EVALUATION OF LOCAL SITE EFFECTS IN LIMA CITY, PERU FROM GROUND MOTION DATA

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SUMARY
The present study aims to examine thoroughly the relation between the local site effects and the local subsurface conditions in Lima city, due to the fact that there is little information related to the seismic amplification in this city. This study analyzes the seismic events observed along the Pacific coast of Lima city, which were recorded by 10 stations. Because of the limitation in data, site amplification factors are evaluated by using three different methods: the standard spectral ratio, the spectral inversion method and the H/V ratio, so as to identify the significant peaks and troughs at all sites.

Keywords: Lima city, site amplification factor, La Molina, Callao, empirical methods

1. INTRODUCTION

A future large earthquake is expected to occur in Lima city, the capital and most densely-populated city of Peru. According to several works (Okal et al. (2006) and Pulido et al. (2010)) the seismic gap that has been identified near coast of Lima city might generate a gigantic magnitude ~9.0 Mw event, which could occur any time within the next 20 years.

The present study uses ground motion records observed along the Pacific coast of Lima city, Peru, in which the seismic events were recorded by 10 stations. The relation between local subsurface conditions and the local site effect in some areas of Lima city are discussed based on the results obtained from three empirical methods.

2. AVAILABLE DATA

Data from 2003 to 2008 was used in this study so as to analysis the site effects at 10 stations. Table 2.1 gives pertinent information on the 17 events used in this work, and Fig. 2.1 shows their locations relative to our recording sites.

Table 2.1. Event Information (– Means the Event Was Not Recorded)

Date yyyy/mm/dd	Hour hr:min	Long. (deg)	Lat. (deg)	Mag. (ML)	Depth (km)	Site CSM	Site CAL	Site MOL	Site CDLCIP	Site CER	Site RIN	Site PUCP	Site MAY	Site LMO	Site NNA
2003/05/08	16:33	-77.40	-12.98	5.4	51	*	-	-	-	-	-	*	-	-	*
2003/05/28	21:26	-77.01	-12.48	5.3	51	*	-	-	-	-	-	-	-	-	-
2005/01/17	11:26	-76.78	-12.10	3.8	54	-	-	-	-	-	-	-	-	-	*
2005/03/02	13:48	-76.14	-11.86	5.7	124	-	-	-	-	*	-	-	-	-	*
2005/07/25	06:51	-77.33	-12.24	4.0	42	*	-	*	-	-	-	-	-	-	-
2005/11/10	16:38	-76.22	-12.26	4.0	71	-	*	-	-	-	-	-	-	-	-
2005/12/27	17:02	-76.57	-12.22	4.5	99	*	-	-	-	-	-	-	-	-	-
2006/05/12	03:45	-77.40	-11.96	4.3	80	-	-	-	-	-	-	-	-	*	-
2006/10/20	10:48	-77.02	-13.55	6.2	43	*	-	*	-	-	*	*	*	-	*
2006/10/22	22:14	-77.60	-12.05	3.8	30	-	-	-	-	-	-	-	-	-	*
2006/10/26	22:54	-76.92	-13.44	5.8	42	-	-	-	-	-	-	-	*	*	-
2006/12/11	21:53	-77.37	-11.64	4.2	54	-	-	*	-	-	-	-	-	*	*
2007/08/15	23:40	-76.76	-13.67	7.0	40	*	*	*	*	*	*	*	*	*	*
2007/08/17	13:18	-76.85	-13.61	5.5	23	*	-	-	-	-	-	-	-	*	-
2008/03/29	06:40	-77.73	-12.17	4.3	48	-	*	-	*	-	-	-	-	-	-
2008/03/29	12:51	-77.25	-12.25	5.3	51	*	*	-	*	-	*	-	-	*	-
2008/06/07	13:06	-77.29	-12.48	5.0	67	*	*	-	-	*	-	-	-	*	-

