Effect of Ground Motion Duration on the Seismic Response of Low- and Mid- Rise RC Buildings in Bangkok

Piyawat Ruksilthong[1,*] and Teraphan Ornthammarath[2]

[1,2] Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand.
**Corresponding author; E-mail address: piyawat.rus@student.mahidol.ac.th*

Abstract

This paper examines the effect of seismic ground motion duration on design and risk of reinforced concrete buildings collapsing in Bangkok, Thailand. Reinforced concrete building models of 2 different heights, six-story and ten-story buildings are examined, which will simulate the natural period of buildings of 0.5 - 1.0 s. A nonlinear incremental dynamic analysis model was used to determine both the MCE and the collapse levels. At the MCE level of shaking, it was discovered that the maximum interstory drifts, shear force, and overturning moments increased with increasing as ground motion duration. However, the increase of interstory drifts, shear force, and overturning moments does not exceed the seismic design standard for building (DPT.1301/1302-61). When records were scaled until the building collapse, it was discovered that scaling long duration records had a greater effect on building shaking than short duration records. Additionally, long duration records increase the probability of the building collapsing and has a lower collapse margin ratios than short duration records compared to the MCE spectrum. Additionally, it was discovered that long duration records have a larger impact when the building's height or natural period increases.

Keywords: Effect of ground motion duration, Long duration, Seismic design in Bangkok, Reinforced concrete building

1. Introduction

When earthquakes occur, the earthquake's characteristics may differ. Although the severity of the earthquakes is comparable, the destructive impact of earthquakes of comparable intensity on structures and buildings vary. Therefore, the effect of ground motion duration on structural damage has become a consideration in many countries that are prone to earthquakes that last for a long duration. The duration of ground motion is derived from the Probabilistic Seismic Hazard Analysis (PSHA) of the site of the structure during the time history analysis and is not expressly stated in the design standards.

Numerous research has examined the relationship between structural damage and the duration of ground motion, but the results vary from having a significant impact on the structure to having no effect at all. Where the conclusions of the effect of ground motion duration on structures vary due to the usage of different models. Using two sets of ground motion record, **Michael Fairhurst et al. (2019)** studied the impacts of the duration of ground motion on structures with shear walls between 6 and 30 stories. In the same spectrum, the records were separated into long and short series. Long duration ground motions were found to impact structures around 20 percent more than short duration ground motion, which is within the acceptable range for design standards. It can be regarded to be the duration of ground motion It may not be a significant issue that will lead to additional structural damage. Meanwhile, by separating seismic recordings into two groups**, Chandramohan et al. (2016)** examined the influence of ground motion duration on current five-story steel moment frames. Both sets used Equivalent Spectrum to set long and short duration records. The results obtained from the research showed that duration of ground motion had a significant impact on structural erosion.

From the assessment of earthquake disasters by the probability method in Bangkok, it was found that the area in the Bangkok Basin There is a risk of an earthquake that lasts for a long dyration

. As a result, the new earthquake resistant building design standard (DPT 1301/1302-61) has determined suitable ground motion to be used in building design by using the Time History Analysis method by creating a Conditional Mean Spectrum (CMS).

This article examines the influence of ground motion duration on reinforced concrete structures with six and ten stories. Two suites of spectrally equivalent records are run at various levels of shaking, from the code MCE level all the way to the collapse level. The code-level movements are run to determine if ground motion duration influences the typical code design of this type of building, while the collapse-level motions are conducted to determine if ground motion duration influences the collapse risk of the structure.

2. BUILDING MODELING

The models of buildings considered in this study are reinforced concrete buildings that are typical of office buildings constructed in Bangkok, Thailand. The buildings represent low-rise and mid-rise buildings in Bangkok. Buildings with 6 and 10 stories are considered. The lateral-resistant system of the buildings are intermediate reinforced concrete moment-resisting frames. The gravity-resistant system of the buildings includes rectangular columns size 0.4m. x 0.6m. and 0.15 m wide slabs at each story. The: inelastic behavior of the structure is considered using the code-based parameters such as response modification factor (R = 5), overstrength factor (Ω = 3.0), and deflection amplification factor (C_d = 4.5). The floor plan of the buildings is shown in Fig 1

