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Correlation between Seismic Intensity Measures and Building Response using Strong Earthquake Records in Korea

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1. Introduction

Seismic intensity measures (SIMs) can be used for representing the damage potential of an earthquake. The acceleration, velocity, and displacement time-histories of earthquake motions can be obtained from earthquake accelerogram, whereas other SIMs need to be derived by an analysis of the seismic acceleration time histories.

Recently, strong earthquakes occurred in the southeastern part of the Korean Peninsula: the 2016 Gyeongju earthquakes of magnitudes 5.8 and 5.1, and the 2017 Pohang earthquake of magnitude 5.4. Since the ground motions recorded from those earthquakes contain high frequency content compared to design ground motions, it is necessary to re-evaluate the correlation between SIMs and damage of structures. Actually, the mean spectral acceleration for recent earthquake records is greater than that of the design spectrum at a high frequency range of greater than around 10 Hz [1].

In this study, correlation coefficients are evaluated to represent the effect of SIMs on structural response (maximum displacement, maximum inter-story drift, and maximum acceleration at the floor) using current earthquake records.

2. Seismic Intensity Measures

The following SIMs are considered in this study: peak-based, duration-based, and frequency-response based measures [2,3,4]. The peak-based measures include peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), and the ratio PGA_{max}/PGV_{max} (Peak A/V). The duration-based measures include Arias' Intensity (ARIAS) and cumulative absolute velocity (CAV). The frequency-response based measures include the spectral intensities of Housner (SI_H), effective peak acceleration (EPA), and spectral acceleration (SA). For input motions, twelve time history records, which were observed in the 2016 Gyeongju earthquakes and the 2017 Pohang earthquake, were used. Tables I and II show the selected seismic excitations and the seismic intensity measures for all seismic excitations, respectively.

Table I: Input ground motions

No.	Earthquake	Mag.	Date	Station	Component
1	Gyeongju	5.1	2016.09.12	MKL	HGE
2	Gyeongju	5.1	2016.09.12	MKL	HGN
3	Gyeongju	5.1	2016.09.12	USN	HGE
4	Gyeongju	5.1	2016.09.12	USN	HGN
5	Gyeongju	5.8	2016.09.12	MKL	HGE
6	Gyeongju	5.8	2016.09.12	MKL	HGN
7	Gyeongju	5.8	2016.09.12	USN	HGE
8	Gyeongju	5.8	2016.09.12	USN	HGN
9	Gyeongju	5.8	2016.09.12	DAU	HGE
10	Gyeongju	5.8	2016.09.12	DAU	HGN
11	Pohang	5.4	2017.11.15	PHA2	HGE
12	Pohang	5.4	2017.11.15	PHA2	HGN

Table II: SIMs for input ground motions

EQ No.	PGA (g)	PGV (m/s)	PGD (m)	Peak A/V (g/m/s)	ARIAS (m/s)	CAV (g-s)	SI_H (m)	EPA (g)	SA (g)
1	0.152	0.033	0.004	4.575	0.048	0.130	0.104	0.031	0.166
2	0.152	0.029	0.004	5.274	0.054	0.118	0.108	0.037	0.371
3	0.357	0.057	0.035	6.266	0.211	0.269	0.174	0.054	0.537
4	0.415	0.072	0.127	5.794	0.278	0.301	0.164	0.062	1.039
5	0.346	0.086	0.007	4.039	0.239	0.272	0.225	0.065	0.407
6	0.275	0.076	0.009	3.608	0.179	0.234	0.284	0.072	0.518
7	0.412	0.118	0.037	3.498	0.670	0.493	0.383	0.129	1.194
8	0.431	0.094	0.175	4.604	0.645	0.518	0.215	0.078	0.870
9	0.179	0.020	0.002	8.770	0.151	0.408	0.055	0.014	0.092
10	0.270	0.032	0.005	8.521	0.296	0.546	0.105	0.023	0.135
11	0.244	0.083	0.019	2.935	0.124	0.188	0.316	0.058	0.334
12	0.274	0.126	0.031	2.185	0.191	0.241	0.539	0.074	0.347

3. Seismic Responses

A dynamic analysis of an auxiliary building for all input ground motions was conducted. The auxiliary building was represented using a stick model. The fundamental natural period of the building was 0.16 s. The maximum displacement at EL+172′ and inter-story drift between EL+156′ and EL+172′, and maximum floor acceleration at EL+156′ are presented in Table III.