Source parameters were determined by the Geophysical Institute of Peru

Because of the fact that not all the events were recorded at all the ten sites as well as the limitation on data, three different empirical methods have been applied in order to get reliable information about the relevant frequencies on seismic amplification factors, such methods are the traditional spectral ratio technique (Borcherdt 1970), the spectral inversion method (Iwata and Irikura 1988) and the horizontal-to-vertical spectral ratio technique (Nakamura 1988). The processing sequence for the data set to compute the spectral ratios relative to a reference site or relative to the vertical component was as follows. From each record we selected a window of 20 sec, beginning at the shear-wave arrival. This window was cosine tapered (10%) and Fourier transformed. The spectral amplitudes were then smoothed by Parzen windows of 0.6-Hz widths.

All the observation sites are shown in Fig. 2.1 on the geological map of Lima city. According to this map, basically most of the stations (sites MAY, CER, RIN, CAL, CDLCIP, CSM, MOL and PUCP) are located on alluvial soil deposits belonging to the Quaternary Holocene (Fig. 2.1), however sites LMO and NNA are located on cretaceous intrusive rock (Fig. 2.1). For this study, we assigned the NNA rock site as the reference site.

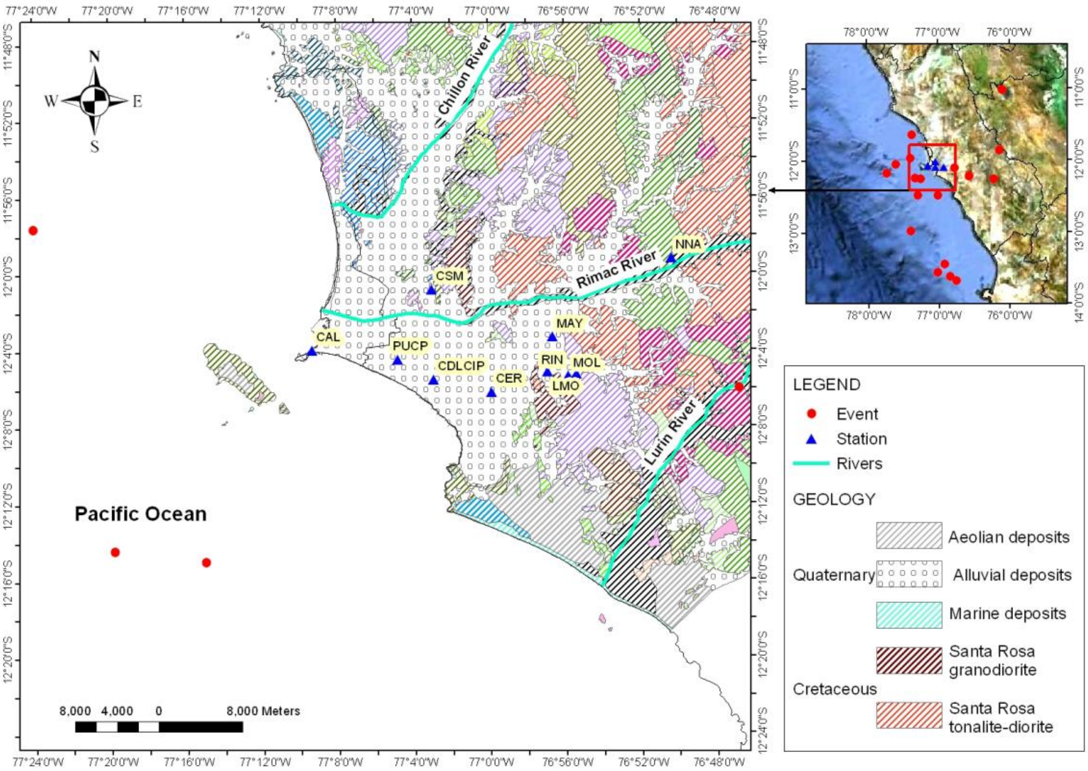

Figure 2.1. Red circles show the epicenter used for this work. Blue triangles represent the stations which are located on the geological map of Lima city.

