA, 2002). It is based on correlations between the buildings' predicted seismic performance and structural typology (frame, shear wall, masonry, infills) (Cardenas *et al.*, 2020). While it is not considered as a perfect method because it is based on expert and non-expert decision which make the method not accurate but, it is very useful and simple to build up a clear vision in determining which areas of a city are generally more vulnerable than others (Shah *et al.*, 2016; Harirchian *et al.*, 2020). Government authorities then have a quantitative tool to help them decide if, and how much, remedial work is required in a particular district (Coskun *et al.*, 2020).

Seismic vulnerability of buildings stock is gaining increasing attention in Malaysia especially after Ranau Earthquake that strike Sabah in year 2015. Therefore, many researches were done in the past few years to study the seismic performance of specific building or building cluster through detailed software modeling analysis. For instance, Kassem *et al.* (2020) examined the seismic performance of a damaged hospital building post Ranau Earthquake in Sabah through an improved empirical seismic vulnerability index method. Besides, Aljwim *et al.* (2020) developed seismic fragility curves to evaluate the vulnerability of two 25-storey concrete wall structure in Malaysia which under influence of near field earthquakes. On the other hand, the vulnerability of that same two buildings were assessed under influence of far-field earthquakes by Aisyah *et al.* (2019) utilizing similar method. Despite all the detailed analysis, there is only a few studies that focus on screening large amount of existing buildings regarding their estimated seismic performance. For example, Jainih and Harith (2020) had conducted a preliminary seismic vulnerability assessment on existing buildings in seven major area near Kota Kinabalu through FEMA-154 method. The combination of preliminary assessment and targeted detailed analysis can help to ensure that the seismic vulnerability of all the existing buildings have been evaluated in a cost and time effective manner, hence preliminary seismic vulnerability assessment such as RVS is equally important as modelling analysis and should be given attention to.

1.2 Problem Statements

In this research, the seismic performance of existing buildings in George Town of Penang state was estimated using RVS approach, where most of the buildings within this areas following the same structural designed regulation of British Standards (BS).

Knowing that, George Town is categorized as low seismicity of 0.05 to 0.07g based on Malaysian National Annex, most of the buildings with difference clusters (low-, mid-, and high-rise) were designed without any attention to seismic loadings. Due to this fact, there is a high possibility to release a new regulation from the government and authorities to enforce and mandate the engineers, specialists in private and public sector to integrate the seismic design for the construction project with medium ductility level (DCM). Besides, from structural perspective view, the mixed-use buildings often have commercial or business space that occupies the ground floor, such spaces lead to problems of soft storeys where the lower columns do not have shear walls (or significantly less shear stiffness) than the remaining upper floors. Moreover, there are many old buildings in George Town especially within heritage area, which most of them are constructed via unreinforced masonry structure that are highly vulnerable to damage from seismic excitation.

Therefore, applying the Rapid Visual Screening (RVS) as preliminary stage for vulnerability assessment will help to manage and implements strategies for the safety of the communities through investigating the vulnerability classes for each building type.

1.3 Objectives

The objectives of this study are:

1. To develop a basic hazard score for different building typology using Web-Based Rapid Visual Screening Approach.

2. To integrate the vulnerability assessment outcome on GIS platform presented in color-coded maps.

1.4 Scope of Work

In this project, preliminary seismic vulnerability assessment is carried out on building stocks within George Town area in Penang, Malaysia to filter out buildings that perform relatively poor during a seismic event. Rapid Visual Screening (RVS) method is adopted due to its time and cost efficiency. The second edition (revised in year 2002) of "sidewalk survey" approach proposed in FEMA 154 Report by Federal Emergency Management Agency, USA is adopted for this project. Since this method was dedicated for typical buildings and local conditions in United States, some modifications are made to accommodate Malaysian conditions (will be further discussed in Chapter 3).

Due to current Covid-19 pandemic, instead of field work, the "sidewalk survey" is conducted via online tool, through Google Earth. Important parameters and basic information of the buildings are observed and recorded in online RVS Malaysian form created in Google Forms. Later, the data will then be compiled and analyzed through

Microsoft Excel while the results are presented through GIS mapping method via ArcGIS Online, which is a free cloud-based mapping and analysis platform. Finally, important trends or patterns are recorded to identify the probable cause related to the overall seismic performance of the buildings within George Town area and suggestions for improvement are proposed accordingly.

1.5 Dissertation Outline

The dissertation for this project consist of 5 chapters, namely Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion. Chapter 1 of this dissertation provide an insight on the background of study, problem statements, objectives, scope of work as well as dissertation outline.

Besides, Chapter 2 breakdowns the research topic into several components while past study and research findings related to each component are discussed. For instances, the mechanism of some of the well-known RVS approaches proposed by different countries are explained. Moreover, past Malaysian seismic vulnerability related studies are compiled and reviewed to determine the research gap.

Next, the approaches adopted to conduct this project are discussed in detail in Chapter 3. All the modifications made with reference to FEMA 154 method are listed out with sufficient explanation while the flow of data collection, analysis and presentation are included as well.

Later, Chapter 4 covers all the research outcomes while discussion is made accordingly to identify important trends, patterns and reasoning behind this project.

Lastly, Chapter 5 concludes the overall achievement of this project regarding the initial targeted objectives. Suggestions and recommendations are provided as reference for those who wish to further improve this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, this research is broken down into several components while the findings and results generated by previous researches related to the components are discussed. Besides, few of case study examples whereby Rapid Visual Screening (RVS) methods are utilized to estimate seismic vulnerability are included. Moreover, this chapter also compiles most of the "seismic vulnerability assessment" related studies done in the past within Malaysia to highlight the research gap.

