Journal of King Saud University – Engineering Sciences 29 (2017) 302–312

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original article

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

Sandy I. Yansiku

Department of Civil Engineering Nusa Nipa University, Jln. Kesehatan No.3, Maumere, NTT Province 86111, Indonesia

ARTICLE INFO

Article history:
Received 25 February 2017
Accepted 4 June 2017
Available online 16 June 2017

Keywords:
Spectrum
Matching
Time history
Artificial
Response

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

---

E-mail address: sandyyansiku@yahoo.com

Peer review under responsibility of King Saud University.

http://dx.doi.org/10.1016/j.jksues.2017.06.002
1018-3639/© 2017 The Author. Production and hosting by Elsevier B.V. on behalf of King Saud University.

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).

Table 1
Spectral data for each site class.

Symbol	Site Classification			
	Rock B	Hard C	Medium D	Soft E
PGA (g)	0.446			
S_S (g)	0.993			
S_1 (g)	0.402			
CRS	1.092			
F_A	1.000	1.003	1.103	0.909
F_V	1.000	1.398	1.598	2.400
S_{MS} (g)	0.993	0.996	1.095	0.903
S_{M1} (g)	0.402	0.562	0.642	0.965
S_{DS} (g)	0.662	0.664	0.730	0.602
S_{D1} (g)	0.268	0.375	0.428	0.643
T_0 (s)	0.081	0.113	0.117	0.214
T_S (s)	0.405	0.564	0.587	1.069
R	8.0			
Risk Category	II			
I_e	1			
C_d	5.5			
	0.0466			
x	0.9			
h_n (m)	35			
C_u	1.4			
T_a	1.143			
Damping ratio	5%			
Seismic design category	D			

Note: Refer to Appendix A for notation information.

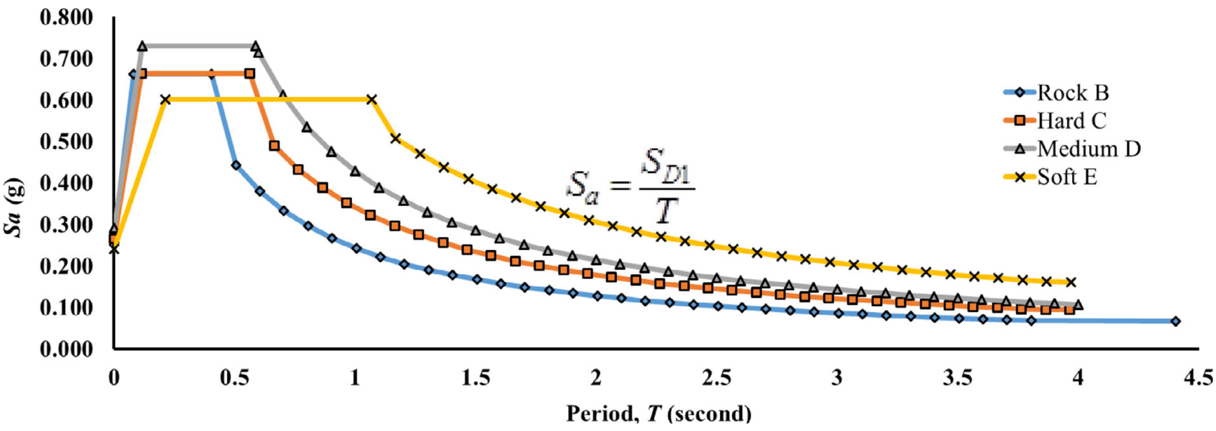


Fig. 1. Target spectral for each site class.

3. Results and discussion

3.1. Matching by seismomatch

Fig. 3 shows the simulation output of five acceleration records in the form of response spectrum curve and the target response spectrum for each site classification. Best matching convergence is shown in Table 5 as results of a certain number of iterations adopting method proposed by (Alatik and Abrahamson, 2010) until reaching the boundary condition and lowest difference. The average of these five spectrums is scaled by 1.15, which is the ratio of the area under spectrum curve between the matched and target spectrum along 0.2T to 1.5T. As can be seen, the red-dashed average spectrums are above the target spectrums along the specified range. As the matching spectrums have met the requirement, the adopted acceleration records can be used in dynamic time history analysis.

3.2. Matching by Etabs

The ASCE 7-05 does not require a certain scaling factor in terms of 3D analyses as long as the average spectrum of matched records is maintained over target spectrum (Kalkan and Chopra, 2010). Since Etabs only provide single matching process without an input of scale factor, the similar scale factors are inputted and calculated in a spreadsheet.

Fig. 4 depicts the matching results of this application of which the average matched spectrums have met the SNI 1726 provision along the important period. Table 6 shows the difference between target spectrums and scaled spectrums. The results, however, rely very much on scaling method. It can be seen in Fig. 5 that spectral matching using Etabs results in better average spectrums and closer to target spectrums than using Seismomatch. Although Seismomatch provides scaling input facility for the user to obtain certain convergence value, ETABS automatically iterates best scaling factor to match the target spectrum. It might be necessary for Seismomatch user to engage number of iterations and trial more scaling factors for better results.

In general, the matching process yields comparable structural responses to the original spectrum. Although the frequency domain method cannot describe time series character of a seismic event which possibly increases total energy of ground motions, the method in Etabs generates closer spectrum response than Seismomatch, which creates wavelets termed as time domain method.

Table 2
Original acceleration records.

