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# Characteristics of vertical ground motions recorded during recent California earthquakes

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ABSTRACT: A study of the relationship of vertical and horizontal ground motions has been conducted for some 15 recent earthquakes that have occurred in California. It is shown that the vertical components of ground motion can be greater than the horizontal accelerations in the region near an earthquake source. It is also shown that there is a period or frequency dependence between the ratio of the vertical to horizontal response spectra. The common practice that assumes that there is constant proportion between the vertical and horizontal ground motions may be either conservative or nonconservative.

## 1 INTRODUCTION

The study of earthquake ground motions has been limited primarily to the examination of the horizontal components. The vertical ground motions have been largely ignored because it has been believed that the most significant damage from earthquakes has been due to the horizontal ground shaking and that the horizontal ground motions are always greater than the vertical ground motions.

The notion that the horizontal ground motions were always greater than the vertical motions has been dispelled by many recent documented instances where the vertical accelerations have exceeded the horizontal accelerations. These observations are probably due to increased density of strong motion instrumentation in seismic areas that have been able to record ground motions, especially in the near field.

Lately, there has been more interest in the characteristics of vertical earthquake ground motions because buildings have become more architecturally unique and more structurally complicated. Whereas it may have been acceptable to ignore vertical ground motions for the design of conventional buildings, the recent advent of seismic base isolation systems for buildings requires that the vertical ground motions be considered as these systems may become unstable if the vertical ground motions cause uplift at any of the isolation elements. Another area where the vertical ground motions may be important to consider would be where sensitive equipment mounted on floors may be adversely affected by amplified vertical ground motions.

When vertical ground motions have been considered, it has been common practice to simplistically assume the vertical ground motions are some fixed proportion of the horizontal ground motions. For spectral analyses, it has been very common to assume that a constant ratio existed between the vertical and horizontal responses over the normal range of structural periods.

## 2 MAXIMUM GROUND ACCELERATIONS

It has been observed in recent earthquakes that the vertical ground accelerations sometimes are as great in amplitude and sometimes even greater than the amplitude of the horizontal components of ground motion. This phenomena was very evident in the strong ground motions that were obtained during the October 15, 1979 Imperial Valley earthquake. Using data from stations reported by the United States Geological Survey (USGS) and the California Strong Motion Instrumentation Program (CSMIP), the ratio of the instrumental peak vertical to horizontal ground accelerations are plotted as a function of distance from the fault rupture zone for the Imperial Valley earthquake in Figure 1.

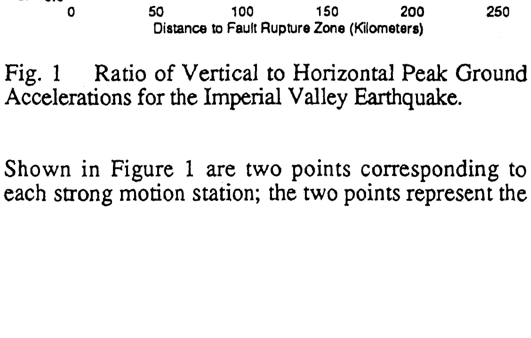


Fig. 1 Ratio of Vertical to Horizontal Peak Ground Accelerations for the Imperial Valley Earthquake.

Shown in Figure 1 are two points corresponding to each strong motion station; the two points represent the ratio of the peak vertical ground acceleration to the peak horizontal ground acceleration for each of the two orthogonal horizontal components recorded at the location.

Figure 2 shows a similar plot except it shows the ratio of the peak vertical ground acceleration to the average of the two horizontal peak accelerations versus distance for the Imperial Valley earthquake.

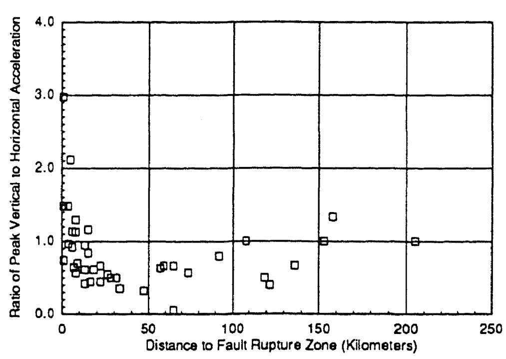


Fig. 2 Ratio of Vertical to Average of Horizontal Peak Ground Accelerations for the Imperial Valley Earthquake.