2.2 Seismic Vulnerability

Based on Cambridge Advanced Learner's Dictionary by Elizabeth Walter, 'vulnerability' describes the quality of being vulnerable, while 'vulnerable' is defined as able to be easily hurt, influenced, or attacked. On the other hand, the term 'vulnerability' can be scientifically interpreted as the degree of susceptibility to negative effects originated from stresses associated with environmental and social change along with the lack of capacity to adapt (Adger, 2006). Therefore, 'seismic vulnerability' is the measure on the degree of susceptibility of people and assets towards damage and harm during a seismic event, which is mainly governed by the structural integrity of buildings and the level of preparedness of the occupants.

Earthquakes are one of the common natural disasters that often came along with great risk to life and property, hence determining the seismic vulnerability of buildings is crucial to improve urban sustainability through identification and insight into optimum materials and structures (Roslee *et al.*, 2018; Harirchian *et al.*, 2020).

2.3 Rapid Visual Screening Method

Generally, there are two approaches to examine the seismic vulnerability of a building, which are through software modelling or actual scaled modelling, and run the models through multiple tests. Both of the approaches will certainly generate results with high accuracy which allow the researchers to visualize the performance of building during a seismic event. However, they often requires complex analysis tools and a lot of detailed inputs such as building materials, reinforcement details and column size, while the assessment process can be time consuming and costly especially for scaled modelling. Due to lack of time, funds and manpower, aforementioned approaches are not suitable for screening large building stocks at once (Coskun *et al.*, 2020).

To fulfill the need to assess the seismic vulnerability of buildings within a city efficiently, an alternative strategy that focus on filtering out vulnerable building has to be implemented (Sözen, 2014), hence Rapid Visual Screening Method (RVS) had been introduced. RVS is a qualitative method that estimate the seismic vulnerability of a large number of structures based on correlations between the buildings' predicted seismic performance and structural typology (Coskun *et al.*, 2020). Generally, RVS utilizes a scoring system to evaluate and estimate the level of risk of the buildings where there are a basic score (also known as structural score) and modifiers that correspond to the building strength and deficiencies towards a seismic event (Ningthoujam and Nanda, 2018). Later, the seismic performance of the building can be predicted from the results of RVS through the final score. Although RVS might not be accurate as the detailed modeling analysis but it is very useful and simple in determining which areas of a city are generally more vulnerable than others (Shah *et al.*, 2016; Harirchian *et al.*, 2020). Therefore, RVS can be used as a preliminary process to screen out structures with high seismic vulnerability in order to perform further detailed test and analysis. In this way there will be less effort needed as all the resources are used efficiently.

There have been a lot studies done in the past, especially by those countries that were located within seismically active regions, in order to develop a more accurate and efficient RVS. The key mechanism of some of the well-known methodologies developed are discussed below.

2.3.1 American Method

FEMA-154 (2002) method by Federal Emergency Management Agency, USA utilize a scoring system for seismic vulnerability assessment purpose. There are a total of three forms correspond to low, mid and high seismicity of the study area, which can be determined by the Spectral Acceleration Response where different scores are introduced. The scoring system can be separated into two components, basic score that varies according to lateral load-resisting system of the building as shown in Table 2.1 and a series of score modifiers assigned to significant features that will affect the seismic performance of the building, which are number of storeys, vertical irregularity, plan irregularity, construction date with reference to initial and latest national seismic code, and soil types. Final score is calculated by taking the sum of basic score and score modifiers, further detailed evaluation is needed if final score of the building is lower than 2. An example of GIS data representation is shown in Figure 2.1 while Figure 2.2 depicts one of the three data collection forms utilized in the preliminary survey.

Table 2.1: Lateral Load-Resisting System in FEMA (2002)

Lateral Load-Resisting System	
W1	Light wood frame, residential or commercial, ≤ 5000 sqft
W2	Wood frame buildings, > 5000 sqft
S1	Steel moment-resisting frame
S2	Steel braced frame
S3	Light metal frame
S4	Steel frame with cast-in-place concrete shear walls
S5	Steel frame with unreinforced masonry infill
C1	Concrete moment-resisting frame
C2	Concrete shear wall
C3	Concrete frame with unreinforced masonry infill
PC1	Tilt-up construction
PC2	Precast concrete frame
RM1	Reinforced masonry with flexible floor and roof diaphragms
RM2	Reinforced masonry with rigid diaphragms
URM	Unreinforced masonry bearing-wall buildings