No.	Event	Code	Duration (s)	Interval (s)	#Output
1	ChiChi	CHI	52.78	0.01	5278
2	Friuli	FRI	36.32	0.01	3632
3	Hollister	HOL	39.93	0.01	3993
4	Imperial Valley	IMV	39.48	0.01	3948
5	El CentroNS	ENS	31.18	0.02	1559
6	El CentroEW	EEW	31.08	0.01	3108
7	El CentroUP	EUP	53.78	0.02	2689
8	Kobe	KOB	40.90	0.01	4090
9	Kocaeli	KOC	34.96	0.01	3496
10	Lander	LAN	48.09	0.01	4809
11	Loma Prieta	LOM	39.90	0.01	3990
12	Northridge	NOR	39.88	0.01	3988
13	Trinidad	TRI	21.40	0.01	2140
14	Lucerne1	LU1	24.05	0.01	2405
15	LucerneZ	LUZ	24.05	0.01	2405
16	Lacc North2	LA2	29.98	0.01	2998
17	New Hall2	NH2	29.98	0.01	2998
18	SMonica2	SM2	29.98	0.01	2998
19	SMonicaZ	SM3	29.98	0.01	2998
20	Petrolia1	PE1	29.98	0.01	2998
21	Petrolia2	PE2	29.98	0.01	2998
22	PetroliaZ	PEZ	29.98	0.01	2998
23	Sylmarff1	SY1	29.98	0.01	2998
24	Sylmarff2	SY2	29.98	0.01	2998
25	SylmarffZ	SYZ	29.99	0.01	2999
26	Yermo1	YE2	39.98	0.01	3998
27	Yermo2	YE2	39.98	0.01	3998
28	YermoZ	YEZ	39.98	0.01	3998

Source: (PEER:NGA database, 2013).

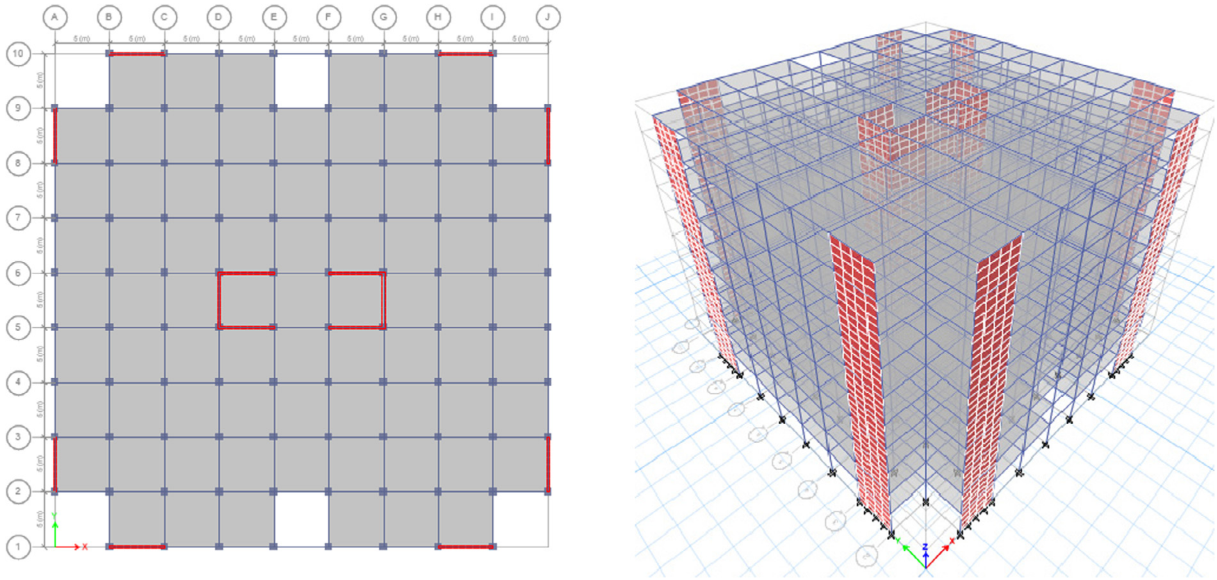


Fig. 2. Proposed 3D Structure model.

Table 3a
Material property.

Parameter	
Concrete strength, $f'c$	25 MPa
Concrete unit weight, γ_c	24 kN/m^3
Elastic modulus of concrete, E_c	23500 MPa
Poisson ratio	0,2
Beam B1 and B2	400 mm × 600 mm
Column K1	700 mm × 700 mm
Slab thickness	120 mm
Shear wall thickness	250 mm

Table 3b
Dead load and live load.

Load type	Unit
Dead load	
Beam self weight	24 kN/m^3
Slab weight	24 kN/m^3
Waterproofing 2 cm at roof	0.14 kN/m^2
Plafond	0.18 kN/m^2
Mechanical Electrical inst.	0.25 kN/m^2
Specie (2 cm)	0.21 kN/m^2
Tile (1 cm)	0.24 kN/m^2
Live load	
Roof	1 kN/m^2
Story 1–9	2.5 kN/m^2

Table 4
Load combinations.

Code	Load combinations	Matched Record	Site Class
046	1.3324DL + 1.3324SW + 1mECHIB + 1LL	Chichi	Rock B
047	1.3324DL + 1.3324SW + 1mEFRIB + 1LL	Friuli	
048	1.3324DL + 1.3324SW + 1mELOMB + 1LL	Loma Prieta	
049	1.3324DL + 1.3324SW + 1mELUCZB + 1LL	Lucerne	
050	1.3324DL + 1.3324SW + 1mELAC2B + 1LL	LaccNorth	
056	1.2536DL + 1.2536SW + 1mEFRIC + 1LL	Friuli	Hard C
057	1.2536DL + 1.2536SW + 1mELOMC + 1LL	Loma Prieta	
058	1.2536DL + 1.2536SW + 1mELAC2C + 1LL	LaccNorth	
059	1.2536DL + 1.2536SW + 1mENEWH2C + 2LL	New Hall	
060	1.2536DL + 1.2536SW + 1mELUCZC + 1LL	Lucerne	
066	1.2161DL + 1.2161SW + 1mECHID + 1LL	Chichi	Medium D
067	1.2161DL + 1.2161SW + 1mEMON2D + 1LL	St.Monica	
068	1.2161DL + 1.2161SW + 1mEMONZD + 1LL	St.Monica	
069	1.2161DL + 1.2161SW + 1mEPET1D + 1LL	Petrolia	
070	1.2161DL + 1.2161SW + 1mESYL1D + 1LL	Sylmarf	
076	1.2809DL + 1.2809SW + 1mEFRIE + 1LL	Friuli	Soft E
077	1.2809DL + 1.2809SW + 1mEKOCE + 1LL	Kocaeli	
078	1.2809DL + 1.2809SW + 1mETRINE + 1LL	Trinidad	
079	1.2809DL + 1.2809SW + 1mEPET2E + 1LL	Petrolia	
080	1.2809DL + 1.28096SW + 1mESYL1E + 1LL	Sylmarf	
091	1.3324DL + 1.3324SW + 1oriELCEN + 1LL	Elcentro	All classes

3.3. Structural response

Since the spectral matching process by Etabs yields better results than by Seismomatch, the matched spectrums in Table 2 are then used to generate new time history accelerograms for each site class with the match-to-target-response-spectrum tool in Etabs. These newly generated accelerograms are then utilized to analyze and observe the response of proposed structure based on the original El Centro accelerogram as the reference.

