The 2018 Structures Congress (Structures18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Effects of near-fault ground motions on response modification factor

*Ju-Hyung Kim[1)], Hyeon-Keun Yang[2)], Jang-Woon Baek[3)] and Hong-Gun Park[4)]

[1),2),3),4)] *Department of Architecture & Architectural Engineering, Seoul National University, Seoul 151-742, Korea*
[1)] *hyungbang@snu.ac.kr*

ABSTRACT

To take account of inelastic behavior of a structure, response modification factor has been introduced in seismic design procedure. The factor was derived statistically from a number of actual ground motion records. However, especially when a near-fault earthquake which is characterized by a high amplitude velocity pulse, a structure subjected to the motion has a high energy demand in relatively fewer cycles of loading. In this paper, the effect of the near-fault earthquake to the inelastic behavior of a structure was addressed and R-μ-T relationship including the effect of near-fault earthquakes has been developed.

1. INTRODUCTION

Much attention has been paid to describe inelastic seismic response of structures realistically. So far response modification factor, *R,* has been widely utilized to represent inelastic behavior of the structure in a simple manner. However, the evaluated *R* factors proposed by several researchers have not considered the effect of near-fault ground motions even though it is expected that near-fault ground motions cause higher ductility demand to structures. Therefore it is required to verify the influence of near-fault ground motions on response modification factors.

2. REVIEW OF PREVIOUS STUDIES

Response modification factor, *R* is a factor that reflects inelastic energy dissipation capability of the structure subjected to an earthquake. Inelastic response of a structure can be evaluated using the factor simply. Response modification factor is

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[1)] Ph.D. Student
[2)] Graduate Student
[3)] Postdoctoral Researcher
[4)] Professor

used not only for the seismic design of a building, also for the assessment of seismic capacity of nuclear power plants against beyond-design-basis earthquake.

Evaluation of response modification factor basically depends on earthquake ground motion, ductility, damping, and fundamental period of a structure. Several researchers have suggested empirical equations to estimate *R*. After the evaluation equation of *R* is proposed by Newmark and Hall(1973), Several equations considering additional variables have been developed as real recorded ground motion data accumulated. Riddell and Newmark(1979) proposed *R* factor to be evaluated depending on the damping ratio. In the study of Nassar and Krawinkler(1991), the post-yield stiffness ratio of a structure was considered in the evaluation of *R* factor. Miranda and Bertero(1994) studied the influence of local site conditions(rock, alluvium, and soft soil deposits) on *R* factor. Fig. 1 shows a comparison of *R* factors proposed by the various studies for ductility ratios equal to 3 and 5(Miranda and Bertero 1994). Except the Miranda's equation, all the equations evaluating *R* factor monotonically increase from 1 to the specified ductility value as fundamental period increases. For higher ductility ratio, the proposed equations show considerable difference of *R* value. Moreover, little attention has been paid to the influence of near-fault ground motion on the *R* value so far.

