Correlation between intensity measure parameters of ground motion earthquakes and structural response of moment resisting steel frames

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Abstract

Identify and select a suitable ground motion intensity measure (IMs) parameters associated with the structural response to specific levels of damages or collapse in structures are very important in the seismic response of structural analyses. This paper investigated the correlation between 25 intensity measure (IMs) parameters of earthquakes and the structural response parameters of 3-, 6- and 12-story moment resisting steel frames (MRSFs). Nonlinear time history analyses are performed for these frames under near- and far-source ground motion records. The maximum story drift ratio (MSDR), the roof drift ratio (RDR), and the maximum base shear force (SF) are chosen as the structural response parameters. The Pearson correlation coefficient with the regression analyses is utilized to display the correlation between the structural response parameter and the ground motion IMs parameters. The results reveal that MSDR appears to be a suitable engineering demand parameter to correlate with most of the ground motion IMs parameters compared to both the RDR and the SF parameters. Also, Max. Incremental velocity (MIV) parameter is considered as the highest correlated IMs parameters with MSDR in both near- and far-source earthquakes.

Keywords: Intensity measure parameters, seismic response of structures, Near-source, Far-source, nonlinear time history analysis

1.0 INTRODUCTION

The main objective of the seismic engineering design is to achieve the life safety and prevent the collapse of the structure. However, until now, the risk of structural failure has not been identified. Determining the risk of collapsing structures depend on their behavior and the site of seismic hazard. The seismic hazard levels are described by using ground motion IMs parameters while the structure behavior is defined by the nonlinear time history analysis. So, it is important to identify and select a suitable ground motion IMs parameter associated with the structural response to design and evaluate the performance of new and existing structures, especially in the active seismic zones. Once the perfect IMs is selected, then the performance of the structures can be evaluated by determining their exposure to specific levels of damages or to collapse.

The correlation between ground motion IMs and seismic structural response parameters has been investigated by many researchers. Markis and Black, (2004) indicating that in both linear and nonlinear structural responses the peak pulse acceleration IM is more demonstrative than the peak pulse velocity for near-fault earthquakes. Riddell (2007) investigated the correlations between 23 ground motion intensity indices with response variables. These variables are elastic, inelastic deformation demands, hysteretic energy, and input energy. The results indicated that the PGA, PGV, and PGD demonstrated an excellent correlation in elastic and inelastic response variables. Also, the best index correlated in the velocity region with both spectral ordinates and energy responses is the Housner’s intensity.
The relating between magnitude and epicentral distance earthquake parameters with damage prediction equation is proposed by Hancock et al. (2008). Yang et al. (2009) studied the relationship between different IMs of near-fault ground motion records and the maximum inelastic displacements of a SDOF structure. The results indicated that the peak ground acceleration (PGA) is the best IM parameter for systems of short-period. Also, peak ground velocity (PGV) and peak ground displacement (PGD) are the particular ground motion IMs parameters for systems of medium and long-period. Perrault and Guéguen (2015) studied the relationship between building response and IMs, such as PGA, PGV, Sd, and CAV. Different types and heights of steel and RC building structures are used in the analysis. The normalized relative roof displacement is considered as the predictability of building response. Also, an empirical model for damage prediction equation based on IMs is proposed. Habibi and Jami (2016) determined the relationship between IM parameters of far-field earthquakes and the target displacement ($T_0$) of 3- and 9-story steel frames. The analysis indicated that HI, SA, SV, and PGV exhibit the strongest correlated while PGA is the weakest correlated parameter with $T_0$.