3.3.1. Maximum story displacement

Structural displacement relies on the structural height and slenderness since the higher and slenderer the structure the more flexible and more prone to the lateral load (Pauly and Priestley, 1992). In the comparison of the maximum displacement at the top story to the base due to the dynamic time history load for site class B in Fig. 6a, the displacement of the tenth story due to the matched ChiChi and Friuli records nearly unchanges while other records significantly differ the displacement of the top story relative to the base. It is interesting from this figure that the displacement characteristic of matched Laccnorth record is comparable to that of the original El Centro record. The maximum displacement at the top story by matched Chichi and Friuli records are 6 mm, while that by matched Loma Prieta record is 20 mm, LucerneZ is 16 mm and Laccnorth is 30 mm. Thus, the average displacement of matched accelerograms is 15.6 mm. The average is about 50% smaller than by the original El Centro accelerogram causing the top story displaces 30 mm. For site class C in Fig. 6b, the displacement patterns appear to be closely similar towards the positive direction. Laccnorth accelerogram yields higher displacement than the original El Centro records due to the lower soil strength of this site. Friuli record causes 30 mm displacement at top story while Loma Prieta, Lucerne, Laccnorth and New Hall records causes the

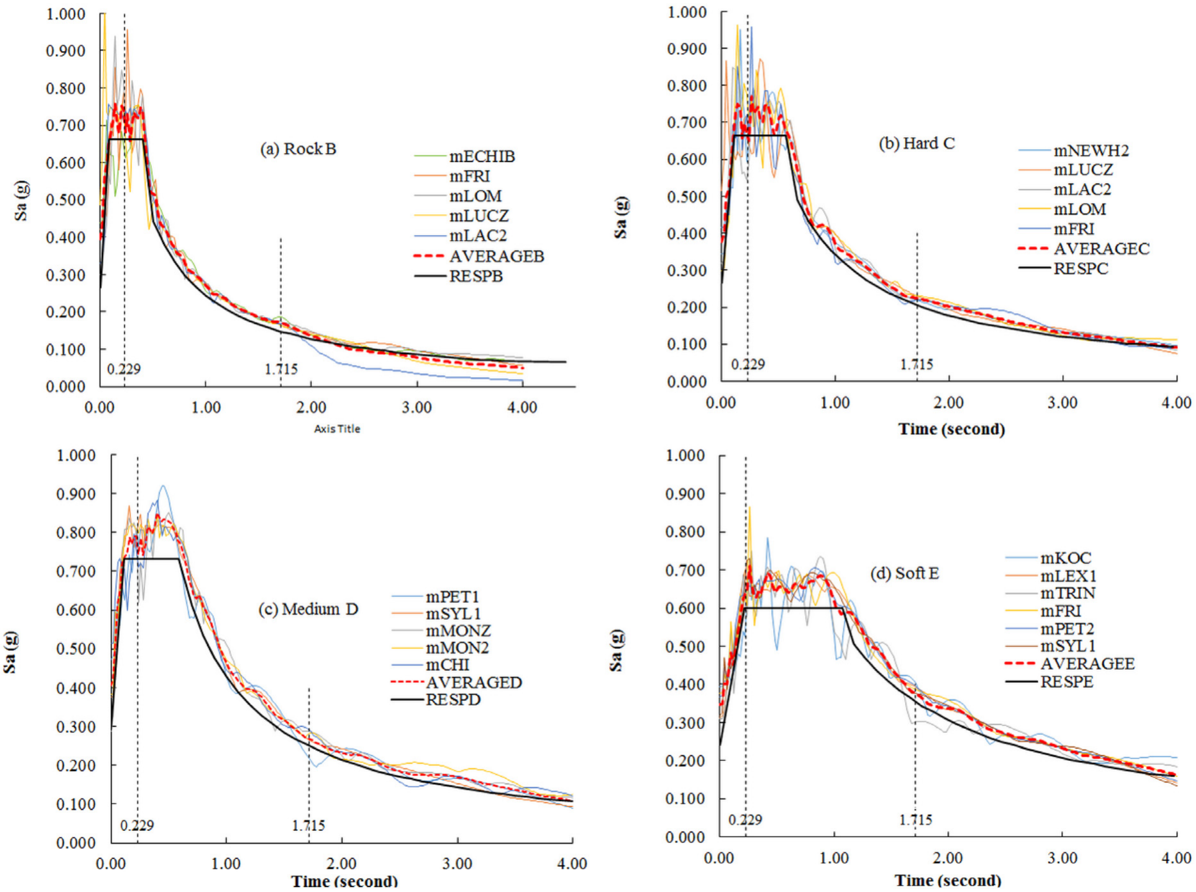


Fig. 3. Matched spectrums by Seismomatch.

Table 5
Convergence of matching by Seismomatch.

Target Spectrum of site	Convergence	#Iterations	Mean Spectrum	
			Ave. difference	Max. difference
Rock B	ChiChi	16	2.41%	12.73%
	Friuli	12		
	Loma Prieta	7		
	Lucerne1	11		
	LucerneZ	6		
	Lacc North2	8		
Hard C	Friuli	26	3.07%	11.35%
	Loma Prieta	13		
	Lacc North2	15		
	New Hall2	28		
	LucerneZ	10		
Medium D	ChiChi	8	3.06%	8.08%
	SMonica2	17		
	SMonica3	25		
	Petrolia1	22		
	Sylmarff1	16		
Soft E	Friuli	17	2.23%	11.48%
	Kocaeli	4		
	Trinidad	23		
	Petrolia2	26		
	Sylmarff1	20		
	Yermo2	16		

Table 6
Matching convergence using Etabs.

