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NATURAL FREQUENCIES OF THE ALLUVIUM DEPOSITS IN THE LOWER TAGUS VALLEY

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ABSTRACT

It is well known that the near surface geology can modify the characteristics of the ground shaking. The surface geology of the Lower Tagus Valley is composed mainly by alluvium deposits, reaching a depth of 60 meters, in some sites. These low-impedance surficial layers may have an important role, increasing the amplitude of the ground shaking for certain frequencies, during an earthquake.

A microtremor survey was performed along the Lower Tagus Valley. The ambient noise was recorded for 5 minutes long at a set of 135 sites selected according to a 2 km wide grid. The maximum entropy power spectrum was obtained for each component at each site. Following Nakamura methodology (Nakamura, 1989) spectral ratios between the horizontal and vertical components were obtained.

This study is part of a project aiming to characterize the surface geologic formations of the Lower Tagus Valley, for improving the seismic risk assessment. The first preliminary results will be presented here.

KEYWORDS

Lower Tagus valley; microtremor measurements; alluvium deposits; predominant frequencies;
site effects; geology influence;

INTRODUCTION

Many recent experimental studies seem to prove that the spectral ratio of horizontal to vertical components (H/V), using microtremor records, provides a good estimate of the characteristics of sedimentary sites (Konno *et al.*, 1994, Duval *et al.*, 1995). This methodology has been used to explain the damage occurred during recent earthquakes, such as the 1989 Loma Prieta and the 1993 Kushiro earthquakes (Ohmachi *et al.*, 1991, Toshinawa *et al.*, 1994). Lermo *et al.* (1994) showed that microtremor measurements and strong motion data are equivalent to determine the natural periods of soft sites. The horizontal to vertical spectral ratio, firstly proposed by Nakamura (1989), showed to be not as time dependent as the one-component Fourier spectra. This technique, based on microtremor measurements, can be applied to seismic hazard studies and for microzonation purposes, and is specially useful in areas of low to moderate seismicity.

The Lower Tagus Valley is a large region located in the central part of Portugal reaching the northern part of the Lisbon town. It is oriented in a NE direction, and takes up an area of 3 200 km^2 approximately. It is covered by extensive layers of alluvium deposits and other fluviatic deposits.

It is well known that the near surface geology can modify the characteristics of the ground shaking. These low-impedance surficial layers may have an important role, increasing the amplitude of the ground shaking for certain frequencies, during an earthquake.

The Lower Tagus Valley region is characterized by a moderate seismic activity with several small and medium earthquakes and some strong earthquakes (figure 1). The main seismogenic sources able to produce large earthquakes affecting this region are: the Gorringe Bank, located in the Atlantic Ocean at approximately 250 km SW from Lisbon and is believed to be responsible for the *1755 Lisbon earthquake*; and the Lower Tagus Valley Fault, believed to be responsible for moderate to strong events in the central part of the country, as the 1531 earthquake, which caused severe damage in the Lisbon town.

Nowadays, several small villages are fixed in this valley, presenting a large concentration of population, and conferring an high level of seismic risk to this region.

The study presented in this paper is part of a project developed with the purpose of characterizing the surface geologic formations of the Lower Tagus Valley, for improving the seismic risk assessment. It includes a microtremor survey consisting on recording the ambient noise at several sites, following approximately a 2 km wide grid that cover the whole region. This project is still under progress and only a few data are already processed. The first preliminary results will be presented here.

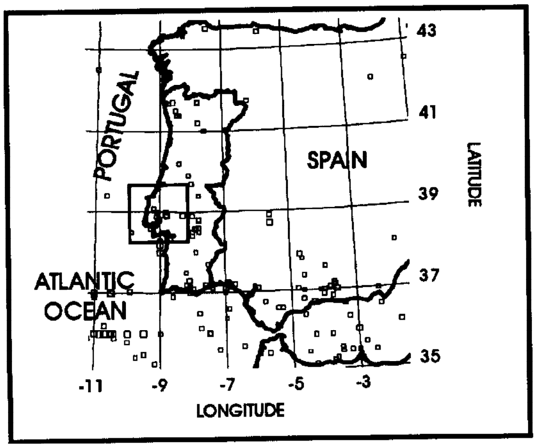

Fig. 1. Historical and instrumental seismicity of the Iberian Peninsula ($M \geq 5.0$)
The black square shows roughly the location of the Lower Tagus Valley

HISTORICAL SEISMICITY OF THE LOWER TAGUS VALLEY

Reports on the historical seismicity of the Portuguese mainland territory are very scarce up to the end of the Middle Age. Reliable references to the earthquakes that affected the country appeared only in the middle of the 14th century and the first earthquake described in some detail occurred in 1531.