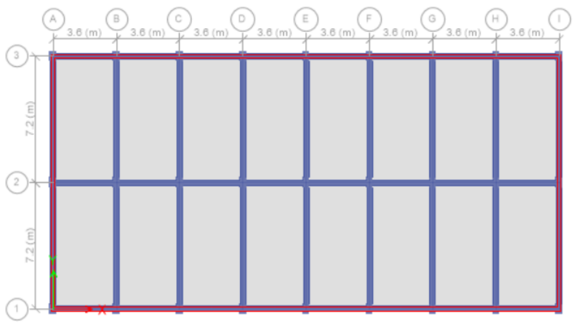
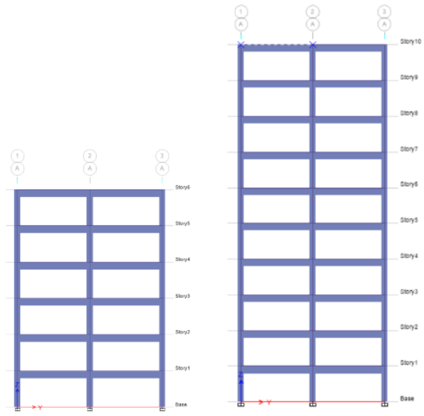


Fig. 1 The layout of model buildings

The floor area is about 400 sq.m. per story, with a story height of 3.6m. Three frames (7.2m bay width) in the Y-direction and nine frames (3.6m bay width) in the X-direction form the structures. Every floor of the structure has the same height of 3.6 meters. The side view of building shown in Figure 2.The building's dead load is comprised of the structure's self-weight, which includes beams, columns, floors, and masonry walls. The superimposed live load is assumed to be 250 kg/m2 for typical floor and 100 kg/m2 for typical roof. The building codes minimum load considerations for superimposed dead and live loads are used ministerial regulations No. 6 (1984). Both buildings (6 story and 10 story) have parameters for beam and column sizes, floor area, the height, and load for each story are the same.



(a) (b)

Fig 2 The side view of (a) 6 story building and (b) 10 story building.

3. GROUND MOTION SELECTION

The earthquake ground motions are chosen for examination from two sources. Record of spectral equivalent duration a significant duration of 5% to 95% ($D_{5\text{-}95}$) was used to measure the duration of a ground motion. $D_{5\text{-}95}$ is the time of energy accumulation from 5% to 95% of a ground motion using the Arias intensity to estimate the stored energy. which can compute the intensity of an Aria from the equation.

$$I_a = \int_0^T a(t)^2\, dt/2g$$

Table 1 Period of the building models

No. of stories	T1 (s)	T2 (s)	T3 (s)
6	0.438	0.433	0.404
10	0.939	0.870	0.799

3.1 *First suit of ground motion*

The first suit of motions contained long duration records. The ground motion selected from earthquake ground motions accompanies earthquake-resistant building design requirements (DPT 1301/1302-61). Using historical methodologies, it is possible to choose appropriate ground motion data for use in building design. By creating the Conditional Mean Spectrum (CMS) for building oscillation periods of 0.5 s and 1.0 s, they can perform a Time History Analysis for an earthquake period of 2475 years. Each district in Bangkok and its environs is divided into ten zones that adhere to the new criteria. Each record of a set of standards (DPT1301/1302-61) will be different in the period of buildings. The oscillation period of 0.5 s and 1.0 s has 4 record each.

3.2 *Second suit of ground motion*

The second suit of motions contained short duration records. The records are downloaded from the Pacific Earthquake

Engineering Research (PEER) center's web-based PEER NGA-West2 database application. Four records are selected from the database to match the number of records in the first suit. The spectral scale of the four selected records is adjusted to be close to the geometric mean spectrum of the standard records (DPT1301/1302-61). The parameters used for selecting short-duration records that magnitude Mw 6.0–7.0, a shear wave velocity range of 0-360 m/s, and a set target period of interest of 0.2T1 to 1.5T1. According to the probability of an earthquake in the Bangkok area. The maximum duration of oscillations, as estimated by **Kempton and Stewart (2006)**, is 20 seconds ($D_{5\text{-}95}$ 20s).

The records from the standard (DPT1301/1302-61) with periods of 0.5 s and 1.0 s are separate because they have different periods. This resulted in the selection of two short series of waves for the 6-story building model with periods close to 0.5s as shown in Table 2 and for the 10-story building model with periods close to 1.0s as shown in Table 3 so that the spectrum of long and short waves would be the same as depicted in Figures 3 and 4.