Target Spectrum	Convergence	Mean Spectrum	
		Ave. difference	Max. difference
Rock B	ChiChi	23.44%	72.01%
	Friuli		
	Loma Prieta		
	LucerneZ		
	Lacc North2		
Hard C	Friuli	16.31%	44.09%
	Loma Prieta		
	Lacc North2		
	New Hall2		
	LucerneZ		
Medium D	ChiChi	10.51%	47.42%
	SMonica2		
	SMonicaZ		
	Petrolia1		
	Sylmarff1		
Soft E	Friuli	11.95%	7.44%
	Kocaeli		
	Trinidad		
	Petrolia2		
	Sylmarff1		

displacement of 25 mm, 33 mm, 25 mm and 21 mm respectively thereby creating 11% lower displacement than the original reference. The displacement pattern of Petrolia record is almost similar to that of the original El Centro record whereas Chichi record is in line with Sylmarff records in site class D as shown in Fig. 6c. The average displacement of matched records for this site is similar to the unmatched El Centro record of 30 mm. In site class E, the yielding average displacement at the top story is 32.4 mm or 7% higher than reference record.

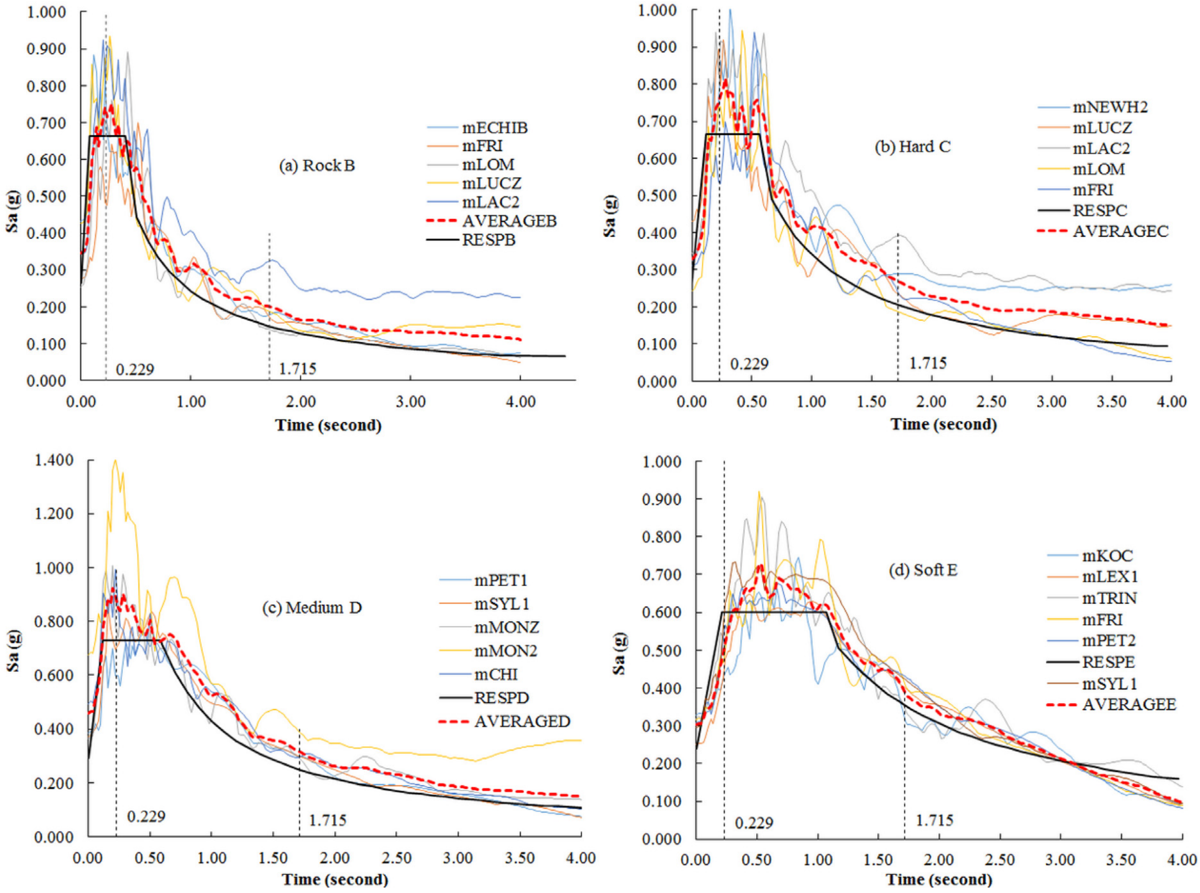


Fig. 4. Matched spectrums by Etabs.

