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SELECTION OF MULTIPLE EARTHQUAKES CONSIDERING VERTICAL GROUND MOTION TO STRUCTURES

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A R T I C L E I N F O

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A B S T R A C T

Current earthquake engineering field ignores the vertical ground motion in design and analysis of the structure system even though in actual condition these two phenomena impose the significant effect to the structure system. The repeated earthquake happened everywhere all over the world with the short time interval while earthquake in vertical excitation also reported as quantitatively occur but always ignored. Therefore, this study attempts to assess the behaviour of structures due to multiple earthquakes with vertical component. For that purpose, this study processed and tabulated more than 500 ground motion data that was recorded all over the world. The data was downloaded from Pacific Earthquake Engineering Research center – New Generation Attenuation (PEER-NGA) database, As a result, About 24% (121 records) of the listed earthquake records show V/H value more than 0.67 or 2/3 rules and most of the event occurred with source distance less than 50km. About 8.0% (40 records) of the showed V/H ratio more than 1.0 with the highest ratio is 4.85 named Borrego in 1942. It seems that vertical ground motion were also one of the factor effecting analysis and design of structures.

1. Introduction

The structural earthquake engineering is usually not considering the vertical component of ground motion but this phenomenon is gradually changing after many events of near field earthquake recorded that indicates the presence of high vertical earthquake. High vertical earthquake also causes great damages to the building as reported by Elnashai & Sarno (2008) and Papazoglou & Elnashai (1996) especially near the source of the earthquake. The damaging effects of the vertical component are more evident since the vertical component attenuates faster than horizontal component (Ghorabarah & Elnashai, 1998). An earthquake causes shaking of the ground in three direction, those are two directions in horizontal and one direction in vertical.

1.1 V/H Ratios

For hundreds of millions of years, plate tectonics forces have shaped or formed the earth gradually as the huge plates under the surface of the earth moved under, over and past one another. The plates are locked or fastened together and unable to release the storing energy at other time. The plates will break free, once the accumulated energy is strong enough. If an earthquake happens in a populated area, it may trigger numerous deaths and injuries and even extensive property damages.

Vertical to horizontal ratio (V/H) always referred to describe the relationship of these ground motions in an event of earthquake. Many of the record shows that the value of horizontal are greater than vertical which is

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give the value of V/H lesser than 1.0 but Table 1 shows otherwise (Elnashai & Sarno, 2008). Some earthquake give V/H ratio greater than 1.0, which is means the vertical excitation is bigger than horizontal excitation.

Table 1: Earthquake with High V/H Ratios. (Elnashai & Sarno, 2008).

EQ	Country	Date	PGA_h (g)	PGA_v (g)	V/H Ratio
Gazli	Ex-USSR	17/05/1976	0.622	1.353	2.17
Coyote Lake	USA	6/08/1979	0.256	0.420	1.64
Loma Prieta	USA	17/10/1989	0.424	0.514	1.21

Most of the seismic code employed vertical spectra that are derived from their horizontal counterparts. The Uniform Building Code (UBC, 1997) recommends that using factor of 2/3 to define vertical spectra from its horizontal spectra as suggested by Newmark et al. (1973). The 2/3 rule for V/H is not conservative in the near field and over conservative at large epicentral distances (Sung & Amr, 2008). Evidence of many earthquake records with V/H ratio more than 1.0 shows that scaling vertical component from its horizontal component using the 2/3 rule can be a serious underestimate. Eurocode 8 (EC8) recommends utilizing factor of 0.45 and 0.9 for Type 1 and Type 2, respectively.

These codes also considered an exclusive adoption of isolated and rare design earthquake while at the same ignoring the phenomena of repeated earthquakes and its influence to the structures. It was found by Taib et al. (2014) that the structural response quantities are expressed in term of variation of axial load. It was reported by Hartzigeogiou & Liolios (2010) that only a few studies on multiple earthquakes have been reported, despite the fact that the problem has been qualitatively acknowledged.

The damages of building structures occurred during the first earthquake may worsen and become completely inadequate after a series of earthquakes. The seven storey of The Van Nuys Holiday Inn hotel suffered serious structural damage in all columns of the third floor during the 1994 Northridge earthquake. The same building had already suffered extensive nonstructural damage during the 1971 San Fernando earthquake (Elnashai & Sarno, 2008).

Earthquake Frequency

Thousands earthquakes happened every year in all over the world especially for small earthquake with magnitude less than 2.5. These small earthquakes usually not felt by human. Moderate to great earthquake may cause damages to the building especially for near field earthquake. Table 2 shows earthquake magnitude and frequency normally happened per year.

At a specific time interval, there will be 10 times less earthquakes for each magnitude unit increase based on the rule of thumb. For example, if there are about 20 major earthquakes every year, only one or two will be great earthquakes.

Table 2: Earthquake Magnitude (USGS, 2015)

Description	Magnitude Range	Average Annually
Great	8.0 or more	1
Major	7.0 7.9	15
Strong	6.0 6.9	134
Moderate	5.0 5.9	1319
Light	4.0 4.9	13,000 (estimated)
Minor	3.0 3.9	130,000 (estimated)
Very Minor	2.0 or less	1,300,000 (estimated)

1. Methodology

In this study, more than 500 near field records were downloaded from Pacific Earthquake Engineering Research center New Generation Attenuation (PEER-NGA) database, then, its V/H ratio were determined. According to Wan Ahmad et al. (2015) and Mohd Noor et al. (2016), PGA can be obtained from the process of attenuation. The V/H ratio obtained tabulated in the graph against its source distance. Ten real earthquake records were selected and listed in Table 3.