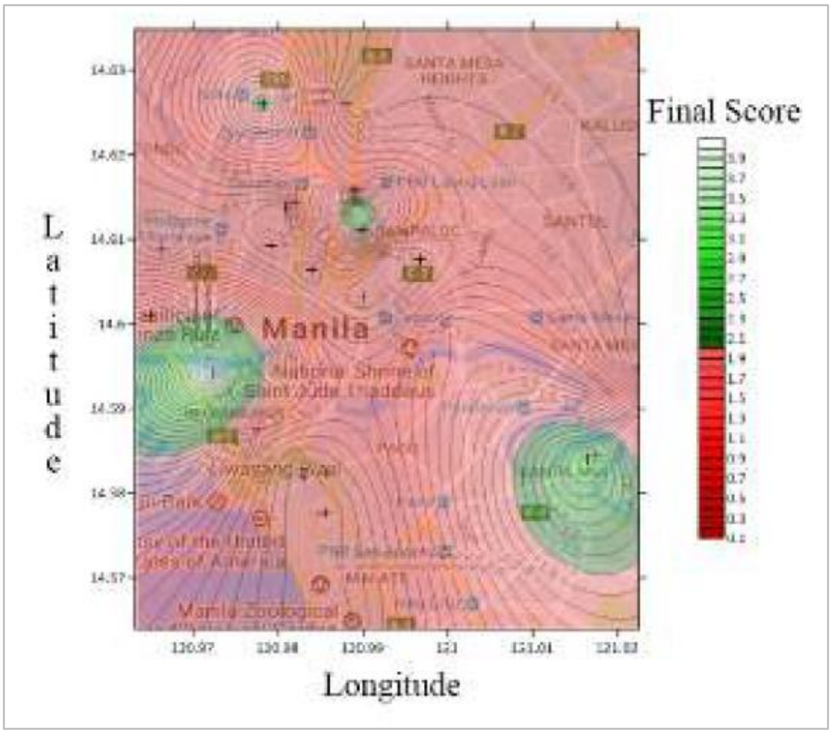
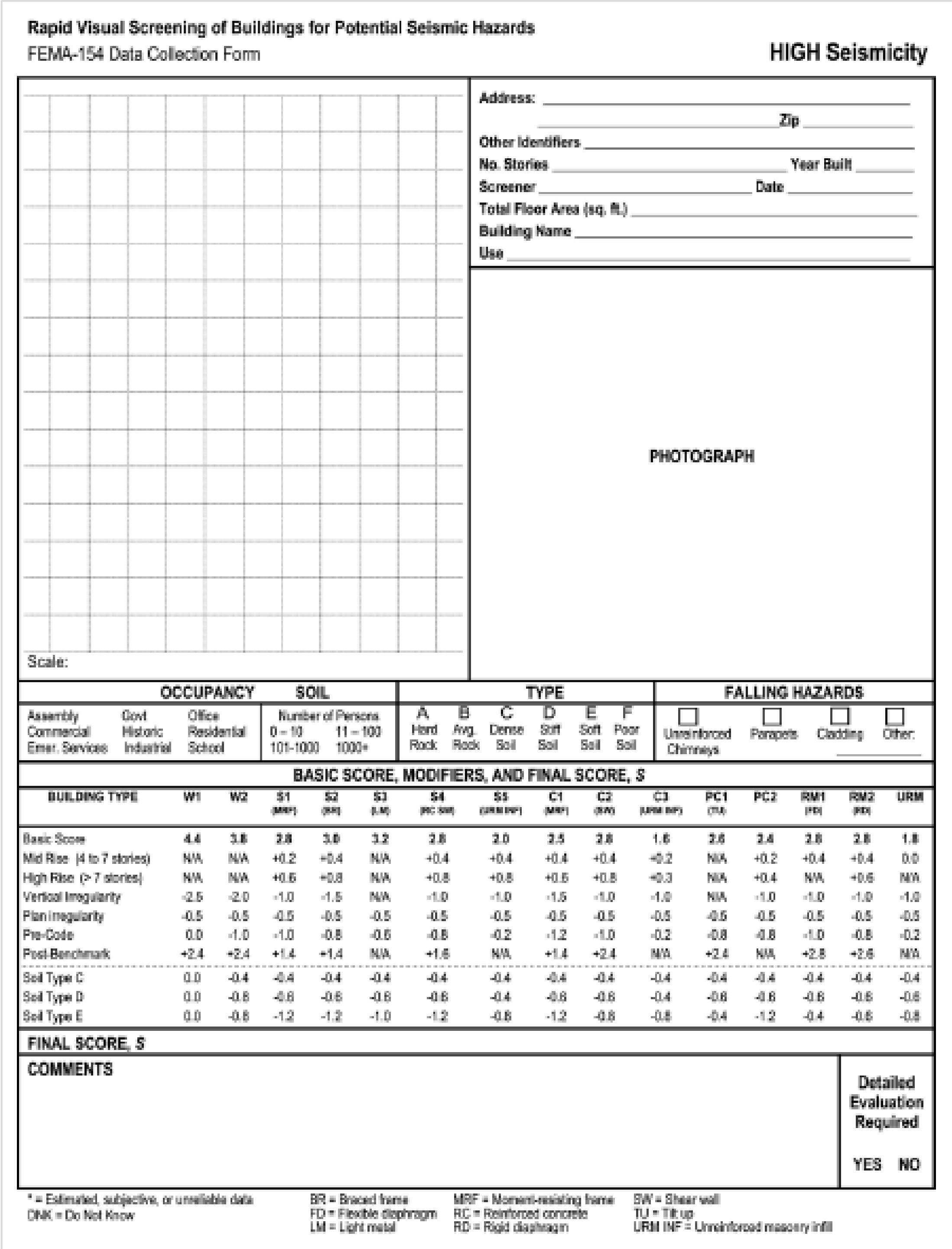


Figure 2.1: Example of RVS results (FEMA-154) presented through GIS mapping (Clemente *et al.*, 2020)



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

HIGH Seismicity

Scale:

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

PHOTOGRAPH

OCCUPANCY			SOIL							FALLING HAZARDS			
Assembly	Govt	Office	Number of Persons	A Hard Rock	B Avg. Rock	C Dense Soil	D Stiff Soil	E Soft Soil	F Poor Soil	Unreinforced Chimneys	Parapets	Cladding	Other:
Commercial	Historic	Residential	0 – 10 11 – 100										
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 2.2: FEMA-154 (2002) data collection form for high seismicity zone

2.3.2 Indian Method

Sinha and Goyal (2004) proposed a 3-level procedures (denoted as S.G. in this context) that should be included in India's national vulnerability assessment methodology, which are Level 1 procedure- Rapid Visual Screening (RVS), Level 2 procedure- Simplified Vulnerability Assessment (SVA) and Level 3 procedure- Detailed Vulnerability Assessment (DVA).