Table 2 Short duration suite for period 0.5sec

Record	Event	Magnitude (M_w)	Year	Scale Factor	$D_{5\text{-}95}$ (sec)
505	Taiwan SMART1(40)	6.32	1986	0.4575	15.4
508	Taiwan SMART1(40)	6.32	1986	0.4303	8.5
3636	Taiwan SMART1(40)	6.32	1986	0.4626	13.4
3647	Taiwan SMART1(40)	6.32	1986	0.4937	16.2

Table 3 Short duration suite for period 1.0sec

Record	Event	Magnitude (M_w)	Year	Scale Factor	$D_{5\text{-}95}$ (sec)
506	Taiwan SMART1(40)	6.32	1986	0.5209	16.2
3637	Taiwan SMART1(40)	6.32	1986	0.5065	14.9
3638	Taiwan SMART1(40)	6.32	1986	0.5032	15.1
3647	Taiwan SMART1(40)	6.32	1986	0.4474	16.2

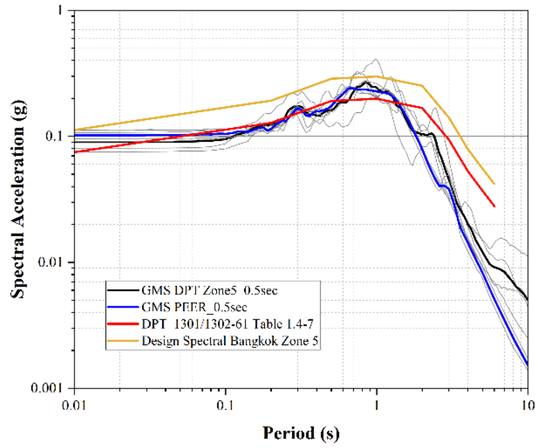


Fig. 3 Comparison of DPT1301/1302-61 and PEER ground motion at conditional mean spectrum at 0.5s for 6-story building.

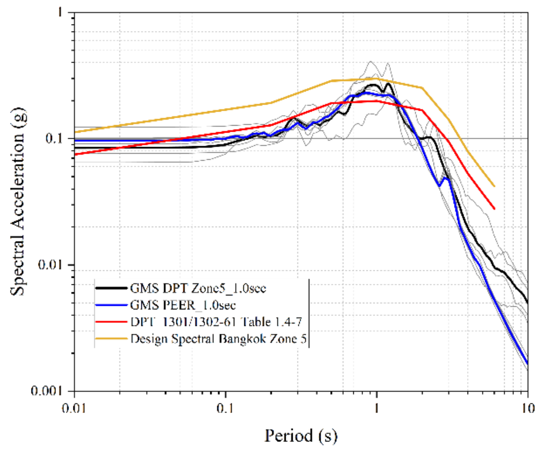
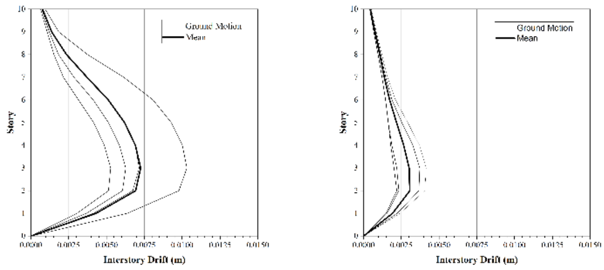


Fig. 4 Comparison of DPT1301/1302-61 and PEER ground motion at conditional mean spectrum at 1.0s for 10-story building.

4. DESIGN-LEVEL ANALYSIS RESULTS

Thailand code-level design and building analysis that codes will be utilized in accordance with seismic-resistant standards (DPT1301/1302-61). It states that ground quake levels have a 2% possibility of occurring in 50 years.

Therefore, the ground motion selected will be scaled to suit the MCE spectrum of buildings in Bangkok. It is used to analyze building models using nonlinear time-history analysis. The effects of interstory drift, story share, and overturning moment for a 10-storey building are shown in Fig 5, 6 and 7.



(a) (b)

Fig 5 Interstory drift results for the 10-story model at the design shaking level for (a) the long duration suite and (b) the short duration suite.