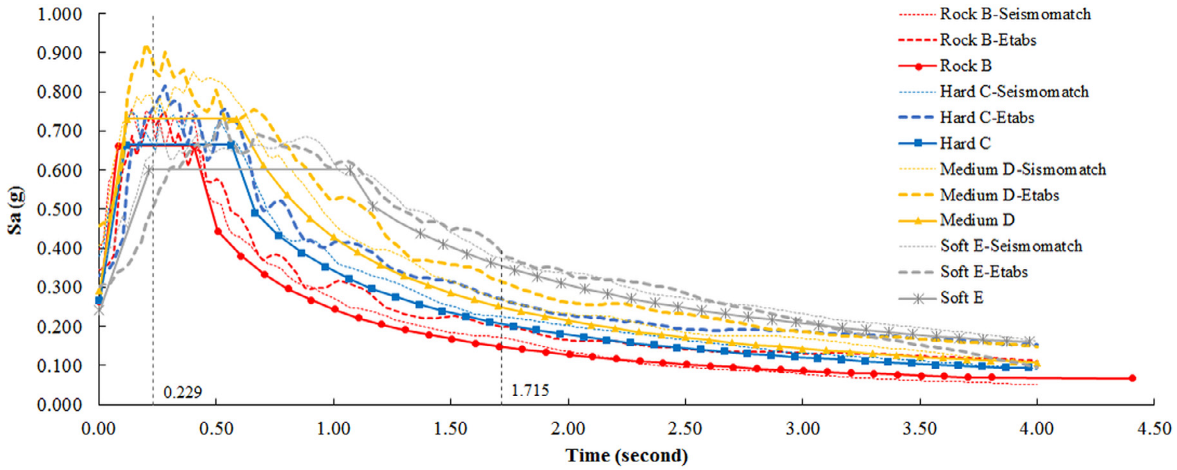
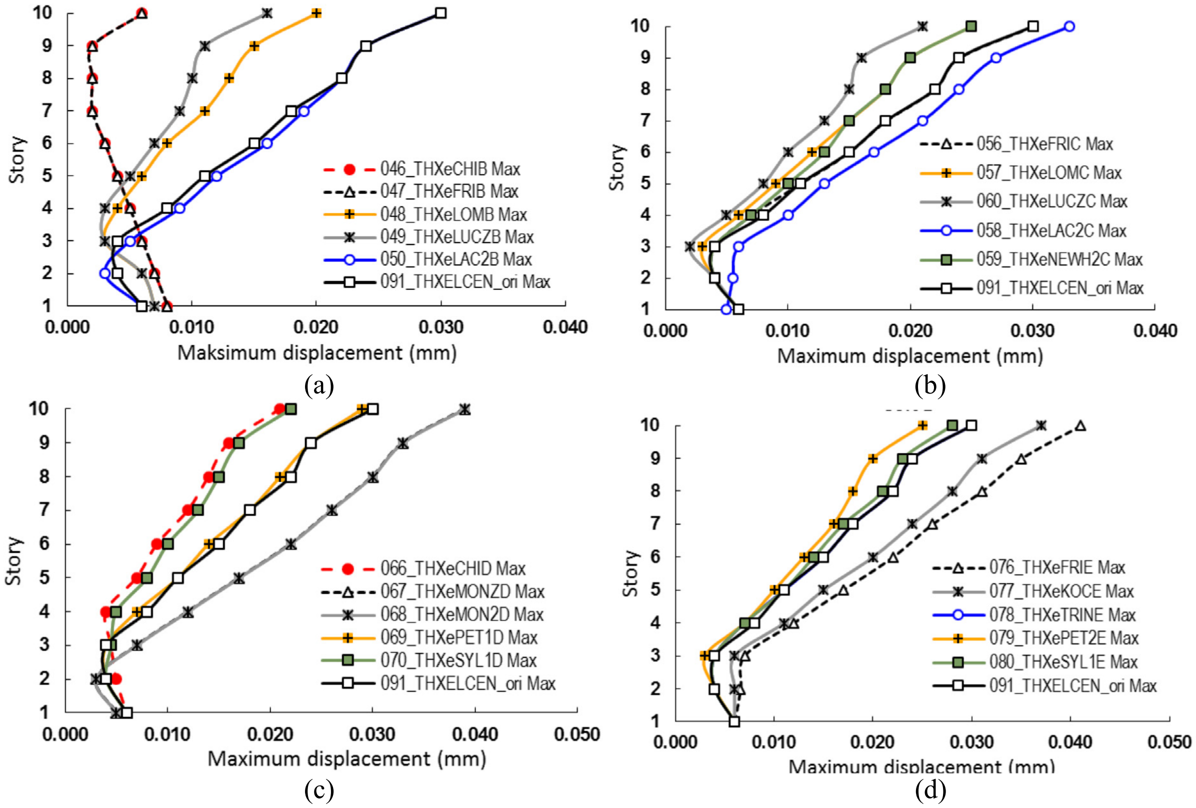


Fig. 5. Scaled spectrum using Seismomatch and Etabs.



(a) (b)

(c) (d)

Fig. 6. Maximum story displacement of each site class.

3.3.2. Base reaction

In Fig. 7 the horizontal axis represents load combination code as seen in Table 5. As can be seen, the proposed structure located in site class E generates higher base reactions than other site classes since soft soil properties require a stronger structure to resist horizontal earthquake load. There is also no substantial difference in base reaction between site class C and D due to the similarity in the seismic response coefficient C_s of the two site classes. The average base force of structure in site class B is 10.65 kN, in class C is 12.35 kN, in class D is 12.31 kN and in class E is 17.44 kN. These values are −30.8%, −19.5%, −19.7% and +13.7% compared to the time history load of the original El Centro accelerogram.

3.3.3. Pier moment

Moment of Pier1 in Fig. 8 shows an identical pattern for all site classes. The difference of pier moment due to the averaged time history records turns to the optimum level at the sixth story in all site classes and decreases to a certain degree at the tenth story. The thick plate set to the shear wall property during structural modeling may increase the stiffness of the shell in each story so that the pier moment differs insignificantly between site classes during dynamic loading. It is obvious that the shear wall system plays major role in earthquake resisting structure. The pier moment of site class B is 2.2% lower than the original El Centro records, whereas that of class C, D and E are 4.4%, 5.8% and 2.2% below the reference record respectively.

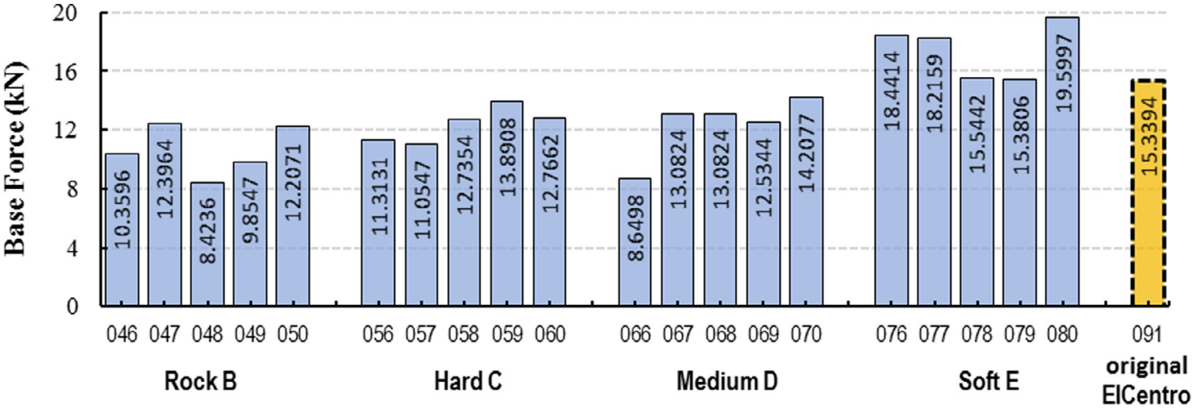


Fig. 7. Base reactions of each site class.