3. EVALUATION OF SITE EFFECTS BY USING DIFFERENT EMPIRICAL METHODS

The different estimates of site amplification factors for the stations are compared in Fig. 3.1. Those obtained from the Standard Spectral Ratio (SSR) are shown by thick solid lines, site factors estimated by Spectral Inversion Method (SIM) are shown by thin lines, and amplitude factors calculated from the Horizontal-to-Vertical Spectral Ratio (HVSR) are shown by dotted lines. The SSR for LMO site is not presented for this work given that we do not count on enough seismic events that were simultaneously recorded both for LMO and NNA sites.

According to Fig. 3.1, the geometrical averages of SSR are very similar with inversion results in the analyzed frequency range from the analysis of small and large events. Results show that the amplification level obtained by the SIM are slightly larger in comparison to the traditional approach introduced by Borcherdt (1970) as we can see for CSM, MAY, CDLCIP, PUCP, CAL, and LMO sites. This may be due to the time window of 20 sec that tend to increase slightly the inversion results with the length of the time window because of the effects of later arrivals of surface waves in the case of a long time window.

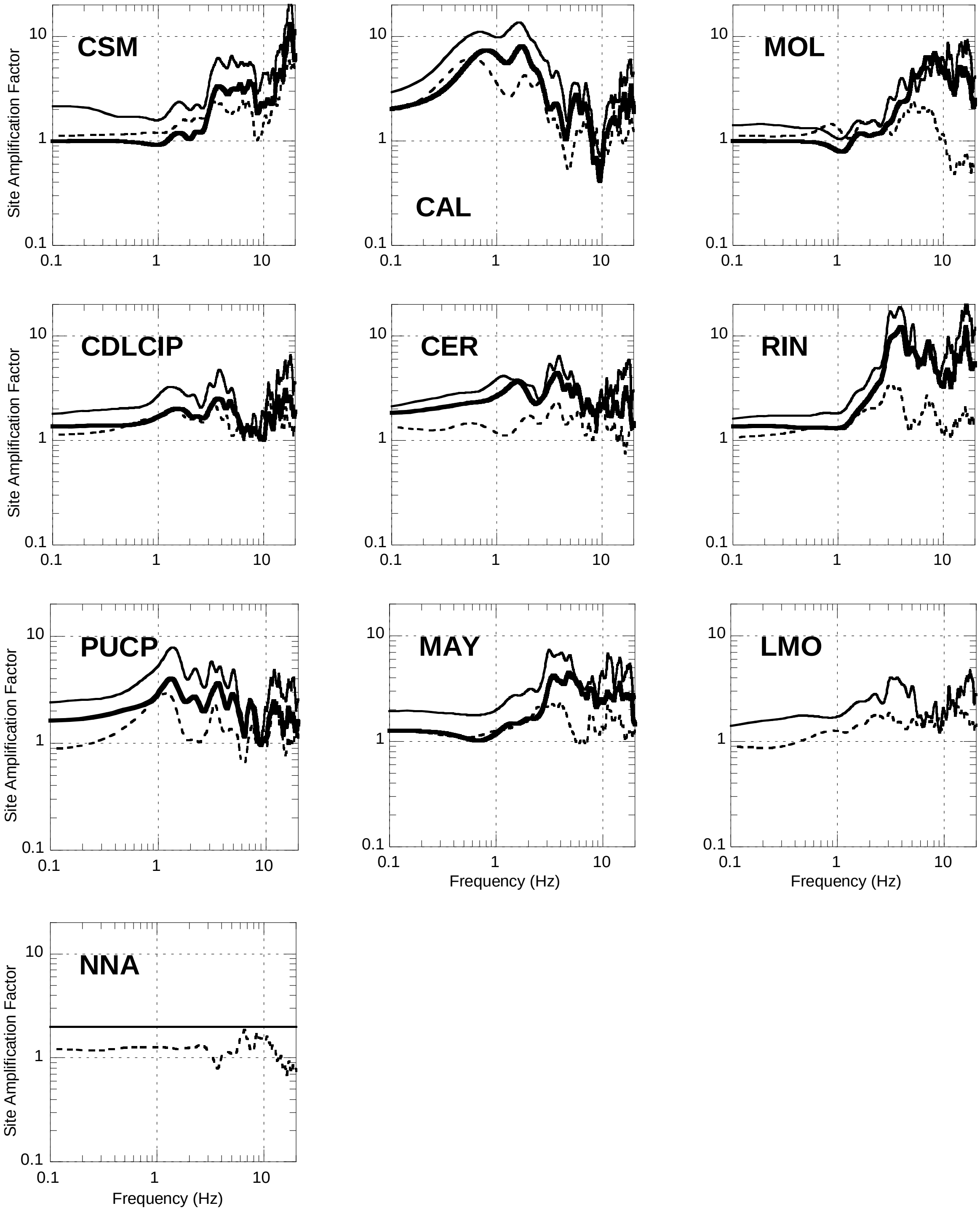

Figure 3.1. Comparison between spectral ratios from the horizontal components with reference to NNA, the Spectral Inversion Method and the Horizontal-to-Vertical Spectral Ratio. Thick solid lines show the geometrical average of two horizontal spectral ratios. Thin solid lines represent the results obtained by the Spectral Inversion Method. Dotted lines show the geometrical average estimated by applying the HVSR.

On the other hand, the geometrical averages of HVSR are also compared with the reference site methods by using the same time window. Results indicate a similarity in the shape of the curves, but HVSR fails for the estimation of the amplification level, since according to Fig. 3.1 most of the sites have much lower amplification in comparison to the other methods. This method assumes that vertical component is expected to be free of amplification, however results obtained by other studies show that subsurface structure influences the vertical component in the same order of magnitude as the horizontal components (Riepl et al. 1998).