It can been seen that the greater maximum vertical accelerations generally occur close to the fault rupture zone for the Imperial Valley earthquake. The same phenomena also occurred in the October 17, 1989 Loma Prieta earthquake (Lew, 1991). The same phenomena was also observed at greater distances (i.e., beyond 100 kilometers).

## 3 ANALYSIS OF STRONG GROUND MOTIONS FROM RECENT CALIFORNIA EARTHQUAKES

To determine the spectral relationship between the vertical and horizontal ground motions, strong ground motion records from 15 recent earthquakes in California were studied. The events are listed in Table 1 along with pertinent information about each event. The acceleration-time histories, Fourier spectra and response spectra were obtained from the California Strong Motion Instrumentation Program (CSMIP) and the United States Geological Survey (USGS).

Figures 3 through 11 show the ratio of the vertical to horizontal response spectra computed for 5% damping for the events listed in Table 1. Because of the limited number of records from Events 3 through 9 at Coalinga, these records have been grouped together and analyzed as a single set. All of the records for each event (or group) were statistically averaged and standard deviations determined. The average ratio of vertical to horizontal response spectra as well as the average plus one and two standard deviations are shown; these would be representative of the 84-percentile and 98-percentile of the data, respectively.

The ratios show several interesting similarities in the data from almost all of the events. With the exception of Coalinga Events 3 to 9, all the ratios exhibit ratios of vertical to horizontal motions greater than unity for structural periods of less than 0.2 to 0.3 seconds for the average of all data. For structural periods greater than 0.2 to 0.3 seconds, the ratio drops dramatically to about one-half or less in most cases. Some of the data suggest that the ratio increases with the structural period, particularly above 1 second. It should be noted that the response spectra data was available for all the periods indicated in Figures 3 to 11. Some of the response spectra data from the Palm Springs earthquake was truncated at about 1.7 seconds; some of the data from the Whittier Narrows event was truncated at about 1.4 seconds; and for the Loma Prieta event, the data was truncated at various periods above 3.3 seconds. Therefore, the ratios above these periods for these earthquakes cannot be treated as reliable.

The data from the Coalinga Events 3 to 9 were all recorded at the same two recording stations and the epicenters of all of these events are all within about 10 to 15 kilometers of the stations. All of these events are generally only of moderate size being from magnitude 4.3 to 6.0

Table 1. Strong Ground Motion Records Analyzed.

| Earthquake Event | Magnitude | Date of Event | No. of Records | Source of Data |
|---|---|---|---|---|
| Coyote Lake | 5.7 | August 6, 1979 | 8 | Porcella et al., 1979 |
| Imperial Valley | 6.6 | October 15, 1979 | 4 | Porter, 1983 |
| Westmorland | 6.0 | April 26, 1981 | 2 | CSMIP, 1981 |
| Coalinga Event 2 | 5.1 | May 8, 1983 | 5 | CSMIP, undated |
| Coalinga Event 3 | 5.1 | June 10, 1983 | 2 | CSMIP, undated |
| Coalinga Event 4 | 5.3 | July 9, 1983 | 2 | CSMIP, undated |
| Coalinga Event 5 | 6.0 | July 21, 1983 | 2 | CSMIP, undated |
| Coalinga Event 6 | 5.0 | July 21, 1983 | 2 | CSMIP, undated |
| Coalinga Event 7 | 5.1 | July 25, 1983 | 2 | CSMIP, undated |
| Coalinga Event 8 | 5.3 | September 9, 1983 | 2 | CSMIP, undated |
| Coalinga Event 9 | 4.3 | September 11, 1983 | 2 | CSMIP, undated |
| Morgan Hill | 6.2 | April 24, 1984 | 19 | Shakal, Huang, Parke, and Sherburne, 1986 |
| Palm Springs | 5.6 | July 8, 1986 | 17 | Huang, Parke, Sherburne, and Shakal, 1987 |
| Whittier Narrows | 5.9 | October 1, 1987 | 34 | CSMIP, 1989 |
| Loma Prieta | 7.1 | October 17, 1989 | 52 | Shakal et al., 1989; Maley et al., 1989 |