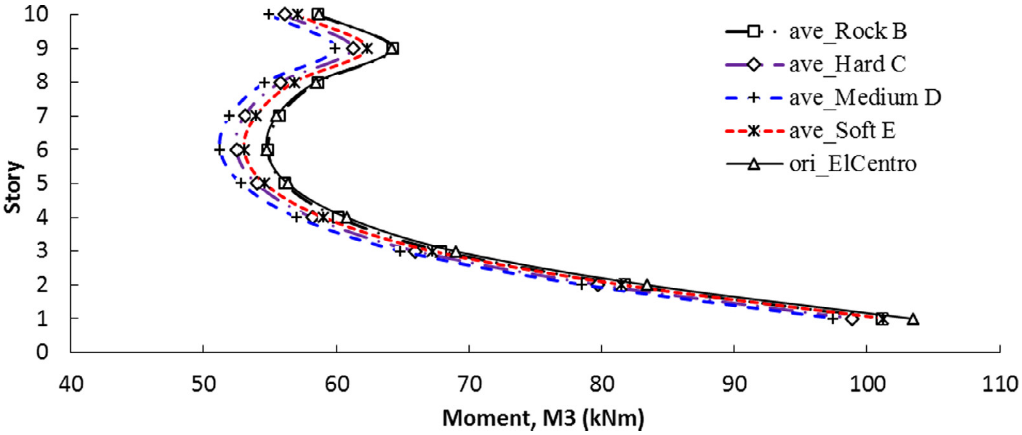


Fig. 8. Top moment of Pier1 (P1).

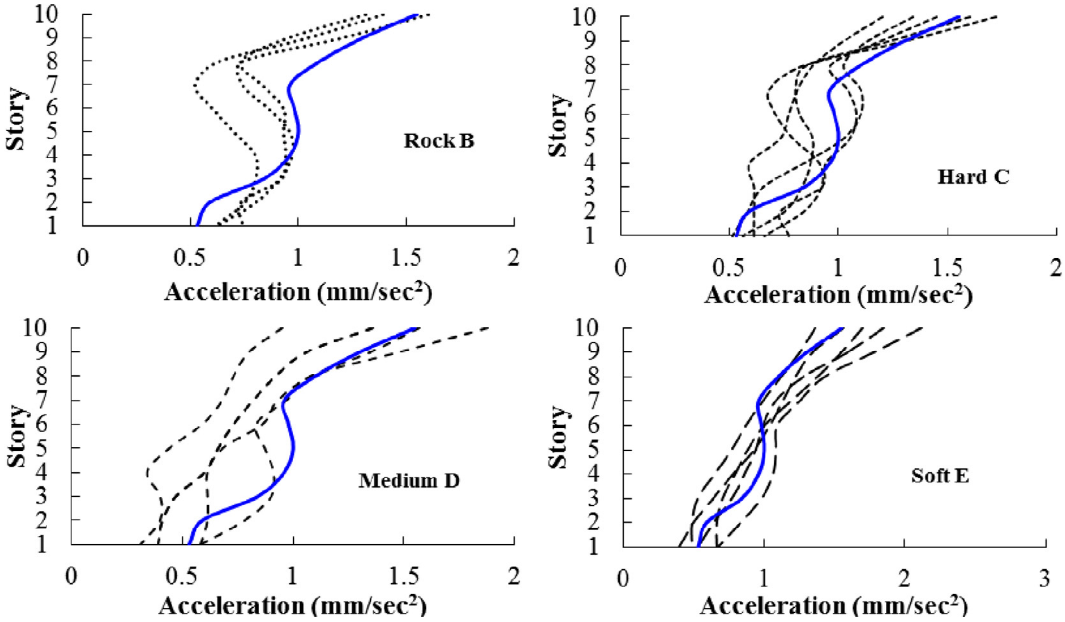
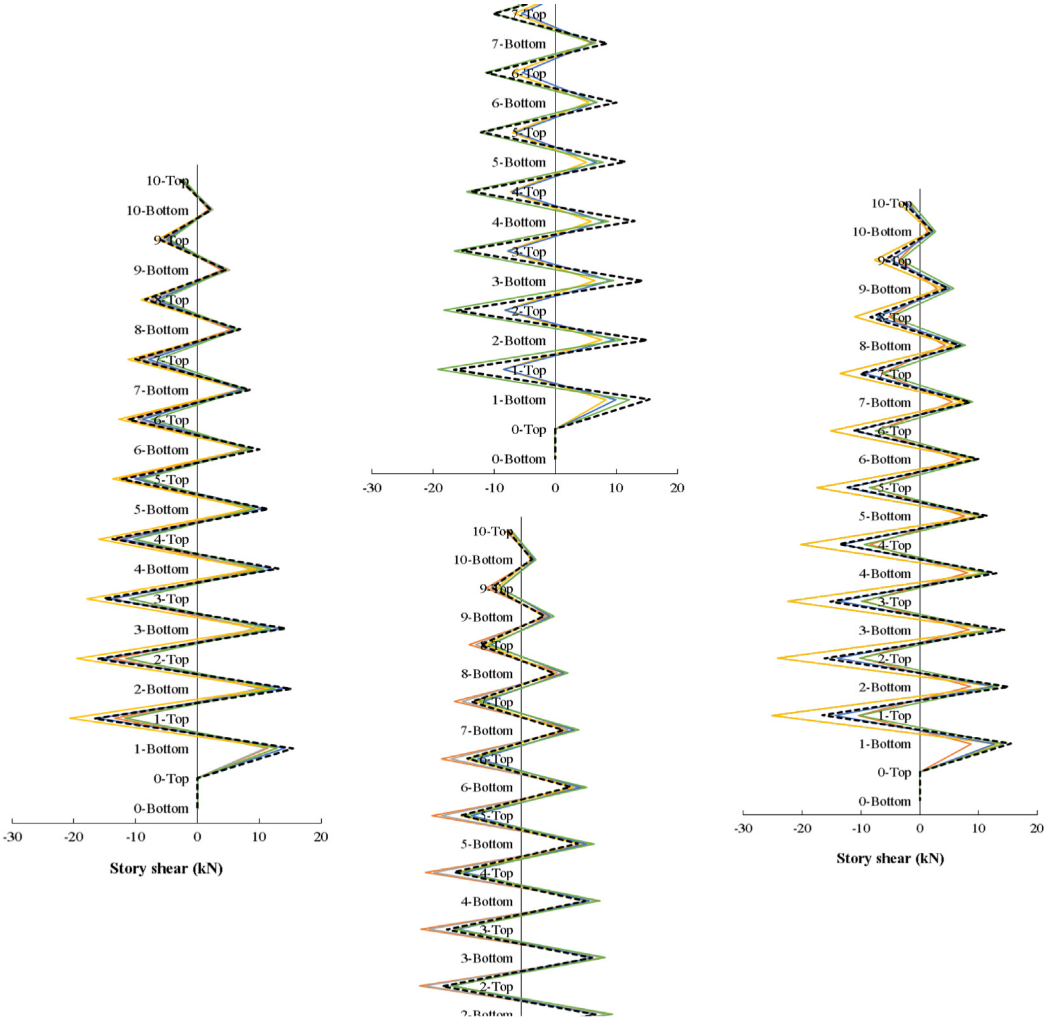