Shokrabadi and Burton (2017) evaluated the effect of ground motion IMs (PGA, Sa (T1), Savg and Sa) in predicting story drift ratio, peak floor acceleration, and residual story drift ratio for two types of rocking building systems. 37 records of near- and far-field ground motions are used in this study. Savg is the most real parameter for expecting transient and residual drift demands while PGA is the best predictor parameter of peak floor accelerations. Kenari and Celikag (2019) evaluated the correlation between different IMs parameters of ground motion and damage parameters in 3-, 5-, 8- and 12-story steel structures. Ordinary (OSR) and pulse-like seismic records (PLSR) earthquake ground motions with the Open SEES program are used in nonlinear time history analysis. The analysis shows that EPV, VSI, and HI have the highest correlation with the MIDR in both OSR and PLSR category. Esfahania and Aghakouchak (2020) investigated the effect of intensity levels of near- and far-fault ground motion on the seismic behavior of two moment resisting steel frames. The roof displacement and inter-story drift are used as seismic demands. These results indicated that the story drifts of near-fault motions in the lower story levels are larger than that for far-fault records. Pinzon et al. (2020) investigated the correlation between IMs of forty pairs of strong ground motion from the Italian database and the MSDR of 3-, 7- and 13-story steel structures. The results indicate that the worst correlation is between PGA and MIDR show. PGV, root-mean-square velocity, and specific energy density intensity-based measures are the higher correlation.

Previous studies are depending on a limit of IMs parameters and did not consider the effect of building heights. This study investigated the correlation between different IMs parameters of near- and far-source ground motions with structural response parameters of 3-, 6- and 12-story MRSFs. The IMs parameters that consider in this study such as peak ground acceleration (PGA), velocity (PGV), displacement (PGD), PGA/PGV ratio, arias intensity (Ia), Housner intensity (HI), cumulative absolute velocity (CAV), A95 parameter, The predominant period ($T_{pa}$), the mean period ($T_{m}$), the number of effective cycles ($N_{ef}$), The damage index (DI), the impulsivity index (IP), the average spectral acceleration (SAavg). The structural response parameters were expressed in terms of the MSDR, RDR, and SF as recommended by Jayaram (2010).

### 2.0 STRONG MOTION DATABASE AND INTENSITY MEASUREMENT PARAMETERS

Near- and far-source ground motion records identified by FEMA P695 (2009) are used in this study. FEMA P695 (2009) took near-source ground motion records for source to site distance less or equal 10 km and far-source for greater than 10 km. The site source distances are given in several different measures such as epicentral, the closest to plane, Campbell, and Joyner-Boore distance. The average of Campbell and Joyner-Boore fault distances was taken as the source to site distance in the PEER NGA database. These ground motions are consisting of 49 acceleration records (each with two horizontal components) with a variety of characteristics. The characteristics of near-field records are the moment magnitudes (M6.5 - M7.9), the average of Campbell and Boore-Joyner fault distances, (1.7-8.8 km), and site class (B, C, and D) as shown in table 1. For far-field records, the moment magnitudes (M6.5 - M7.6), the average of Campbell and Boore-Joyner fault distances, (11.1-26.4 km), site class (C and D) are shown in table 2. The references and definitions of 25 IMs seismic parameters are presented in Table 3, which are used in this study. These parameters are determined by Seism Signal 2018 software (2018).

