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MICRO ZONING THE CITY OF TUNIS USING BOTH BACKGROUND NOISE AND WEAK MOTIONS

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SUMMARY

Tunis City and its surroundings are not in an extremely seismic zone; but its present development on lagoonal lands with bad-geotechnical qualities requires that seismic hazards be seriously taken into account. Tunis City is not equipped with seismic micro zoning yet. Two measurement campaigns have been carried out to evaluate the site response: Nakamura's technique and the traditional transfer function method. The first approach, by means of recording background noise, covered 250 sites following a netting obtained from a geotechnical zoning previously established on recent data. The second campaign, by means of recording the seismicity of Tunis City has been carried out, during 15 weeks , thanks to the mobile seismological network of French Research Laboratory, CETE Méditerranée. Sediment to bedrock spectral ratio has been computed both with weak motion data (SBSR) and background noise (SBNR). Horizontal to vertical components ratio has also been computed with background noise (HVNR) and weak motion (HVSR). The four ratios have been compared. For a given site, all of them restore the same fundamental resonance frequency. Only SBNR and SBSR give higher modes of resonance. In addition, the results of these two last methods, peak frequencies and corresponding amplifications, are quite comparable. Therefore, Sediment to Bedrock Spectral Ratio method from background noise records (SBNR) seems to be sufficient to evaluate the site response in Tunis City. This experiment shows that it is possible to realise a serious micro zoning in developing countries, with very limited equipment.

INTRODUCTION

The experimental evaluation of the soil response, the seismic site effect, reflects the amplification (or the decrease), in relation of frequency, undergone by a seismic wave, when crossing the last ten meters of its propagation, due to the soil structure. Recording the site seismicity compared with that of a reference to the rock is the best experimental estimation, since the useful parameter is directly measured. This technique is called Sediment to Bedrock Spectral Ratio method. However, it encounters major practical difficulties, mainly the long duration of measurements (hence a high cost) and the difficulty of carrying out seismic measurements in town, due to the ambiant noise. The "H/V Background Noise" method consists in recording, during a few minutes, the site seismic background noise and in computing the horizontal to vertical components spectra ratio . The theory of this method is still a field of research; however, its experimental validity seems to be well established as it gives the fundamental resonance frequency and a correct estimation of the amplification level of the site. This method is also applied to earthquake records and gives similar results

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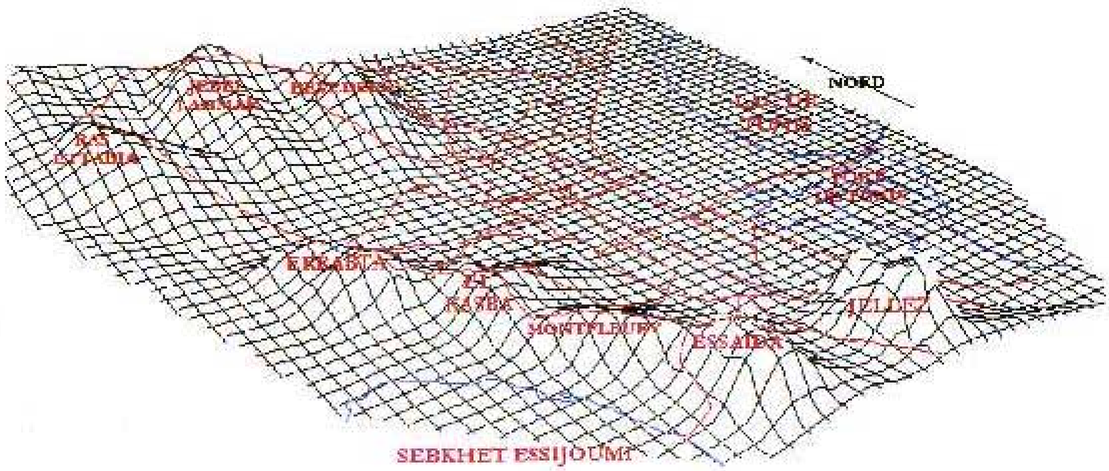
THE SITE OF TUNIS.

