A GIS- Based Seismic Vulnerability Assessment of an RC-Buildings in Malaysia Using an Improved Seismic Vulnerability Index Approach

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Abstract

The levels of earthquake hazard, building vulnerability, and exposure are correlated with the seismic risk assessment of built-up areas. Vulnerability assessment is well known as a very important subject for the safety of reinforced concrete (RC) buildings and the mitigation of impact on built-up from natural phenomena like earthquake. In 2015, Malaysia was subjected to a moderate earthquake, whereby many buildings and facilities were significantly damaged due to the Ranau earthquake event. It is worth to note that knowledge about the number of unusable and collapsible buildings in Malaysia under possible earthquakes is a crucial point for planning suitable intervention strategies from the structural perspective view. Therefore, the improved Seismic Vulnerability Index (SVI) approach is well known as an analytical approach that is applied to classify the vulnerability classes of 30 RC-buildings based on three Earthquake Resistant Designs (ERDs) (low-ERD, moderate-ERD, and high-ERD) located on Penang Island. The parametric analysis was by using non-linear time history analysis based on set of far-field and near-field seismic records. The results indicated that the SVI values classified the buildings as to have partial to total collapse in the case of low-ERD. However, the buildings suffered from moderate to heavy damages of structural elements and very heavy damages of non-structural elements in the case of moderate-ERD. Meanwhile, the SVI values classified buildings as to have slight to moderate damages of structural elements and heavy of non-structural elements in the case of high-ERD. Afterwards, the mean damage grade of selected buildings for IMs (VII, VIII, IX) for far-field and near-field were clarified before and after ERD implementation. All available data for SVI values of the 30 RC-buildings were integrated into Geographical Information System (GIS) 3D Mapping.

Keywords: Seismic Vulnerability Index; Earthquake Resistant Design; Far-Field, Near-Field; GIS.

1. Introduction

Recent earthquakes showed that earthquake engineering research needs to evaluate the vulnerability of existing buildings that lack sufficient seismic resistant properties [1]. In fact, earthquake risks are expected in cities whereby structures and buildings are built without considering seismic forces. Therefore, the scientific community continues to develop more detailed frameworks to determine the seismic performance and capacities of existing structures [2–6].

Several state-of-the-art approaches for seismic risk assessment contribute towards the assessment and evaluation of structural damage and structural performance of an individual building or a large area in a city [7–11]. Vulnerability index method is a risk approach that is used to express the damage level of a large number of structures or even a single building. This type of vulnerability assessment is categorised as an empirical or qualitative approach which depends on a detailed analysis of post-earthquake damage data and expert opinion. However, a detailed analysis requires large input data that may be impossible to collect in many developing countries; for example, in Malaysia which has limited data on seismic event observations.

Lack of empirical approach lends power and credit to analytical approach, which has the ability to improve the original vulnerability index method by considering features and parameters that affect the building response, such as beam-column joint connection, support boundary condition, horizontal diaphragm system, type of soil, ductility level, horizontal and vertical mass irregularity, and material strength, as recently proposed by Kassem et al. in 2019 and 2020 [12,13] by developing analytical seismic vulnerability index (SVI). In this research, 30 RC-buildings located in Malaysia were assessed through their SVI development and mean damage grade values for three different vulnerability classes denoted by earthquake resistant design (ERD) principles.

2. Improved Seismic Vulnerability Index (SVI) Approach

Kassem et al. [12] proposed a new approach which aimed to improve the empirical vulnerability index (GNDT [14] and European Macroseismic [15]) by developing a Seismic Vulnerability Index (SVI) through the use of an analytical technique. The technique is by conducting a Non-Linear Parametric Analysis (NL-PA) via simulating a set of earthquake records with different Far-Field (FF) and Near-Field (NF) seismic scenarios on the 30 RC-buildings that are classified as gravity loading structural system. This is an alternative to specialist decisions and judgements. The following represents the phases used in this approach:

- **Stage 1**: Information and data set gathered on the 30-RC buildings to be quantified.
- **Stage 2**: Assigning and designing seismic vulnerability parameters (P1 to P8) based on the original approaches.
- **Stage 3**: Distributing and identifying types of vulnerability into three Earthquake Resistant Design (ERD) classes (low-ERD, moderate-ERD, and high-ERD).
- **Stage 4**: Selecting an array of artificial seismic records which were utilised based on Non-Linear (NL) simulating platform via employing the Non-Linear Time History Analysis (NL-THA).
- **Stage 5**: Estimating the SVI by using the NL-DA, ranging from 0 to 1 (from less vulnerable to the most vulnerable).
- **Stage 6**: Quantification of mean damage grades or vulnerability curves for five damaged states (D1, D2, D3, D4, and D5).
- **Stage 7**: Schematise the results in Geographical Information System (GIS) form for SVI at different seismic intensities and classify the mean damage grade for each scenario (VII, VIII, and IX).

A number of parametric studies have been carried out to apply this method, which specifies and calibrates the structural parameters that affect the vulnerability of RC-buildings, and it was found that several parameters affected the physical vulnerability of the structure.

2

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In this study, eight modelled parameters were selected and followed the initiated approach with some modifications according to the GNDT and categorised into three vulnerability classes, namely low-ERD, moderate-ERD and high-ERD. Without taking into account past damage findings and applying non-linear parametric analysis, the eight model parameters (P1 to P8) had a direct impact on the structural behaviour. The selected modelled parameters for SVI analytical approach and their vulnerability classed distribution are shown in Table 1.

Table 1 – Selected modeled parameter and their ERD-vulnerability classes [13].

Modelled Parameters	Vulnerability Classes-ERD		
	Low- ERD	Moderate-ERD	High-ERD
P1: Beam-Column Joint Connection.	No Rigid offset length	Semi Rigid offset length (0.5)	Full Rigid offset length (1.0)
P2: Boundary Conditions	Hinged Support	Mixed Boundary Conditions	Fixed Support
P3: Horizontal Diaphragm System.	Flexible	Semi Rigid	Rigid
P4: Type of Soil.	Based on EC8 and Malaysia National Annex, in addition to ground motion scaling w.r.t target spectrum		
P5: Ductility Level.	Assigned Ductility Behavior from EC8		
P6 and P7: Horizontal and Vertical Mass Irregularity.	Mass Location at the Top	Mass Location at the Bottom.	Uniform Mass Distribution
P8: Concrete Strength.	Based on International Codes and Recommendations		
Engineering Demand Parameter			
Top Maximum Displacement using Incremental Dynamic Analysis			

If the structure is not constructed according to seismic regulations and has poor seismic efficiency, the low-ERD class is specified. When the structure is in moderate performance to withstand seismic loading, moderate-ERD class is taken into account. For High-ERD class is when the structural system is explicitly seismically constructed.

3. Strong Ground Motion Selection

Ground motion selection is one of the essential factors for reliable dynamic analysis to obtain the SVI through Non-Linear Time History Analysis (NL-THA) practices in which the compiling of sufficient ground motion records is a vital step in Non-Linear Dynamic Analysis (NL-DA) results. In this research, 20 strong ground motion records, which were divided into two segments, were investigated between far-field and near-field seismic records that were considered in this work, and in compliance with the basic standard specifications of the international codes downloaded from the COSMOS and PEER databases. With reference to FEMA P695, two sets of far-field and near-field ground motions were needed to be employed for vulnerability assessment of structures. According to Wang [16], and Vega et al. [17] different parameters should be considered when choosing ground motions, whereby a variety of parameters should be considered, including magnitude (Mw), Peak Ground Acceleration (PGA), distance from source such as near field (< 20 km) or far-field (> 20 km) and soil type. Like most earthquakes in Malaysia, the identified frequency and magnitude were within a magnitude (Mw) that ranged from 5 to 8, because the majority of events were of these intensities. Although Malaysia is located at a stable part of the Eurasian plate, buildings were built on soft soil. Therefore, they were shaken by far-field earthquakes that occurred in regions as far as Sumatra as most structures were constructed on soft soil of Type D features. According to Malaysia NA 2017, all the selected records were scaled with respect to the targeted response spectrum. Besides, for this work contributing the near-field ground motions (< 20 km) was a crucial step for earthquake engineers to build up a clear vision on how the high seismicity pulse could affect the SVI index value. Therefore, the classification

distance from site to source for far-field and near-field was not precisely clarified, as recommended by the FEMA P695 report (2009), the limit of source-to-site distance between the earthquakes of the far-field and near-field ground was defined as 10 km, but the source distance attributed to the strong ground motion had a major impact on the near-field whereby the structure was assigned as proposed by Alwaeli et al. [18] and Davoodi et al. [19]. Database record variability was assured by the inclusion of a sufficient large number of seismic records from considerable extent earthquake events in each ground motion record set, as shown in Table 2 and Table 3.