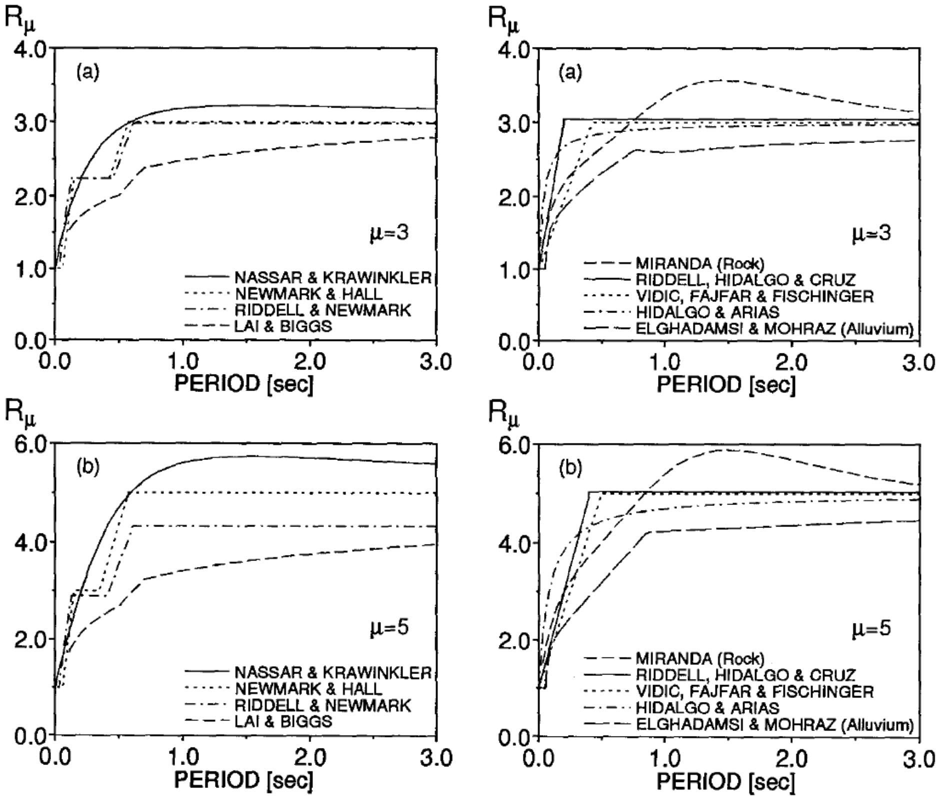

Fig. 1 Comparison of strength reduction factors proposed in various studies for (a) ductility=3, and for (b) ductility=5 (Miranda and Bertero(1994))

3. NEAR-FAULT GROUND MOTIONS

Near-fault ground motion is characterized by distinctive pulse-like velocity time histories(Malhotra 1999, Huang and Chen 2000). Typically, the pulse is found at the early stage of earthquake and rapidly diminishes. However, the shape of the pulse-like velocity varies depending on the occurrence of permanent displacement. Chi-Chi earthquake(1999) time history ground motion recorded at two different station is depicted in Fig. 2.

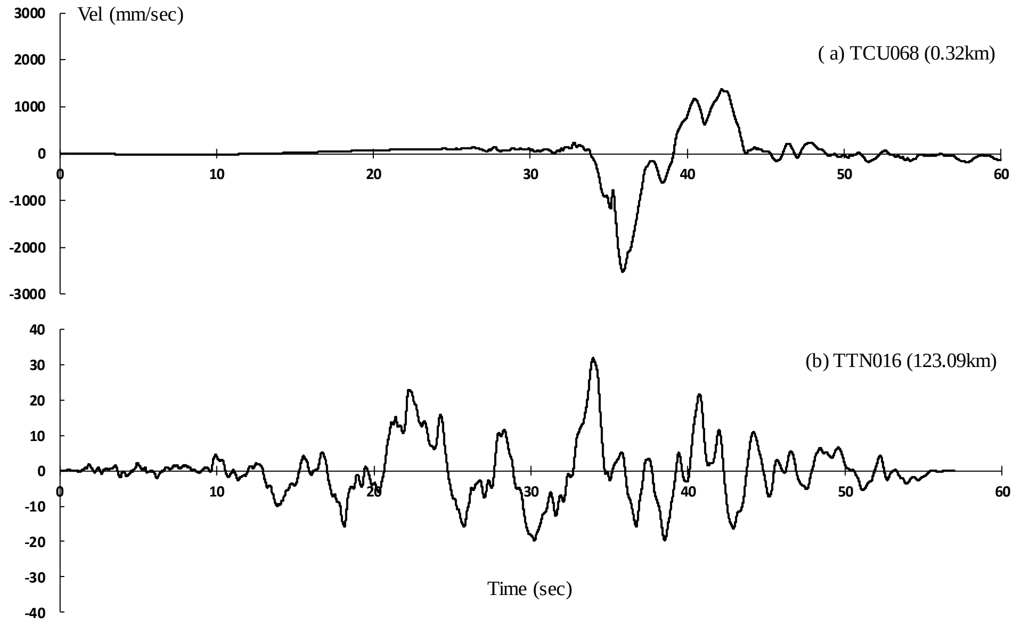

Fig. 2 Chi-Chi earthquake(1999) Ground motion records (a)TCU068 (b)TTN016

As shown in Fig. 2 (a), ground motion time history data recorded at the near-fault station shows typical characteristics of near-fault earthquake; long-period, pulse-like velocity wave. On the other hand, far-fault earthquake in Fig. 2 (b) shows periodic(filtered) ground motion over a longer period of time. Strong motion duration measured at the two stations are listed on Table. 1.