<table>
<thead>
<tr>
<th>NO</th>
<th>Event</th>
<th>Year</th>
<th>Station Name</th>
<th>M</th>
<th>Component</th>
<th>PGA [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Imperial Valley-06</td>
<td>1979</td>
<td>El_Centro_Array #6</td>
<td>6.5</td>
<td>140 230</td>
<td>0.41 0.44</td>
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<tr>
<td>2</td>
<td>Imperial Valley-06</td>
<td>1979</td>
<td>El_Centro_Array #7</td>
<td>6.5</td>
<td>140 230</td>
<td>0.34 0.46</td>
</tr>
<tr>
<td>3</td>
<td>Irpinia-Italy-01</td>
<td>1980</td>
<td>Storno</td>
<td>6.9</td>
<td>270 230</td>
<td>0.25 0.36</td>
</tr>
<tr>
<td>4</td>
<td>Superstition Hills-02</td>
<td>1987</td>
<td>Parachute Test Site</td>
<td>6.5</td>
<td>225 315</td>
<td>0.46 0.38</td>
</tr>
<tr>
<td>5</td>
<td>Loma Prieta</td>
<td>1989</td>
<td>Saratoga Aloha</td>
<td>6.9</td>
<td>90 90</td>
<td>0.51 0.32</td>
</tr>
<tr>
<td>6</td>
<td>Erzincan, Turkey</td>
<td>1992</td>
<td>Erzincan</td>
<td>6.7</td>
<td>EW NS</td>
<td>0.52 0.59</td>
</tr>
<tr>
<td>7</td>
<td>Cape Mendocino</td>
<td>1992</td>
<td>Petrolia</td>
<td>7</td>
<td>0 90</td>
<td>0.66 0.59</td>
</tr>
<tr>
<td>No.</td>
<td>Event</td>
<td>Year</td>
<td>Station Name</td>
<td>M</td>
<td>Component</td>
<td>PGA (g)</td>
</tr>
<tr>
<td>-----</td>
<td>-------------</td>
<td>-------</td>
<td>-----------------------</td>
<td>-----</td>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>1</td>
<td>Northridge</td>
<td>1994</td>
<td>Beverly Hills-Mulhol</td>
<td>6.7</td>
<td>9</td>
<td>0.27</td>
</tr>
<tr>
<td>2</td>
<td>Northridge</td>
<td>1994</td>
<td>Canyon Country-WLC</td>
<td>6.7</td>
<td>0</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>Duzce, Turkey</td>
<td>1999</td>
<td>Bolu</td>
<td>7.1</td>
<td>90</td>
<td>0.46</td>
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<tr>
<td>4</td>
<td>Hector Mine</td>
<td>1999</td>
<td>Hector</td>
<td>7.1</td>
<td>90</td>
<td>0.29</td>
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<td>5</td>
<td>Imperial Valley</td>
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<td>Delta</td>
<td>6.5</td>
<td>140</td>
<td>0.31</td>
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<td>6</td>
<td>Imperial Valley</td>
<td>1979</td>
<td>ElCentro Array #11</td>
<td>6.5</td>
<td>140</td>
<td>0.37</td>
</tr>
<tr>
<td>7</td>
<td>Kobe, Japan</td>
<td>1995</td>
<td>Nishi-Akashi</td>
<td>6.9</td>
<td>90</td>
<td>0.53</td>
</tr>
<tr>
<td>8</td>
<td>Kobe, Japan</td>
<td>1995</td>
<td>Shin-Osaka</td>
<td>6.9</td>
<td>90</td>
<td>0.52</td>
</tr>
<tr>
<td>9</td>
<td>Kocaeli, Turkey</td>
<td>1999</td>
<td>Duzce</td>
<td>7.5</td>
<td>90</td>
<td>0.30</td>
</tr>
<tr>
<td>10</td>
<td>Kocaeli, Turkey</td>
<td>1999</td>
<td>Arcelik</td>
<td>7.5</td>
<td>90</td>
<td>0.20</td>
</tr>
<tr>
<td>11</td>
<td>Landers</td>
<td>1992</td>
<td>Yermo Fire</td>
<td>7.3</td>
<td>270</td>
<td>0.24</td>
</tr>
<tr>
<td>12</td>
<td>Landers</td>
<td>1992</td>
<td>Cool water</td>
<td>7.3</td>
<td>LN</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Table 2: Far-source earthquake records
The parameters (IMs) of ground motions are:

<table>
<thead>
<tr>
<th>No.</th>
<th>Intensity Measure Parameters</th>
<th>Formulation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Peak ground acceleration (PGA)</td>
<td>$PGA = \max</td>
<td>a(t)</td>
</tr>
<tr>
<td>2</td>
<td>Peak ground velocity (PGV)</td>
<td>$PGV = \max</td>
<td>v(t)</td>
</tr>
<tr>
<td>3</td>
<td>Peak ground displacement (PGD)</td>
<td>$PGD = \max</td>
<td>d(t)</td>
</tr>
<tr>
<td>4</td>
<td>PGA/PGV ratio</td>
<td>-</td>
<td>Dobry, 1978</td>
</tr>
<tr>
<td>5</td>
<td>Root-Mean-Square of Acceleration RMS (g)</td>
<td>$a_{rms} = \sqrt{\frac{1}{t_a} \int_0^{t_a} a(t)^2 dt}$</td>
<td>Kramer, 1996</td>
</tr>
<tr>
<td>6</td>
<td>Root-Mean-Square of velocity RMS (cm)</td>
<td>$v_{rms} = \sqrt{\frac{1}{t_a} \int_0^{t_a} v(t)^2 dt}$</td>
<td>Kramer, 1996</td>
</tr>
<tr>
<td>7</td>
<td>Root-Mean-Square of velocity RMS (cm)</td>
<td>$d_{rms} = \sqrt{\frac{1}{t_a} \int_0^{t_a} d(t)^2 dt}$</td>
<td>Kramer, 1996</td>
</tr>
<tr>
<td>8</td>
<td>Arias density ($I_a$)</td>
<td>$I_a = \frac{\pi}{2} \int_0^{t_a} a(t)^2 dt$</td>
<td>Arrias, 1970</td>
</tr>
<tr>
<td>9</td>
<td>Characteristic intensity ($I_c$)</td>
<td>$I_c = \frac{(a_{rms})^{2/5}}{T_0} \sqrt{\frac{1}{T_0}}$</td>
<td>Kramer SL., 1996</td>
</tr>
<tr>
<td>10</td>
<td>Specific energy density (SED)</td>
<td>$SED = \int_0^{t_a} v(t)^2 dt$</td>
<td>Kramer SL., 1996</td>
</tr>
<tr>
<td>11</td>
<td>The cumulative absolute velocity (CAV)</td>
<td>$CAV = \frac{1}{0.5} \int_0^{t_a} a(t) dt$</td>
<td>EPRI, 1988</td>
</tr>
<tr>
<td>12</td>
<td>Acceleration spectrum intensity: (ASI)</td>
<td>$ASI = \int_{0.25}^{0.5} S_a(\varepsilon = 0.05, t) dt$</td>
<td>Housner, 1952</td>
</tr>
<tr>
<td>13</td>
<td>Velocity spectrum intensity (VSI)</td>
<td>$VSI = \int_{0.25}^{0.5} S_v(\varepsilon = 0.05, t) dt$</td>
<td>Housner, 1952</td>
</tr>
<tr>
<td>14</td>
<td>Housner intensity (HI)</td>
<td>$HI = \int_{0.25}^{0.5} S_a(\varepsilon = 0.05, t) dt$</td>
<td>Housner, 1952</td>
</tr>
<tr>
<td>15</td>
<td>Sustained maximum acceleration (SMA): (g)</td>
<td>The third highest absolute value of acceleration/velocity in the time-history</td>
<td>Nuttli, 1979</td>
</tr>
<tr>
<td>16</td>
<td>Sustained maximum velocity (SMV): cm/sec</td>
<td>-</td>
<td>Nuttli, 1979</td>
</tr>
<tr>
<td>17</td>
<td>Effective peak acceleration (EPA)</td>
<td>$EPA = \frac{\text{mean } (a_{rms}^{0.5} \varepsilon = 0.05)}{V}$</td>
<td>Nuttli, 1979</td>
</tr>
<tr>
<td>18</td>
<td>$\alpha_m$ parameter</td>
<td>The level of acceleration that has up to 95% of the arias intensity</td>
<td>Miramada, 1993</td>
</tr>
<tr>
<td>19</td>
<td>The predominant period (T_p)</td>
<td>$T_p = 0.5 \int_{0.25}^{0.5} T_0 d(t)$</td>
<td>Rathje et al., 1998</td>
</tr>
<tr>
<td>20</td>
<td>The mean period (T_m)</td>
<td>$T_m = \frac{\sum C_i^2 / f_i}{\sum C_i^2}$</td>
<td>Rathje et al., 1998</td>
</tr>
<tr>
<td>21</td>
<td>Max. incremental velocity (MIV)</td>
<td>The maximum area under the acceleration curves between two zero crossings of the accelerogram.</td>
<td>Rathje et al., 1998</td>
</tr>
</tbody>
</table>

Table 3: The intensity measure parameters (IMs) of ground motions.
3.0 CHARACTERISTICS OF MOMENT-RESISTING STEEL FRAMES