Tunis city is built in a basin, the valley of Tunis, and is bounded by relief on northern side (Belvedere, Jebel Lahmar and Ras Ettabia), western side (Errabta, El Kasba, Montfleury and Essaîda) and southern side (Jellez) as shown in figure 1. Tunis Valley is an ancient valley of Oued Medjerda, which opens towards the Lake of Tunis and Mediterranean Sea eastwards.

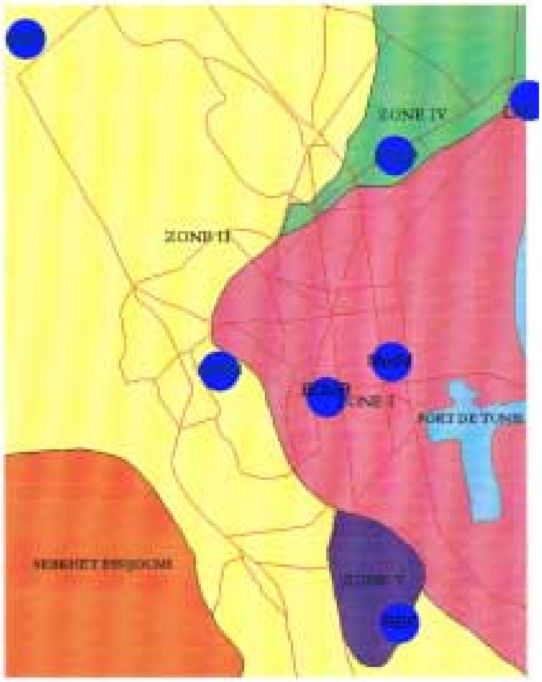


‘ Figure 1: The Valley of Tunis: the relief, the coasts and the main roads’

During the orogenesis, Ben Ayed (1983) admits that the site of Tunis has undergone a global uplift accompanied by the subsidence of the basins of the Lake of Tunis and Sebkhet Essijoumi.

Quaternary deposits overlying a Pliocene substratum almost exclusively occupy the basin of Tunis (with the exception of the anthropic formations). Among these sediments, we have to distinguish the ancient continental-Quaternary lands from the recent-Quaternary ones, mainly represented by silt. One of rare deep drillings carried out in the city, shows a few 360 m of sediments in feet of the Belvédère hill. Electric investigations, carried out across the Lake of Tunis (Ammar, 87), evaluate, as for them, with 600m the thickness of sediments in the Lake and its immediate surroundings.

Tunis substratum is defined here in geotechnics terms. It is about the first deep layer characterised by the ratio EM/(Pl-P0)>11 to 12. EM is the pressiometric modulus and (Pl-P0) the corresponding limit pressure. This so-called substratum is dominantly argillaceous. Its roof is highly disturbed: it sometimes outcrops at the slopes of the relief, then disappears deeper than 70m in the proximity of the Lake of Tunis.



‘Figure 2: Geotechnical Zoning of Tunis city.’

GEOTECHNICAL ZONING OF TUNIS.

Figure 2 shows the principal geotechnical entities:

Zone I is a succession of embanking, of a silty complex and of crusty argillaceous-sandy formations which constitute the substratum. Silty complex is sometimes interrupted by sandy and argillaceous lens like intervals; Silty layer has variable thickness: about 20m at station “BOUR”, 70m at station “MedV” and up to 100m at station “LAC” .

Zone II surrounds the previous one and includes the slopes of the northern and western relief. It consists of two well-differentiated horizons: a tuffy cover with average features and an argillaceous-sandy substratum, clear more resistant. The tuffy cover varies in thickness (4m on Errabta hill slopes and probably 10m at station “KASB”).