The RVS from Level 1 procedure was developed with reference to FEMA-154 (2002), whereby the evaluating mechanism was preserved while some modifications were made to the scoring values and components to suit Indian conditions. Similarly, there are a total of three forms which correspond to Zone II, Zone III and Zone IV & V seismic zone as per IS 1893:2002 (Part 1). However, for the basic score part, S.G. reduced the type of lateral load-resisting system for wood and steel structure; completely remove tilt-up construction, precast concrete and reinforced masonry structure; but further subdivide unreinforced masonry structure into four categories (Table 2.2). On the other hand, for score modifiers, S.G. combined pre-code and post benchmark from FEMA-154 into code detailing and change the soil category from "dense, stiff and soft soil" to "medium, soft and liquefiable soil". Similarly, final score is calculated by taking the sum of basic score and score modifiers, however S.G. suggest to take 0.7 instead of 2 as cut off score to determine whether to proceed with Level 2 procedure or not. Further description on the component of the 3-level procedures are included in "Seismic Evaluation and Strengthening of Existing Buildings" published by Indian Institute of Technology Kanpur (IITK) (Rai, 2005). An example of GIS data representation is shown in Figure 2.3 while Figure 2.4 depicts one of the three data collection forms utilized in the preliminary survey.

Table 2.2: Lateral Load-Resisting System in S.G.

Lateral Load-Resisting System	
Wood	Wood frame
S1	Steel frame
S2	Light metal frame
C1	Concrete moment-resisting frame
C2	Concrete shear wall
C3	Concrete frame with burnt brick masonry infill wall
URM1	Unreinforced masonry with seismic band and rigid diaphragms
URM2	Unreinforced masonry with seismic band and flexible diaphragms
URM3	Unreinforced burnt brick or stone masonry (cement mortar)
URM4	Unreinforced masonry (lime mortar)

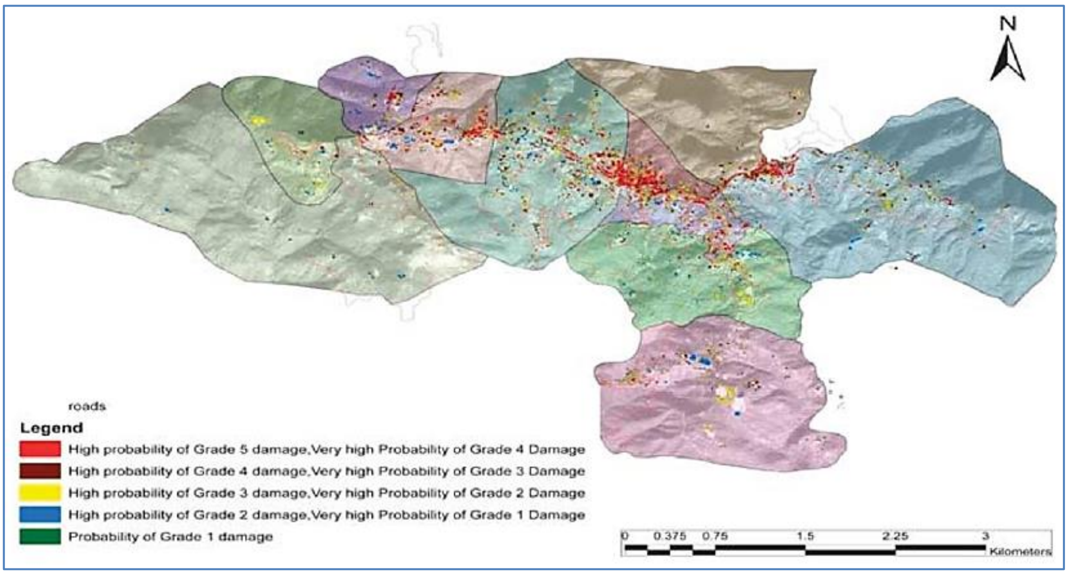
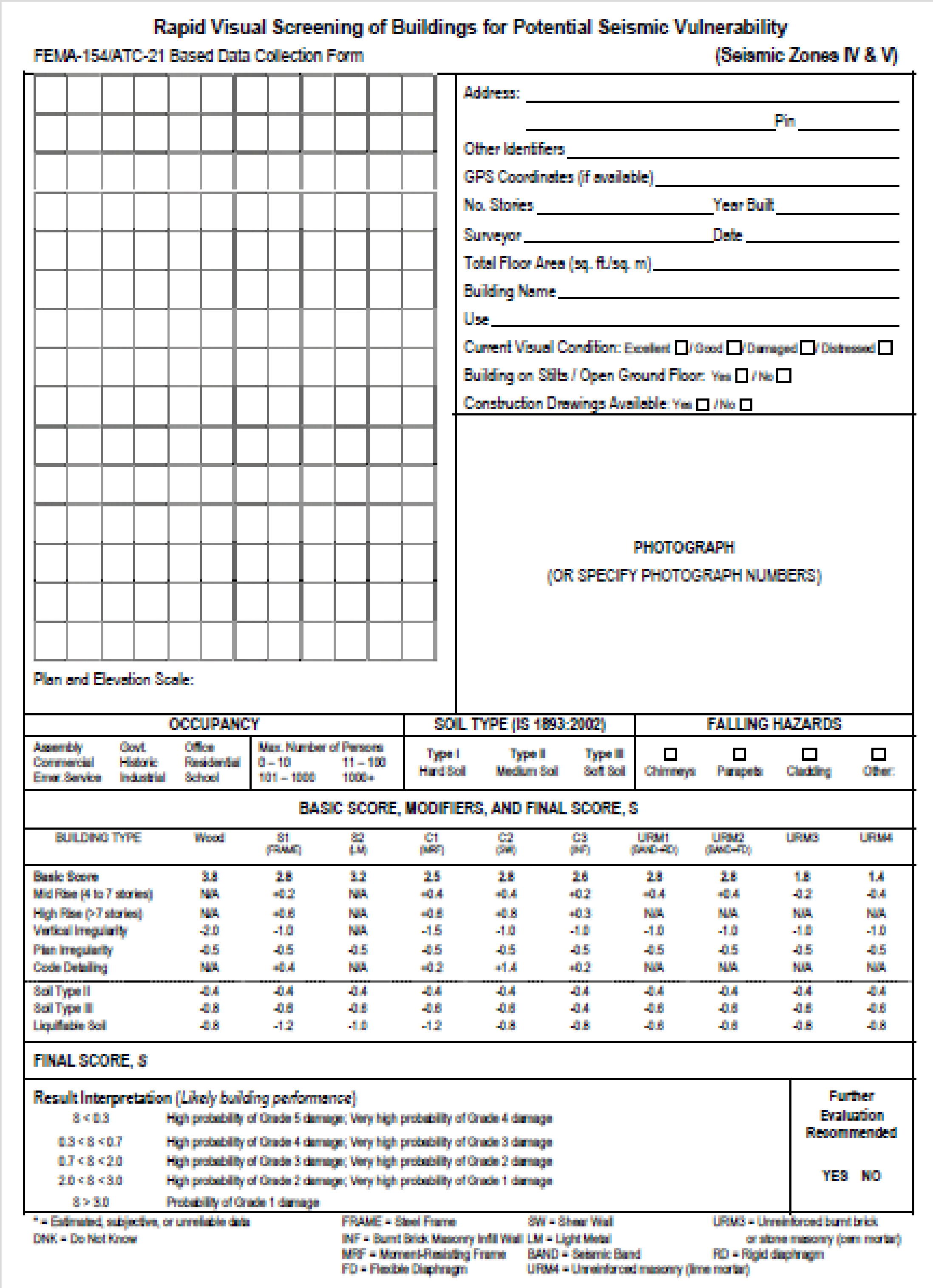


