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Original article

Impact of artificially seismic loading on the response of building structure in various site classifications

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ABSTRACT

The lack of local ground motion records has led to a direct adoption of El Centro accelerogram in time history technique as the most reliable method to observe structural responses. Program based simulations with respect to the provision of Indonesian standard were engaged to obtain artificial seismic accelerations for each site classification. Time history technique is utilized to analyze and compare the response of a dual system structure against seismic loadings in terms of maximum story displacement, base reaction, pier moment, story acceleration and story shear.

Spectral matching process using Etabs yields better average spectral curves than using Seismomatch. This, however, relies upon the scaling method and number of iterations. Structural analysis results show that the artificial records of Lacc North, Friuli, Petrolia and Trinidad create extreme story displacement and story acceleration for site class B, C, D and E in that order. Artificial load of Friuli, Lucerne and Sylmarf yield the largest base reactions whereas maximum story shear is caused by the artificial ground motion of Chichi, Laccnorth, Petrolia and Trinidad for the ordered site classes. The average displacement at the top story of matched accelerogram or site B is 50% below the displacement by the original El Centro record while for site C the displacement reduces 10% and remains stabled in site D but increases 7% in site E. The base reaction falls about 20%–30% in site B, C and D and rises 14% in site E. Pier moment due to matched records decreases up to 6% as compared to the influence of reference record in all sites while story acceleration experienced 17% increase in site B. The artificial time history records adversely affect on the story shear response up to 51% higher than El Centro record. The result of F.TEST shows 77% difference between both techniques. The selection of correct, appropriate and sufficient ground motion records may produce ideal artificial accelerations and it is, therefore, profound to select such records since the possible difference may affect the final design of the building structure using linear time history analysis.

1. Introduction

Building structures with extreme characteristics such as vertical and horizontal irregularity were commonly analyzed using static equivalent or response spectrum method since these approaches cannot exactly demonstrate the non-linear behavior of real ground motions. Time history method tends to be the most appropriate and accurate technique to estimate structure response due to dynamically linear and non-linear seismic loadings (Huang, 2014). Time history analysis requires earthquake acceleration records of proposed structure location. Despite the advantages of using original seismic records, structural designers often deal with the lack of sufficient strong motion records to meet the seismic provision (Fahjan and Ozdemir, 2008). Indonesian standard, SNI 1726:2012 requires the minimum of five records of horizontal ground motions with specific seismic aspects to perform time history analysis (BSN, 2012). However, local earthquake records with such characteristics may not be currently available and hence direct utilization of earthquake records with similar seismic characteristics such as El Centro and Kobe appears to be the only option for time history analysis.

Limits of local seismic data in Maumere, East Nusa Tenggara province struggling with 6.8-SR earthquake event in 1992 has led

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to the use of merely 1940 El Centro (North-South component, Peknold Version with 1500 data points at an equal spacing of 0.02 s) earthquake records in time history analysis. This condition reduces the comprehensiveness of dynamic time history analysis either linear or non-linear (Huang, 2014). Research into alternative methods to overcome the unavailability of seismic data has been turned towards the utilization of artificial earthquake records generated from a spectral matching process based on certain seismic code. ASCE 7-05 allows ground motion simulations whenever the required number of appropriate records is not available (Kalkan and Chopra, 2010). However, the process requires certain criteria to select appropriate ground motion records. A selected strong motion record has to include three records in orthogonal directions and should satisfy certain characteristic of peak ground acceleration, magnitude, velocity, distance, soil properties (Takhirov et al., 2005) as well as basin and directivity effect (Kalkan and Chopra, 2010). Site conditions play significant role on the ground motion behavior compared to other factors. Nevertheless, it remains important to use a closest to target spectrum accelerogram to ensure the initial time history characteristics and the speed of matching process either manually or by certain convergence software (Fahjan and Ozdemir, 2008). Numbers of spectral matching software (RSPMatch09, Seismosoft, ETABS and SIMQKE) are currently available and commonly used to generate artificial ground motion records (Katsanos, 2010). Although there is less confidence in capturing substantial features, such applications perform numerical simulations to generated artificial spectrum compatible accelerograms with respect to frequency or time domain method (Alatik and Abrahamson, 2010). Furthermore, spectrum matching does not seem to lead to significant bias in structural analysis results (Grant and Diaferia, 2012).

