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GEOPHYSICAL ASPECTS OF THE LISBON TOWN SITE EFFECTS AND THE 1755 EARTHQUAKE

Abstract

The 1st November 1755 earthquake was the greatest earthquake ever felt in Lisbon. Its occurrence increased the interest of the scientific community for the explanation of the mechanisms of earthquake generation. Its effects, observed for almost all over Europe, shocked the public opinion.

In this paper a general view of the damages produced by the 1755 earthquake is presented and some geophysical aspects, important for the seismic behaviour of the town, are described. Using some experimental results as an auxiliary tool, an attempt to correlate the general distribution of damages with the site geophysical characteristics is made.

Introduction

Due to its particular situation, Lisbon has suffered in the past several violent quakes: more than 120 earthquakes were felt since the 11th century, 9 of them caused important damages and 4 reached an intensity (MMI) greater than or equal to VIII [1,2]. The most recent large earthquake was the famous "1755 Lisbon Earthquake" which caused the destruction of great part of the town [3]. In this century, though several quakes were felt, none caused severe damage. But strong tremors can happen at any moment: a high magnitude earthquake at a long epicentral distance (like the one in 1755), or a moderate magnitude earthquake at a shorter epicentral distance (for instance, due to the activity of some faults near the town, as it occurred in 1531).

It is well known that local soil and topography have a clear influence on seismic wave propagation. Examples of these effects were widely observed in the recent earthquakes of Mexico (1985), Armenia (1988) and Loma Prieta (1989). However, the exact influence of these factors is not yet well understood.

Lisbon presents many geological contrasts and its topography is very irregular. Since 1980 there has been a great concern with local effects in the town and several experimental and theoretical studies were made [4]. Despite all the work produced, the different aspects of the problem are not yet completely clarified, and more work (specially field work) is needed to try to understand the behaviour of the town in the past earthquakes and to foresee its behaviour on future earthquakes.

Geology and topography of the town: a short description

The geology of Lisbon is quite complex presenting many contrasts, as it can be seen in the geological map of the county, published by the Serviços Geológicos de Portugal at the scale of 1:10 000 [5]. In the western zone, there is a predominance of rock masses essentially composed of basalt and limestones, while towards the east, this structure is covered by progressively thicker Miocene deposits. These sediments have a differentiated lithology which gives them different geotechnical properties. Figure 1 displays a sketch of the geotechnical map based on the surface geology and on the geotechnical properties of the different formations. As far as dynamic characterisation is concerned, soils were classified into 5 categories according to shear wave velocities [6].

The topography of the town is also irregular, presenting several hills separated by narrow valleys which are the remnants of old streams. These valleys are filled in with thin alluvial recent deposits (20m maximum thickness) which have a low seismic impedance; this may have important consequences for the seismic response of the town. Figure 2 displays a sketch of the general topography of the town, showing its great variety.