Table 2 – Far-field ground motions

No.	Earthquake Event	Year	Station	Mw	Source-to-site distance R (km)	PGA (g)
1	Imperial Valley-06	1979	El-Centro Array # 11	6.53	12.56	0.37
2	Superstitions Hills-02	1987	El-Centro Imp. Co. Cent	6.54	18.2	0.36
3	Kobe/Japan	1995	Abeno	6.9	24.85	0.23
4	Kocaeli/Turkey	1999	Duzce	7.51	15.37	0.31
5	Chi-Chi/Taiwan	1999	CHY101	7.62	9.94	0.34
6	Duzce/Turkey	1999	Bolu	7.14	12.04	0.74
7	Loma Prieta	1989	WAHO	6.93	17.47	0.37
8	Northridge-01	1994	Tarzana-Cedar Hill A	6.69	15.6	0.99
9	Chi-Chi/Taiwan	1999	TCU095	7.62	45.18	0.37
10	Sabah/Malaysia	2015	Ranau	5.9	60	0.13

Table 3 – Near-field ground motions

No.	Earthquake Event	Year	Station	Mw	Source-to-site distance R (km)	PGA (g)
1	San Fernando	1971	Pacoima Dam	6.61	1.81	1.22
2	Imperial Valley-06	1979	El-Centro Array #4	6.53	7.05	0.48
3	Cape Mendocino	1992	Petrolia	7.01	8.18	0.59
4	Kocaeli/Turkey	1999	Yarimca	7.51	4.83	0.23
5	Bam/Iran	2003	Ban	6.6	1.7	0.81
6	Darfield/New Zealand	2010	GDLC	7.0	1.22	0.76
7	Darfield/ New Zealand	2010	TPLC	7.0	6.11	0.30
8	Landers	1992	Lucerne	7.28	2.19	0.73
9	Chi-Chi/Taiwan	1999	TCU049	7.62	3.76	0.28
10	Kobe/Japan	1995	KJMA	6.9	0.96	0.83

4. Analytical Seismic Vulnerability Index Quantification

A series of step-by-step time history dynamic analysis was performed to quantify the Seismic Vulnerability Index (SVI) of the selected 30-RC buildings. In each vulnerability class the weighting coefficient calculation for each parameter was carried out by numerical modelling procedure. Finite element (FE) models were developed for each parameter. Then Incremental Dynamic Analysis (IDA) was performed to determine the weighting coefficients. Indeed, by assigning the maximum top displacement as a damage measure, the building vulnerability was precisely measured or evaluated by calculating the weighting coefficient for each particular parameter, as shown in Eq. (1) to Eq. (4).

From the incremental dynamic analysis, the weighting coefficients were obtained for each parameter based on top maximum displacement according to the formula below,

4

$$K_i = \frac{D_{max}}{\sum_{i=1}^{i=3} D_{max}} \tag{1}$$

Where, (i) represents three vulnerability classes and D_{max} represents top maximum displacement.

Then for each parameter, an average factor was calculated based on the number of earthquake records, as shown in Equation (2), where N is number of seismic records.

$$K_L = \frac{\sum_{i=1}^{i=n} K_i}{N} \tag{2}$$

Then the coefficients obtained from Equation (2) have to be normalised by dividing the weighting coefficients with a value which represents the sum of the coefficients of the low-ERD class, as shown in Equation (3).

$$K_n = \frac{\sum_{i=1}^{i=n} K_i}{\sum K_{L(Low-ERD)}} \tag{3}$$

Lastly, from the normalised factor obtained in Equation (3), the SVI of each vulnerability class was determined.

$$SVI = \sum_{n=i}^{n=j} K_n \tag{4}$$

Where, (n) in this analysis characterises number of modelled parameters from n = 1 to n = 8.