Figure 2.3: Example of RVS results (S.G. Method) presented through GIS mapping (Joshi and Kumar, 2010)



Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

FEMA-154/ATC-21 Based Data Collection Form (Seismic Zones IV & V)

Address: ______________________

______________ Pin ______

Other Identifiers ______________________

GPS Coordinates (if available) ______________________

No. Stories ______________ Year Built ______

Surveyor ______________ Date ______

Total Floor Area (sq. ft./sq. m) ______________________

Building Name ______________________

Use ______________________

Current Visual Condition: Excellent ☐ / Good ☐ / Damaged ☐ / Distressed ☐

Building on Stilts / Open Ground Floor: Yes ☐ / No ☐

Construction Drawings Available: Yes ☐ / No ☐

PHOTOGRAPH

(OR SPECIFY PHOTOGRAPH NUMBERS)

Plan and Elevation Scale:

OCCUPANCY				SOIL TYPE (IS 1893:2002)			FALLING HAZARDS			
Assembly Commercial Emer. Service	Govt. Historic Industrial	Office Residential School	Max. Number of Persons 0 – 10 11 – 100 101 – 1000 1000+	Type I Hard Soil	Type II Medium Soil	Type III Soft Soil	☐ Chimneys	☐ Parapets	☐ Cladding	☐ Other:

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

BUILDING TYPE	Wood	S1 (FRAME)	S2 (LM)	C1 (MRF)	C2 (SW)	C3 (INF)	URM1 (BAND+RD)	URM2 (BAND+FD)	URM3	URM4
Basic Score	3.8	2.8	3.2	2.5	2.8	2.6	2.8	2.8	1.8	1.4
Mid Rise (4 to 7 stories)	N/A	+0.2	N/A	+0.4	+0.4	+0.2	+0.4	+0.4	-0.2	-0.4
High Rise (>7 stories)	N/A	+0.6	N/A	+0.6	+0.8	+0.3	N/A	N/A	N/A	N/A
Vertical Irregularity	-2.0	-1.0	N/A	-1.5	-1.0	-1.0	-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
Code Detailing	N/A	+0.4	N/A	+0.2	+1.4	+0.2	N/A	N/A	N/A	N/A
Soil Type II	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type III	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.8	-0.6
Liquifiable Soil	-0.8	-1.2	-1.0	-1.2	-0.8	-0.8	-0.6	-0.6	-0.8	-0.8

FINAL SCORE, S

Result Interpretation (*Likely building performance*)

		Further Evaluation Recommended
$S < 0.3$	High probability of Grade 5 damage; Very high probability of Grade 4 damage	
$0.3 < S < 0.7$	High probability of Grade 4 damage; Very high probability of Grade 3 damage	
$0.7 < S < 2.0$	High probability of Grade 3 damage; Very high probability of Grade 2 damage	YES NO
$2.0 < S < 3.0$	High probability of Grade 2 damage; Very high probability of Grade 1 damage	
$S > 3.0$	Probability of Grade 1 damage	

* = Estimated, subjective, or unreliable data
DNK = Do Not Know

FRAME = Steel Frame
INF = Burnt Brick Masonry Infill Wall
MRF = Moment-Resisting Frame
FD = Flexible Diaphragm
SW = Shear Wall
LM = Light Metal
BAND = Seismic Band
URM4 = Unreinforced masonry (lime mortar)
URM3 = Unreinforced burnt brick or stone masonry (cem mortar)
RD = Rigid diaphragm

Figure 2.4: S.G. data collection form for seismic zones IV & V

2.3.3 Turkish Method

Earthquake Master Plan of Istanbul (EMPI) was published by Metropolitan Municipality of Istanbul (IMM) in year 2003 as a collaborative effort of 4 universities namely Boğaziçi University (BU), Yildiz Technical University (YTU), Istanbul Technical University (ITU) and Middle East Technical University (METU), which were coordinated by Prof. Dr. Atilla Ansal. EMPI proposed a 3-stage building assessment procedure to evaluate the seismic vulnerability of the existing buildings, the First Stage Assessment falls under RVS category where a total of three methods had been introduced (IMM, 2003).

