Comparative study of the simulation ground motion by amplitude scale and spectral matching

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Abstract. Dynamic analysis is more accurate than static analysis in determining a response of structure due to earthquake loads. The limitation of this analysis is the lack of recorded ground motion data of an earthquake for the entire territory of Indonesia. Therefore, according to the Indonesian Code, it is permitted to use seismic data from other locations that have similar seismic characteristics. In application, ground motions need to be modified to match the Indonesia design code. There are two modification methods, which are amplitude scaling and spectral matching. Thus, the purpose of this study is to determine the reliability of these two methods. As the result, the response spectra of the ground motion modified by the spectral matching method present a similar pattern to the target response spectra compared to the amplitude scaling method. Ground motions modified by the spectral matching method generate Peak Ground Acceleration (PGA) values almost the same as the target PGA values. In contrast, the modified motions with amplitude scaling provide diverse PGA values that are not the same as the target PGA. From this study, the utilization of the spectral matching method is recommended in modifying ground motion data for dynamic analysis.

1 Introduction

Earthquake loads on buildings are the loads generated by ground motions during an earthquake. This force can affect the structure and cause damage and even collapse. In the event of an earthquake, the building is allowed to suffer damage but not collapse so that people inside the building can get out safely.

Time history analysis is a way to determine the dynamic response of a structure by using the past occurrence of earthquakes. SNI 1726:2019 provides analytical procedures for designing earthquake loads. To carry out the analysis required a minimum of 5 pairs of earthquake records \[1\]. Time history earthquake data for earthquake events in Indonesia is difficult to obtain, unlike earthquake data in other countries such as Japan, the United States, and many other countries. The earthquake data can be used in Indonesia by modifying it to suit conditions in Indonesia. According to SNI 8899:2020, the process of modifying ground motion can be carried out by the method of amplitude scaling and spectral matching \[2\]. In this study, the differences between these two methods will be examined.

2 Methodology

2.1 Numerical modeling

Case studies were conducted to carry out a comparative analysis of modifications to earthquake data. The structural model used is a moment-bearing frame structure consisting of 10 floors, as shown in Figure 1 below.

Fig. 1. Structural model.

The layout of the structure consists of 4 spans in the x direction and also in the y direction, as shown in Figure 2. Each span has a typical span length. The total span in the
The y direction of 20 meters is greater than the whole span in the x direction of 16 meters.

The structure is made of reinforced concrete with a concrete quality of 30 MPa and a reinforcement quality of 420 MPa. More detailed specifications of the case studies used can be seen in Table 1.

![Structure layout](image)

**Fig. 2.** The structure layout.

**Table 1.** Structure properties data.

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Location</td>
<td>Pekanbaru</td>
</tr>
<tr>
<td>Structure System</td>
<td>Moment frame</td>
</tr>
<tr>
<td>Type of soil</td>
<td>Soft Soil</td>
</tr>
<tr>
<td>Number of storey</td>
<td>10 storey</td>
</tr>
<tr>
<td>Typical story height</td>
<td>5m</td>
</tr>
<tr>
<td>Beam</td>
<td>30/45 cm</td>
</tr>
<tr>
<td>Column</td>
<td>55/55 cm</td>
</tr>
<tr>
<td>Plate</td>
<td>10 cm</td>
</tr>
<tr>
<td>Concrete compressive strength</td>
<td>30 MPa</td>
</tr>
<tr>
<td>Rebar yield strength</td>
<td>420 MPa</td>
</tr>
</tbody>
</table>

### 2.2 Spectral response

#### 2.2.1 Spectral response target

The target of response spectra is determined based on the design response spectra in accordance with the Indonesian Code (SNI 1726:2019). The general procedure to obtain the design response spectrum is initially by obtaining ground motion parameters at short period $S_s$ and $S_1$ from the maximum consideration earthquake (MCE) ground motion maps for bedrock with a critical damping ratio of 5% in Indonesia. The following procedure is to classify soil conditions at the site to modify the bedrock response spectrum for non-rock areas. The amplification factors, $F_a$, $F_v$, to modify the bedrock response to a response of certain soil conditions follow the provisions of the code. Calculation of the adjusted MCE spectral response parameters $S_{ms}$ and $S_{m1}$, and finally, we get the design response spectra parameters $S_{d0}$ and $S_{d1}$.

The spectrum response parameters, $S_s$ and $S_1$, for Pekanbaru city in Riau province of Indonesia can be seen in Figure 3. We got $S_s$ of 0.463 g and $S_1$ of 0.337 g. Based on the dominant soil conditions found in Pekanbaru, this case study takes site class D. Parameters are classified in category D. This indicates that the building must be designed with tighter detailing. The whole spectral response parameters are described in Table 2.