However, according to several scarce reports, the earthquake that occurred in 1344 is believed to have its epicenter located in the Lower Tagus Valley, because it has caused large damage in the central part of the country, but there are no news about its effects in Spain or in the southern part of Portugal (Moreira, 1979).

Although there are not many details about this event, it is known that it produced important damages in the town of Lisbon and great number of casualties (Moreira, 1991). Its estimated magnitude is about 7.0 and MM intensities of IX-X were felt in some villages along the Tagus valley, as follow from the interpretation of historical reports.

The first earthquake described in detail by the chroniclers, occurred on the 26th of January 1531. The descriptions allowed to locate the epicenter and to know the destructions caused in the different villages. Furthermore, it was the earthquake of greatest magnitude (about 7.5) which epicenter was located in the central region of the country (Senos *et al.*, 1994).

The epicenter was located between Vila Franca de Xira and Azambuja and the maximum MM intensity reached was IX-X. It was followed by a large agitation of the Tagus river waters. In Lisbon, where the damages are only comparable to those of the 1755 earthquake, MM intensities of VIII and IX were reported and the most important damages were observed in the "downtown" alluvium valley and hillsides. About 25% of the houses were damaged and 10% suffered total collapse; 2% of the population was killed (Henriques *et al.*, 1988).

Four centuries later, on the 23rd April 1909 an earthquake took place that caused great destruction in the region of Benavente (figure 2). The epicenter of this earthquake was located in the Lower tagus Valley (38,9° N; 8,8° W) and its magnitude was estimated between 6.5 and 7.1. It was the biggest earthquake that occurred in the XX century in this region.

The village of Benavente was completely destroyed and St° Estevão and Samora had large damages. The MM intensity attributed to this zone was IX. In this region 46 people were killed and 75 were seriously injured.

Like the precedent earthquake, it was followed by an important agitation of the Tagus river waters (Moreira, 1991). During the following months several aftershocks were felt. The 4th May 1909, the 2nd August and the 17th August 1909 were the most important ones.