Method I and II were developed by METU which both utilize a scoring system to evaluate the buildings. Firstly, an initial score is assigned based on the number of storeys and the Peak Ground Velocity (PGV) of the region, later vulnerability score penalties are introduced thus the final seismic performance score (PS) is calculated using Equation 2.1.

$$PS = (\text{Initial Score}) - \sum [(\text{Vulnerability Parameter}) \times (\text{Vulnerability Score})] \quad (2.1)$$

The difference between Method I and II are their targeted building category and vulnerability parameters introduced. Method I will be applied to 1-7 storey reinforced concrete buildings, which the parameters are soft storey, heavy overhangs, apparent building quality, short column, ponding effect and topography effect (Figure 2.5); while Method II is designated for 1-5 storey masonry buildings, which focus on apparent building quality, wall opening ratio, orientation of wall openings and pounding effect (Figure 2.6). Figure 2.7 illustrates an example of GIS data mapping for RVS utilizing Turkish Method I.

Story #	Zone I 60<PGV<80	Zone II 40<PGV<60	Zone III 20<PGV<40		Heavy Overhang	Apparent Quality	Short Column	Pounding	Topographic Effects
1, 2	90	125	160	0	-5	-5	-5	0	0
3	90	125	160	-10	-10	-10	-5	-2	0
4	80	100	130	-15	-10	-10	-5	-3	-2
5	80	90	115	-15	-15	-15	-5	-3	-2
6, 7	70	80	95	-20	-15	-15	-5	-3	-2

Vulnerability Parameters

Soft story : No (0); Yes (1)
Heavy overhangs : No (0); Yes (1)
Apparent quality : Good (0); Moderate (1); Poor (2)
Short columns : No (0); Yes (1)
Pounding effect : No (0); Yes (1)
Topography effect : No (0); Yes (1)

Figure 2.5: Data collection form for Method I of First Stage Assessment proposed in EMPI

Number of Stories	Zone I PGV>60	Zone II 40<PGV<60	Zone III PGV<40	Apparent Quality	Wall Openings	Opening Orientation	Pounding Effect
1,2	100	130	150	-10	-5	-2	0
3	85	110	125	-10	-5	-5	-3
4	70	90	110	-10	-5	-5	-5
5	50	60	70	-10	-5	-5	-5

Vulnerability Parameters

Wall openings: Small (0); Moderate (1); Large (2)
Opening orientation : Regular (0); Less regular (1); Irregular (2)
Apparent quality : Good (0); Moderate (1); Poor (2)
Pounding effect : No (0); Yes (1)

Figure 2.6: Data collection form for Method II of First Stage Assessment proposed in EMPI

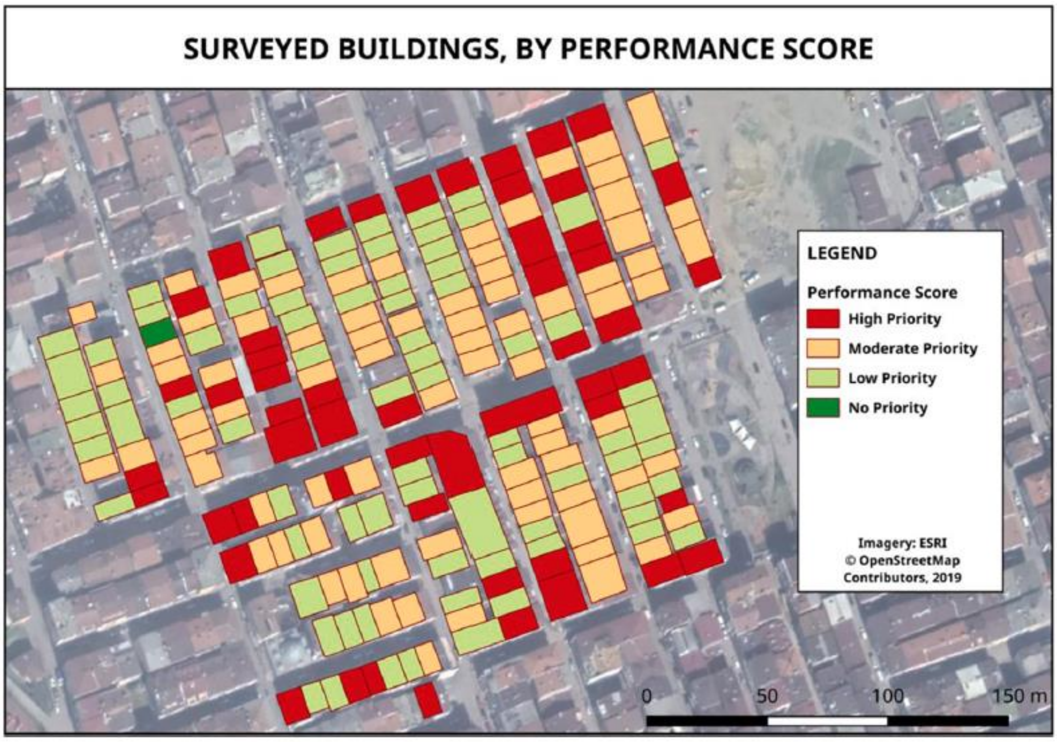


Figure 2.7: Example of RVS results (Turkish Method I) presented through GIS mapping (Özsoy Özbay, Sanrı Karapınar and Ünen, 2020)

On the other hand, BU and YTU had developed Method III that utilize a simple calculation to determine the life safety and collapse prevention performance of existing buildings during a seismic event through the ratio of building drift ratio capacity (D_c) to building drift ratio demand (D_d). Firstly for D_d calculation, short period spectral acceleration (S_S) and one-second spectral acceleration (S_1) of the study area are required to determine standard "elastic" acceleration spectrum with 5% damping (S_{ae}) through Equation 2.2, 2.3 or 2.4.

$$S_{ae} = (1 + 1.5T / T_o)\, S_S / 2.5 \qquad , (T < T_o) \qquad (2.2)$$

$$S_{ae} = S_S \qquad , (T_o \leq T \leq T_S) \qquad (2.3)$$

$$S_{ae} = S_1 / T \qquad , (T > T_S) \qquad (2.4)$$

which,

$T_S = S_1 / S_S$

$T_o = 0.2\ T_S$

$T = 0.15\ n$, (Reinforced Concrete Buildings)

$T = 0.075\ n$, (Masonry Buildings)

where n refer to the number of building storeys excluding basement(s).