The correlation between the ground motions IMs parameters with structural response parameters was measured using 3-, 6- and 12-story MRSFs. These frames are designed with PGAs equal to 0.125g according to the seismicity region of these frames which are located in Alexandria, Egypt. The design spectrum of soil type "C" for dense or medium dense sand soil was used. In all structures, the floor plan has 3-bays with 8.0 m in each direction; the first story height is 4.6 m and 3.6 m for the upper stories, as shown in Figure 1 to Figure 4. The dead and live loads on all floors are 5 KPa and 2.5 KPa, respectively. These frames are designed according to ECP-201 (2012) and ECP-205 (2008) for strong column-weak beam requirements with ductility reduction factor and drift ratio equal to 7 and 0.75%, respectively. Wide flange sections of steel members are selected from the ASTM (1985) with yield stress and modulus of elasticity of steel equal to 345 MPa and 200 GPa, respectively. The strain hardening ratio is equal to 1%. The exterior columns sizes are not the same as the sizes of the interior column at every floor level. Beams have the same section on the same floor level. The rigid connections between beam and columns are taken for all buildings. Panel zone strength, lateral-torsional buckling strength, slenderness ratios, and other design code requests for members have been applied. The details of cross-sections of the 3-, 6- and 12-story MRSFs are summarized in Table 4.

The Drain-2dx program (1992) is used in the analysis of the three frames under nonlinear time history analysis. 49 acceleration records of near- and far-source ground motion records identified by FEMA P695 (2009) without scaling are used in this study. The beams and columns of frames are modeled using the fiber beam-column element (type 15). This element is divided into segments without presenting further degrees of freedom and then each segment is divided into fibers. For each fiber, the stress-strain curve for concrete and steel type should be defined. Also, the shape function of the element is changed with changing the state of these elements without adding extra nodes or elements as indicated by Prakash and Powell (1992). The 3% viscous damping was taken in the first two natural modes of these frames.

![Figure 1 Elevation of the 3-story MRSF](image1)

![Figure 2 Elevation of the 6-story MRSF](image2)

![Figure 3 Elevation of the 12-story MRSF](image3)

![Figure 4 Plan of the three buildings](image4)
### 4.0 INTENSITY MEASURES VERSUS STRUCTURAL RESPONSE CORRELATION

The correlation between the ground motion IMs and the structure performance parameters are computed with the Pearson correlation coefficient as:

\[
\rho = \frac{\sum_{i=1}^{N}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i - \bar{X})^2 \sum_{i=1}^{N}(Y_i - \bar{Y})^2}}
\]  

In which \(X\) and \(Y\) are the mean values of \(X_i\) and \(Y_i\) respectively, and \(N\) is the number of pairs of values \((X_i, Y_i)\) in the data. The range of this factor is between -1 and 1. Nonlinear time history analysis for 3-, 6- and 12-story MRSFs are performed under near- and far-source ground motion records identified by FEMA P695 [9]. After that, the regression analyses are used to present the correlation between structural response parameters and IMs parameters through the following sections.

#### 4.1 Correlation Between Structural Response Parameters

The Pearson correlation coefficients between structural response parameters for 3-, 6- and 12-story MRSFs are determined as indicated in Table 5. For near-source records, the correlation between MSDR and RDR is a moderate correlation with SF in 3- and 6-story frames and strong correlation in the 12-story frame. By far-source records, the correlation between the MSDR and RDR is a strong correlation with SF in all frames. Also, the correlation between the MSDR and RDR is strong in all frames for both near- and far-source earthquakes. This outcome can be referring to the fact that both MSDR and RDR are established based on the displacement requirement.

#### 4.2 Correlation Between Earthquake Intensity Measures And Structural Response

Figure 5 presents the absolute values of correlation coefficients between the MSDR and IMs of near- and far-source earthquakes in the 3-story MRSF. In near-source earthquakes, MIV has the best correlation with MSDR, followed by PGV, \(V_{rms}\), HI, VSI, and \(S_{avg}\); whereas the weakest correlated IMs are DI, TS, SMA, \(N_{avg}\), CAV, and \(I_0\). By far-source earthquakes, VSI and HI are the strongest correlated parameters, followed by \(S_{avg}\), MIV, PGV, and \(a_{rms}\); whereas the remnant IMs parameters are weakest correlated with MSDR. Also, it can be seen that the highest correlation coefficients between the MSDR and most of seismic IMs parameters by far-source records that are more than near-source records.