Zone III concerns the northern and western hilltops. This zone limits are not well defined and are not represented on Figure 2. These are mostly argillaceous lands with good to very good geotechnical features as it is the case at station “ENIT”.

Zone IV is characterised by the little common following succession which includes, from top to bottom: argillaceous sandy tuffy rocks, then grey silts with bad geotechnical features, and finally, a more compact argillaceous substratum. At station “ETAP”, we estimate the thickness of the first layer up to 20m and the thickness of silts between 5m to 15m.

Zone V includes the southern Tunis relief, Jellez-Sidi Bel Hassen hill; it consists of Lower Eocene and Cretaceous limestone and marly limestone.

MEASUREMENT CAMPAINS .

The first approach of the seismic site effects of Tunis City is based on the “H/V background noise” method (BOUDEN-ROMDHANE & Al, 1998). The campain covered 250 measurement points following the geotechnical zoning described above: the principle is to have background noise “sections” crossing the existing geotechnical entities.

The second approach of the seismic effect is based on the transfer function method, also called Sediment to Bedrock Spectral Ratio method. The seven stations of the mobile seismological network of CETE were used to record the seismicity of Tunis and to establish the transfer functions between the various sites. The sites selected (REF, BOUR, KAS, LAC, ENIT, MedV and ETAP) are shown in figure 2 and are representative of the geotechnical units described before. During the period of recording, approximately 15 weeks, ten seismic events were recognized by the whole of the network. They are local seism, teleseisms, as well as rock blasting in career organized for our study.

The recording was carried out in continuous mode, with the sampling step of 125 Hz. The sensors can restitute vibrations going from 0.02 micrometer/s up to 10.1 micrometers/s. Background noise measurements were also carried out automatically in calm periods of the night.

SIGNAL PROCESSING.

Both weak motions and background noise are used to establish the following ratios:
SBSR is the Sediment to Bedrock Spectral Ratio computed with earthquake or rock blasting records as used traditionally;
SBNR is the Sediment to Bedrock Noise Ratio estimated with background noise;
HVSR is the Horizontal to Vertical Spectra components Ratio computed with weak motions;
HVNR is the same ratio as above, evaluated with background noise as Nakamura recommendations.
All these ratios require the spectrum computation. These spectra must be averaged and smoothed. As for the ambient noise, the processing sequence is thus as follows:
real signal re-establishment by trace deconvolution if necessary;
automatic selection of the windows to be processed from an adjustable trigger; few minutes of noise records are needed;
application of an adjustable ratio hanning apodisation function;
window adjustable covering in relation to apodisation ratio;
spectrum computation of the three traces (S_{NS}, S_{EW}, S_V) and smoothing according to lower amplitude;
Average spectra computation.
Finally, the following five curves, function of the frequency, are obtained:

$$HVNR_{NS} = \frac{S_{NS}}{S_V} \text{ (also } \frac{NS}{V}\text{)},\ HVNR_{EW} = \frac{S_{EW}}{S_V} \text{ (also } \frac{EW}{V}\text{)},$$

$$SBNR_{NS} = \frac{(S_{NS})_{Sediment}}{(S_{NS})_{Bedrock}},\ SBNR_{EW} = \frac{(S_{EW})_{Sediment}}{(S_{EW})_{Bedrock}} \text{ and } SBNR_{V} = \frac{(SV)_{Sediment}}{(SV)_{Bedrock}}.$$

These curves permit to define, for each point, the resonance frequency of the underground column and the corresponding magnification.
As for the earthquake and rock blasting records, only the must "energetic" window spectra (supposed to correspond to Rayleigh waves) is computed as follows:
signal division in windows with length equal to the windows of noise calculated above,
application of an adjustable ratio hanning apodisation function so as to limit the effects of edges,
spectrum computation of the three traces (S_{NS}, S_{EW}, S_V) and smoothing,
average spectra computation.
The following curves, function of frequency, are obtained:

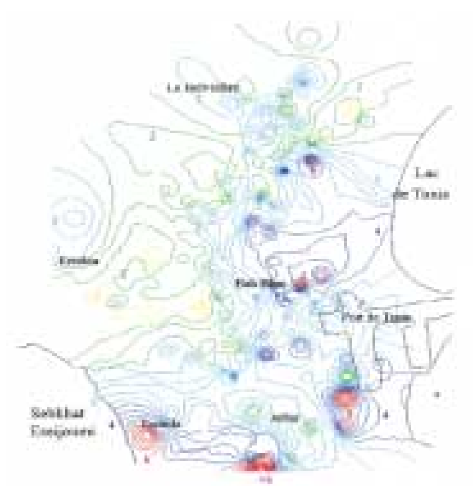
$$HVSR_{NS} = \frac{S_{NS}}{S_V} \text{ (also } \frac{NS}{V}\text{)},\ HVSR_{EW} = \frac{S_{EW}}{S_V} \text{ (also } \frac{EW}{V}\text{)},$$

$$SBSR_{NS} = \frac{(S_{NS})_{Sediment}}{(S_{NS})_{Bedrock}},\ SBSR_{EW} = \frac{(S_{EW})_{Sediment}}{(S_{EW})_{Bedrock}} \text{ and } SBSR_{V} = \frac{(SV)_{Sediment}}{(SV)_{Bedrock}}.$$

RESULTS.

Figures 3-a and 3-b represent isovalue maps of interpolated Nakamura parameters: peak frequency value and corresponding magnification. It is important to emphasise the very good stability in time and in space of these results, as well as a good correlation between geotechnical characteristics and Nakamura parameters.

'Figure 3-a: Interpolated peak frequency value'



'Figure 3-b: Interpolated amplification'

As an example, the following results concern site 'BOUR'; all the other instrumented sites show the same tendencies:
Figure 4 shows SBSR, function of frequency, computed with earthquakes records.
Figure 5 shows SBNR, function of frequency, computed with ambient noise recorded before earthquakes and during calm periods of the night.
Figure 6 gathers the mean values of both SBSR and SBNR.
Finally, figure 7 represents curves of both mean values of HVSR and HVNR.

COMMENTS.

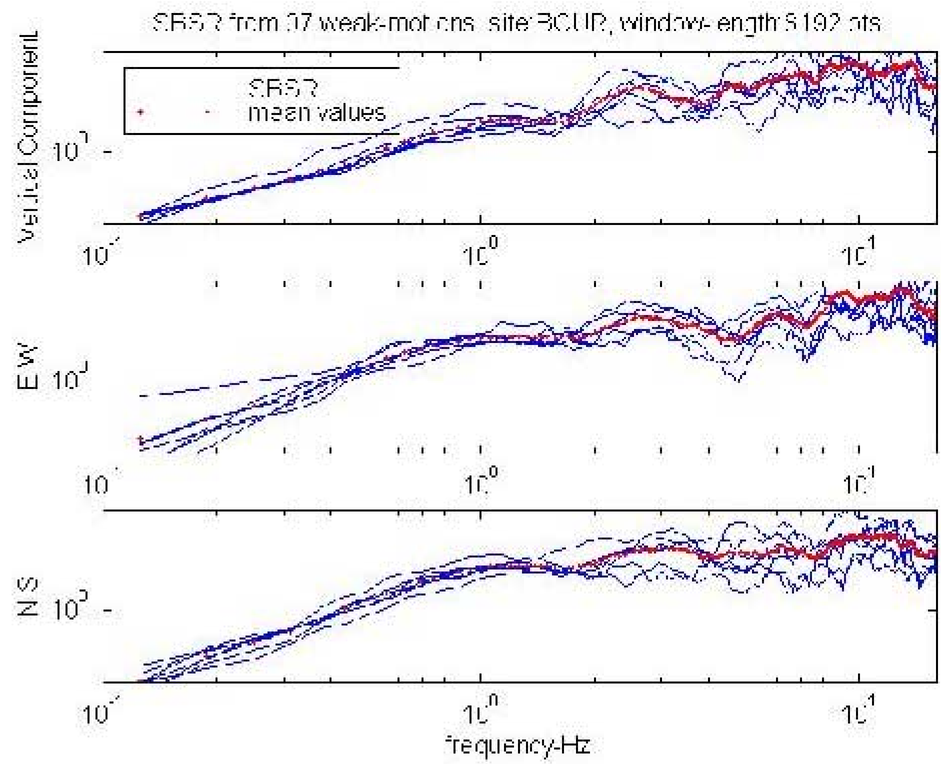
Results from SBSR and SBNR are quiet similar both for amplified frequencies and respective magnifications.