Table. 1 Strong motion duration of Chi-Chi earthquake(1999) (TCU068, TTN016)

Station Name	5%-75% Duration (sec)	5%-95% Duration (sec)
TCU068	7.5	13.2
TTN016	25.3	36.2

Two earthquakes occurred in last three years in South Korea also showed near-fault earthquake characteristics though the magnitude is much lower than Chi-Chi earthquake and no permanent displacement has been observed.

Due to the distinctive velocity pulse, when a structure is in inelastic deformation range, most of inelastic energy dissipation is concentrated in that pulse. Fig. 3 shows a comparison of inelastic response subjected to near-fault ground motion and far-fault ground motion, respectively.

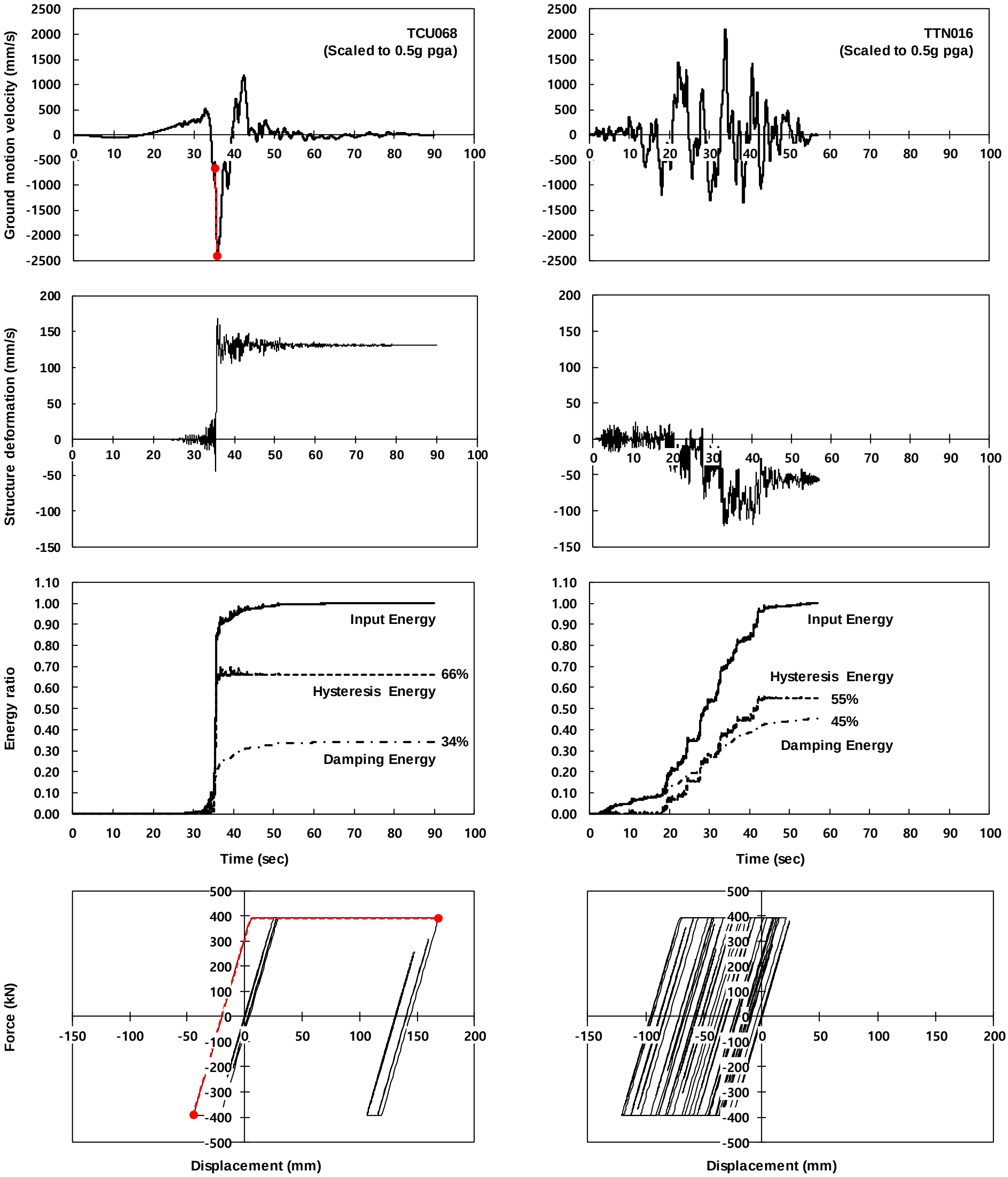

Fig. 3 Inelastic responses of near-fault ground motion, and far-fault ground motion (pga: 0.5g)

Each pga value of the two ground motions was scaled to be 0.5g. Energy values are normalized to the maximum input energy. The third row of Fig. 3 shows hysteretic behavior of an elasto-plastic SDF system (Natural period: 0.5s, damping ratio: 5%, mass: 100kg). Obviously, in case of near-fault earthquake, most of the inelastic energy

is dissipated within a cycle resulting in higher ductility demand. Additionally, the ratio of the damping energy to the input energy was lower in near-fault earthquake.
Therefore, if a site is expected to be affected by near-fault earthquake, the effect of near-fault earthquake should be taken into consideration in seismic design and assessment.

4. EVALUATION OF RESPONSE MODIFICATION FACTORS

It has been confirmed that the near-fault earthquakes can cause large ductility demand of structures, the influence of near-fault earthquake should be considered in the assessment of response modification factor, *R*. Three parameters were chosen which determine the characteristics of ground motions. Three parameters are:

- Epicentral distance (Near-fault earthquake / Far-fault earthquake)
- Frequency component (Low-frequency earthquake / High-frequency earthquake)
- Strong motion duration (Short strong motion duration / Long strong motion duration)