![Spectral response parameter](image)

**Fig. 3.** The spectral response parameter of the MCER earthquake acceleration.

**Table 2.** Spectral response parameter.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectra at short period ($S_s$)</td>
<td>0.463 g</td>
</tr>
<tr>
<td>Spectra at 1 sec. ($S_1$)</td>
<td>0.337 g</td>
</tr>
<tr>
<td>Amplification acceleration ($F_a$)</td>
<td>1.805</td>
</tr>
<tr>
<td>Amplification velocity ($F_v$)</td>
<td>2.652</td>
</tr>
<tr>
<td>Design spectra at short period ($S_{d0}$)</td>
<td>0.577 g</td>
</tr>
<tr>
<td>Design spectra at 1 sec. ($S_{d1}$)</td>
<td>0.596 g</td>
</tr>
<tr>
<td>Initial period ($T_0$)</td>
<td>0.214 second</td>
</tr>
<tr>
<td>Short period ($T_s$)</td>
<td>1.070 second</td>
</tr>
<tr>
<td>Long period ($T_L$)</td>
<td>20 second</td>
</tr>
</tbody>
</table>

The acceleration response for Pekanbaru city according to Indonesia code can be seen in Figure 4, where maximum response at constant acceleration of 0.577 g.

![Acceleration response](image)

**Fig. 4.** Acceleration response for Pekanbaru city in accordance with SNI 1726:2019.

#### 2.2.2 Earthquake Data

Seven earthquake data are used in this research. Earthquake data is taken from the PEER ground motion database managed by the Pacific Earthquake Engineering Research Center (PEER) [3]. The selection of earthquake data is based on the magnitude and duration of the earthquake and the source of the earthquake. The
magnitude of the earthquake was selected in the range of 6 to 8 due to the strong earthquake category. The distance between the earthquake source and the station location is also considered. The distance is taken from earthquake sources that are less than 60 km from the station. The selected earthquake data are listed in Table 3. The time history graph of this earthquake data is shown in Figure 5.

![Fig. 5. Time history of the earthquake acceleration.](image)

Table 3. Selected earthquake data.

<table>
<thead>
<tr>
<th>Earthquake (sta.)</th>
<th>Mag.</th>
<th>Dist. (km)</th>
<th>Vs30 (m/s)</th>
<th>PGA (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Centro (Array #9) 1940</td>
<td>6.95</td>
<td>6.09</td>
<td>213.4</td>
<td>EW 0.281</td>
</tr>
<tr>
<td>Kern County (Taft) 1952</td>
<td>7.36</td>
<td>38.89</td>
<td>385.4</td>
<td>EW 0.042</td>
</tr>
<tr>
<td>Kobe, Japan (Takatori) 1955</td>
<td>6.90</td>
<td>1.47</td>
<td>256.0</td>
<td>EW 0.348</td>
</tr>
<tr>
<td>Chi-Chi, Taiwan (CHY080) 1999</td>
<td>7.62</td>
<td>2.69</td>
<td>496.2</td>
<td>EW 0.809</td>
</tr>
<tr>
<td>Loma Prieta (LGPC) 1989</td>
<td>6.93</td>
<td>3.88</td>
<td>594.8</td>
<td>EW 0.563</td>
</tr>
<tr>
<td>Sanfernando (Castaic) 1971</td>
<td>6.61</td>
<td>22.63</td>
<td>450.2</td>
<td>EW 0.225</td>
</tr>
<tr>
<td>Irpinia Italy (STN) 1980</td>
<td>6.90</td>
<td>10.84</td>
<td>382.0</td>
<td>EW 0.027</td>
</tr>
</tbody>
</table>

2.3 Modification of ground motion

Any ground motion to be used in dynamic analysis must be scaled to match or even exceed the target response spectra [1, 2]. Modification of the ground motion can be done with the Amplitude scaled method and the spectral matching method. Seven pairs of earthquake time history data, as shown in Figure 5, will be modified in two methods in this study.

2.3.1 Amplitude scaled

Modification of ground motion begins with selecting the ground motion data recorded to be scaled. The selected ground motion data is then used to calculate the structural response for a single degree of freedom (SDOF) with a wide variety of natural periods. The structural response employed is the acceleration response referred to in the study as the original spectral response.

The following step is to determine the period range to be scaled. The period range corresponds to the vibration period that predominantly contributes to the dynamic response of the structure also known as the fundamental period. The upper limit of the period is greater than or 2.0 times the period and should not be less than 1.5 times. The lower limit period should not exceed 20% of the period. In this study, the period range applied is 0.2T to 1.5T [4-6].