In addition, the vulnerability classifications were based on values obtained by the SVI whereby five ranges of damage were described (negligible, minor, moderate, partial collapse, and total collapse):

- Green 1 for vulnerability index values between 0.10–0.20, signifying insignificant to light damage.

- Green 2 for vulnerability index values between 0.20–0.40, signifying light to moderate damages.

- Orange 3 for vulnerability index values between 0.40–0.55, signifying moderate to heavy damages.

- Orange 4 for vulnerability index values between 0.55–0.70, signifying partial collapse.

- Red 5 for vulnerability index values between 0.70–1.0, signifying total collapse.

5. Seismic Vulnerability Index Mapping

All available data of the 30 RC-buildings were compiled and incorporated into Geographical Information System (GIS) environment which performed spatial analysis and presented the associated distribution, with a selected area of 1 km^2 assumed to be located in Peninsular Malaysia (Fig.1).
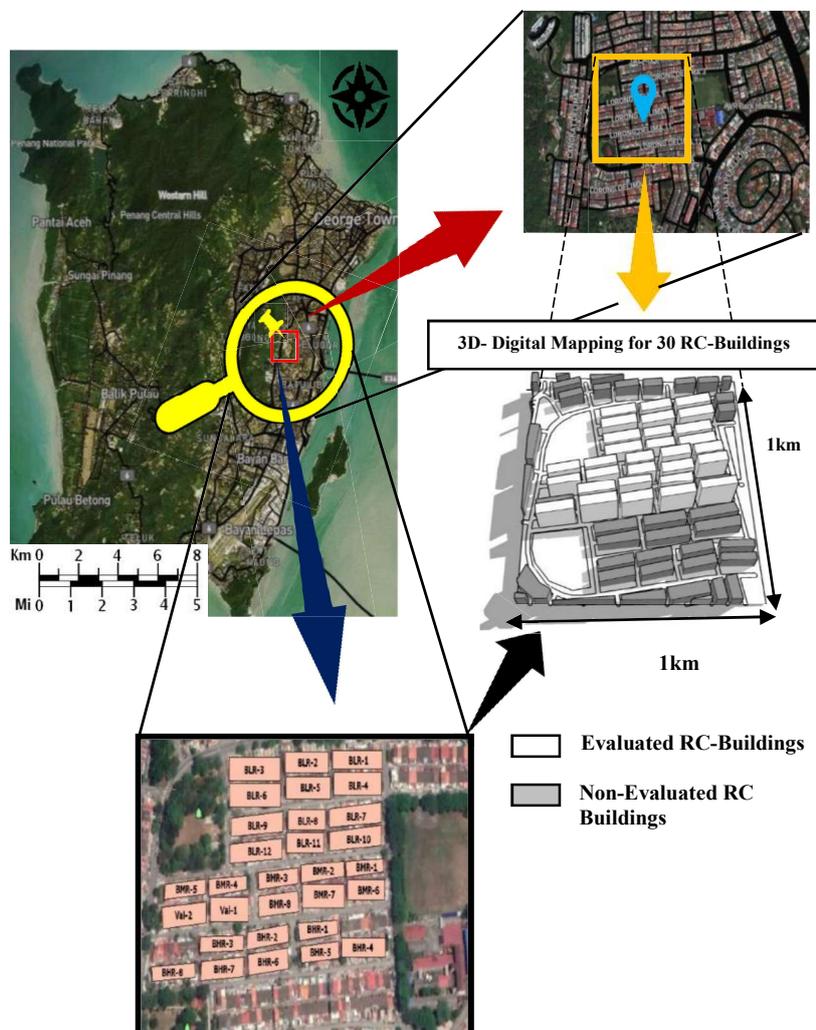

Fig. 1 – Case study area (1km^2) selected from Malaysia.

Fig. 2 and Table 4 show the SVI for Far-Field (FF) and Near-Field (NF) seismic motions, actual building designing system, and design structures (ERD), which were defined by moderate-ERD and high-ERD vulnerability classes.