#### Table 4 Cross-section details of the 3-, 6- and 12-story MRSFs.

<table>
<thead>
<tr>
<th>Story</th>
<th>Beams</th>
<th>Exterior column</th>
<th>Interior column</th>
<th>Story</th>
<th>Beams</th>
<th>Exterior column</th>
<th>Interior column</th>
</tr>
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<tr>
<td>1</td>
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<td>W14x61</td>
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<td>1</td>
<td>W30x108</td>
<td>W14x257</td>
<td>W14x311</td>
</tr>
<tr>
<td>2</td>
<td>W18x40</td>
<td>W14x38</td>
<td>W14x109</td>
<td>2</td>
<td>W30x108</td>
<td>W14x193</td>
<td>W14x311</td>
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<tr>
<td>3</td>
<td>W18x35</td>
<td>W14x53</td>
<td>W14x109</td>
<td>3</td>
<td>W30x99</td>
<td>W14x193</td>
<td>W14x257</td>
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</tbody>
</table>

#### Table 5 Correlation coefficients among structural response parameters

<table>
<thead>
<tr>
<th>Frames</th>
<th>Near-source</th>
<th>Far-source</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>SF</td>
<td>RDR</td>
</tr>
<tr>
<td>3-story</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>RDR</td>
<td>0.63</td>
<td>1.00</td>
</tr>
<tr>
<td>MSDR</td>
<td>0.63</td>
<td>0.99</td>
</tr>
<tr>
<td>SF</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>6-story</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>RDR</td>
<td>0.60</td>
<td>1.00</td>
</tr>
<tr>
<td>MSDR</td>
<td>0.56</td>
<td>0.92</td>
</tr>
<tr>
<td>SF</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>12-story</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>RDR</td>
<td>0.86</td>
<td>1.00</td>
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<tr>
<td>MSDR</td>
<td>0.75</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Figure 5 presents the correlation coefficients between the RDR and IMs of near- and far-source earthquakes in the 3-story MRSF. In near-source earthquakes, MIV has the best correlation with RDR, followed by PGV and $V_{rms}$. Meanwhile, the poor correlation IMs are DI, SMA, $T_p$, CAV, and $I_a$. By far-source earthquakes, HI has the best correlation with RDR, followed by VSI, $S_{avg}$, and MIV. Meanwhile, the lowest correlation IMs are $PGA/PGV$, $I_p$, SED, DI, and CAV. Also, it can be seen that the highest correlation coefficients between the RDR and most of seismic IMs parameters by near-source records that are more than far-source records.

Figure 6 presents the absolute values of correlation coefficients between the RDR and IMs of near- and far-source earthquakes in the 3-story MRSF. In near-source earthquakes, $MIV$ has the best correlation with RDR, followed by PGV and $V_{rms}$. Meanwhile, the poor correlation IMs are DI, SMA, $T_p$, CAV, and $I_a$. By far-source earthquakes, HI has the best correlation with RDR, followed by VSI, $S_{avg}$, and MIV. Meanwhile, the lowest correlation IMs are $PGA/PGV$, $I_p$, SED, DI, and CAV. Also, it can be seen that the highest correlation coefficients between the RDR and most of seismic IMs parameters by near-source records that are more than far-source records.

Figure 7 presents the absolute values of correlation coefficients between the SF and IMs of near- and far-source earthquakes in the 3-story MRSF. In near-source earthquakes, the correlation between the SF and the ground motion IMs parameters are weak correlations. While in far-source earthquakes, HI has the best correlation with SF, followed by VSI and $S_{avg}$; whereas the remnant IMs parameters are the weakest correlated with SF. Also, the highest correlation coefficients between the SF and most of seismic IMs parameters by near-source records are more than those by far-source records.
Correlation coefficients between SF and IMs of near- and far-source for the 3-story MRSF

Figure 8 presents the absolute values of correlation coefficients between the MSDR and ground motions IMs parameters of near- and far-source earthquakes for the 6-story MRSF. In near-source earthquakes, MIV has the best correlation with MSDR, followed by PGV, $V_{rms}$, HI, and Ip; whereas the weakest correlated IMs are SMA, $I_a$, $d_{rms}$, DI, CAV, and PGA. By far-source earthquakes, $S_{a,avg}$, HI, and VSI are the strongest correlated parameters; whereas the weakest correlated IMs are $T_m$, Ncy, PGA/PGV, $V_{rms}$, and SED. Also, it can be seen that the highest correlation coefficients between the MSDR and most of seismic IMs parameters by far-source records that are more than near-source records.