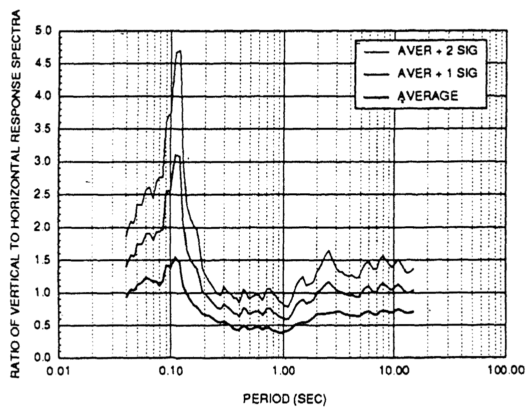


Fig. 3 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Coyote Lake Earthquake

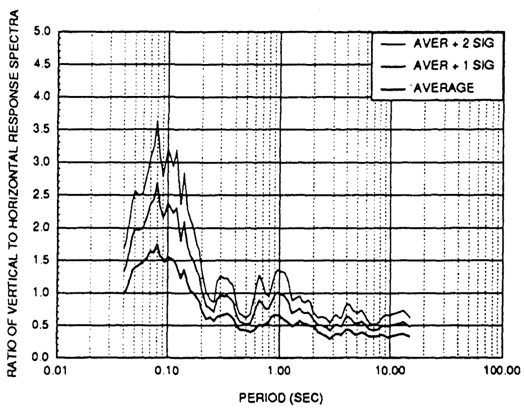


Fig. 4 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Imperial Valley Earthquake

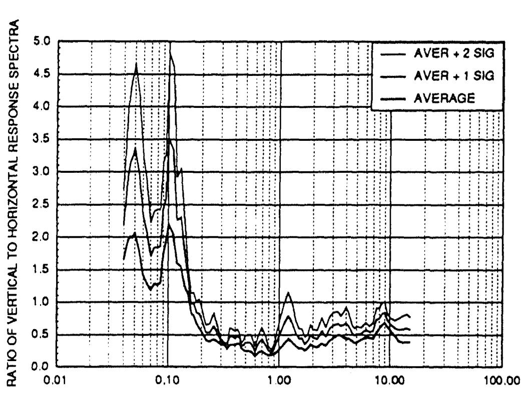


Fig. 5 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Westmorland Earthquake

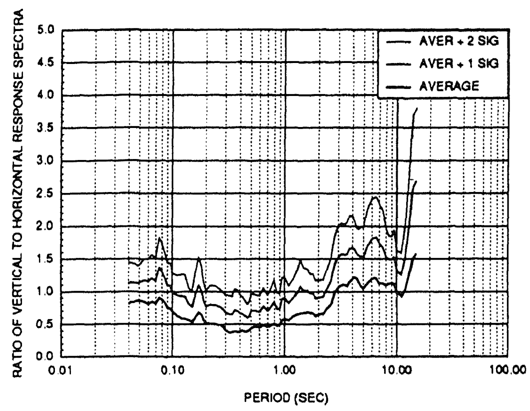


Fig. 6 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Coalinga Event 2

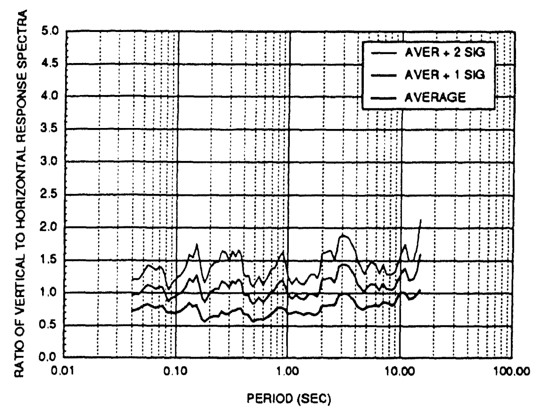


Fig. 7 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Coalinga Events 3 to 9

