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The Effects of Low-pass Filters of Peak Ground Acceleration

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1. Introduction

This paper studies actual records of earthquake waveforms to analyze attenuation characteristics of peak ground Acceleration(PGA) resulting from low-pass filters. For this purpose, we acquired raw data of major earthquakes around the world including the Western U.S., Taiwan, Italy, Iran, and Turkey etc., and analyzed peak ground acceleration(PGA) values before and after passing through low-pass filters. In addition, we presented results of analyzing case studies, such as the automatic shutdown of a nuclear power plant in the Niigata Prefecture, Japan on July 16, 2007 when an earthquake (magnitude 6.8) shook the plant beyond its design basis, and the earthquake (magnitude 9.0) that occurred off the Pacific coast of Tohoku on March 11, 2011.

2. Methods and Results

As the raw data of each analysis, we obtained accelerated waveforms of the world's major earthquakes from the Pacific Earthquake Engineering Research Center (PEER, http://peer.berkeley.edu/smcat) and that of the 2007 and 2011 earthquakes in Japan from K-NET (http://www.kyoshin.bosai.go.jp/kyoshin/quick),which is operated by the National Research Institute for Earth Science and Disaster Prevention (NIED).

The low-pass filter applied in this analysis was the 5 pole Butterworth filter (Fig. 1). This filter begins attenuation at 10 Hz, and there is an attenuation of -3 dB at 14 Hz (approximately 71% of the input signal voltage is passed). This filter provides differential attenuation in high frequencies.

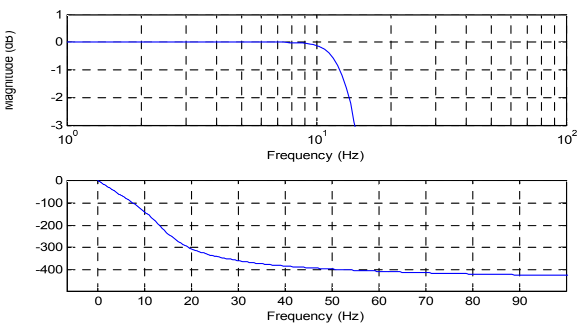


Fig. 1. The characteristics of Butterworth 5-pole filter which was applied in this study.

The general mechanism behind earthquakes is such that the stronger the earthquake, the wider the area of the seismic source. As such, the main energy frequency of large earthquakes are shifted to a low-frequency spectrum. This is supported by Allen and Shearer (2009)[1], who showed that earthquakes with a magnitude of 5.0 or higher have a corner frequency (fc) less than 10 Hz (Fig. 2).

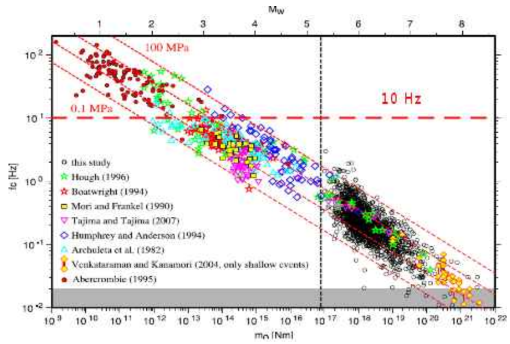
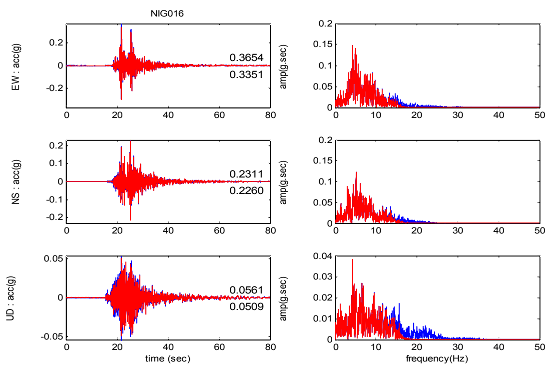


Fig. 2. Corner frequency versus seismic moment and moment magnitude(Allen and Shearer, 2009

The horizontal and vertical components of peak ground acceleration of each earthquake before and after passing through low-pass filters are analyzed (Fig 3, Table 1).



(a) (b)

Fig. 3. An example of peak ground acceleration value before(blue color) and after(red color) passing through low-pass filters. (a) waveforms and (b) fourier spectra

Fig. 3 shows the waveform and Fourier spectrum of each earthquake. In Fig. 3, the unfiltered waveforms and spectrums are colored in blue, while the filtered results are shown in red. To make it easier to discern the effect of low-pass filters on PGA, we have written the values before filtering in the top area, and that after filtering in the bottom. For the component with the largest PGA value of three-component acceleration waveforms, we evaluated the effect of filters on PGA (degree of attenuation) by dividing the original PGA (A) over the PGA after filtering (B) to get the ratio A/B. In this process, some sections below the standard low-pass frequency of 10 Hz take on a value smaller than 1 due to the design characteristic of the Butterworth filter (Table 1). Thus, PGA values can be amplified (by up to 1.7%) when a filter is applied. For cases when the value of A/B exceeded 100%, we rounded down such values to 100%.