In Seismosoft, the target spectrum can be created by computing the spectrum of a specific accelerogram or by simply loading a user-defined spectrum. The user can combine many matched accelerograms in order to obtain a combined mean spectrum that fulfils the user's requirements regarding maximum and mean misfit (Seismosoft, 2016). The strong-motion parameters such as elastic response spectra, pseudo-spectra, overdamped response spectra, root-mean-square (RMS) of acceleration, velocity and displacement can be computed for the matched accelerograms. This software can be used in combination with records selection tools and records appropriateness verification algorithms to define adequate suites of records for non-linear dynamic analysis of new or existing structures (Hancock and Boomer, 2007). On the other hand, as structural analysis software, ETABS provides an integrated spectral matching tool to create artificial time history data although it has not as many features as Seismomatch that was developed specially for spectral matching purposes. ETABS also provides options to match spectrum response either by frequency or time domain method.

This study aims to perform time history matching simulation to generate artificial time history acceleration for dynamically linear time history analysis of particular structure in each site classification according to Indonesian seismic code. Moreover, this study observes and compares the structural response of a 10-story building structure in terms of maximum story displacement, base reaction, pier moment, story acceleration and story shear due to the matched seismic acceleration between original and artificial acceleration.

2. Methodology

2.1. Response spectrum

The proposed structure of this study locates in Maumere, East Nusa Tenggara, Indonesia . Seismic parameters were obtained from (PuskimPU, 2011) and calculated based on standard SNI 1726 (BSN, 2012) for four site classifications B, C, D and E as shown in Table 1. These parameters yield spectral response curves for each site class as shown in Fig. 1.

2.2. Ground motion records

There are three types of accelerogram: artificial, synthetic and real accelerogram (Fahjan, 2008) and in this study, earthquake records are extracted from the Pacific Earthquake Engineering Research Center (PEER:NGA database, 2013). SNI 1726 stipulates that selected time history records which consistently control ground motions should be scaled such that time history response is close to the designed structural spectrum response (BSN, 2012). Seismic acceleration records used in this simulation include 28 strong earthquake motion records extracted from PEER earthquake database website that match Flores earthquake characteristics as shown in Table 2. The seismic event was in December, 12th 1992 05:29:26 UTC with magnitude of 7.8 Mw, 27.7 km depth, Vs_{30} of 686 m/s, rough slip mechanism (USGS, 2014), fault length of 110 km, 35 km fault width, fault plane strike type, total duration of 70 s and average moment release of 7.75×10^{20} Nm (Beckers and Lay, 1995). The duration interval of selected records are corrected for data normalizing in the matching process using Seismomatch 2016. This software computes the difference and iterates each accelerogram to obtain best matching spectrums with respect to the target spectral (Seismosoft, 2016) for each site with a maximum difference of 15% and average maximum difference of 5%. Since matching accelerograms requires certain scaling method, this simulation adopts scaling technique integrating area under spectrum curve (Alatik and Abrahamson, 2010) such that the resulting spectral curve is not less than the target spectrum within the range from 0,2T to 1,5T. In comparison to Seismomatch, this simulation also uses Etabs for spectral matching although this application is merely available for a single record at one matching process adopting frequency domain method. The method modifies Fourier amplitude of a record based on the ratio of original spectral and simulated spectral with fixed phase (CSI, 2010). Spectral matching will yield 5 seismic acceleration records with best matching convergence for each site class. By obtaining these five records whose average spectral meet the requirement, the matched acceleration can be used to observe structural behavior with linear time history analysis.

2.3. Structural configuration, material property and loadings

Proposed structure in this study is a ten story 3D frame as shown in Fig. 2, story height of 3.5 m with the span of 5 m. Table 3a provides material property and dimension of columns, beams and shear walls. Applied loads include self-weight (SW), superimposed dead load (DL), live load (LL) as shown in Table 3b. Seismic loadings refer to Indonesian standard SNI 1726:2012 (BSN, 2012). The given notation for the static equivalent load is EQX, dynamic spectrum response load is RESPX and dynamic time history load is THX. The static equivalent analysis takes into account building weight and loads in Table 3b and it is assumed 30% live load applied to each story.

Table 4 shows load combinations for linear time history analysis due to five best matching accelerations. Several terms such as ms (matching Seismomatch), me (matching Etabs) and e (Etabs) are generated for ease nomenclature. In addition to that, the response of the 3D structure can be observed based on the highest or the extreme structural response since this study uses less than 7 records for each site class (ASCE, 2006).