For CSM, MAY, CER and CDLCIP stations, even though the amplification level does not fit very well among the analyzed empirical methods, the same peaks and troughs can be identified by the three methods for these four stations. Site effects on these curves (Fig. 3.1) show several peaks of amplification between 3 and 8 Hz as well as a small bump that occurs between 1 and 2 Hz, which is more evident for CER station. Furthermore, relatively large ratios at high frequencies of 10 Hz, moreover for CSM station that has the highest amplification in comparison to the other three sites. There is also a significant trough at about 9 Hz, for CDLCIP site the prominent trough varies in the frequency range between 6 and 10 Hz.

The different estimates for PUCP station show that several peaks of amplification can clearly be distinguished in the frequency range between 1 and 8 Hz, at least four peaks, as well as a trough at about 9 Hz as the previously mentioned stations.

For MOL station, the amplification level both for the SSR and the inversion method are in good agreement for the frequency range investigated. Higher amplifications occur at frequencies larger than 3 Hz as we can see in Fig. 3.1. Amplification effects evaluated by the HVSR do not coincide well with the other methods, however the shape of the site spectra is similar.

The site response at RIN site is dominated by three prominent peaks which are well predicted in the three methods, even though the HVSR predicts a lower amplitude in comparison to the reference site methods. The strongest peaks of amplification occur between 3-4 Hz, 7-8 Hz, and frequencies larger than 10 Hz.

For CAL station in comparison to the other sites which amplification levels are larger at higher frequencies, this site shows clearly that strongest amplifications appear at frequencies lower than 3 Hz for the three methods, however amplifications at higher frequencies also occur but are comparatively low. In addition, a trough at about 9-10 Hz has also been detected.

The station located on a rock outcrop, LMO site, has relatively small variations against frequency given that rock sites have local site response.

Finally, the result of horizontal-to-vertical spectral ratio for NNA site, the reference station, shows that the average transfer function is flat for frequencies lower than 3 Hz, nonetheless no significant trends appear but values are around one. Furthermore, the frequency response at NNA site has a trough, and the trough makes the peaks at frequencies larger than 10 Hz for soft soil sites. That is why, sediment sites show peaks at frequencies larger than 10 Hz that are attributed to the spectral response of NNA given that a relatively strong trough is found.