Table III: Seismic responses

EQ No.	Max. Disp. (cm)	Max. Story-Drift, ×E-05	Max. Floor Acceleration (g)
1	0.110	5.063	0.169
2	0.225	7.688	0.346
3	0.345	11.063	0.563
4	0.585	20.500	0.883
5	0.291	11.375	0.558
6	0.351	11.188	0.592
7	0.757	24.625	1.069
8	0.552	19.313	0.900
9	0.062	3.880	0.188
10	0.105	5.375	0.282
11	0.261	9.563	0.429
12	0.266	8.500	0.409

4. Correlation between Seismic Intensity Measures and Responses

In this study, two correlation coefficients are calculated. The first one is the correlation coefficient after Pearson

[5], which shows how well the data fit a linear relationship. The second one is the rank correlation coefficient after Spearman [5], which shows how well the data agree with monotonic ranking.

4.1 Pearson Correlation Coefficient

The Pearson's correlation coefficient (PCC) between two variables, X and Y, is given by

$$\rho_P = \frac{\sum_{i=1}^{N}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i-\bar{X})^2\sum_{i=1}^{N}(Y_i-\bar{Y})^2}}, \qquad (1)$$

where $\bar{X}$ and $\bar{Y}$ are the mean values of X_i and Y_i data, respectively, and N is the number of pairs of values (X,Y) in the data.

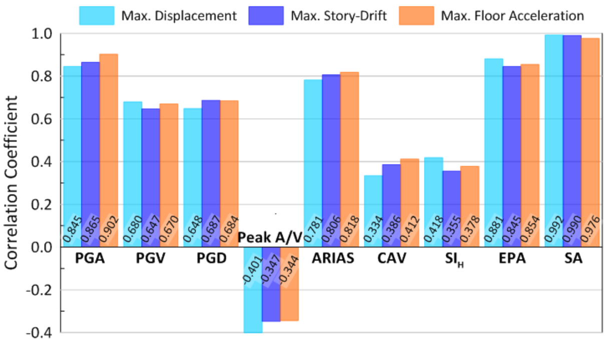

Fig. 1. PCC for different SIMs.

Fig. 1 shows PCCs between all SIMs and the seismic response of the auxiliary building. The maximum displacement has a very strong correlation to SA, EPA, and PGA, whereas a weak correlation occurs with respect to CAV and Peak A/V. Both the maximum inter-story drift and the maximum floor acceleration have a very strong correlation to SA, PGA, EPA, and ARIAS, whereas a weak correlation occurs with respect to Peak A/V and SI_H. This is due to high-frequency earthquakes. A negative correlation was found between Peak A/V and seismic responses.

4.2 Spearman Rank Correlation Coefficient

The Spearman's rank correlation coefficient (SRCC) between two variables, X and Y, is given by

$$\rho_S = 1 - \frac{6\sum_{i=1}^{N}D^2}{N(N^2-1)}, \qquad (2)$$

where *D* denotes the differences between the ranks of corresponding values of X and Y, and N is the number of pairs of values (X,Y) in the data.

Fig. 2 shows SRCCs between all SIMs and the seismic response of the auxiliary building. The maximum displacement has a very strong correlation to SA, PGD, PGA, and EPA, whereas a weak correlation occurs with respect to CAV and Peak A/V. Both the maximum inter-story drift and the maximum floor acceleration have a very strong correlation to SA, PGA, PGD, and EPA, whereas a weak correlation occurs with respect to CAV and Peak A/V. In addition, Peak A/V has a negative correlation with seismic responses.

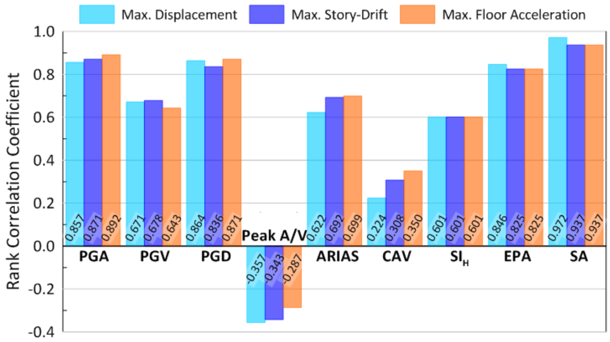

Fig. 2. SRCC for different SIMs.

5. Conclusions

The correlations between SIMs and the seismic response of the auxiliary building have been evaluated using current strong earthquake records. SIMs that have the strongest correlations with structural responses include SA, PGA, and EPA. On the other hand, SIMs that have the weakest correlations include Peak A/V and CAV. The best intensity measure for Korean earthquake ground motions is SA. PGA is a good intensity measure for hazard and fragility analyses.

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