The subsequent step is to calculate the scale factor. The scale factor is calculated for the dominant period range using the following formula:

\[ SF = \frac{\sum_{i=1}^{n} A_i \cdot A_j}{\sum_{i=1}^{n} A_i^2} \]  

\[ (1) \]
in which:

\( A_t = \) Amplitude of the spectral response target

\( A_j = \) Amplitude of the original spectral response

The results of the spectral response after being modified by the amplitude scale method can be seen in Figure 6. As shown in Figure 6, it can be seen that there is an adjustment of the maximum response due to scaling. This adjustment can increase or decrease the maximum response depending on the peak ground acceleration (PGA). The Irpinia earthquake data, as shown in Figure 5(m) and 5(n), produce an amplification of the maximum response after scaling.

![Fig. 6. Spectral response of ElCentro (EW) with Amplitude scaled.](image)

The scale factor will be multiplied by the acceleration value of the time history data from the first to the last second. Figure 7 shows the ground motion data after multiplying by the scale factor. There was an increase in the PGA from 0.281 g before scaling to 0.291 after scaling.

![Fig. 7. ElCentro (EW) ground motion with Amplitude scaled.](image)

### 2.3.2 Spectral matching

Spectra matching is a more complex method than amplitude scaling. This method not only depends on the Amplitude adjusted to the earthquake intensity but also considers the frequency or period spectra of the target response spectrum. The fast Fourier transform (FFT) is utilized to help analyze the frequency components of the ground motion [7, 8].

The modification procedure is initiated by selecting the original ground motion to be adjusted and defining the required parameters, such as the number of iterations, damping value, and target response spectra. The original ground motion is scaled so that the peak ground acceleration (PGA) corresponds to the target response spectra multiplied by a defined scale factor. This is a crucial step to get a good initial estimate of the adjusted spectra, as the actual motion intensity can be very different from the spectra design and, therefore, requires a higher number of iterations for convergence. Fourier transform is performed to convert the response spectra into ground motion data in time series. The Fourier transform of the ground motion is defined as:

\[
\tilde{u}_g(\omega) = \int_{-\infty}^{\infty} u_g(t) \cdot e^{-i\omega t} \, dt
\]

The results of the spectral response after modified by spectral matching method can be seen in Figure 8. In Figure 8, it can be seen that the modified spectral response with spectral matching is almost close to the target spectral from the initial period to the longer period. The maximum acceleration response after scaling is at 0.596 g. This is very different from the previous Figure 6.

![Fig. 8. Spectral response of ElCentro (EW) with spectral matching.](image)

When the modification spectral response is converted into the form of a time series using FFT, the ground motion graph is obtained, as shown in Figure 9. The PGA value found is smaller than the PGA value in Figure 7 earlier, which was 0.203 g.
3 Research results

3.1 Spectral response

The response of the earthquake spectra can be affected by the different characteristics of the frequency and Amplitude. High-frequency data tend to have a different spectral response than low-frequency. Spectral responses for all earthquake data are presented in Figure 10. Compared with the target response spectra, it can be seen that the response spectra from the Chichi, Loma, and Kobe earthquakes produce responses that are higher than the target response spectra of Indonesian, while the other data are lower.

The amplitude scaling of the whole ground motion data can be seen in Figure 11. The spectral response of each ground motion data generated has deviations that are away from the target response spectra, as in the short period area in the range of 0.0 to 1.0 seconds. At periods greater than 1.0 seconds, the original response spectra will follow the target response spectra pattern.

Furthermore, the modification with the spectral matching method for all ground motions is shown in Figure 12. Unlike the previous method, all spectral responses are close to the target spectral.

3.2 PGA comparison

The PGA values of all modified ground motions data both with the method of amplitude scale and spectral matching, have been presented in Table 4.
Table 4. Comparison of PGA values.

<table>
<thead>
<tr>
<th>Earthquake (sta.)</th>
<th>PGA (g)</th>
<th>Original</th>
<th>Amplitude Scaled</th>
<th>Spectral Matching</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Centro (Array #9) E</td>
<td>0.28</td>
<td>0.290</td>
<td>0.203</td>
<td></td>
</tr>
<tr>
<td>Kern County (Taft) E W</td>
<td>0.04</td>
<td>1.317</td>
<td>0.235</td>
<td></td>
</tr>
<tr>
<td>Kobe, Japan (Takatori) E W</td>
<td>0.34</td>
<td>0.169</td>
<td>0.250</td>
<td></td>
</tr>
<tr>
<td>Chi-Chi, Taiwan (CHY080) E W</td>
<td>0.80</td>
<td>0.085</td>
<td>0.240</td>
<td></td>
</tr>
<tr>
<td>Loma Prieta (LGPC) E W</td>
<td>0.56</td>
<td>0.106</td>
<td>0.215</td>
<td></td>
</tr>
<tr>
<td>Sanfernando (Castaic) E W</td>
<td>0.22</td>
<td>0.389</td>
<td>0.260</td>
<td></td>
</tr>
<tr>
<td>Irpinia Italy (STN) E W</td>
<td>0.02</td>
<td>2.993</td>
<td>0.271</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Intensity Arias