Fig. 9. Story acceleration.

3.3.4. Story acceleration

Bold line curves in Fig. 9 depict story acceleration of the original El Centro record whereas dashed curves represent story acceleration of ground motion record in various site classification. The maximum acceleration of Sylmarff record at top story reaches 2.12 mm/s^2 in soft soil condition and it is the highest acceleration of all followed by Sylmarff record in medium strength soil about 1.88 mm/s^2, Loma Prieta in hard soil about 1.72 mm/s^2 and



Rock B Hard C Medium D Soft E

Fig. 10. Story shear.

Table 7
F.TEST result.

Site Class	Combo Code	Difference between *matched* and *original* records (%)								
		Story Displacement		Base Reactions	Pier Moment		Story Acceleration		Story Shear	
B	046	0.0003	77.07	30.58	0.7878	12.86	0.0006	67.64	0.7122	70.82
	047	0.0003			0.7722		0.0162		0.0153	
	048	0.1326			0.9144		0.6513		0.0083	
	049	0.0214			0.8870		0.1062		0.0164	
	050	0.9919			0.9957		0.8437		0.7067	
C	056	0.9794	37.64	19.48	0.9220	10.90	0.2539	39.94	0.4266	49.77
	057	0.5682			0.8720		0.7903		0.1913	
	058	0.8142			0.9438		0.9135		0.9876	
	059	0.5057			0.8735		0.7681		0.6516	
	060	0.2508			0.8438		0.2773		0.2546	
D	066	0.1819	58.43	19.74	0.8037	11.64	0.3533	31.46	0.0340	62.25
	067	0.3500			0.9633		0.9459		0.4627	
	068	0.3500			0.9633		0.9459		0.4627	
	069	0.9457			0.8744		0.6767		0.6648	
	070	0.2512			0.8131		0.5049		0.2634	
E	076	0.3394	35.15	−13.67	0.9575	5.18	0.4815	50.14	0.2534	38.04
	077	0.5220			0.9848		0.5232		0.4043	
	078	0.9794			0.9498		0.8614		0.8735	
	079	0.5526			0.9136		0.3522		0.8265	
	080	0.8493			0.9355		0.2748		0.7403	

Laccnorth in rock soil about 1.6 $\mathrm{mm/s^2}$. Hence, it is proven that structure in stronger soil condition experiences less acceleration than that in weaker soil strength. In the comparison of structural acceleration due to the selected ground motion records to the original El Centro record, it visually appears that the biggest difference occurs in site class B since the acceleration of selected records shows wider fluctuation.

3.3.5. Story shear

Fig. 10 illustrates shear behavior at the top and bottom location of each story for various site classes. The story shear of the proposed structure due to time history load of matched accelerogram in site class E generally creates better convergence to the dashed reference accelerogram. In contrast, the highest divergence pattern is shown in site class B since matched accelerogram patterns graphically differ away from the reference El Centro record. The maximum shear force occurs at the top location of the first story around 19.17 kN in site class B, 20.56 kN in class C, 25.07 kN in class D and 20.04 kN in class E, which is 15.7%, 24.1%, 51.3% and 21% greater than the shear force due to El Centro record of 16.57 kN at similar story.

3.4. Response difference

This study uses spreadsheet F.TEST function to determine whether two array data of each response type have different variances. The first array data is of single matched accelerogram and the second array represents reference accelerogram. The result of F.TEST is grouped based on site class and then averaged to obtain the overall difference between matched and original accelerograms. Table 7 shows the result of F.TEST with respect to the maximum story displacement, base reaction, pier moment, story acceleration and story shear. It is apparent from Table 7 that the use of single ground motion record (i.e. El Centro) in time history analysis of the proposed structure severely differs the output of maximum story displacement, story shear and story acceleration whereas moment of the pier is only affected below 13%. For site class B, the difference level of response also follows the aforementioned order. For site class C the major difference is of story shear, story acceleration and story displacement, while base reaction and pier moment differ below 20%. In medium and soft soil condition, story shear and story acceleration notably outweigh other response types respectively.

4. Conclusion

The spectral matching process of 28 strong ground motion records shows that ETABS yields better mean spectrum shape than Seismomatch and has resulted in five best accelerograms for each site class which are then applied to a 10-story building structure to observe structural response and compare the difference due to the artificial accelerograms and the original El Centro record.

