Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

3-3-11

TOPOGRAPHICAL AMPLIFICATION - A REALITY ?

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SUMMARY

Aftershocks of the 3 March 1985 Central Chile earthquake (M_S = 7.8) recorded at a temporary dense array established at Canal Beagle are used to quantify the range of frequencies over which amplification of seismic energy takes place due to topographical effects. Buildings on the ridges of Canal Beagle were extensively damaged during the main shock. Furthermore, two sets of records obtained at a ridge after the May 2, 1983, Coalinga earthquake ($M_S = 6.7$) also depict amplification within specific frequency bands.

Topographical amplification of seismic energy, documented by analysis of the two data sets, is shown to be a reality in the range of frequencies of engineering interest.

INTRODUCTION

In different parts of the world, topographical amplification has been hypothesized by post-earthquake chasers. Limited theoretical and experimental studies on ridge effects were performed by a number of authors including Boore (Refs.1 and 2), Bard and Tucker (Ref.3) and Davis and West (Ref.4). Shiga and others (Ref.5) have performed theoretical studies on effects of irregular geophysical features on seismic ground motions. The results of their study of the features, particularly of hills, display various degrees of frequency-dependent amplification of motion. Ridge effects were observed in many hill towns of southern Italy during post-earthquake studies of the Campania–Basilicata (Italy) earthquake of 1980 (Refs. 6 and 7).

During the 3 March 1985 Central Chile earthquake ($M_S = 7.8$) at Canal Beagle, a heavily populated subdivision of the coastal town of Viña del Mar, the observed damage pattern of structures attributed to amplification due to topographical effects was substantiated by frequency dependent spectral ratios developed from aftershock recordings using a temporary dense array (Refs.8 and 9). These spectral ratios showed that amplification occurs on these ridges within the frequency ranges of the structures that are damaged.

Following the May 2, 1983 Coalinga earthquake ($M_S = 6.5$), aftershocks were recorded by strong-motion accelerographs temporarily stationed on a small ridge within the Anticline Ridge formation (Ref.12). The spectral ratios developed from this data set also show amplification of motions at the crest of the ridge as compared to the two gulley sites approximately 100–150 meters apart.

THE CANAL BEAGLE (CHILE) CASE

In Figure 1, typical velocity seismograms from one event are shown corresponding to a set of temporary dense array stations (CBA–CBG) established as shown in Figure 2. The seismograms, plotted to the same scale, show the degree of amplification of motions at the ridge stations CBB, CBC, CBE and CBF as compared to CBA which is in the canyon, as well as two reference stations (MUN and VAL) in downtown Viña del Mar (an alluvial site) and at Valparaiso (an amphibolite gneiss rock site), respectively. These reference stations MUN and VAL are approximately 2 km and 6 km from Canal Beagle, respectively and are in the vicinity of the Chilean Strong-Motion Network stations. The Canal Beagle subdivision stations (CBA–CBG) were all sited on alluvial deposits and decomposed granite (locally know at Maicillo). In selecting the particular sites of stations, care was taken to have representative ridge, canyon, and main hilltop locations in order to be able to distinguish the ridge effect. Since the Canal Beagle stations are further away from the epicenter than the reference rock station, VAL, conservatively, the distance effect can be neglected; therefore, the spectral ratios of stations CBA/VAL provided in Figure 3 display the frequency-dependent geological amplification at Canal Beagle relative to the rock station in Valparaiso. On the other hand, since Canal Beagle stations are close to one another (see Figure 2 for scale) and are all sited on similar geology, the spectral ratio of motions at a ridge station with respect to the station CBA at the canyon, represents the topographical amplification function, $T_t(\omega) = (A_2(\omega)/A_1(\omega))$ where $A_i(\omega)$ is the Fourier amplitude spectrum at station i. In Figure 4, then, the frequency-dependent topographical amplification is clearly depicted in the spectral ratio plots (between 0–10 Hz) of stations on the ridges with respect to station CBA, which is in the canyon.

In general, the spectral ratios show that the frequency ranges for which horizontal amplification of motion occurs are 4–8 Hz for the canyon relative to the rock site (Figure 3) and 2–4 Hz as well as 8 Hz for the ridges of Canal Beagle relative to the canyon (Figure 4). The frequency range of 2–4 Hz is well within the fundamental frequencies of the four- and five-story buildings observed to be heavily damaged during the main event of March 3, 1985. On the other hand, the frequencies of the two four-story undamaged buildings in the canyon are outside the frequencies (4–8 Hz) for which amplification occurred in the canyon relative to the rock site. These spectral ratios (as well as others to follow) were smoothed with a triangular weighting function with width of 0.15 Hz. Other sets of velocity seismograms and superimposed spectral ratios from different events related to topography of Canal Beagle depict repeatability of frequency-dependent amplification and are documented elsewhere (Refs. 8 and 9).