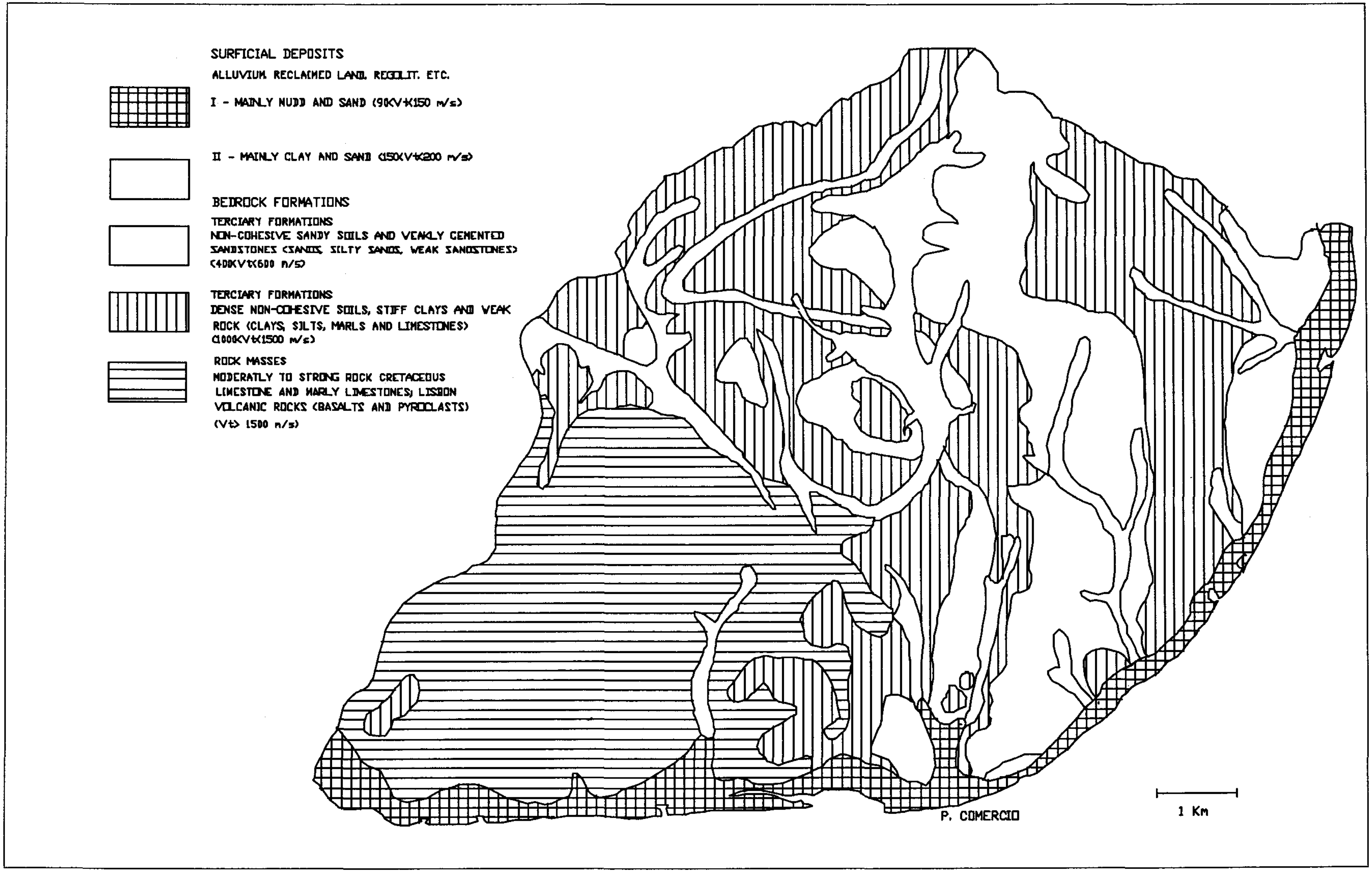

Figure 1 - Geotechnical map of the Lisbon County

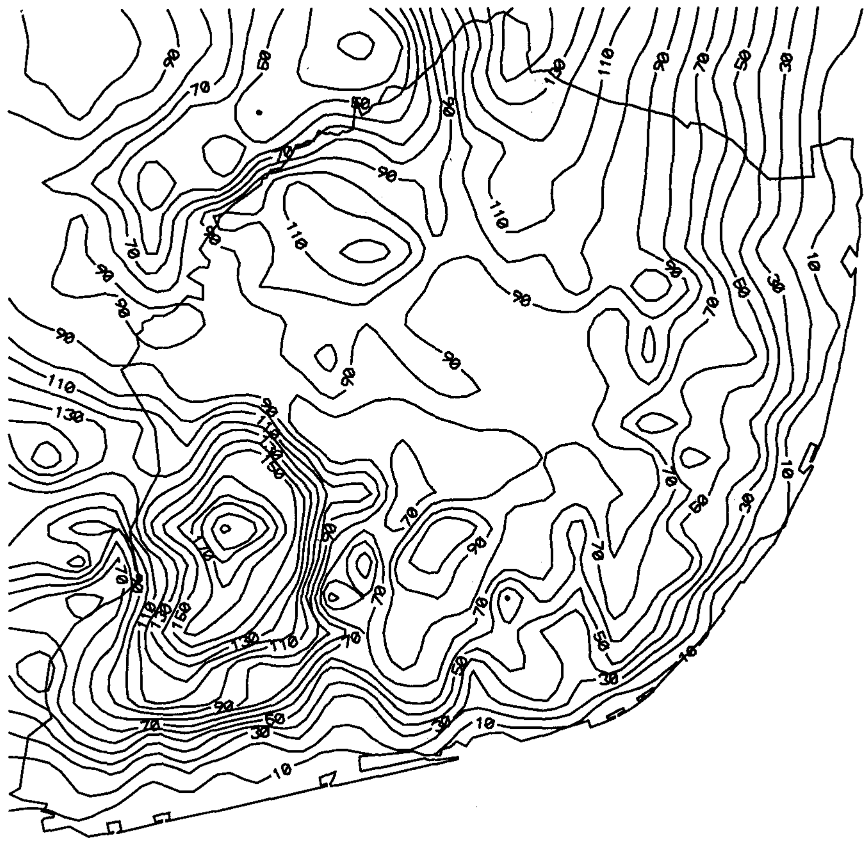

Figure 2 - General view of the Lisbon topography

Historical seismicity and the 1755 earthquake

Among the earthquakes which caused intensities greater than or equal to VIII in the town of Lisbon, the 1531 and the 1755 are the most recent ones. These two earthquakes are believed to correspond to the two main seismogenetic sources affecting the town of Lisbon: the Lower Tagus Valley, a near source believed to be responsible for the 1531 earthquake, and the Gorringe Bank, a distant source believed to be responsible for the 1755 earthquake.

The 1531 earthquake, reached an intensity of VIII to IX over the town, and the most important damages were observed in the downtown alluvium and hillsides. Liquefaction phenomena and landslides were observed. An anomalous rise on the river level was observed throughout the Tagus Valley. A sulphurous scent was set free, showing the ancient volcanic activity of the Lisbon area. About 25% of the houses were damaged and 10% suffered total collapse.

On November 1st, 1755, Lisbon was surprised by a violent earthquake which effects were felt throughout Europe. For instance the water in the Lamond Lake, in Scotland, vibrated for one hour and a half with an amplitude of 60 cm. This is considered by several authors the biggest earthquake ever occurred and has an estimated magnitude of 8.5 to 9 [2].

In Lisbon it caused severe damage, and it was felt with an intensity of IX to X in the Southeast zones (downtown and central hills), and VIII in the remainder zones of the town [3], figure 3.