Next, S_{ae} is used to calculate elastic displacement spectrum (S_{de}) through Equation 2.5. Later, inelastic displacement spectrum (S_{di}) is obtained by taking the product of S_{de} and an empirical factor (C_d) which governed by number of building storeys as stated in Equation 2.6.

$$S_{de} = (T / 2\pi)^2 S_{ae} \qquad (2.5)$$

$$S_{di} = C_d\ S_{de} \qquad (2.6)$$

Lastly, by assuming average storey height of 3m, D_d is obtained via Equation 2.7.

$$D_d = Sdi / (2n + 1) \qquad (2.7)$$

The calculation of D_c is relatively simple, which is taken as the product of basic drift ratio capacity (D_{co}) and a series of capacity reduction factors (C_c). Different values are assigned to those parameters that will impact the building seismic performances. For instance, pounding effect and apparent building quality; weak storeys, short column and façade columns resting on cantilever at ground level for RC buildings; wall opening ratio, wall opening arrangement and number of storeys for masonry buildings. Finally, comparison can be made on the seismic vulnerability of all the buildings which undergo

Method III First stage assessment based on their respective capacity/demand ratio (D_c/D_d).

2.3.4 Canadian Method

A RVS method is introduced by Rainer *et al.* (1993) in Manual for Screening of Buildings for Seismic Investigation published by National Research Council Canada (NRCC). This method utilize a scoring system with reference to FEMA 154 but focus on different parameters such as seismicity (A), soil conditions (B), type of structure (C), building irregularities (D) which includes vertical irregularities, horizontal irregularities, short column, soft storey, pounding effect, building modifications and deterioration of buildings, building importance (E) and non-structural hazards (F). The final score of this RVS is known as Seismic Priority Index (SPI), which is the sum of Structural Index (SI) and Non-Structural Index (NSI), the formulae for the calculations are shown below.

$$SPI = SI + NSI \tag{2.8}$$

$$SI = A \times B \times C \times D \times E \tag{2.9}$$

$$NSI = B \times E \times F \tag{2.10}$$

From the SPI, government can then decide on how much priority should be given to the targeted building regarding seismic mitigation measure, whereby

$SPI < 10$, (low priority)

$10 \leq SPI \leq 20$, (medium priority)

$SPI > 20$, (high priority)

Extra attention should be given to building with SPI greater than 30 as the building can be considered as potentially seismic hazardous.

2.4 FEMA P-154

In year 1988, the publication of the FEMA 154 Report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* had introduce a “sidewalk survey” approach that group existing buildings into two categories, namely those which are acceptable as to risk to life safety or those which might possess seismic hazard which detailed evaluation by design professional experienced in seismic design is required.

On the following decade, feedbacks on its purposes, the ease-of-use of the document, and perspectives on the accuracy of the scoring system upon which the procedure was based were provided through extensive application where more than 70,000 buildings within United States were evaluated by either private sectors or government agencies. Combining the feedbacks from previous applications with in-depth researches and development data under the National Earthquake Hazards Reduction Program (NEHRP), the FEMA 154 Report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* had been revised hence second edition was released in year 2002. The second edition handbook revised the scoring system with reference to the ground motion criteria in the FEMA 310 Report, *Handbook for Seismic Evaluation of Buildings—A Prestandard* (FEMA 310, 1998), and the damage estimation data generated in FEMA-funded HAZUS damage and loss estimation methodology (Federal Emergency Management Agency (FEMA), 2015) while preserving the original framework and screening procedures. Besides, with increased knowledge on the expected distribution, severity, and occurrence of earthquake ground shaking, the scale used to classify the seismicity regions was modified. (FEMA, 2002)

Harirchian *et al.* (2020) had conducted a research which compares the practicality of three RVS methods, namely American FEMA P-154 method, Indian IITK-GGSDMA method and Turkish EMPI method, through their assessment results and observed RC buildings damage data in the Bingöl region, Turkey post 1 May 2003 earthquake. Although the findings concluded that FEMA P-154 is not economical since it overestimates the damage states of the buildings after seismic event, this result if viewed from other perspective, can be considered as an advantage as it represents a more conservative approach thus may minimize the risk of missing out crucial buildings that are seismic hazardous hence ensure essential detailed analysis are carried out when necessary.

2.5 Rapid Visual Screening Case Study

RVS method had always been the popular choice for researchers to conduct preliminary seismic risk assessment and screening on large number of existing buildings due to its cost and time saving attributes as the RVS method will help to narrow down the building inventory which further detailed assessment and analysis are necessary. Some of the recent case study examples around the globe will be listed in Table 2.3 below.

Table 2.3: RVS case study examples around the globe

Author	Research Description
Clemente *et al.* (2020)	Preliminary seismic vulnerability assessment of 26 hospital buildings in Manila, Philippines through FEMA P-154 (2015) level 1 method.
Kegyes-Brassai (2019)	Preliminary seismic vulnerability assessment of over 5000 existing buildings in Gyor, Hungary through modified FEMA 154 (2002) method and results are compared to pushover analysis of typical buildings on district level.
Khan *et al.* (2019)	Preliminary seismic vulnerability assessment of a representative sample of different building use-types in Malakand, Pakistan through FEMA P-154 (2015) level 1 method.
Sarmah & Das (2018)	Preliminary seismic vulnerability assessment of 100 random selected building in Guwahati City, India through modified FEMA P-154 (2015) level 1 method.
Joshi & Kumar (2010)	Preliminary seismic vulnerability assessment of 3339 existing building in Mussoorie Town, India through S.G. method.
Kapetana & Dritsos (2007)	Preliminary seismic vulnerability assessment of 456 reinforce concrete buildings in Athens, Greece through USA, Greece, New Zealand, India and Canada RVS methods, and comparing the results with actual damage data of the buildings post 1999 Athens earthquake.