Correlation coefficients between MSDR and IMs of near- and far-source for the 6-story MRSF

Figure 9 presents the absolute values of correlation coefficients between the RDR and IMs of near- and far-source earthquakes for the 6-story MRSF. In near-source earthquakes, $V_{rms}$ has the best-correlated parameter, followed by MIV, PGV, and IP. Meanwhile, the poor correlation IMs are $I_a$, PGA, $I_c$, CAV, ASI, SMA, and $A_{95}$. By far-source earthquakes, HI and $S_{a,avg}$ are the strongest correlated parameters, followed by VSI and CAV. Meanwhile, the lowest correlation IMs are EDA, PGA, ASI, PGD, and $d_{rms}$. Also, it can be seen that the highest correlation coefficients between the RDR and most of the seismic IMs parameters by near-source records that are more than far-source records.
Figure 9 presents the absolute values of correlation coefficients between the SF and IMs of near- and far-source earthquakes for the 6-story MRSF. In near-source earthquakes, the correlation between the SF and the ground motion IMs parameters are weak correlations except for the IP parameter. By far-source earthquakes, HI is the strongest correlated parameter followed by $S_{\text{avg}}$, VSI, SMV, and $I_a$; whereas the remnant IMs parameters are the weakest correlated with SF. Also, it can be seen that the highest correlation coefficients between the SF and most of seismic IMs parameters by far-source records are more than those in near-source records.

Figure 11 presents the absolute values of Pearson correlation coefficients between the MSDR and IMs of near- and far-source earthquakes in the 12-story MRSF. In near-source earthquakes, MIV has the best correlation with MSDR, followed by PGV, IP, and $V_{\text{rms}}$; whereas the weakest correlated IMs are $d_{\text{rms}}$, CAV, DI, PGA, and $I_a$. By far-source earthquakes, $S_{\text{avg}}$ is the strongest correlated parameters followed by HI, VSI, and MIV; whereas the weakest correlated IMs parameters are $N_{\text{cy}}$, Tm, PGA/PGV, and SED. Also, it can be seen that the highest correlation coefficients between the MSDR and most of seismic IMs parameters by far-source records are more than those in near-source records.
Figure 11 presents the absolute values of correlation coefficients between the RDR and IMs of near- and far-source earthquakes in the 12-story MRSF. In near-source earthquakes, $V_{\text{rms}}$ has the best-correlated parameter, followed by MIV, PGV, $T_{\text{m}}$, and $I_P$. Meanwhile, the poor correlation IMs are PGA, $A_{95}$, $I_c$, ASI, $I_a$, CAV, arms, and EDA. By far-source earthquakes, $S_a,\text{avg}$ is the strongest correlated parameters, followed by HI, VSI, and MIV. Meanwhile, the lowest correlation IMs are $N_{cy}$, $T_{\text{m}}$, PGA/PGV, and SED. Also, it can be seen that the highest correlation coefficients between the RDR and most of seismic IMs parameters by far-source records that are more than near-source records.

Figure 12 presents the absolute values of correlation coefficients between the RDR and IMs of near- and far-source earthquakes in the 12-story MRSF. In near-source earthquakes, $V_{\text{rms}}$ has the best-correlated parameter, followed by MIV, PGV, $T_{\text{m}}$, and $I_P$. Meanwhile, the poor correlation IMs are PGA, $A_{95}$, $I_c$, ASI, $I_a$, CAV, arms, and EDA. By far-source earthquakes, $S_a,\text{avg}$ is the strongest correlated with SF, followed by HI and VSI; whereas the remnant IMs parameters are weakest correlated with SF. Also, it can be seen that the highest correlation coefficients between the SF and most of seismic IMs parameters by near-source records are more than those in far-source records.