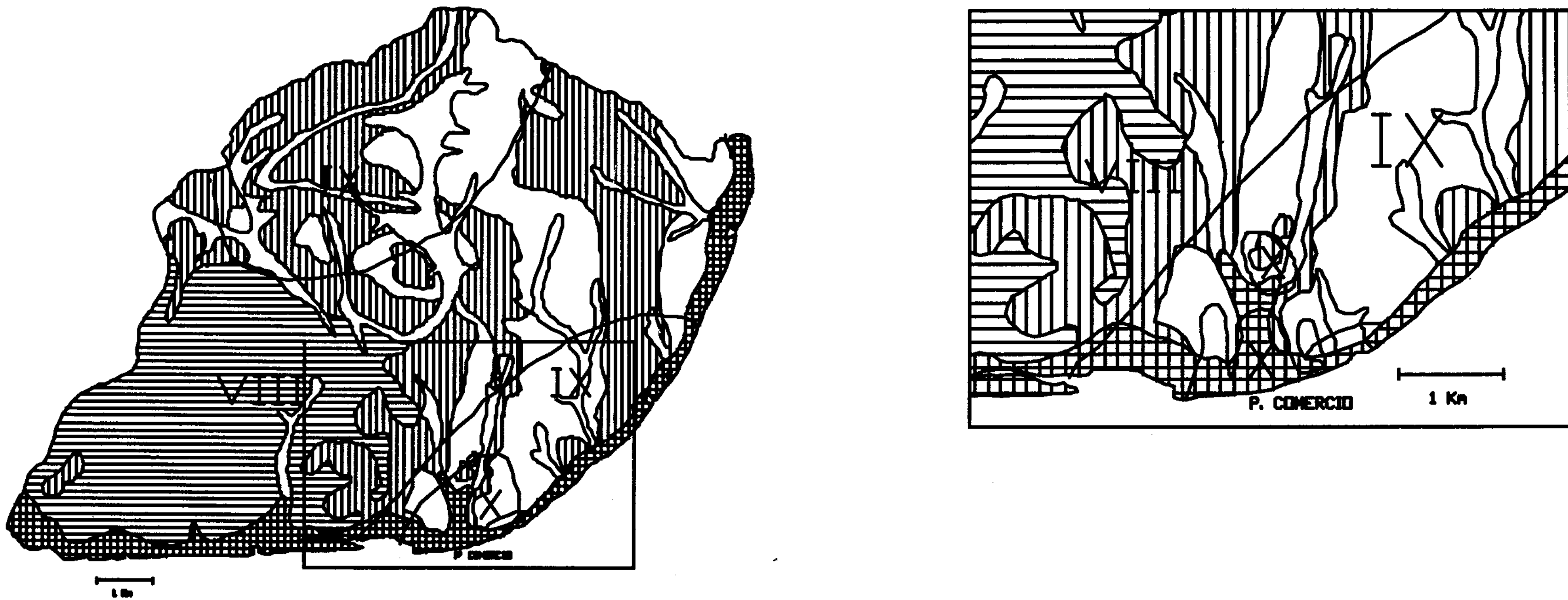

Figure 3 - Isosseimals of the November 1st 1755 earthquake in Lisbon

After the quake a tsunami occurred, increasing the damage on the riverside zones, and a big fire propagated for 5 to 6 days in the central part of the town, destructing a great part of the monuments which had resisted to the main shock. At the end, 32 churches, 31 monasteries, 15 convents, 53 palaces and 60 chapels were completely destroyed; among the 20 000 existent houses only 3 000 were not severely damaged and about 10% of the population died [7].

The isosseimal curves presented in figure 3, show an irregular spatial damage distribution which is an evidence of the existence of site effects. The structures with lower natural frequency (2 - 2.5 Hz) were more damaged than those with higher natural frequency (8 - 10 Hz) [2], showing the importance of the shock spectral characterisation and of the seismic behaviour of each geological unit.

Local effects: examples and theoretical modelling

In general, site effects can be separated in two kinds due to: (i) a great impedance contrast between the surface formation and the bedrock; (ii) an irregular topography. Enclosed in the first kind are the alluvial valleys which present "soft" sediments over a hard rock. In the second kind are the several hills which could experience the effects of diffracted seismic waves on the top and on the hillsides.

In 1991 an experimental study was performed in Lisbon, in order to look for site effects in some alluvial valleys as well as in the Castle hill [8]. The field experiment consisted on recording the seismic impact produced by two explosions made in the Tagus River bed. The seismic stations were located on rock sites, on alluvial sites and on the bottom and the top of the hill.

Figure 4 displays the transversal component of the seismic signals recorded on the Alcântara Valley. Station 32 was located on the riverside and station 33 was located inside the alluvial valley which is filled with soft sediments (the thickness of these sediments was 30m under station 32 and 15m under station 33); station 35 was located on a rock formation, the same which is beneath the sediments of the valley.