The SVI for FF seismic motions in the case of actual building designing system ranges from 0.641 to 0.741, with a mean value of 0.706. Almost 70% (21 RC-buildings) had SVI of more than 0.70 and 30% (9 RC-buildings) had an index of more than 0.55 but less than 0.7. The SVI in the case of moderate-ERD vulnerability class ranged from 0.532 to 0.670, with a mean value of 0.644. Therefore, all selected buildings had SVI index which was below 0.7 but more than 0.55. Nevertheless, SVI in the case of high-ERD vulnerability class ranged from 0.359 to 0.530, with a mean value of 0.475. Almost 20% (6 RC-buildings) had SVI of above 0.50 and 80% (24 RC-buildings) had index of less than 0.50, including 2 RC-buildings with an index of less than 0.4.

Conversely, the SVI for NF seismic motions, which concerned the actual building designing system ranged from 0.685 to 0.823, with a mean value of 0.743. Almost 93% (28 RC-buildings) had SVI of over 0.70 and

6

6% (2 RC-buildings) had an index of more than 0.55 but less than 0.7. The SVI in the case of moderate-ERD vulnerability class ranged from 0.606 to 0.798, with a mean value of 0.685. Almost 37% (11 RC- buildings) had SVI of above 0.70 and 63% (19 RC-buildings) had an index of above 0.55 but less than 0.70. Nevertheless, the SVI of high-ERD vulnerability class, ranged from 0.447 to 0.672, with a mean value of 0.529. Almost 27% (8 RC-buildings) had SVI of above 0.55 and 73% (22 RC-buildings) had index between 0.40 and 0.50.

Table 4 – SVI values for the selected RC-building for FF and NF seismic scenarios.

Building no.	Building ID.	SVI (Far-Field)			SVI (Near-Field)		
		Moderate-ERD	Actual	High-ERD	Moderate-ERD	Actual	High-ERD
No.1	BLR-1	0.633	0.699	0.465	0.606	0.691	0.467
No.2	BLR-2	0.586	0.681	0.458	0.607	0.685	0.447
No.3	BLR-3	0.661	0.723	0.509	0.637	0.706	0.48
No.4	BLR-4	0.642	0.700	0.457	0.698	0.731	0.494
No.5	BLR-5	0.624	0.705	0.491	0.687	0.746	0.551
No.6	BLR-6	0.532	0.641	0.392	0.644	0.719	0.513
No.7	BLR-7	0.648	0.699	0.448	0.721	0.740	0.558
No.8	BLR-8	0.663	0.716	0.484	0.673	0.729	0.484
No.9	BLR-9	0.593	0.651	0.359	0.683	0.713	0.572
No.10	BLR10	0.661	0.720	0.499	0.685	0.745	0.551
No.11	BLR-11	0.657	0.706	0.462	0.679	0.743	0.55
No.12	BLR-12	0.674	0.722	0.493	0.693	0.743	0.535
No.13	BMR-1	0.637	0.717	0.514	0.664	0.733	0.507
No.14	BMR-2	0.66	0.711	0.473	0.674	0.731	0.52
No.15	BMR-3	0.675	0.714	0.467	0.686	0.745	0.517
No.16	BMR-4	0.677	0.726	0.5	0.69	0.743	0.51
No.17	BMR-5	0.59	0.677	0.44	0.715	0.759	0.6
No.18	BMR-6	0.62	0.688	0.443	0.696	0.745	0.54
No.19	BMR-7	0.664	0.713	0.475	0.655	0.752	0.484
No.20	BMR-8	0.644	0.708	0.48	0.706	0.745	0.529
No.21 to No.24	BHR-1	0.630	0.723	0.477	0.639	0.788	0.495
No.25	BHR-(2-5)	0.625	0.741	0.465	0.706	0.772	0.501
No.26	BHR-6	0.682	0.735	0.486	0.739	0.767	0.566
No.27	BHR-7	0.699	0.722	0.523	0.729	0.800	0.549
No.28	BHR-8	0.699	0.737	0.523	0.729	0.823	0.549
No.29	BMR-9	0.630	0.702	0.477	0.639	0.711	0.495
No.30	BMR-10	0.625	0.697	0.465	0.706	0.736	0.501

For both seismic motions (FF and NF), the SVI values indicated that the buildings faced partial to total collapse in regard to the actual building design system. However, the buildings suffered moderate to heavy damages of structural elements and very heavy damages of the non-structural elements in the case of moderate-ERD. The SVI values classified the buildings as experiencing slight to moderate damage of structural elements and heavy damage of non-structural elements in the case of High-ERD, as shown in Table 5 and Table 6.