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. In the case of base reaction, artificial time history load of Friuli, Lucerne and Sylmarf yield the largest response for the ordered site classes. For story shear response, the extreme forces for each ordered site class are due to the artificial ground motion of Chichi, Laccnorth, Petrolia and Trinidad.

The average displacement at the top story of matched accelerogram for site B is a half of the displacement by the original El Centro record while for site C the displacement due to matched records reduce 10%, it remains stabled in site D and increases 7% in site E. The average base reaction reduces 20%–30% in site B, C and D but rises 14% in site E. Pier moment due to matched records decreases 2%–6% as compared to the reference record effect while story acceleration experienced notable difference in site B. The artificial time history records adversely affect the story shear response up to 51% higher than El Centro record. The impact difference of each response type by F.TEST shows unclear pattern but the change in both techniques reach over 77%. All in all, the selection of appropriate and sufficient earthquake records may produce ideal artificial earthquake accelerations for linear time history analysis and it is, therefore, profound to select correct, appropriate and sufficient seismic records since the possible difference may affect the final design of the building structure.

Acknowledgements

The author wishes to acknowledge the support from the Department of Civil Engineering at Nusa Nipa University and Yayasan Pendidikan Tinggi Nusa Nipa Maumere, Indonesia for every useful support in this research.

Appendix A. Appendix A

See Table A1.

Table A1
List of symbols.

Symbol	Note	Source
PGA (g)	Peak Ground Acceleration	BSN (2012)
S_S (g)	Short period spectral acceleration	BSN (2012)
S_1 (g)	1-s spectral acceleration	BSN (2012)
CRS	Specific risk coefficient	BSN (2012)
F_A	Short period site coefficient	BSN (2012)
F_V	Long period site coefficient	BSN (2012)
S_{MS} (g)	Modified short period spectral acceleration = Ss/F_A	Calculated
S_{M1} (g)	Modified 1-s spectral acceleration = S_1/F_V	Calculated
S_{DS} (g)	Short period spectral acceleration at 5% damping ratio = 2 $S_{MS}/3$	Calculated
S_{D1} (g)	1-s spectral acceleration at 5% damping ratio = $2S_{M1}/3$	Calculated
T_0 (s)	$0.2S_{D1}/S_{DS}$	Calculated
T_S (s)	Lower period of scaling range = S_{D1}/S_{DS}	Calculated
R	Earthquake reduction factor	BSN (2012)
I_e	Building importance factor	BSN (2012)
C_d	Amplified deflection factor	BSN (2012)
T_a (s)	Approached fundamental period = $C_t\, h_n^x$	Calculated
C_t	Parameter for T_a	BSN (2012)
x	Parameter for T_a	BSN (2012)
h_n (m)	Structure height	Calculated
C_u	Upper limit coefficient of calculated period	BSN (2012)
S_a (g)	Response spectrum acceleration = S_{D1}/T	Calculated

References

Alatik, L., Abrahamson, N., 2010. An improved method for nonstationary spectral matching. Earthquake Spectra 26, 601–617. http://dx.doi.org/10.1193/1.3459159.

ASCE, 2006. Seismic design requirements for building structures. In: Minimum Design Loads for Buildings and Other Structures. ASCE, Reston VA, pp. 59–85. http://dx.doi.org/10.1061/9780784408094.

Beckers, J., Lay, T., 1995. Very broadband seismic analysis of the 1992 Flores, Indonesia, earthquake ($M_w = 7.9$). J. Geophys. Res. Solid Earth 100, 18179–18193. http://dx.doi.org/10.1029/95JB01689.

BSN, 2012. Earthquake Resistant Planning Procedures for Building Structures. Jakarta, Indonesia.

CSI, 2010. ETABS Extended Three Dimensional Analysis of Building Systems (User's Manual). Computers and Structures Inc, California, U.S.A..

Fahjan, Y., Ozdemir, Z., 2008. Scaling of earthquake accelerograms for non-linear dynamic analysis to match the earthquake design spectra. In: 14th World Conference on Earthquake Engineering.

Fahjan, Y.M., 2008. Selection and Scaling of Real Earthquake Accelerograms to Fit the Turkish Design Spectra. Tek. Dergi 19, 4423–4444.

Grant, D.N., Diaferia, R., 2012. Assessing adequacy of spectrum-matched ground motions for response history analysis. Earthquake Eng. Struct. Dyn. 42, 1265–1280.

Hancock, J., Boomer, J.J., 2007. Using spectral matched records to explore the influence of strong-motion duration on inelastic structural response. Soil Dyn. Earthquake Eng. 27, 291–299.

Huang, K., 2014. Minimum Number of Accelerograms for Time-History Analysis of Typical Highway Bridges. Concordia University Montreal.

Kalkan, E., Chopra, A.K., 2010. Practical Guidelines to Select and Scale Earthquake Records for Nonlinear Response History Analysis of Structures.

Katsanos, E.I., 2010. Selection of earthquake ground motion records: A state-of-the-art review from a structural engineering perspective. Soil Dyn. Earthquake Eng. 30, 157–169.

Pauly, T., Priestley, M.J.N., 1992. Seismic Design of Reinforced Concrete and Masonry Buildings. John Wiley & Sons Inc., New York, USA.

PEER:NGA database, 2013. Pacific Earthquake Engineering Research [WWW Document]. Univ. California, Berkeley. URL http://ngawest2.berkeley.edu/ (accessed 8.4.16).

PuskimPU, 2011. Spectral value of surface acceleration of MCER with 1% probabilities of exceedance in 50 years [WWW Document]. URL http://puskim.pu.go.id/Aplikasi/desain_spektra_indonesia_2011/ (accessed 9.15.16).

Seismosoft, 2016. Seismomatch.

Takhirov, S.M., Fenves, G.L., Fujisaki, E., Clyde, D., 2005. Ground Motions for Earthquake Simulator Qualification of Electrical Substation Equipment.

USGS, 2014. M 7.8 – Flores region, Indonesia [WWW Document].