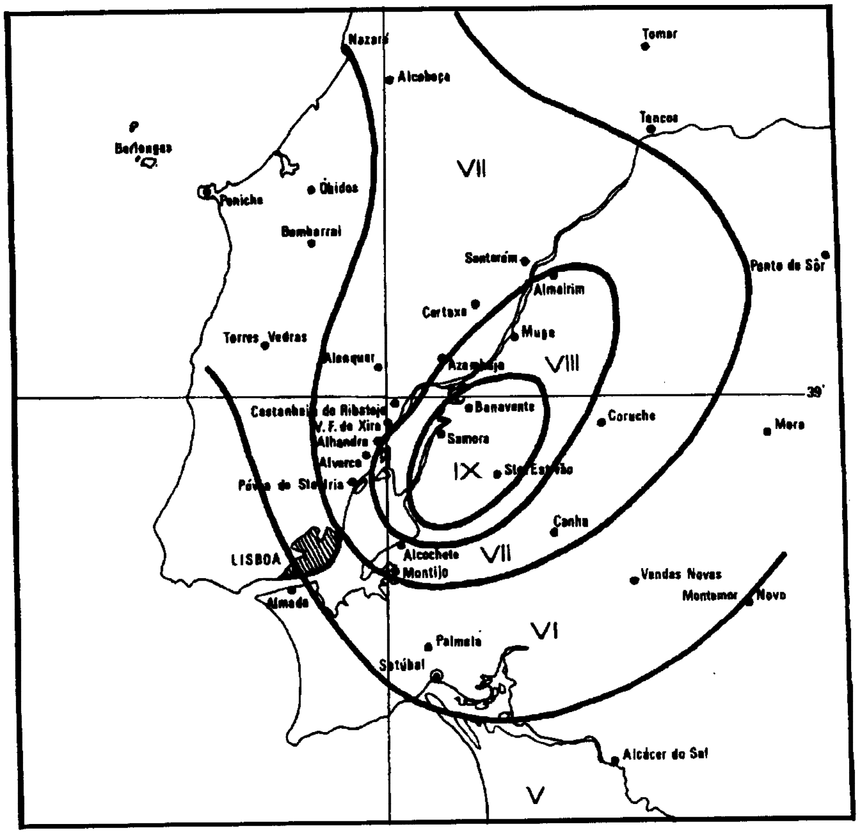

Fig. 2. MM Intensities for the 23rd April 1909 earthquake (adapted from Moreira, 1991)

This earthquake was the first strong event recorded in Portugal, at the seismic station of the Geophysical Institute of Coimbra, and it triggered the quick development of the national seismic network.

MORPHOLOGY AND GEOLOGY OF THE LOWER TAGUS VALLEY

This description is based on the explanation notes of the geologic maps of the region, at the scale 1:50 000, mainly compiled by Zbyszewski (1953-1979).

The Lower Tagus Valley is the region which corresponds to the last part of the Tagus river basin and which is located in the central part of Portugal. During this last course, the Tagus river flows in the southwest direction, discharging next to the Lisbon town.

This area is mainly a large plateau, slightly dipping to the river. From west to east it is possible to divide this region in four distinct natural zones (figure 3):

1 - The miocene and pliocene plateau of the right margin;
2 - The plain where the river flows;
3 - The fluviatic terraces of the left margin;
4 - The miocene and pliocene plateau of the left side of the river.

The plateau on the left margin is much more large than the one on the right margin.

In the area covered by this study, from Constância to Lisbon, the valley is very wide, reaching 17 km near Lisbon.