The Intensity Arias (IA) of the modified ground motion can show the magnitude of ground motion calculated based on the modifications that have been made to the data. Therefore, one of the requirements for the modified ground motion results to be accepted and declared accurate is when the arias intensity of the original and modified time history data are quite similar.

Fig. 13. Comparison of PGA value after modification.

Figure 13 shows the comparison of the original PGA with the results of modification with scaled Amplitude and spectral matching. It can be seen that the spectral matching method produces PGA values that are closer to the target PGA value of Pekanbaru.

Pekanbaru has a PGA value of 0.219, while the spectral matching method using Loma and Kern earthquake data has a PGA value closest to the Pekanbaru PGA of 0.215 g and 0.203 g, respectively. While in the PGA amplitude scaling method, the closest to the target are the ElCentro and Kobe earthquakes of 0.169 g and 0.290 g.
Fig. 14. Comparison of Intensity Arias.

Figure 14 shows the intensity arias of the ground motion data. It can be seen that the spectral matching method is more similar to the intensity arias of the original time history. This indicates that the nonstationary characteristics of the original ground motion are not interfered with by the modification method.

3.4 Case study analysis

3.4.1 Structure displacement

A case study was conducted of the dynamic analysis using three dynamic load, first the original ground motion, then the dynamic load modified by Amplitude scaled and the modified spectral matching. The displacement that occurs is then observed [9, 10].

As shown in Figures 15 and 16, The spectral matching method has a smaller displacement than the level displacement using the original earthquake time history data. The spectral matching method has a lower level of displacement than the displacement of using the original ground motions. In contrast, the results of the analysis using the amplitude scale method produce larger displacements. This occurs because the ground motion modification process changes the PGA value where the PGA value of the modified amplitude scale is greater than the original PGA.

3.4.2 Story drift

Story drift is an important parameter to observe in assessing the structure response to lateral loads. Figures 17 and 18 show the story drift for each elevation. The largest story drift using the original ground motion occurs at elevation 30 m (6th story). Elevation 25 m (5th story) has the most significant story drift using the spectral matching method but when using the amplitude scaling method the largest story drift occurs at elevation 15 m (3rd story).

Fig. 15. Displacement in x-direction.

Fig. 16. Displacement in y-direction.

Fig. 17. Story drift in x-direction.

Fig. 18. Story drift in y-direction.
### 3.4.3 Story shear

The base shear indicates the magnitude of the earthquake-induced lateral load that occurs at the base of a structure. This shear force will be distributed to each story proportional to the inter-story stiffness, also known as story shear. The story shear can be affected by the height of floors, the distance between columns, and the type of infill wall. The greater the inter-story drift, the greater the shear story.

Figures 19 and 20 show the story shear. The base shear force in the x-direction, due to ElCentro (EW), is 5000 kN due to the original ground motion. The amount of base shear decreased due to ground motion modification, which amounted to 4300 kN due to amplitude scale and 4100 kN due to spectral matching.

On the other hand, the base shear force in the y-direction, ElCentro (NS), amounted to 4500 kN, and due to the modification of ground motions, an increase occurred. The story shear value that occurs is similar to the base shear force pattern.

![Fig. 19. Story shear in x-direction.](image1)

![Fig. 20. Story shear in y-direction.](image2)

### 4 Conclusion

In this study, ground motion data modification in accordance with the spectral response target comply with the Indonesian code is presented. A comparative study was conducted in this research to compare the amplitude scale modification and spectral matching methods. Seven pairs of earthquake records, East-West (EW) and North-South (NS) were utilized. Later, the results of ground motion modification are applied to a case study with a 10-story model located in Pekanbaru to see the consequences. The conclusions of this study include:

1. The response spectra of the ground motion data modified by the spectral matching method present a similar pattern to the target response spectra compared to the amplitude scaling method.
2. Ground motions modified by the spectral matching method for the whole earthquake data generate PGA values that are almost the same as the target PGA values. In contrast, the modified motions with amplitude scaling provide diverse PGA values that are not the same as the target PGA.
3. The application of ground motion data in dynamic analysis produces various structural responses such as displacement, story drift and story shear. From this study, the utilization of the spectral matching method is recommended in modifying ground motion data for dynamic analysis.

### References