To verify the effect of each variable, 30 ground motion data were selected. The information of each ground motion is listed in Table. 2. There is no clear distance criterion defining near-fault earthquake. However, in this study, earthquakes with an epicentral distance of less than 25km were classified as near-fault earthquakes.

Table. 2 Ground motion data

No	EQ. name	Year	M	R_{jb} (km)	Dur. 5-75% (sec)	Freq.
1	Loma Prieta	1989	6.93	2.8	1.42	-
2	Loma Prieta	1989	6.93	3.22	2.08	-
3	San Fernando	1971	6.61	0.0	5.42	L
4	Tabas	1978	7.35	1.79	8.28	L
5	Landers	1992	7.28	2.19	8.64	H
6	Kocaeli	1999	7.51	7.57	5.8	-
7	Kocaeli	1999	7.51	3.62	6.34	-
8	Tottori	2000	6.61	15.23	10.28	H
9	Tottori	2000	6.61	15.58	2	L
10	Parkfield-02	2004	6	4.66	1.7	L
11	Friuli	1976	5.3	8	1.44	H
12	Friuli	1977	5.4	9	0.54	-
13	Montenegro	1979	6.9	21	7.62	L
14	Montenegro (aftershock)	1979	5.1	8	1.06	L
15	Gyeongju	2016	5.8	22	1.6	H
16	Whittier Narrows-01	1987	5.99	23.4	2.9	H
17	San Fernando	1971	6.61	89.72	5.62	L

18	Loma Prieta	1989	6.93	83.37	5.06	L
19	Chi-Chi	1999	7.62	101.24	14.02	L
20	Chi-Chi 02	1999	5.9	78.6	11.46	H
21	Whittier Narrows-02	1987	5.27	25.04	3.72	H
22	Hector Mine	1999	7.13	185.92	14.26	L
23	Niigata	2004	6.63	100.37	15.78	H
24	Montenegro	1979	6.9	105	3.92	H
25	Montenegro	1979	6.9	55	11.7	L
26	Montenegro (aftershock)	1979	5.8	50	1.7	H
27	Griva	1990	6.1	51	5.02	L
28	Near coast of Filiatra	1993	5.2	27	4.5	H
29	Kozani	1995	6.5	60	7.72	L
30	Strofades	1997	6.6	136	7.96	L

30 time-history response of elasto-plastic SDF model with 5% damping were analyzed. Average *R* value of 30 ground motions were plotted and compared to two equations proposed in prior studies in Fig. 4. Except for the periods less than 0.125s, Riddell-Newmark(1979) equation generally gives conservative *R* values. On the other hand, Nassar-Krawinkler(1992) equation generally shows reasonable *R* values especially for periods less than 0.5s. However, as ductility and period increase, Nassar-krawinkler(1992) equation tends to overestimate the energy absorption capacity.