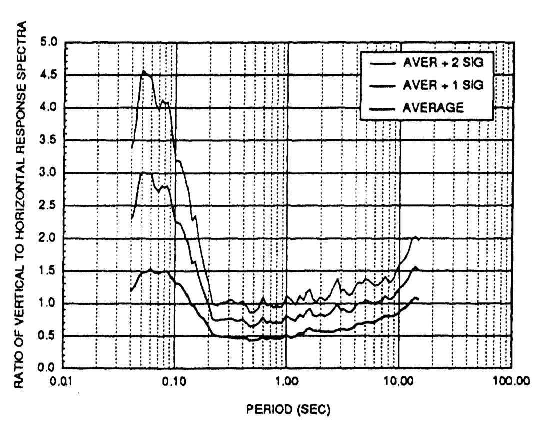


Fig. 8 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Morgan Hill Earthquake

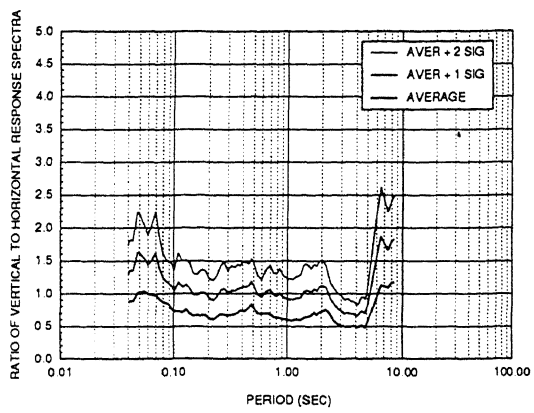


Fig. 9 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Palm Springs Earthquake

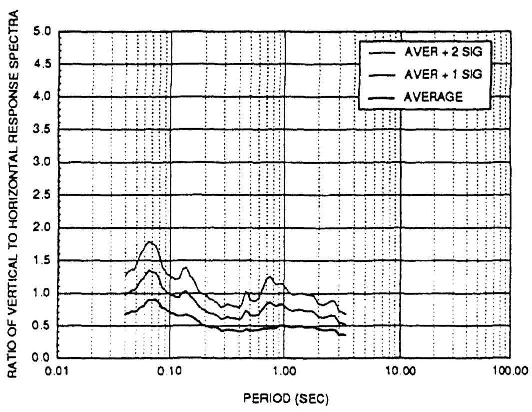


Fig. 10 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Whittier Narrows Earthquake

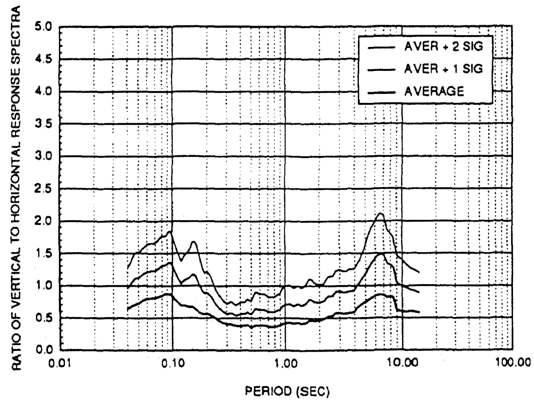


Fig. 11 Ratio of Vertical to Horizontal Response Spectra for 5% Damping - Loma Prieta Earthquake

## 4 CONCLUSION

The analyses of recent California earthquake strong ground motions indicate that there is a strong dependence on period (or frequency). The normal practices of assuming the vertical accelerations to be a set proportion (like two-thirds) of the horizontal accelerations may be either conservative or unconservative depending upon the structural period of interest.

Additional research is planned to determine whether site-specific soil and geologic conditions may have an influence on the vertical accelerations and how they may relate to the horizontal accelerations. Another parameter to be studied is the dependence on distance to the fault rupture or energy release zone of an earthquake; all of the data from Coalinga Events 3 to 8 were obtained at relatively close distances and do not follow the general trend of the other data. The nature of the source mechanism may have some influence and needs further study.

It would also be desirable to conduct similar studies on earthquake data from other parts of the world other than California or the Western United States.

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