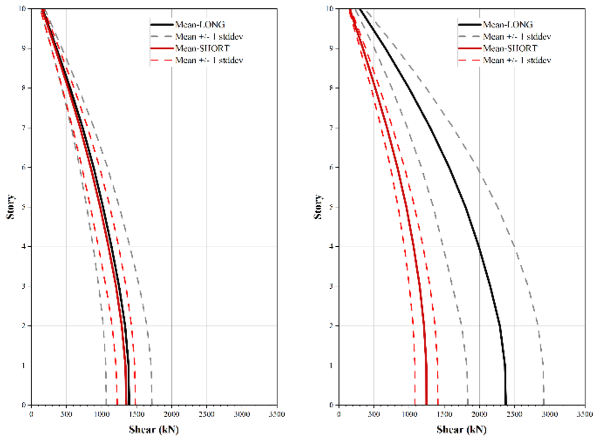
DPT substitutes interstory drift for structural damage and is restricted to buildings planned with an interstory drift of no more than 0.01 of each story height. Each story of this structure has the same height of 3.6 meters. This indicates that the maximum permissible interstory drift for a building is 0.036 meters. From nonlinear time history analysis of the structure of the resulting interstory drift, as shown in Figure 5, no record set exceeds the limitations of this standard.

The shear effect and overturning moment of the building varied between the two sets of records. The shear force in the X-axis, which is the long direction of the building, along with the building plan, show similar results. However, the shear force in the Y-direction, which is the short direction of the building according to the building plan, was found that records with a long duration had significantly greater shear values than records with a short duration. Long-duration records have shear values that are 1.9 times larger than short-duration records. Regarding shear, the overturning moment on the X-axis is 1.9 times more significantly different for long-duration records than for short-duration records. On the Y axis, the overturning moment is comparable.

Additionally, the mean interstory drift for each of the other models is summarized in Table 4. The results were similar for the two buildings (6-storey and 10-storey).

Table 4 Mean of maximum interstory drifts summary for all structure models

No. of stories	Mean of maximum drifts (m)	
	Long duration suit	Short duration suit
6	0.0025	0.0016
10	0.0073	0.0036

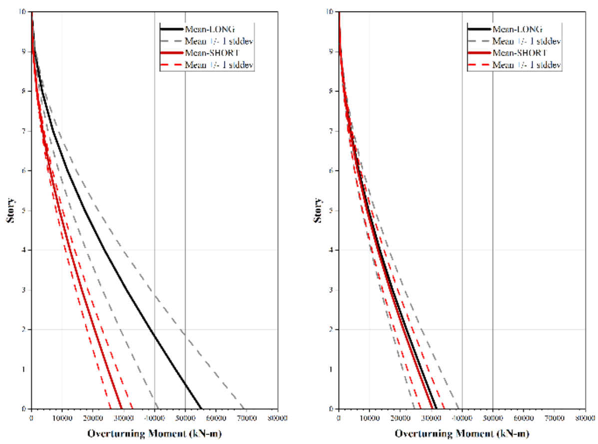


(a) (b)

Fig 6 Story shear force results for 10-story model at the design shaking level for (a) the X-direction and (b) the Y-direction (The red line show average sheer force of short duration suit and the black line show average sheer force of long duration suit.)

5. COLLAPSE-LEVEL ANALYSIS

Determine if a long duration of ground motion enhances the risk of collapse for intermediate reinforced concrete moment-resisting frames at higher shaking levels. Both ground motion sets are progressively increased till collapse. In this study, a collapse level was defined as interstory drift over 5 percent. The interstory drift limit is based on research by **Michael Fairhurst et al. (2019)**, and this selected 5 percent restriction exceeds the highest limit of standard design (DPT1301/1302-61) and goes through the point where the incremental dynamic analysis (IDA) curve becomes flat. That must refer to the limit of the research because the standard DPT1301/1302-61 has only the upper limit of the interstory drift is set at the design level, but no limits on the collapse level are clearly defined.



(a) (b)

Fig 7 Overturning moment results for 10-story model at the design shaking level for (a) the X-direction and (b) the Y-direction
(The red line shows average overturning moment of short duration suit, and the black line shows average overturning moment of long duration suit.)