Table 5 – SVI damage classification and description for the 30 selected-RC buildings in case of FF scenario.

Vulnerability Classes	Mean SVI for the 30-RC-Buildings	SVI Classes	Description
Actual Designing System	0.706	Red 5	Partial to Total Collapse at certain seismic intensity
Moderate-ERD	0.644	Orange 4	Moderate to Heavy for Structural-elements, and Very Heavy for Non-Structural elements
High-ERD	0.475	Orange 3	Slight to Moderate for Structural-elements, and Heavy for Non-structural elements

Table 6 – SVI damage classification and description for the 30 selected-RC buildings in case of NF scenario.

Vulnerability Classes	Mean SVI for the 30-RC-Buildings	SVI Classes	Description
Actual Designing System	0.743	Red 5	Partial to Total Collapse at certain seismic intensity
Moderate-ERD	0.685	Orange 4	Moderate to Heavy for Structural-elements, and Very Heavy for Non-Structural elements
High-ERD	0.529	Orange 3	Slight to Moderate for Structural-elements, and Heavy for Non-structural elements

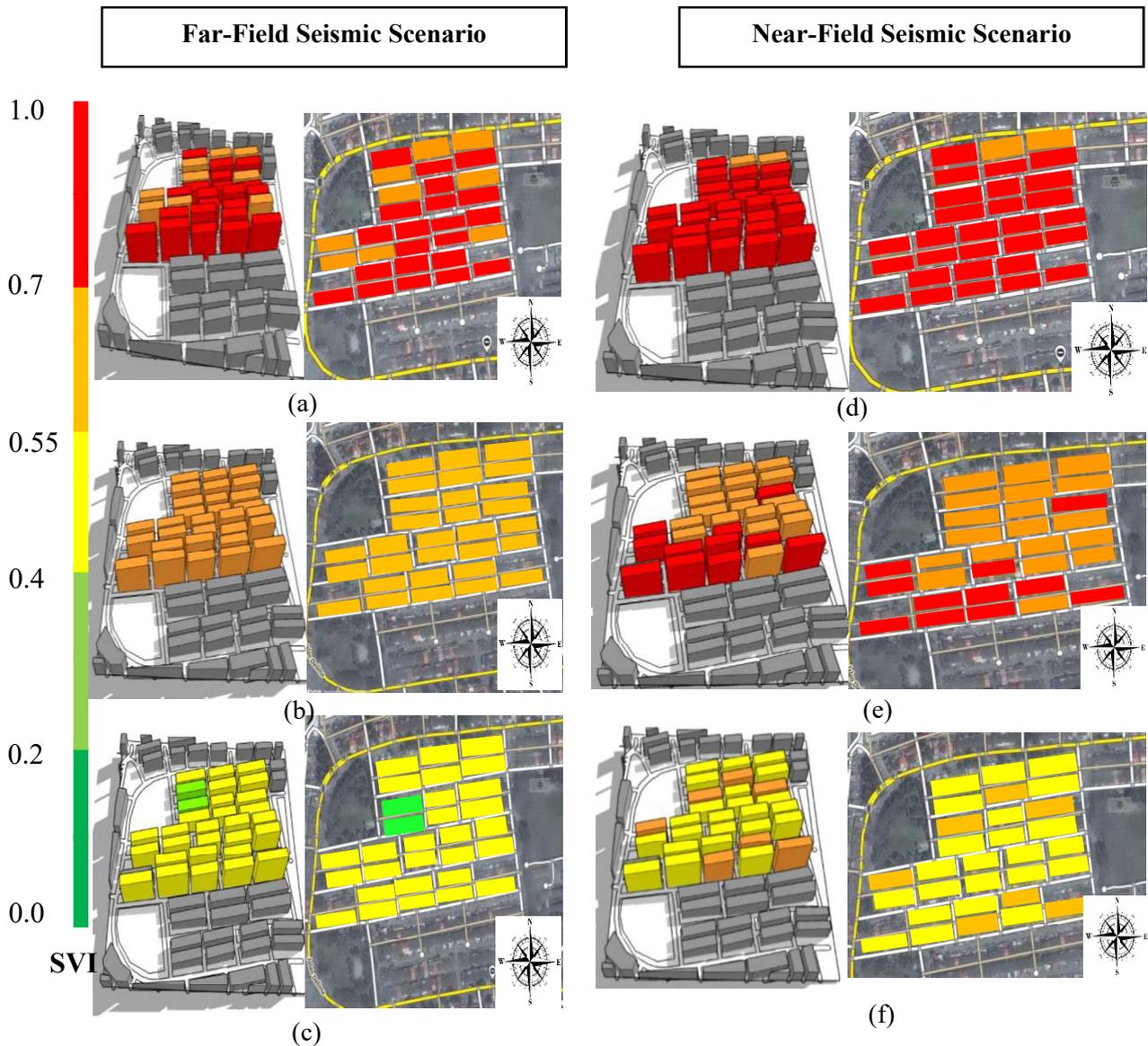| Far-Field Seismic Scenario | Near-Field Seismic Scenario |