These earthquakes record with source distance less than 25 km, vertical peak ground acceleration (PGA_v) more than 0.25g and with V/H ratio from 0.3 to near 2.0 were finalized and selected to be used in this research. These selected ten real earthquakes record were arranged by ascending V/H ratio and labelled as EQ01 to EQ10.

Table 3: Ten Selected Real Near Field Earthquakes

EQ No.	EQ Name	PGA (H)	PGA (H)	PGA (V)	V/H
01	Morgan Hill	0.71	1.3	0.39	0.3
02	Imperial Valley	0.59	0.78	0.43	0.55
03	Chalfant Valley	0.4	0.45	0.32	0.72
04	Tabas Iran	0.84	0.85	0.69	0.81
05	Coalinga	0.41	0.45	0.38	0.84
06	Loma Prieta	0.44	0.53	0.54	1.02
07	Imperial	0.38	0.46	0.54	1.17
08	Westmorland	0.37	0.5	0.84	1.69
09	Ghazli, USSR	0.61	0.72	1.26	1.76
10	Nahanni,Canada	0.98	1.1	2.09	1.9

The selected models were designed to withstand for the gravity and seismic load with horizontal peak ground acceleration of 0.2g, these earthquake ground records then were normalized for compatibility reasons. The normalized ground motions and factors used were tabulated in Table 4.

Thus, the above mentioned ground motions were factored by 0.1538 (Morgan Hill), 0.2564 (Imperial Valley), 0.4444 (Chalfant Valley), 0.2353 (Tabas Iran), 0.4444 (Coalinga), 0.3774 (Loma Prieta), 0.4348 (Imperial), 0.4000 (Westmorland), 0.2778 (Ghazli, USSR) and 0.1818 (Nahanni, Canada).

The maximum PGAv were also multiplied with the same factor for the normalized purposes. This normalization process resulted all ground motions has the same value of maximum PGAh but different value for PGAv. EQ01 (Morgan Hill) showed the smallest PGAv value of 0.06g and EQ10 (Nahanni, Canada) showed the maximum value of PGAv of 0.38g. According to Hartzigeogiou's (2010) method and also used by Faisal et al. (2012), these normalised ground motions were combined to become repeated earthquake.

Table 4: Normalized Seismic Data

EQ No.	EQ Name	Factor	Normalized PGA (H)	(H)	(V)
01	Morgan Hill	0.1538	0.11	0.2	0.06
02	Imperial Valley	0.2564	0.15	0.2	0.11
03	Chalfant Valley	0.4444	0.18	0.2	0.14
04	Tabas Iran	0.2353	0.20	0.2	0.16
05	Coalinga	0.4444	0.18	0.2	0.17
06	Loma Prieta	0.3774	0.17	0.2	0.20
07	Imperial	0.4348	0.17	0.2	0.23
08	Westmorland	0.4000	0.15	0.2	0.34
09	Ghazli, USSR	0.2778	0.17	0.2	0.35
10	Nahanni, Canada	0.1818	0.18	0.2	0.38

4. Result and Analysis

All 500 earthquake records downloaded and been tabulated by V/H ratio versus source distance in km as shown in Figure 1. About 24% (121 records) of the listed earthquake records show V/H value more than 0.67 or 2/3 rules and most of the event occurred with source distance less than 50km. About 8.0% (40 records) of the showed V/H ratio more than 1.0 with the highest ratio is 4.85 named Borrego in 1942. This earthquake record showed PGAh and PGAv of 0.068g and 0.33g, respectively.

This result is consistent with other finding by Kim & Elnashai, (2008), Perumall, (2013), Ambraseys & Simpson (1996), Papazoglou & El nashai (1996), Collier & Elnashai (2001) and Elgamal & He (2004) that many data of near field ground motion records showed V/H ratio higher than 2/3 and peak vertical ground acceleration suggested may be greater than the horizontal value.

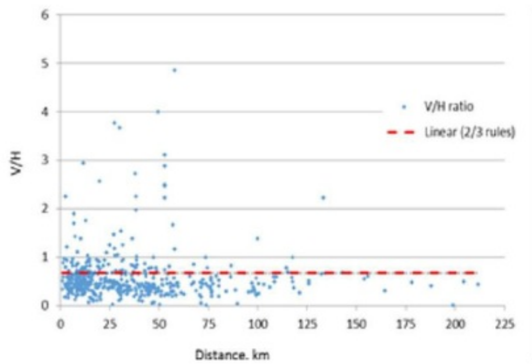

Figure 1: V/H ratio vs Distance (D) in km for 500 near field earthquakes.

Perumal (2013) studied 400 earthquake data on the COSMOS Strong-Motion Virtual Data Centre (VDC). The same analysis was carried out in this study for 500 earthquake data but from different source (PEER-NGA database) and not limited to certain event of earthquake.

5. Conclusions

Ten real earthquakes record were selected and normalized to be used for other research which was arranged by ascending V/H ratio and labelled as EQ01 to EQ10. These ten earthquakes are from all 500 earthquake records downloaded and been tabulated by V/H ratio versus source distance. List of the summary are shown in Table 5.

Table 5: Data Summary

V/H Ratios	Percentage	Numbers
< 0.67	68%	339
0.67	24%	121
1.0	8%	40

With this summary provided, it seems that vertical earthquake cannot be ignored in term of analysis and design.

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