The collapse mechanism considered in the study models (6-story and 10-story) was defined as interstory drift over **5 percent**. The building collapse pattern is caused by the bending moment of the building's columns from scaling up ground motion until stresses in steel and concrete reach their yield stress. The columns on the first floor are collapse first and affects to the columns on the next floor. The collapse of the columns caused the building to collapse like a pancake.

The fragility curve produced from the 6-story model for the two ground motion sets is depicted in Figure 8. In this graph, a scale of 100% corresponds to a 2% 50-years shaking level based on the design code level (DPT301 or 1302-61).

For the 6-story building, the long suit had a median collapse level of 230% and the short suit had a median collapse level of 315% of the design scale in order. The median collapse scale levels for other models are summarized in Table 5. To induce collapse, the short-duration suit must be scaled 40 to 60 percent higher than the long-duration suit. The minimum required collapse scaling increase is 37% for a 6-story building, while the maximum collapse scaling increase is 62% for a 10-story model. Considering the 6-story model's low duration in comparison to the 10-story model, for building system intermediate reinforced concrete moment-resisting frames, when the height of the building increases, the building will be affected by longer cycle periods and will sustain greater inelastic damage. That is, the duration of ground motion will increase the probability of the building collapsing.

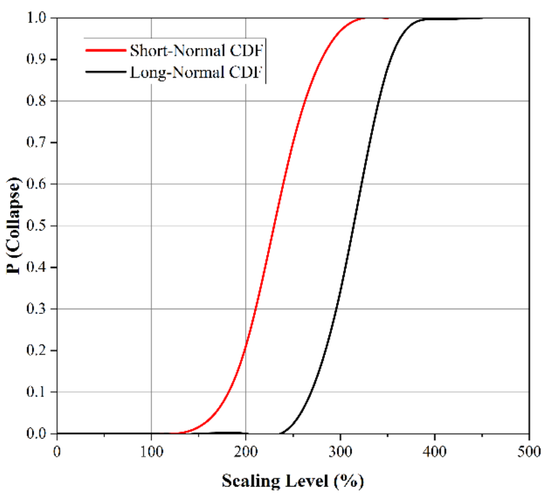


Fig 8 CDF results for the long and short duration suites for 6-story building

Table 5 Mean collapse scaling level for all building modeling

No. of stories	Median collapse scaling level (% of 2 % in 50-year)		
	Long duration suit	Short duration suit	Short/Long
6	230	315	1.37
10	170	275	1.62

These results show that the duration of ground motion have a considerable effect on the probability of collapse of this reinforced concrete building. The long duration suit increases the probability of collapse by 2% 50-years shaking level. Also, the building's modal effective mass makes it more likely that it will collapse the higher it is.

In Thailand, only new high-rise buildings are designed for a 2% probability 50-years shaking level, making these newly built high-rise buildings have a very low probability of collapsing. However, most small to medium sized buildings in Thailand are not designed to resist earthquakes. As Thailand is located in a low-risk earthquake zone, it is believed that designing a small-to medium-sized building to withstand earthquakes is not worthwhile. However, based on the effects of numerous earthquakes in Thailand, the structures that suffered the most damage were the smaller buildings. According to this research, not only large buildings are affected by the duration of ground motion, but small buildings are also affected by the duration of ground motion.

6. CONCLUSIONS

In this study, sets of reinforced concrete buildings were analyzed using two records. The spectral equivalent short duration is set to the code level of 2 percent in 50-years shaking level, and it is anticipated that the building will sustain minimal damage. Longer motions were up to 2 times more likely to generate interstory drift at this shaking intensity However, both sets of ground motion still had shear force, overturning moment, and interstory drift not exceeding Thailand's design standards followed by standard (DPT1301/1302-61), but intermediate reinforced concrete moment-resisting frames are also significantly affected by the long duration of ground motion.

When the ground motion was recorded, it was scaled gradually to very high oscillation levels using IDA (incremental dynamic analysis). The median collapse level of the model is significantly affect by ground motion duration. To induce structural collapse, short duration sets require a 30 to 40 percent bigger scaling factor than long duration sets. This means that the duration of ground motion may be a factor in determining the level of shaking that is expected to cause structural damage in the building. and considering the higher level of shaking which is expected to cause more damage to the structure, the duration becomes an important parameter as the results of the research of **Chandramohan et al. (2016).**

The results presented in this study are for intermediate reinforced concrete moment-resisting frames constructed in the Bangkok Basin Zone 5, Thailand only. The number of records samples to be analyzed is limited to the number of records of standard (DPT1301/1302-61). As a result, statistical analysis may not be very reliable. To improve the dependability of the research, it may be necessary to analyze standard records samples from the Bangkok Basin in other zones.