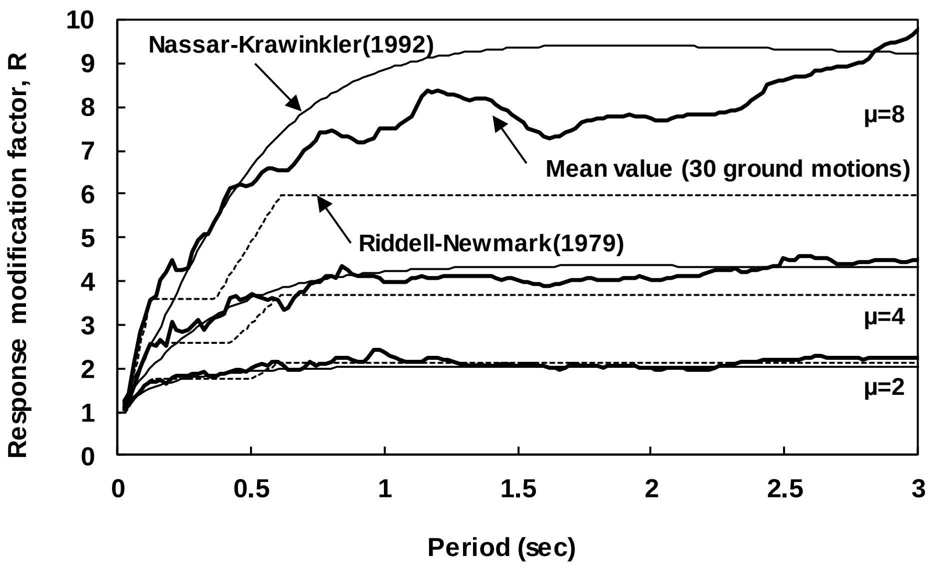

Fig. 4 Average strength reduction factors of 30 ground motions

To evaluate the influence of the three parameters mentioned above on the *R* factor, the spectrum was regenerated for each parameter. Fig. 5 shows the variation of *R* factors.

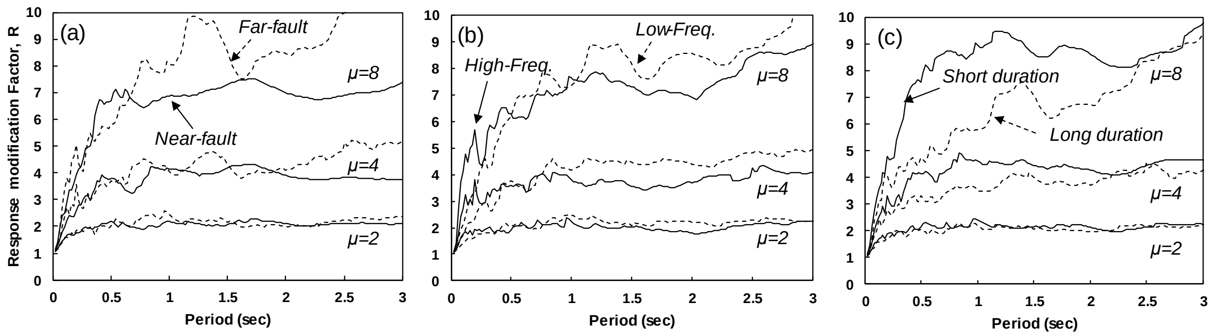

Fig. 5 Response modification factors:
(a) epicentral distance, (b) Frequency component, (c) Strong motion duration

4.1 Epicentral Distance (Fig. 5 (a))

For the same ductility demand, the difference of *R* value between near-fault and far-fault ground motion is negligible for structures with fundamental periods less than 0.5s as Nassar and Krawinkler(1992) have concluded. R. However, it turned out that epicentral distance would substantially affect results of other two parameters (frequency component, and strong motion duration). The influence of epicentral distance on frequency component and strong motions duration is as follows.