HVNR and HVSR give also good correlation as pointed out in previous investigations.

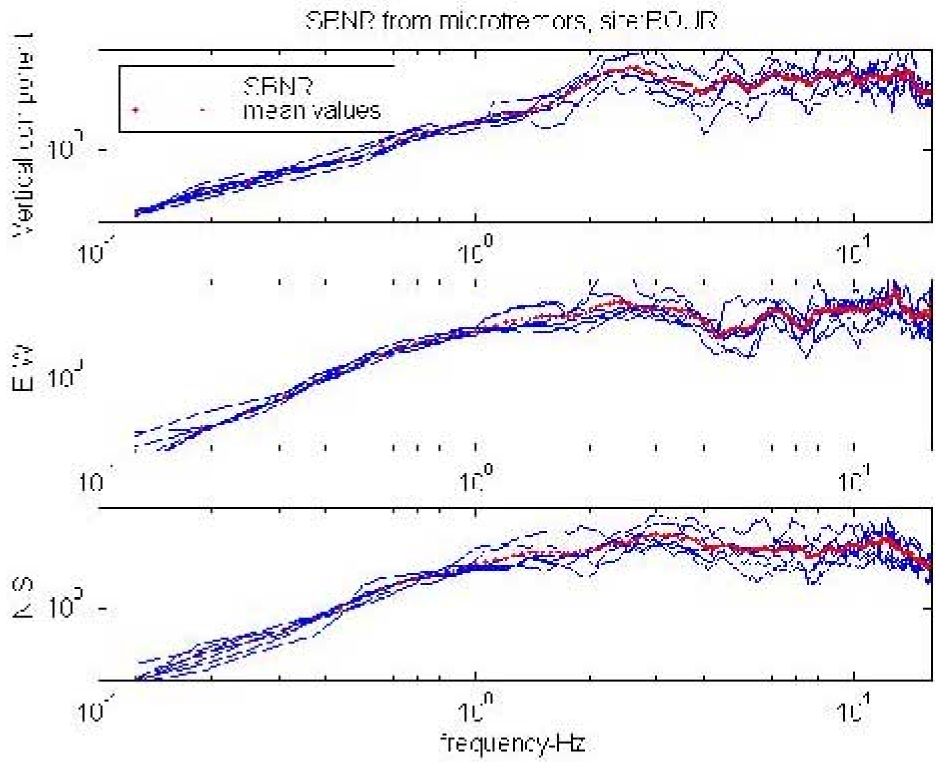
HVNR and HVSR give equivalent amplification than SBSR and SBNR for the fundamental resonance frequency. At higher frequencies, the tendency is different: SBSR and SBNR give higher amplifications than HVNR and HVSR.