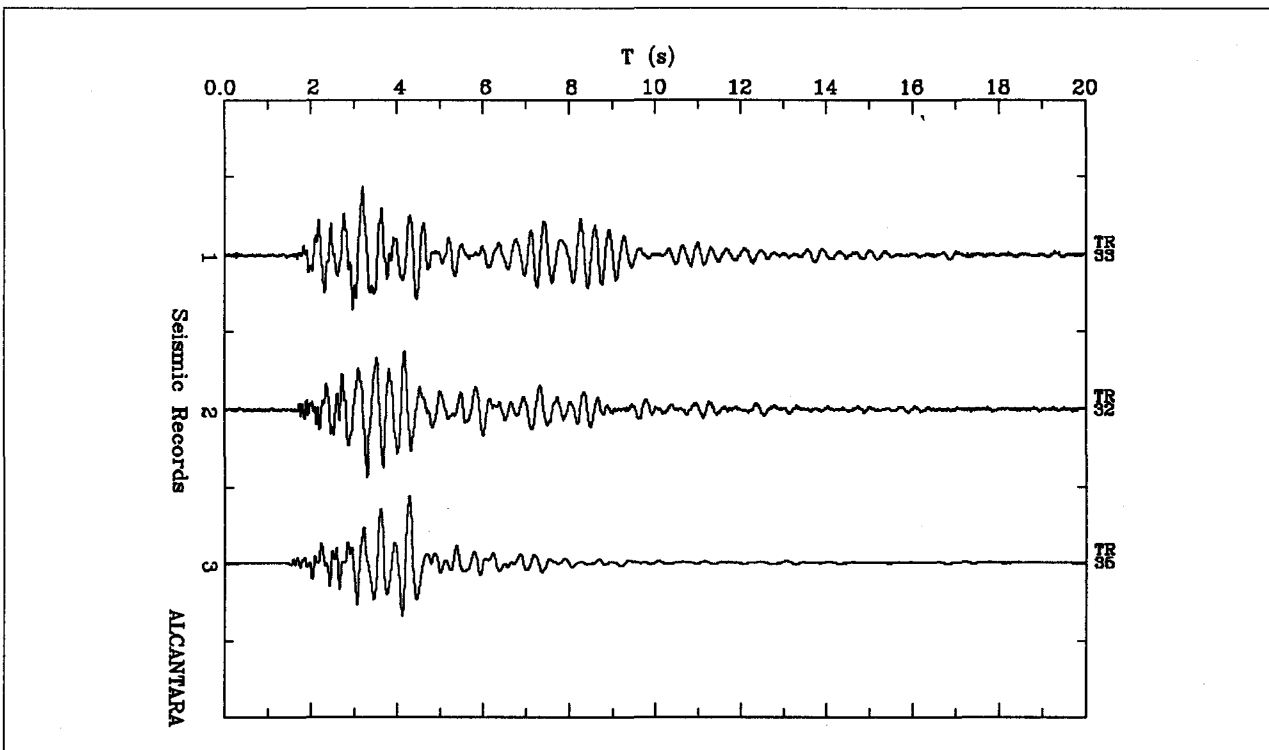

Figure 4 - Seismic signals recorded in the Alcântara Valley

Figures 5 and 6 display the Fourier spectra of the seismic records. It can be seen that the stations located on the alluvial valley exhibit a spectral energy greater than that of the station located on rock, showing an amplification for some specific frequencies. Figure 7 displays the spectral ratio between these stations: for 2Hz the amplification is greater than 6 for station 32, and greater than 3 for station 33; for 4Hz the amplification reaches almost 4, for station 32, and almost 3 for station 33; for 5.7Hz the amplification is greater than 8, for station 32, and almost 3 for station 33.

These results show the importance of the thickness of the sediments under the alluvial valley.

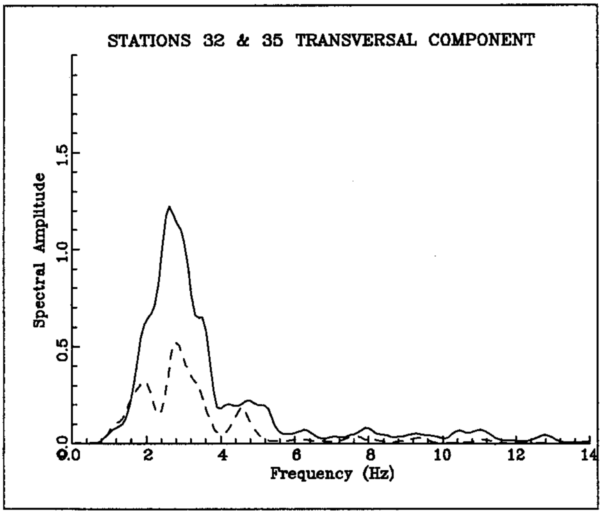

Figure 5 - Fourier velocity spectra (mm/s) for stations 32 (full line) and 35 (broken line)

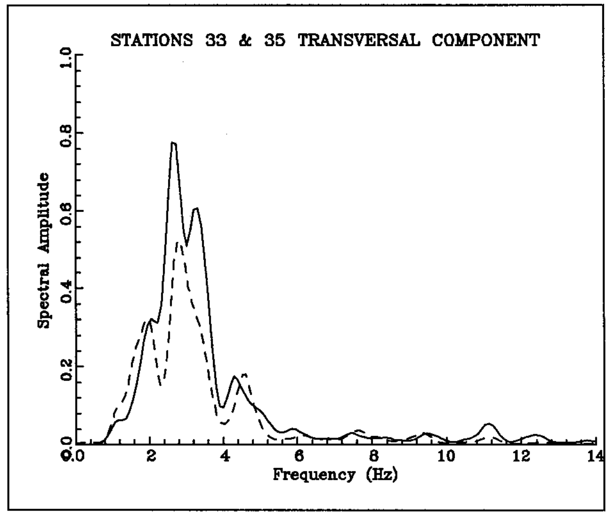

Figure 6 - Fourier velocity spectra (mm/s) for stations 33 (full line) and 35 (broken line)