4.2 Frequency Component (Fig. 5 (b))

It can be figured out in the figure that R value can be amplified or de-amplified depending on the relation between earthquake frequency contents and building natural period. For shorter periods less than 0.5s, *R* values of high-frequency earthquake tend to show higher values, while for longer periods over 1.0s, *R* values of low-frequency earthquake are larger. This phenomena is the result of large deformation of elastic system due to resonance. However, it is expected that the degree of amplification varies depending on the earthquake type: near-fault, and far fault. In Fig. 6, Response modification factors are plotted for near-fault earthquake and far-fault earthquake, respectively.

Generally, for both cases of (a), and (b), R values of high-frequency earthquake is larger in short periods, while *R* values of low-frequency earthquake is larger in long periods. More specifically, far-fault earthquakes show more clear tendency. In case of far-fault earthquake, *R* values corresponding to high-frequency earthquake is much larger than that of low-frequency earthquake around natural period of 0.2~0.3s. On the other hand, little difference has been observed in near-fault earthquake. This is because far-fault ground motion generally shows periodic excitation for longer periods of time sufficient to generate resonance, whereas near-fault ground motion is composed of half- or one sinusoidal wave, or single pulse, which is insufficient to generate resonance. As a result, in case of near-fault earthquake, frequency components has less influence on response modification factor, *R*.

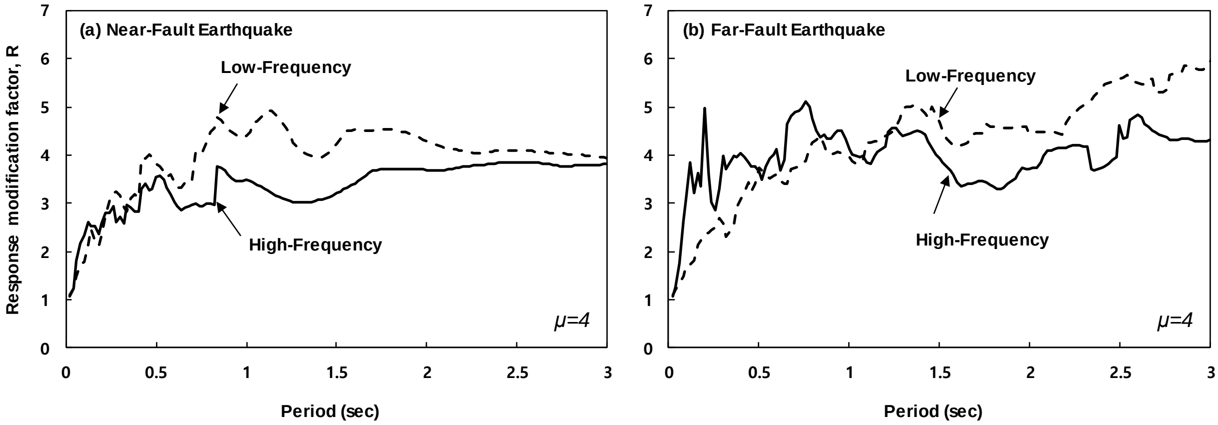

Fig. 6 Response modification factors and earthquake frequency components: (a) Near-fault earthquake, (b) Far-fault earthquake

4.3 Strong Motion Duration (Fig. 5(c))

Strong motion duration is a representative indicator of structural damage. It was observed that response modification factors decreased as the strong motion duration increased. The reason is that the earthquakes with long strong motion duration can cause larger inelastic deformation of a structure than short strong motion duration earthquakes.

However, the level of de-amplification by strong motion duration is different between near-fault earthquakes and far-fault earthquakes. Fig. 7 shows the effect of strong motion duration for near-fault earthquakes and far-fault earthquakes, respectively.

Near-fault earthquakes de-amplified *R* values significantly for periods over 0.3s, whereas small change of *R* values were observed in far-fault earthquakes. In case of far-fault earthquake, strong motion duration is determined by the number of cycles of ground motions. On the contrary to this, in case of near-fault earthquake, strong motion duration is determined by the period of one large pulse. Therefore, near-fault earthquake with long strong motion duration shows long period of a pulse causing large inelastic deformation.