4. LOCAL SURFACE CONDITIONS AND LOCAL SITE EFFECTS

According to the Fig. 2.1, most of the stations are located on Quaternary alluvial deposits with the exception of the rock sites LMO and NNA. CSM, MOL, CER and CDLCIP sites are installed on alluvial gravel deposits that cover a large portion of Lima city. The site response at these stations are characterized by relatively large peaks at around 3-8 Hz, which represent the resonant modes between the poorly graded gravel deposit and other shallow materials that overlie this deposit. PUCP site is also placed on alluvial gravel deposits, nonetheless this site shows several prominent peaks being the most significant at about 1-2 Hz (Fig. 3.1). Our results suggest the presence at the surface of relatively softer soil layers that might contribute to the local response at this site.

MAY and RIN sites are installed on sand and sill deposits with a thickness less than 10 m. At MAY station, spectral ratios show slightly large amplitudes at about 3-5 Hz due to the presence at the surface of these relatively soft layers but with a thickness less than 3 m that overlie on alluvial gravel. However, the site response at RIN station is dominated by a prominent peak between 3 and 4 Hz, which represents the first resonant mode at this site. This station shows the largest amplification factor in comparison to the other sites in this frequency range due to the medium dense sand deposits with a thickness larger than 5 m according to a soil pit near at this site. This significant peak that responds at about 3 Hz has also been detected by Stephenson et al. (2009).

On the other hand, CAL station shows a different behavior of amplification since important amplifications appear in the range frequency lower than 3 Hz due to the fact that this station is placed on gravel layer that overlies on a thick clay deposit.

5. DISCCUSSION

Even though most stations are located on alluvial soil deposits belonging to the Quaternary Holocene, the presence at the surface of a soft soil layer influences in the site response, such evidence is moreover seen in the stations installed in La Molina (RIN and MOL sites) and Callao (CAL site) districts, places that back in time have been reported to be affected by the influence of local subsurface conditions.

Both MOL and RIN stations, located at La Molina district, have the highest amplification levels at high frequencies (over 3 Hz) in comparison to the other sediment sites that are also located on quaternary deposits.

Works developed by Lee and Monge (1968) and Stephenson et al. (2009) report that this place has a complex subsurface structure that might contribute to the local site response at La Molina. In terms of our results, the horizontal-to-vertical spectral ratio for both stations present much lower amplitudes in comparison to the reference site methods, Riepl et al. (1998) reports that it is probably the complex subsurface structure that influences the vertical component in a similar manner to the horizontal components, that makes the amplification level lower.

In addition, MOL, RIN and CSM sites show strong peaks at frequencies larger than 10 Hz, this may be caused by topographic effects given that these stations are installed very close to a hill, so further studies are needed to have a better understanding.

The site response for CAL station shows highest amplifications for frequencies lower than 3 Hz in accordance to the gravel layer that overlies on a thick clay deposit, nonetheless a relatively large peak is also detected in the frequency range 5-8 Hz, which is also detected for the rest of sediment sites but with different amplification levels. This peak may correspond to the fundamental mode of the alluvial gravel deposit with a thickness of at least 86 m.

6. CONCLUSSION

In spite of the limitation of data, the application of the three empirical methods has allowed to evaluate the site effects on examined sites, since information about frequencies at which important amplification might appear have been provided for the study area.

Our results indicate that sediment sites show prominent peaks in the frequency range at 3-8 Hz, due to the surface layers that overlie on the alluvial gravel deposits. Most of these stations show relatively high amplification levels. Nonetheless, CAL site shows a different behavior of amplification because of soft clay layer that underlies on this site.

From the stations installed in La Molina district, a significant peak at about 3 Hz has been detected in RIN site, which has also been detected by other studies. Due to amplification level obtained by the horizontal-to-vertical spectral ratio which is much lower in comparison to the reference site methods, our results suggest that this occurs because of the complex near-subsurface structure that exists in La Molina.

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