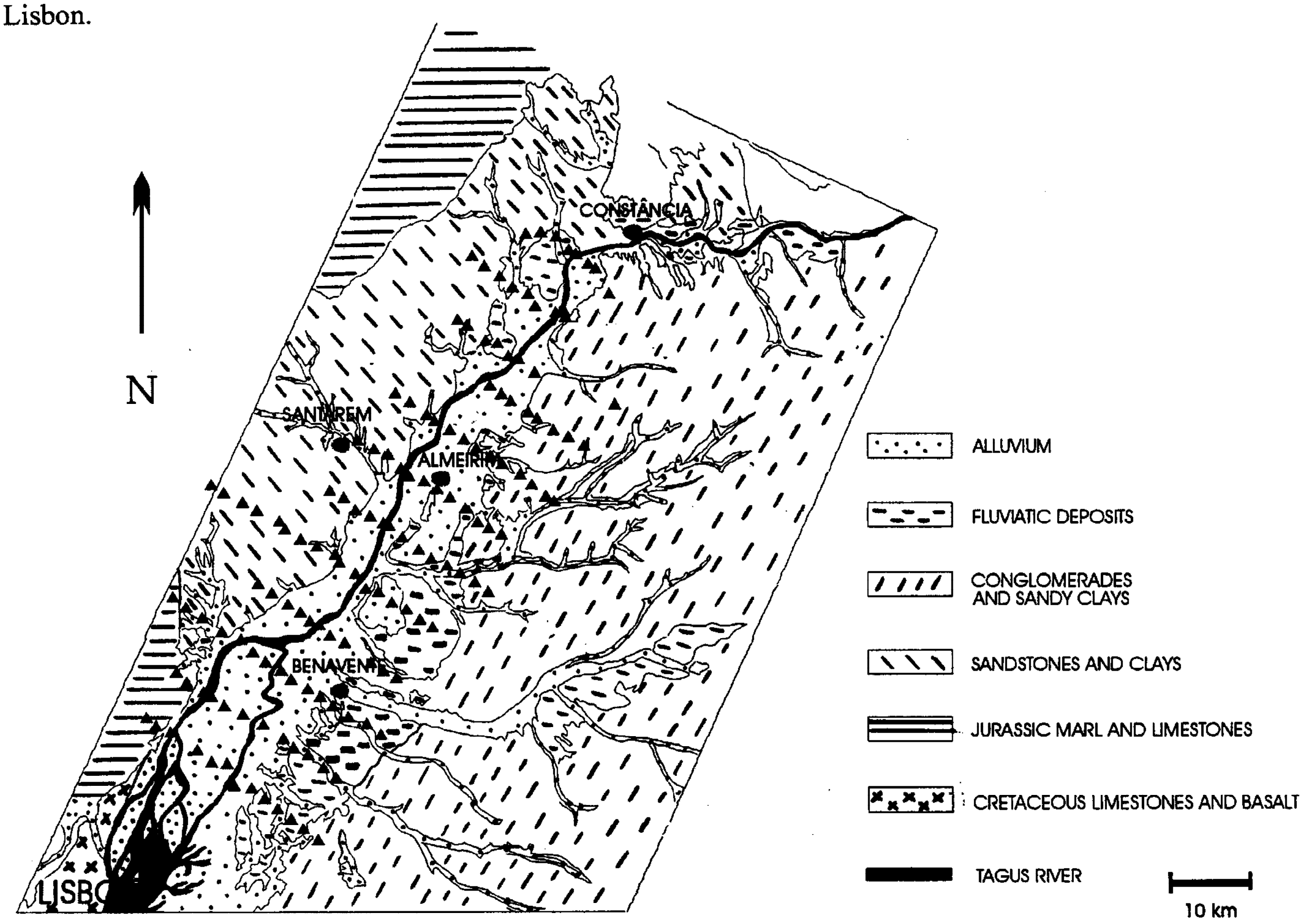

Fig. 3. Sketch of the geological map of the Lower Tagus Valley (adapted from SGP, 1992). The little triangles are the locations of the recording sites

The most representative soils belong to the ceno-antropozoic cover. From top to bottom they are composed by recent alluvium, quaternary deposits of fluviatic terraces, pliocene sandstones and conglomerates, and a thick layer of sandy clays and sandstones. These geological formations, that cover the Tagus basin, were deposited over an hercynian bedrock (probably the basement).

On the right margin, after the pliocene and miocene formations, eocene, cretaceous and jurassic formations outcrop, mainly composed by silts, clays, marls and limestones. In the southern part of the valley, the Jurassic formations are very close to the river (less than 500 m, near Vila Franca de Xira) and in Lisbon, cretaceous limestones and basalt reach the river margin.

The course of the river is partially conditioned by fractures, which could be related to the development of the Tagus basin. The deflection of the river bed to west, near Benavente, is believed to be caused by tectonic activity that should be accompanied by seismic activity. The earthquakes referred above (1344, 1531 and 1909) are the evidence of the tectonic activity of the Lower Tagus Valley Fault. This fault, that follows close the course of the river, is not directly visible on the field, due to the thick cover of the valley. However, it was detected by seismic methods and it can be delineate by satellite photography (Santarem *et al.*, 1976; Cabral *et al.*, 1988).

METHODOLOGY

The Nakamura's technique is well described in several papers (Nakamura, 1989; Lermo *et al.*, 1993) and is based on the following assumptions: *(i)* microtremors are essentially composed by Rayleigh waves propagating in a surface layer overlaying an half-space; *(ii)* for all frequencies of interest, the spectral ratio between the horizontal component and the vertical component of the motion at the bottom of the layer is equal to unity. In these conditions, the site effect due to surface geology is well estimated by the spectral ratio between the horizontal component and the vertical component of the motion at the surface (H/V). These assumptions were already tested experimentally and several papers have been published showing the applicability of the method (Duval, 1994; Teves-Costa *et al.*, 1995).

EXPERIMENT DESCRIPTION AND DATA PROCESSING

The experiment consisted on recording 5 minutes of seismic noise at the selected sites of the network (see figure 3). The observations were performed with two portable seismic stations, a Kinemetrics SSR-1 and a Lennartz Mars-88, with Lennartz seismometers which natural period is 1 second. These two kinds of instruments were already used in microtremor experiments, providing the same results (Teves-Costa *et al.*, 1995).