THE COALINGA (CALIFORNIA, USA)—ANTICLINE RIDGE CASE

Following the May 2, 1983 earthquake ($M_S = 6.5$) near Coalinga, several accelerographs were installed temporarily to record aftershocks (Ref.10). The general location map of the Coalinga anticline, Coalinga, the epicenter of the main shock (May 2), that of the May 9 aftershock, and the locations of the permanent accelerograph stations in the vicinity are shown in Figure 5a. The geology of the anticline is best described as weathered sandstone (sedimentary) at the surface and harder sandstone (Pliocene) below.

Several smaller ridges and gulleys are superimposed on the anticlinal hill. Four temporary and closely spaced accelerographs were installed at the top of a small ridge adjacent to two gulleys of the Coalinga anticline particularly for the purpose of recording aftershocks. These temporary stations are shown in Figure 5b as ARF (Anticline Ridge Free Field-on the ridge, approximately 3 meters from an abondoned oil well rig pad), ARP (Anticline Ridge Pad), ARN

(Anticline Ridge North-in the gulley) and ARS (Anticline Ridge South-in the gulley). While the accelerograph on the pad (ARP) was anchored, the accelerograph at ARF as well as ARN and ARS were placed under a pile of sand bags to prevent them from sliding or rocking.

For brevity, the uncorrected acceleration time histories of one of the several aftershocks (September 9, 1983 at 0916 UTC, $M_s = 5.3$) recorded by the temporary stations are provided in Figure 6. The east-west component of the accelerograph of station ARP did not function properly during both events and are therefore excluded from the processed data.

The frequency dependent spectral ratios derived from Fourier spectra of the corresponding component pairs (the ridge versus gulley stations) are provided in Figure 7. These ratios show amplification of motions between 1 to 6 Hz and at 7.5 Hz.

CONCLUSIONS

Seismograms recorded from aftershocks of these earthquakes in Chile and the United States are processed to calculate spectral ratios that represent only the effect of topography. Because the stations for which these ratios were calculated have the same geology and are closely spaced, the effects of both local geology and distance can be removed. In the case of Canal Beagle (Chile), the spectral ratios repeatedly show various levels of amplification from 2 to 5 Hz and at 8 Hz. In the case of Coalinga, similar trends exist. Topographical amplification should therefore be considered in microzoning of localities exhibiting such features.

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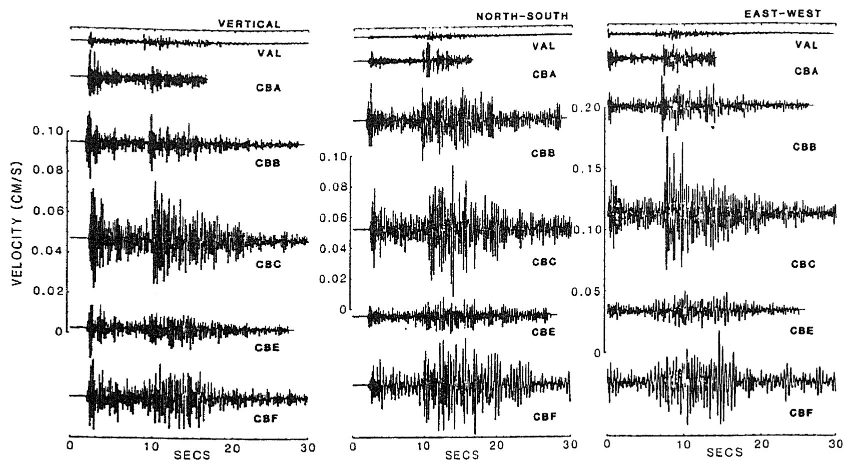

Figure 1. A typical set of scaled velocity seismograms—event 2100652 corresponding to Julian 210 (July 29, 1985) at 06:52 GMT—for the vertical and horizontal components, respectively, from the reference station VAL and Canal Beagle stations CBA, CBB, CBC, CBE, and CBF. Stations CBB, CBC, CBE, and CBF are on the ridges.