Results from the first and the second approach of site effect in Tunis city are complementary as the transfer function method give all the amplified frequencies with the right value of amplification. Thus, all the instrumented sites show an amplification of the signal below of frequency 2Hz:

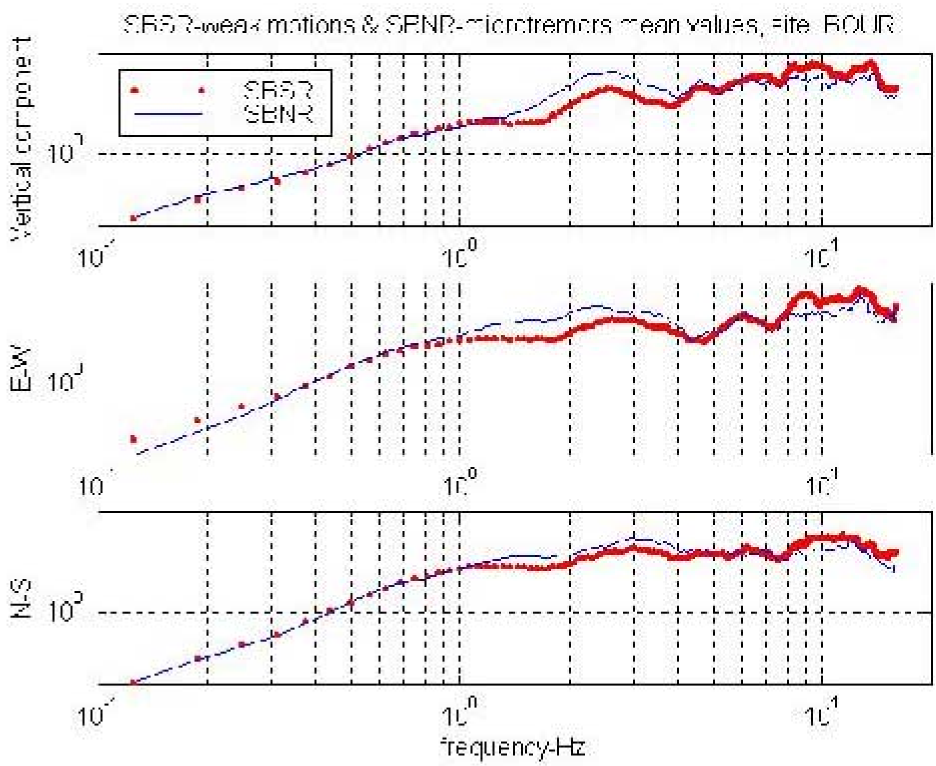
This amplification is the most important (level 10 to 15) for site ‘MedV’ (Zone I) and the peak frequency is about 1Hz.. The silty fillings of 65m thickness, over more compact clays with significant difference of impedance are without any doubt at the origin of the spectacular modification of the signal.



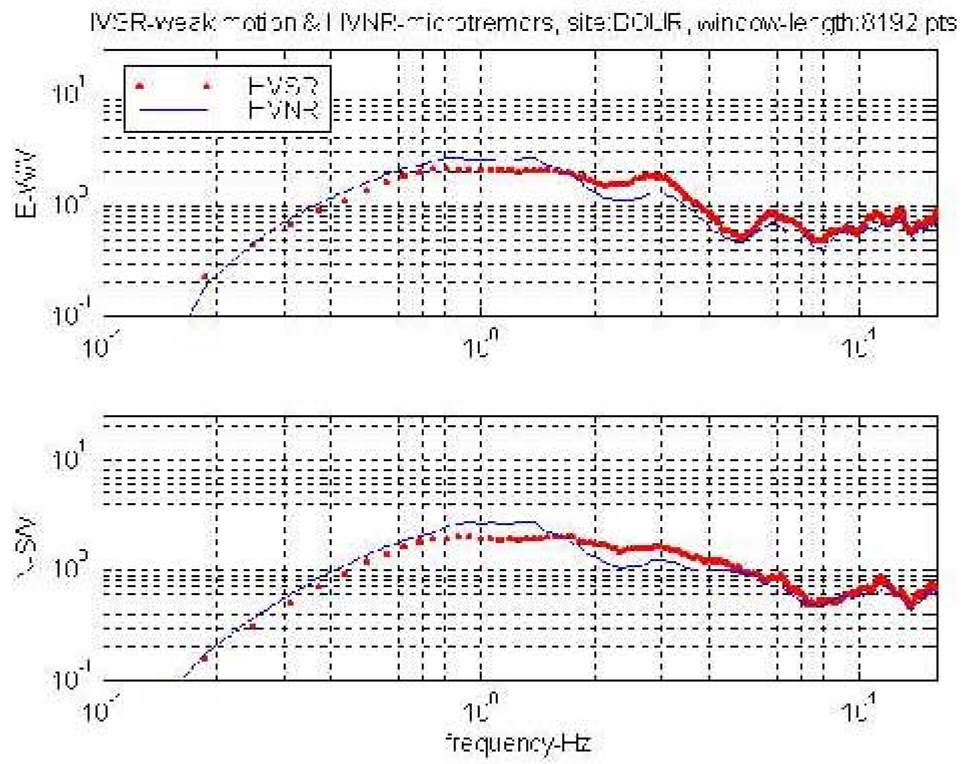
‘Figure 4.’