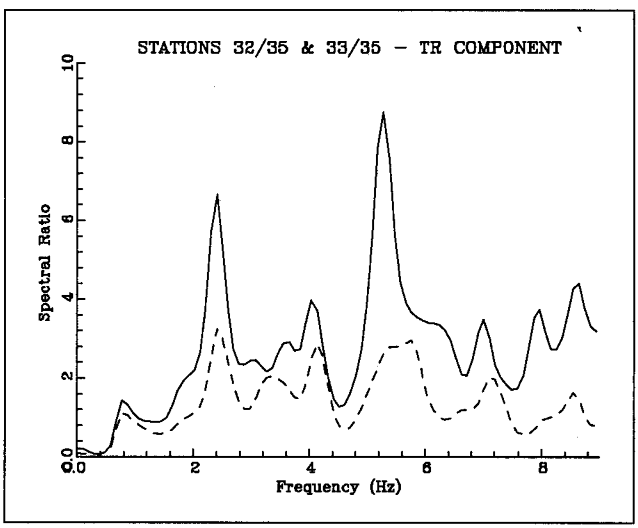

Figure 7 - Spectral ratio for stations 32/35 (full line) and 33/35 (broken line)

The seismic behaviour of the Castle hill can be observed by the analysis of the seismic signals recorded on this hill, figure 8. Station 3 was located on the bottom and station 9 on the top of the hill. The rock formation under these stations is mainly composed by clays and weakly cemented sandstones, corresponding to the "softer" tertiary formation of the geotechnical map. Unfortunately the stations located on the hillsides did not record the explosions.

In figure 8 it can be seen that station 9 presents greater amplitudes for frequencies between 1.7 Hz and 2.2 Hz and also, a coda wave more important for the same frequency range. The Fourier analysis shows that the spectral ratio reaches a value near 6 for this frequency range (figures 9 and 10).

This result shows the importance of topographical structures on the characterization of seismic propagation.