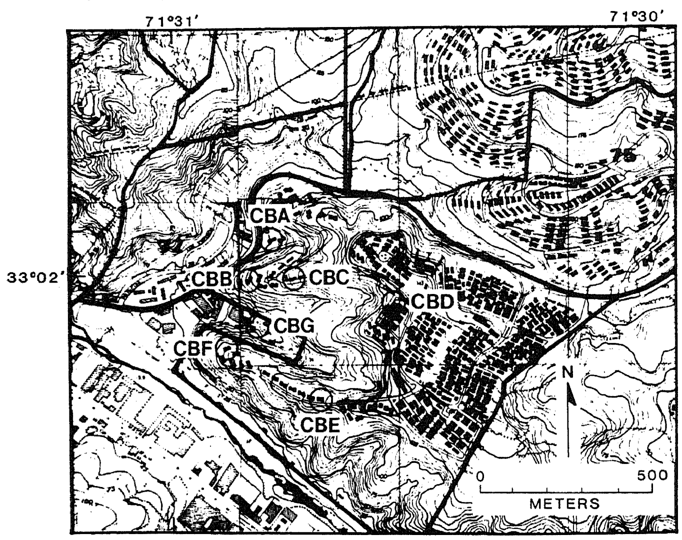

Figure 2. Detailed topography of Canal Beagle. The ridges and the buildings on them as well as the stations established for aftershock studies are indicated. Contour interval is 5 meters.

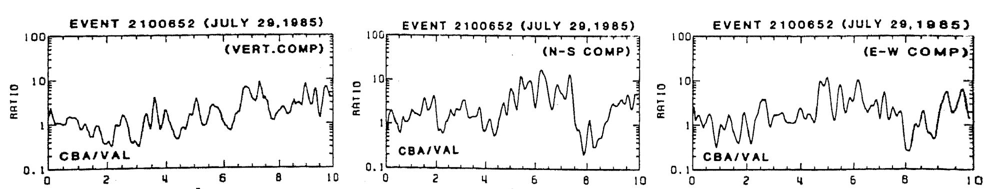

Figure 3. Spectral ratios of event on July 29, 1985 (Julian 210) at 06:52 GMT for the vertical and horizontal components (N–S and E–W), respectively, of stations CBA/VAL.

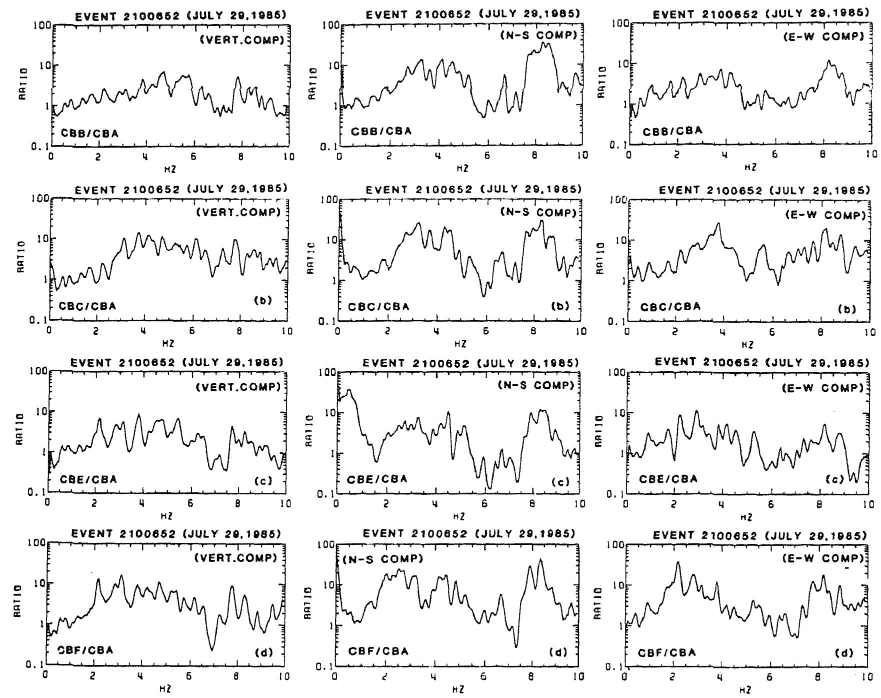

Figure 4. (a) Spectral ratios of event on July 29, 1985 (Julian 210) at 06:52 GMT for the vertical and horizontal components (N–S and E–W), respectively, of stations CBB/CBA. Station CBB is on one of the ridges and station CBA is in the canyon. Spectral ratios of event on July 29, 1985 (Julian 210) at 06:52 GMT for the vertical and horizontal components (N–S and E–W), respectively, of stations (b) CBC/CBA, (c) CBE/CBA, and (d) CFB/CBA. Stations CBC, CBE, and CBF are on the ridges.