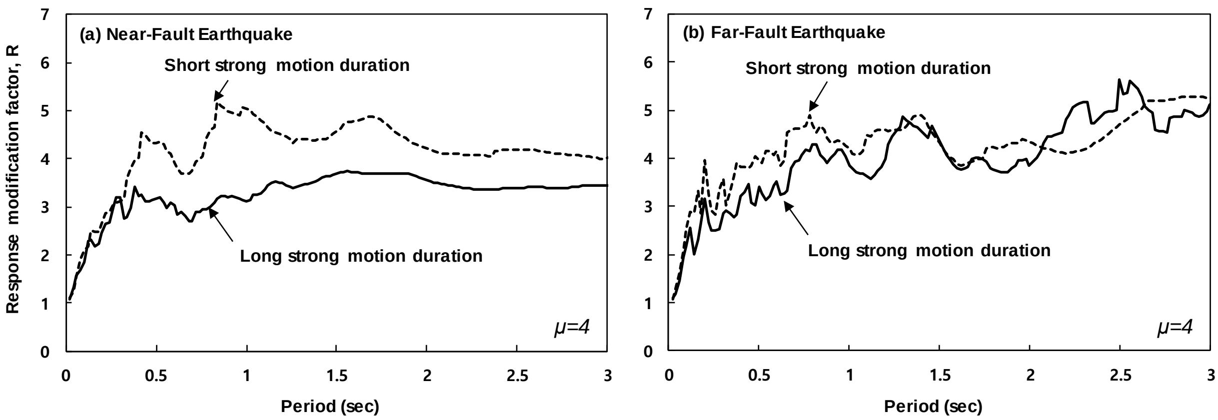

Fig. 7 Response modification factors and strong motion duration:
(a) Near-fault earthquake, (b) Far-fault earthquake

5. CONCLUSION

Inelastic seismic response of structures can be simply evaluated by using response modification factor, *R*. However, it was found from simple idealized SDF model that response modification factor significantly varies depending on the characteristics of ground motions. The effect of three earthquake parameters are analyzed in this study: epicentral distance, earthquake frequency component, strong motion duration.

Especially, near-fault earthquakes characterized by a high amplitude velocity pulse should be considered in the evaluation of response modification factor. Current response modification factors can underestimate ductility demand of the structure subjected near-fault earthquake. Further study is needed to evaluate response modification factor quantitatively including near-fault ground motion effects addressed in this paper.

REFERENCES

Kalkan, E., and Kunnath, S. K., (2006), "Effects of Fling and Forward Directivity on Seismic Response of Buildings," Earthquake Spectra, 22(2), 367-390

Kalkan E., and Kunnath, S. K., (2007), "Effective Cyclic Energy as a Measure of Seismic Demand," Journal of Earthquake Engineering, 11, 725-751

Malhotra, P.K., (1999), "Response of Buildings to Near-Field Pulse-Like Ground Motions," Earthquake Engineering and Structural Dynamics, 28, 1309-1326

Miranda, M., and Bertero, V.V., (1994), "Evaluation of Strength Reduction Factors for Earthquake-Resistant Design," Earthquake Spectra, 10(2), 357-379

Nassar, A.A., Osteraas, J.D., and Krawinkler, H., (1991), "Seismic Design Based on Strength and Ductility Demands," Earthquake Engineering, 10th World Conference, 5861-5866

Newmark, N.M., and Hall, W. J., (1973) "Seismic Design Criteria for Nuclear Reaactor Facilities," Building Practices for Disaster Mitigation, National Bureau of Standards, U.S. Department of Commerce, 209-236

Newmark, N.M., and Riddell, R., (1979), "Inelastic Spectra for Seismic Design," Proceedings of the 7th World Conference on Earthquake Engineering, 4, 129-136.

Huang, C.T., and Chen, S.S., (2000), "Near-Field Characteristics and Engineering Implications of the 1999 Chi-Chi Earthquake," Earthquake Engineering and Engineering Seismology, 2(1), 23-41