Fig. 2 – Seismic Vulnerability Index distribution for different seismic scenarios, (a): Mean SVI-FF, (b) SVI-FF with Moderate-ERD, (c): SVI with High-ERD-FF, (d): Mean SVI-NF, (e): SVI-NF with Moderate-ERD, and (f): SVI-NF with High-ERD.

6. Direct Physical Damage-Mean Damage Grade

In certain aspects of risk assessment, direct physical damage to buildings is the starting point, such as mean damage grade (μ_D) and the description of corresponding damage state, as shown in Table 7. The mean damage grade is calculated by using Eq. (5).

$$\mu_D = 2.55 \times \left[1 + \tanh\left(\frac{I + 7 \times SVI - 13}{Q} \right) \right] \tag{5}$$

9

Table 7 – Mean damage grade values and corresponding damage states.

Mean damage grade interval	Most probable damage state	Description of damage
D0 [0.0-0.5]	None	No damage
D1 [0.5-1.5]	Slight	Negligible to slight damage
D2 [1.5-2.5]	Moderate	Slight structural (S), moderate non-structural (NS)
D3 [2.5-3.5]	Substantial to Heavy	Moderate structural (S), heavy non-structural (NS).
D4 [3.5-4.5]	Very Heavy	Heavy structural, very heavy non-structural (NS)
D5 [4.5-5.0]	Destruction	Very heavy structural (S), total or nearly collapse

The physical damage values (mean damage grade) for FF seismic motions with actual building designs ranged from 1.345 to 3.021 on the intensity measure (IM of VIII), which is well known as the Ranau seismic event, with a mean value of 2.496. Where, 4 buildings (13%) were categorised into "slight" damage of structural and non-structural elements and 10 buildings (33%) were categorised into "slight" structural damage and "moderate" non-structural damages, while 16 buildings (54%) were categorised into "moderate" structural damage and "heavy" non-structural damage.

As for the NF seismic motions, during the same intensity level (VIII), the damage grade range of the selected buildings was more vulnerable and higher by 20%, as compared to FF seismic motions. It ranged between 2.034 and 4.186, with a mean value of 3.096. Meanwhile, 4 buildings (13%) were categorised into "slight" damage of structural elements and "moderate" damage of the non-structural elements, and two buildings (6%) were categorised into "heavy" structural damage and "very heavy" non-structural damage, as well as 24 buildings (81%) categorised into "moderate" structural damage to "heavy" non-structural damage.

Therefore, the mean total damage for the 30 existing RC-buildings were categorised into "substantial to heavy damage" whereby in the damage description, structural elements suffered moderate susceptibility and very heavy losses to non-structural elements for FF and NF.