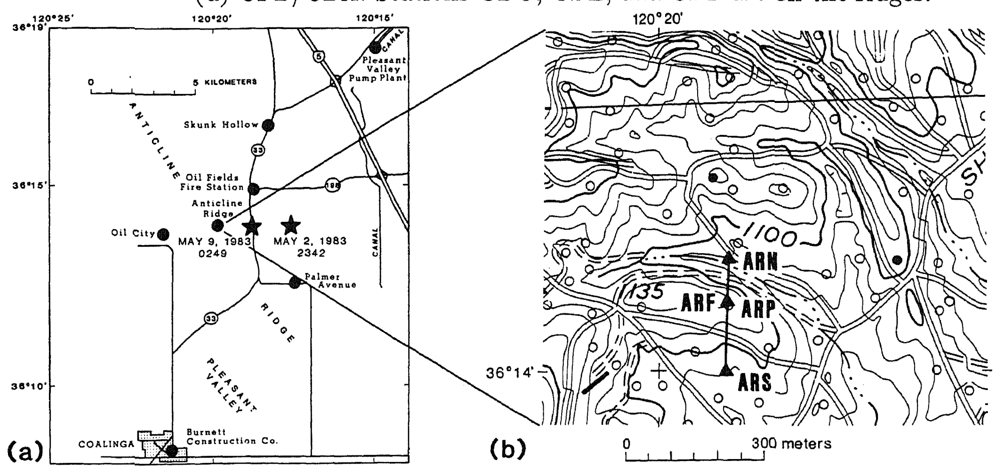

Figure 5. (a) The general location map of Coalinga and Coalinga anticline. The epicenter of the main shock (May 2) and one of the aftershocks (May 9) as well the permanent accelerograph stations (dots) are shown. (b) The topography of the small ridge at Coalinga anticline where temporary stations (ARF, ARP–both at the top of the ridge and ARN and ARS at the two gulleys north and south of the ridge) were established.

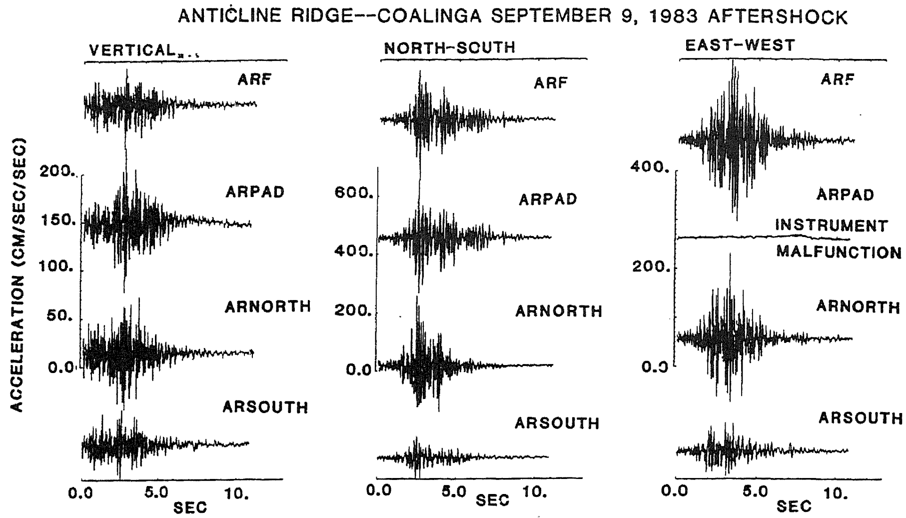

Figure 6. A typical set of scaled acceleration motions recorded at the Coalinga Anticline Ridge temporary array during the September 9, 1983 aftershock (0916 UTC–$M_s = 5.3$).

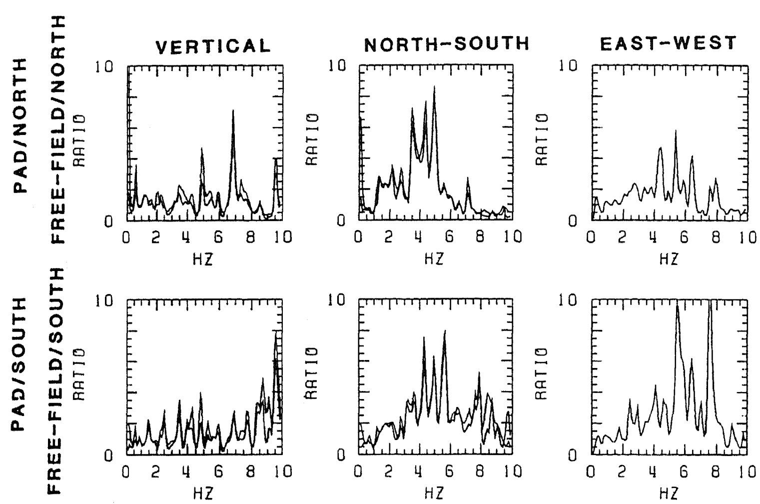

Figure 7. Spectral ratios of the September 9, 1983 aftershock for the vertical and horizontal components (N–S and E–W), respectively. The vertical and north-south spectral ratios (the pad versus north, free-field versus north, pad versus south and free-field versus south) are superimposed.