In order to observe the lowest predominant frequencies, the records were first filtered, using a 8-pole band-pass Butterworth filter between 0.1 Hz and 5.0 Hz. Then the maximum entropy power spectrum was obtained, for a selected 2 minutes long window, for each component. The H/V ratios were then computed dividing the vectorial sum of the two horizontal components by the vertical component.

The choice of the maximum entropy power spectrum instead of Fourier amplitude spectrum was made because the first method provided a better definition of the predominant frequency peaks. In a first stage, the two methodologies were tested, giving similar results for the predominant frequency peak. However, the maximum entropy spectrum gives a slightly higher amplitudes (after the convenient corrections). Due to this fact, the analysis in terms of spectral ratio amplitudes must be considered with care.

ANALYSIS AND INTERPRETATION OF THE DATA

The H/V curve was obtained for each site. The frequency analysis was made between 0.7 and 10.0 Hz. The

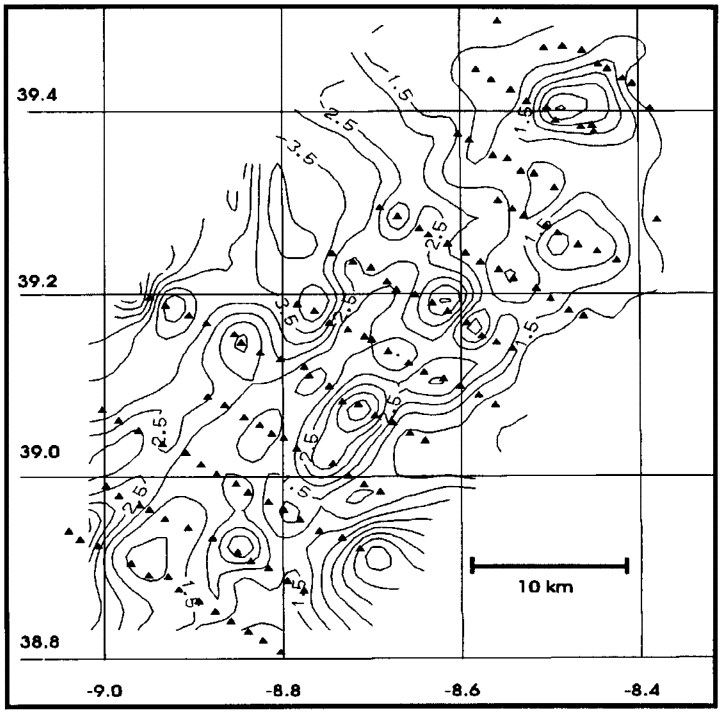

Fig. 4. Maximum peak frequencies between 0.7 and 10.0 Hertz

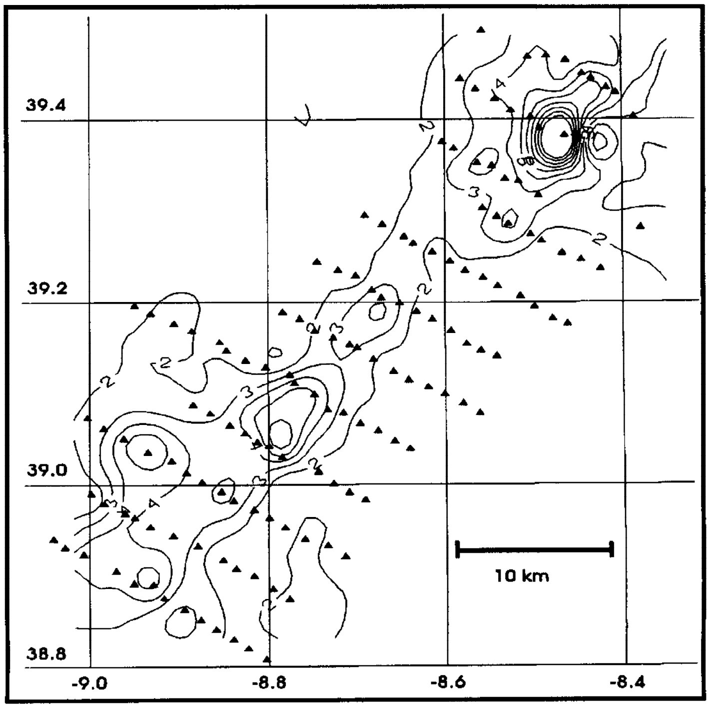

Fig. 5. Amplitudes of the peak frequencies presented in figure 4

peak frequency (the frequency for which the maximum amplitude occurs) was picked automatically. However, all the H/V curves were analyzed in order to detect eventual anomalies. The results were plotted in terms of level curves and are present in figures 4, 5 and 6. These figures can be compared with figure 3 considering the sites location.