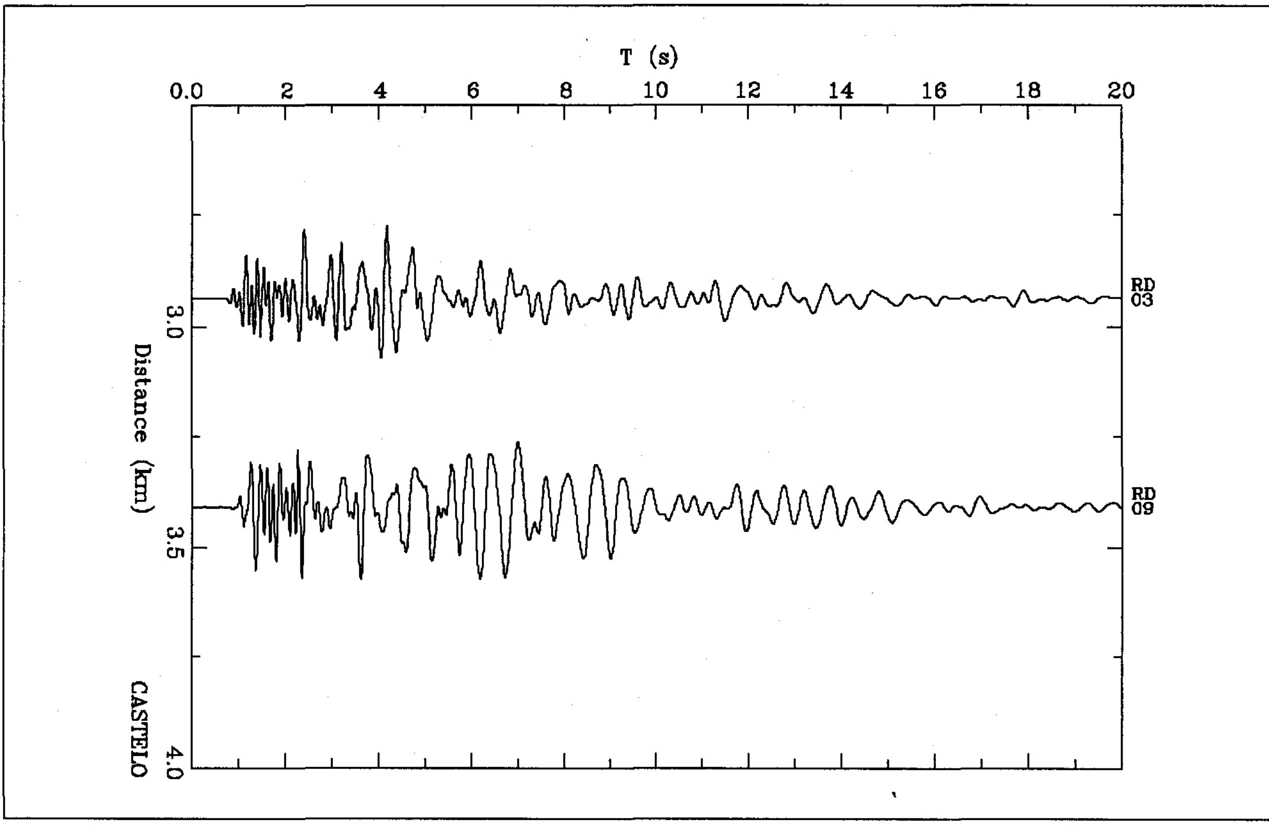

Figure 8 - Seismic signals recorded on the Castle hill

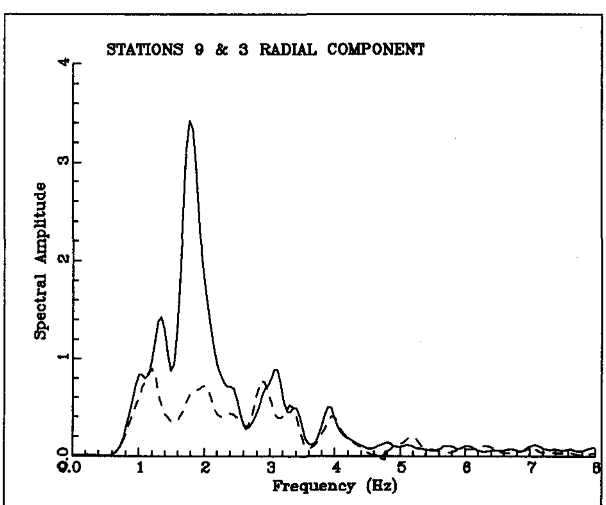

Figure 9 - Fourier velocity spectra (mm/s) for stations 9 (full line) and 3 (broken line)

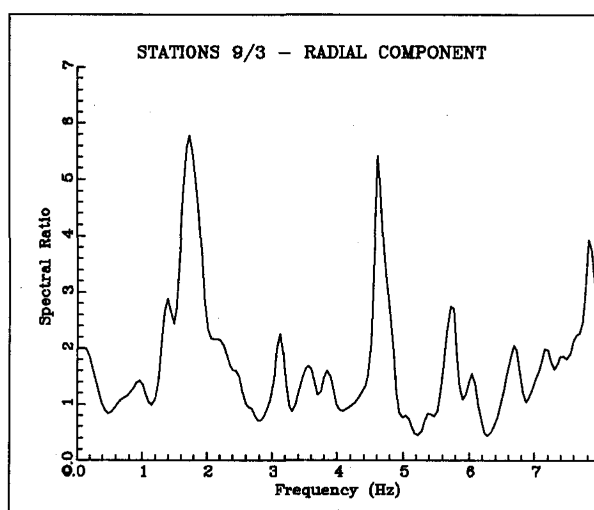

Figure 10 - Spectral ratio for top/bottom records on the Castle hill

Conclusion

The experimental study performed in Lisbon was made in order to study the amplitude of the soil vibration and its predominant frequencies. It is necessary to expand these studies in order to determine the azimuthal dependence for the seismic propagation as well as other geophysical properties. Some geotechnical aspects which were not taken into account, as the liquefaction potential and slope instability, seem to be very important according to historical reports.

The two examples presented here show the importance of a detailed study for the different zones of Lisbon, in particular the zones where special structures are implemented (for instance, hospitals, fire-men head quarters, government buildings, historical monuments, etc.), or the zones where there is a great concentration of people (for instance, business zones during the day and residential zones during the night).

With the knowledge achieved until now, it is possible to design different seismic scenarios (corresponding to a high magnitude earthquake at a long epicentral distance and to a moderate magnitude earthquake at a shorter epicentral distance) for the Lisbon city [6]. Nevertheless, a more detailed study is required in order to better understand the seismic behaviour of the town as to the local effects presented on the historical data.

References

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