Table 1. The result of peak ground acceleration value before and after passing through low-pass filters.

Earthquake	Station ID	PGA(g) Before Filtering (A)	After Filtering (B)	ratio (A/B)
Niigata Tsuezu, Japan (07/07/16) Kashiwazaki Kariwa NPP accident (Mw=6.8)	NIG016	0.3654	0.3351	92
	NIG018	0.6803	0.6838	100
	NIG017	0.2476	0.2448	99
	NIG014	0.1107	0.1104	100
	NIG019	0.4635	0.4655	100
	NIG013	0.1421	0.1402	99
	NIG024	0.2171	0.2201	100
	NIG025	0.2281	0.2278	100
	NIG022	0.1549	0.1550	100
	NIG012	0.1432	0.1405	98
	NGN001	0.1659	0.1654	100
	NGN002	0.2315	0.2315	100
Great Tohuku, Japan (11/03/11) Fukushima Daiichi NPP Accident (Mw=9.0)	MYG002	0.6714	0.6388	95
	MYG001	0.4336	0.4395	100
	MYG010	0.4671	0.4835	100
	IWT008	0.3299	0.3152	96
	IWT012	0.6021	0.6008	100
	MYG006	0.5825	0.5733	98
	MYG015	0.4186	0.4195	100
	MYG009	0.5585	0.5383	96
	MYG017	0.3560	0.3492	98
	IWT011	0.3486	0.3491	100
	IWT005	0.2406	0.2326	97
	IWT016	0.2407	0.2391	99
	MYG014	0.5050	0.4925	98
	FKS006	0.5361	0.5106	95
Chi-Chi, (Taiwan) Main Shock (99/09/20, (Mw=7.6)	029	0.2773	0.2759	99
	035	0.2517	0.2522	100
	034	0.3097	0.3076	99
	024	0.2780	0.2778	100
	047	0.1855	0.1851	100
	ALS	0.1828	0.1827	100
	006	0.3644	0.3574	98
	015	0.1573	0.1573	100
	004	0.0999	0.0983	98
	010	0.2265	0.2159	95
	014	0.2627	0.2625	100
	016	0.1051	0.1051	100
Duzce (Turkey) Earthquake (99/11/12) (Mw=7.1)	1058	0.1106	0.1014	92
	1059	0.1474	0.1482	100
	DZC	0.5353	0.5369	100
	531	0.1593	0.1574	99
	1062	0.1142	0.1125	99
	1061	0.1066	0.1037	97
	1060	0.0532	0.0544	100
	BOL	0.8224	0.8264	100
Kobe (Japan) Earthquake (95/01/17) (Mw=6.9)	NIS	0.5093	0.5068	100
	TAK	0.6155	0.5945	97
	KJM	0.8213	0.8152	99
	KAK	0.3447	0.3334	97
	TAZ	0.6935	0.6912	100
	SHI	0.2432	0.2430	100
Izmit (Turkey) Earthquake (99/08/17) (Mw=7.4)	SKR	0.3764	0.3565	95
	IZT	0.2195	0.2117	96
	YPT	0.3489	0.3482	100
	GBZ	0.2440	0.2372	97
	DZC	0.3578	0.3580	100
	ATK	0.1637	0.1640	100
	CNA	0.1788	0.1788	100
	ATS	0.2486	0.2491	100
Landers (U.S) (92/06/28) (Mw=7.4)	JOS	0.2840	0.2853	100
	FHS	0.1355	0.1365	100
	NPF	0.1392	0.1401	100
	DSP	0.1708	0.1684	99
	YER	0.2448	0.2429	99
	WWT	0.1289	0.1169	91
	TPP	0.1062	0.1061	100
	BRS	0.1352	0.1330	98
Parkfield (U.S) (04/09/28) (Mw=6.1)	MIDDLE	0.4251	0.4165	98
	FROEL	0.4704	0.4242	90
	EADES	0.3795	0.3694	97
	VINEY	0.2774	0.2656	96
	HOG	0.2593	0.2568	99
	DONNA	0.3736	0.3737	100
	WORK	0.3345	0.3302	99
	JACK	0.1745	0.1726	99
Northridge (U.S) (94/01/17 (Mw=6.7))	JEN	0.6170	0.6199	100
	PAR	0.5538	0.5295	96
	LOS	0.4716	0.4858	100
	GLE	0.1570	0.1553	99
	MUL	0.4904	0.4989	100
	BVA	0.2138	0.2094	98
	CCN	0.2556	0.2551	100
	CMR	0.1247	0.1240	99

3. Conclusions

As shown above, from analyzing the effects of low-pass filters of PGA for data from major earthquakes, we found that most PGA values after filtering were at least 90% of the original PGA values. Since low-pass filters affect PGA values by less than 10%.

REFERENCES

[1] B.P. Allmann and Peter M, Shearer, 2009, Global Variation of Stress Drop for Moderate to Large Earthquakes, Journal of Geophysical Research, Vol. 114, B01310, 2009

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