Figure 4 gives the frequency of maximum peak amplitude between 0.7 and 10.0 Hertz. As compared with figure 3 it can be noted that near the river (alluvium deposits) the peak frequency lies between 1.5 and 2.5 Hertz. The high peak frequencies appear on the right margin, near the more consistent formations (sandstones and clays); however, it should be noted that the higher frequency picked was 5.5 Hertz.

To analyze in a better way these peak frequencies, it is necessary to observe the amplitude of the peaks. Figure 5 shows the amplitude of the frequency peaks exhibited in figure 4. It can be noticed that these amplitudes are not very high: about 3, near the river, and less than 2 in the more distant sites. Only one site presents an exception with the peak amplitude reaching a value of 10. This is a site bordering the river, located over alluvium cover, but no special reason was found to explain this high value.

It was found that the alluvium sites exhibited peak frequencies around 2.0 Hertz. In order to observe this phenomena in more detail, the peak frequencies between 0.7 and 3.0 Hertz were plotted, figure 6. It is clear, from this figure, that crossing the river, from southeast to northwest, the peak frequencies are increasing, suggesting a correlation with the surface geology (see figure 3).

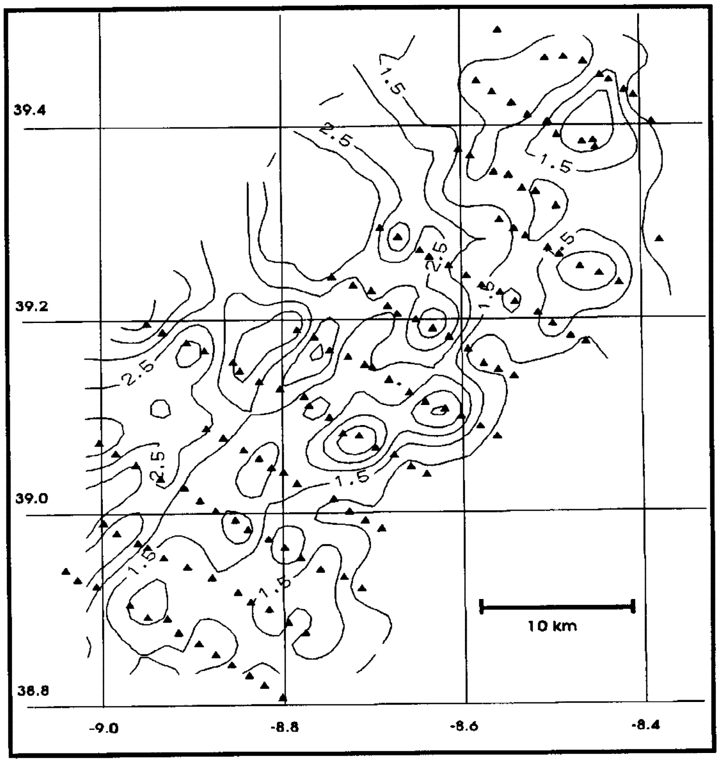

Fig. 6. Maximum peak frequencies between 0.7 and 3.0 Hertz

FINAL REMARKS

These preliminary results do not allow to draw serious conclusions. It is necessary to process the remaining data, which correspond to two intermediate profiles performed between each two already processed, and to analyze in more detail the surface geology, specially in what concerns the thickness of the alluvium layers and of the soft deposits. Geological profiles will be performed and seismic refraction profiles are foreseen in order to better characterize the shallow formations. When all this information will be available, the authors expected to interpret with accuracy the subsequent results.
However, it can be noticed that these preliminary results already exhibit a fair correlation between the analysis of the microtremor measurements and the surface geology suggesting that the methodology adopted is adequate to characterize the shallower formations.

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