From the brief review on past examples utilizing RVS methodologies as a tool for preliminary seismic vulnerability assessment, it is no doubt that these methods are really convenient and have played an important role in overall seismic mitigation effort by the government.

2.6 Seismic Vulnerability Studies Related to Structures in Malaysia

In the past 10 years, there was a rise in concern of the performance of Malaysian buildings and structures under seismic influence, hence a plethora of researches had been conducted mainly towards four directions, which are detailed vulnerability assessment of individual selected building (Table 2.4), detailed vulnerability assessment of selected building or structure cluster (Table 2.5), development of new seismic vulnerability assessment methodologies (Table 2.6) and preliminary vulnerability assessment of large building inventories (Table 2.7).

Table 2.4: Researches conducted in the past 10 years on the detailed vulnerability assessment of individual selected building

Author	Research Description
Kassem *et al.* (2020)	Examination of the seismic performance of a Hospital Building damaged during the Ranau earthquake in Sabah through an improved empirical seismic vulnerability index (SVI).
Nizamani *et al.* (2018)	Seismic vulnerability assessment of a horizontally unsymmetrical building (a 12 storey hotel building from Ipoh, Perak) to local and far field earthquakes through Response Spectrum Analysis.
Ahmadi *et al.* (2014)	Analytical seismic vulnerability assessment of an industrial building in Peninsular Malaysia.
Kamarudin *et al.* (2014)	Investigation on the seismic performance of school building of SMK Bukit Tinggi damaged during the Bukit Tinggi earthquakes in Pahang through ambient noise study with Fourier Amplitude Spectra (FAS) analysis.

Table 2.5: Researches conducted in the past 10 years on the detailed vulnerability assessment of selected building or structure cluster

Author	Research Description
Aljwim *et al.*, (2020)	Seismic vulnerability assessment of two 25-storey tall concrete wall structures in Malaysia under near-field earthquakes through the development of seismic fragility curves.
Aisyah *et al.* (2019)	Seismic vulnerability assessment of two 25-storey tall concrete wall structures in Malaysia under far-field earthquakes through the development of seismic fragility curves.
Alih & Vafaei (2019)	Investigation and discussion on the performance of reinforced concrete buildings and wooden structures during the 2015 Mw 6.0 Sabah earthquake in Malaysia.
Ghazali *et al.* (2019)	Determination of nonlinear response of 3 concrete box girder bridges with different pier heights through pushover and incremental dynamic analysis.

Rosman *et al.* (2019)	Investigation on the effect of infill panels in seismic vulnerability of low-ductile RC frames through Incremental Dynamic Analysis (IDA) on three, six, and nine storeys RC frame buildings designed for gravity and lateral loads based on the common practices in Malaysia.
Fazilan *et al.* (2018)	Seismic vulnerability assessment of low-ductile reinforced concrete frame buildings in Malaysia through the development of seismic fragility curves.
Tan *et al.* (2018)	Seismic vulnerability assessment of low- and mid-rise reinforced concrete buildings in Malaysia (a three-storey reinforced concrete office frame building and a four-storey reinforced concrete school building with unreinforced masonry infill walls) designed by considering only gravity loads through fragility analysis.
Ramli and Adnan (2016)	Research on the effect from Sumatran earthquakes towards Malaysian bridges design.
Ismail *et al.* (2011)	Seismic vulnerability assessment of 8 public buildings in Sabah through Finite Element Modeling (FEM) under different types of analyses including Time Historey Analysis (THA) considering low to medium earthquake intensities.

Table 2.6: Researches conducted in the past 10 years on the development of new seismic vulnerability assessment methodologies

Author	**Research Description**
Sauti *et al.* (2020)	Proposal of method and framework for assessing and calculating the seismic vulnerability index at district level for Malaysia condition through multivariate data analysis.
Kassem *et al.* (2019)	Development of seismic vulnerability index methodology for reinforced concrete buildings based on nonlinear parametric analyses with reference to the Italian GNDT and the European Macro-seismic approaches.
Yusoff *et al.* (2019)	Introduction of a new solution to the prediction on the seismic damage index of buildings with the application of hybrid back propagation neural network and particle swarm optimization (BPNN-PSO) method based on damage indices of 35 buildings around Malaysia.

Table 2.7: Researches conducted in the past 10 years on the preliminary vulnerability assessment of large building inventories

Author	**Research Description**
Jainih & Harith (2020)	Preliminary seismic vulnerability assessment of existing buildings in seven major areas near Kota Kinabalu, Sabah through FEMA 154 (2002) method.
Roslee *et al.* (2018)	Preliminary seismic vulnerability assessment of Ranau area in Sabah through proposed physical vulnerability assessment methodology with the aid of literature review and secondary data.
Ghafar *et al.* (2015)	Preliminary seismic vulnerability assessment of existing buildings in Kundasang, Sabah through FEMA P-154 (2015) level 1 method.

By a quick review through previous seismic vulnerability related studies done regarding to Malaysian condition, it is no doubt that research which focus on preliminary seismic vulnerability assessment of existing buildings is insufficient, hence this project which focus on preliminary seismic vulnerability assessment in Penang is much needed in order to provide a quantitative tool for the government to decide if, and how much, remedial work is required in a particular district (Coskun *et al.*, 2020). The data from this preliminary screening is presented to the public through GIS mapping method, hence allow further assessment to be done in the future based on the outcome of this project.