Figure 13 presents the absolute values of correlation coefficients between, the SF and IMs of near- and far-source earthquakes in the 12-story MRSF. In near-source earthquakes, IP has the best-correlated parameter, followed by $V_{\text{rms}}$, PGV, MIV, $T_{\text{m}}$, and PGA/PGV. The remnant IMs parameters are the weakest correlated parameters with SF. By far-source earthquakes, $S_a,\text{avg}$ has the best correlation with SF, followed by HI and VSI; whereas the remnant IMs parameters are weakest correlated with SF. Also, it can be seen that the highest correlation coefficients between the SF and most of seismic IMs parameters by near-source records are more than those in far-source records.
Figure 13: Correlation coefficients between SF and IM of near- and far-source for the 12-story MRSF

Table 6: Correlation coefficients between IMs and structural response parameter of 3-story MRSF

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Table 7: Correlation coefficients between IMs and structural response parameter of 6-story MRSF

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<td>RDR</td>
<td>SF</td>
<td>MSDR</td>
<td>RDR</td>
<td>SF</td>
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<tr>
<td>PGA</td>
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<td>0.329</td>
<td>0.011</td>
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<td>PGA/PGV</td>
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<td>0.140</td>
<td>-0.185</td>
<td>-0.049</td>
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<tr>
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<td>0.102</td>
<td>0.005</td>
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<td>0.212</td>
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<td>0.461</td>
<td>0.343</td>
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Tables 6, 7, and Table 8 present the Pearson correlation coefficients between the structural response parameter and IMs of near- and far-source earthquakes in the 3-, 6- and 12-story MRSFs. Based on the observation of these tables, it can be found that in general, the MSDR is the best-correlated parameter with most of seismic IMs parameters than RDR and SF. Also, SF is the weakest correlated parameter with most of seismic IMs parameters. These results are consistent with the results obtained by Jayaram (2010).

Also, among all of the MRSFs, the correlation values of MSDR parameters with SMV are the highest range of correlation values with 6-story MRSF. While in far-source, the correlation value of MSDR parameters with SMV is the highest range of correlation values with 6-story MRSF. Also, among all of the MRSFs, the correlation between RDR and MIV is the highest range of the correlation value with 3-story MRSF. While in far-source, the correlation values of MSDR parameters with HI is the highest range of the correlation value with 6-story MRSF. Also, among all of the MRSFs, the correlation values of SF parameters with IP are the highest range of correlation values with 12-story MRSF. While in far-source, the correlation values of MSDR parameters with Sa, avg is the highest range of correlation values with 6-story MRSF. Also, among all of the MRSFs, the MIV parameter is considered as the highest correlated IMs parameters of near- and far-source earthquakes with MRSF. While the poorly correlated ground motion IMs parameters are Nv, Tp, and darc. In the three MRSFs, there is not much difference in Pearson coefficients between the structural response parameters and IMs of near- and far-source earthquakes. Thus it can be concluded that the results aren’t correlated to the frame heights and they can be advanced for all the MRSFs.

5.0 CONCLUSIONS

The present study has investigated the correlation between 25 IMs parameters of near- and far-source of earthquakes and the seismic response parameter of 3-, 6- and 12-story
MRFs. The seismic response parameter was expressed in terms of the MSDR, RDR, and SF. Based on an estimation of the correlation coefficients, the following conclusions can be drawn:

The maximum story drift ratio appears to be a suitable engineering demand parameter to correlate with most of seismic IMs parameters compared to the roof drift ratio and the maximum base shear force.

1. The maximum base shear force is the weakest correlated parameter with most of seismic IMs parameters compared to the roof drift ratio and the maximum story drift ratio.

2. For near-source earthquakes, MIV, PGV, \(V_{\text{MSH}}\), HI, VSI, and \(S_{\text{AVG}}\) are considered as the highest correlated IMs parameters with both MSDR and RDR.

3. For far-source earthquakes, \(S_{\text{AVG}}\), HI, VSI, and MIV are considered as the highest correlated IMs parameters with both MSDR and RDR.

4. In both near- and far-source earthquakes, the maximum incremental velocity (MIV) parameter is considered as the highest correlated IMs parameters with MSDR. Also, the number of effective cycles \((N_{\text{e}})\) is considered as the weakest correlated IMs parameters.

5. The correlation between the structural response parameters and IMs of near- and far-source earthquakes are not correlated to the frame heights.

6. The results of the analysis provide suitable evidence on how intensity measure parameters of ground motion earthquakes and structural response affect the safety levels of seismic design of buildings.

References