Acknowledgement

This article's research was conducted as part of the first author's master's thesis, which was funded by the Mahidol University.

References

[1] BRADY, M. D. (1975). A STUDY ON THE DURATION OF STRONG EARTHQUAKE GROUND MOTION. Bulletin of the Seismological Society of America. Vol. 65, 581-626.

[2] Chandramohan, R., Baker, J. W., and Deierlein, G. G., 2016a. Impact of hazard-consistent ground motion duration in structural collapse risk assessment, Earthquake Engineering and Structural Dynamics 45, 1357–1379.

[3] Chandramohan, R., Baker, J. W., and Deierlein, G. G., 2016b. Quantifying the influence of ground motion duration on structural collapse capacity using spectrally equivalent records, Earthquake Spectra 32, 927–950.

[4] Cornell, D. V. (2002). Incremental dynamic analysis. EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, 491-514.

[5] Cosenza, E., Iervolino, I., and Manfredi, G., 2004. On ground motion duration and engineering demand parameters, In Performance-based Seismic Design, Concepts and Implementation: Proceedings of an International Workshop, 28 June–1 July, 2004, Bled, Slovenia.

[6] Department of Public Works and Town & Country Planning (DPT), 2019. DPT Ground Motion Data available at https://sites.google.com/view/dpt1302/download (last accessed 27 February 2022).

[7] Earthquake Shaking Resistance Building Design Standards (DPT1301/1302-61), 2021, The standard for Seismic Analysis and Design of Buildings Located in the Thailand Region, Thailand.

[8] Hancock, J., and Bommer, J. J., 2006. A state-of-knowledge review of the influence of strongmotion duration on structural damage, Earthquake Spectra 22, 827–845

[9] Iervolino, I., Manfredi, G., and Cosenza, E., 2006. Ground motion duration effects on nonlinear seismic response, Earthquake Engineering and Structural Dynamics 35, 21–38.

[10] J.C. Foschaar, J. B. (2012). Preliminary Assessment of Ground Motion Duration Effects on Structural Collapse.

[11] Jonathan Hancock and Julian J. Bommer, M. (2006). A State-of-Knowledge Review of the Influence of Strong-Motion Duration on Structural Damage. Earthquake Spectra, Volume 22, 827-845.

[12] JULIAN J. BOMMER and ALEJANDRO MART´INEZ-PEREIRA. (1999). THE EFFECTIVE DURATION OF EARTHQUAKE STRONG MOTION. Journal of Earthquake Engineering, Vol. 3, 127-172.

[13] Kempton, J. J., and Stewart, J. P., 2006. Prediction equations for significant duration of earth-quake ground motions considering site and near-source effects, Earthquake Spectra 22(4),985–1013.

[14] Meera Raghunandan, A. B. (2013). Effect of ground motion duration on earthquake-induced structural collapse. Structural Safety 41, 119-133.

[15] Michael Fairhurst, M. A. (2019). Effect of Ground Motion Duration on Reinforced Concrete Shear Wall Buildings. Earthquake Spectra, Volume 35, 311-331.

[16] Nakhorn POOVARODOM, P. W. (2004). DYNAMIC CHARACTERISTICS OF NON-SEISMICALLY DESIGNED REINFORCED CONCRETE BUILDINGS WITH SOFT SOIL CONDITION IN BANGKOK. 13th World Conference on Earthquake Engineering.

[17] Pacific Earthquake Engineering Research Center (PEER), 2014. PEER Ground Motion Database, available at http://ngawest2.berkeley.edu (last accessed 1 March 2022).

[18] Pennung-WARNITCHAI. (2004). DEVELOPMENT OF SEISMIC DESIGN REQUIREMENTS FOR BUILDINGS IN BANGKOK AGAINST THE EFFECTS OF DISTANT LARGE EARTHQUAKES. 13th World Conference on Earthquake Engineering.

[19] Young-Ji Park, A. H.-S. (1985). SEISMIC DAMAGE ANALYSIS OF REINFORCED CONCRETE BUILDINGS. Journal of Structural Engineering, Vol. 111, 740-757.