‘Figure 5.’



‘Figure 6.’



‘Figure 7.’

A significant amplification (level 5) is recorded at site ‘LAC’(Zone I) for frequencies even lower (0.5Hz to 1Hz); it is certainly not ascribable with the surface sandy layer. A deeper reflector would justify the phenomena observed.

Sites ‘BOUR’ (Zone I) and ‘ETAP’(Zone IV) amplify the signal in a more moderate way (level 3) starting from 0.8 Hz. Here too, deep reflectors would be at the origin of the modification of the signal.

At site ‘KAS ‘(zone II), the signal is also moderately amplified (level 3) starting from 0.3 Hz and extends constant, without major peak, up to 8 Hz. The surface tuffy layer does not seem to cause site effect, probably because of little contrast impedance with deeper clays.

Site ‘ENIT’ (zone III) amplifies little (level 1 to 2) and uniformly the signal with a probable increase of amplification with 8 Hz. There still, the weak variation of impedance of the geological formations in place would justify the weak site effect.

At ‘REF’ (Bedrock), the signal is modified very little; HVNR and HVSR are close to the unit and confirm to us, the good choice of the site of reference.

CONCLUSIONS.

HVNR and HVSR seem to restore the fundamental resonance frequencies with equivalent to little lower magnifications than SBSR and SBNR. This technique is rapid and economic as it requires very limited equipment . It gives a first evaluation of the site effect as shown above.

Referring to the classical use of SBSR method, the results are available only if Signal to Noise Ratios, for both sediment and bedrock are acceptable and higher than an arbitrary value (of the order of 2 or 3). Thus, the SBSR method is hardly usable in sites with important level of urban noise. For Tunis city, it is no more true, as SBNR and SBSR give comparable results: amplified frequencies and corresponding amplification levels. The surface waves, captured in the basin, seem to behave like secondary signals and excite the underground layers in a same way as weak motions .

Sediment to Bedrock Noise Ratio method seems to be sufficient to evaluate the site effect by recording only few minutes noise on bedrock and on site at the same time.

The amplifications at very low frequencies, visible on geotechnical Zone I are probably caused by deep reflectors with strong contrast of impedance and not by the so-called Pliocene argillaceous substratum. The highest amplifications are observed, as for them, on sites in immediate edge of the Lake of Tunis, 'MEDV' and 'LAC', characterised by under-consolidated fillings. The assumption of deep reflectors is plausible if it is pointed out that the valley of Tunis is a zone of collapse and subsidence. The deep reflector would be the subsided compartment of the Cretaceous roof (calcareous and marls) which outcrops in the south of the basin of Tunis ,on Jellez-hill, and disappears abruptly towards the Lake of Tunis.

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