As the intensity increased to Level IX, the damage grades for FF seismic motions ranged from 3.70 to 4.670 with a mean value of 4.440. However, it ranged between 4.240 and 4.950 with a mean value of 4.650 for NF seismic motions. This implied that the expected damage for the 30 buildings elevated to 'heavy damage' category for the structural components and 'very heavy' damage in the non-structural components for both FF and NF seismic motions. Table 8 displays the number and percentage of buildings for the actual design of the building under various damages and intensities.

Table 8 – Number and proportion of buildings with different damage grades under different intensities for the FF and NF seismic motions with actual building design.

Macroseismic Intensity	Slight	Moderate		Substantial to Heavy		Very Heavy	
	Slight (S and NS)	Slight (S)	Moderate (NS)	Moderate (S)	Heavy (NS)	Heavy (S)	Very Heavy (NS)
VIII-FF	4 (13%)	10 (33%)		16 (54%)		0	
IX-FF	0	0		0		30(100%)	
VIII-NF	0	4 (33%)		24 (81%)		2(6%)	
IX-NF	0	0		0		30(100%)	

10

However, once the ERD concept was utilised it helped to improve seismic resistance and reduce damage deficiency appearance on the structure for both moderate-ERD and high-ERD classes of both seismic motions. Meanwhile, if the system is planned and constructed to be intermediate and moderately resistant, the ERD effect efficiently improves the seismic performance at the moderate intensity Level (VIII), which is not highly effective as the high-ERD during the high intensity Level (IX). Table 9 and Table 10 present the number and proportion of buildings under different damage states and intensities for moderate-ERD and high-ERD vulnerability classes, respectively.

Table 9 – Number and proportion of buildings with different damage grades under different intensities for the FF seismic motions with Moderate-ERD class.

Macroseismic Intensity	Slight	Moderate		Substantial to Heavy		Very Heavy	
	Slight (S and NS)	Slight (S)	Moderate (NS)	Moderate (S)	Heavy (NS)	Heavy (S)	Very Heavy (NS)
VIII-FF	11 (37%)	19 (63%)		0		0	
IX-FF	0	0		6(20%)		24(80%)	
VIII-NF	6(20%)	16 (53%)		8 (27%)		0	
IX-NF	0	0		0		30(100%)	

Table 10 – Number and proportion of buildings with different damage grades under different intensities for the FF seismic motions with High-ERD class.

Macroseismic Intensity	None	Slight	Moderate		Substantial to Heavy		Very Heavy	
	No Damage	Slight (S and NS)	Slight (S)	Moderate (NS)	Moderate (S)	Heavy (NS)	Heavy (S)	Very Heavy (NS)
VIII-FF	29(97%)	1 (3%)	0		0		0	
IX-FF	1(3%)	20(67%)	8(27%)		1(3%)		0	
VIII-NF	0	22(74%)	7 (23%)		1 (3%)		0	
IX-NF	0	6(20%)	18(60%)		5(17%)		1 (3%)	

7. Conclusion

Based on the analysis results, the following conclusions were drawn,

1. The Epi-central distance does not have a direct impact on the SVI value since the building is categorised under Far-Field (FF) and Near-Field (NF) ground motions as well as being in the red class whereby it shows its harm effect when the mean damage grade is investigated at different intensity measures for near-field scenario.

2. The seismic design regulations (ERD in selected buildings) have contributed immensely by providing significant enhancement to building resistance performance. This is due to reduction in the damage grade achieved as compared to the actual building damage related to mean SVI values. Therefore, when the seismic intensity is at Level VIII for both seismic scenarios, the ERD effect contributes towards improving seismic resistance and reduces the appearance of damage in the structure of both moderate-ERD and high-ERD classes. Although the ERD effect efficiently enhances seismic performance at moderate intensity Level (VIII), when the system is designed and built to be intermediately and moderately resistant, as well as not extremely effective, it often includes high-ERD at the high intensity Level (IX).

3. Another finding is the integration of Geographical Information System (GIS) as a 3D mapping tool to map different seismic scenarios and intensities which can interpret the present study on a large scale. This is a major form of assistance for authorities responsible for the rehabilitation of existing

11

buildings, including cultural heritage buildings to develop a database that concerns pre-earthquake assessments.

8. Acknowledgment

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