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Surface Soil Effects Study Using Microtremor Observations in Nablus City, Palestine

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Abstract. The city of Nablus is located in one of the highest seismic hazard areas in Palestine, and many buildings were completely destroyed in the city during the historical earthquakes. The population of Nablus city is rapidly increasing and new urbanizing areas are growing to the eastern and western parts where they are located at soft sediments. Consequently, the evaluation of surface soil effects is very important from a standpoint of earthquake disaster mitigation. A landform classification geotechnical map was modified by analyzing available boreholes logs and seismic refraction data. Microtremor measurements were carried out at about 16 sites in the study area and Nakamura's method (1989) was applied for determining predominant periods. The results showed that predominant period, determined at rock site in different locations of the city, is about 0.55 sec whereas at soft soil sites, in the center of the city, the predominant period reaches more than 1.0 sec. At medium soil sites, mainly in the western part of the city, the predominant period ranges between 0.65-0.75 sec. The obvious difference of the predominant periods between hard rocks and soft soil sites reflects the surface soil cover and it coincides with the variations of geological outcrops. Three main surface soil units, which have different site effects, were figured out from this study.

Keywords: microtremors, soil effects, Nakamura's method, seismic microzoning.

دراسة تاثيرات تربة السطح باستخدام رصد الاهتزازات الصغيرة في مدينة نابلس، فلسطين

ملخص: تعد مدينة نابلس واحدة من أكثر مناطق الخطر الزلزالي في فلسطين، حيث تعرضت الكثير من مبانيها الى الدمار الكامل عبر الزلازل التاريخية، كما أنها تظهر تزايداً في عدد السكان وامتداد عمراني باتجاه الجزء الشرقي والغربي من المدينة ذات الرسوبيات اللينة وبالتالي فإن تقييم تأثيرات تربة السطح تعتبر على قدر من الأهمية للتخفيف من خط الزلازل. لقد جرى بدايةً تطوير خارطة جيوتقنية للمدينة بتحليل معطيات لقياسات آبار وتسجيلات سيزمية. ومن ثم رصد

الاهتزازات الصغيرة على حوالي16 محطة موزعة لتغطي مختلف التكوينات الجيولوجية. أظهرت نتائج حسابات التسجيلات المرصودة على الصخور الصلبة أن فترة الزمن الطبيعي السائد حوالي 0.55 ثانية، بينما وصلت قيمة الزمن السائد على الرسوبيات الطرية في وسط المدينة الى أكثر من واحد ثانية. وأما قيمة الزمن الطبيعي المحسوبة من القياسات المسجلة على تكوينات صخرية متوسطة الصلابة فقد تراوحت بين 0.65-0.75 ثانية. هناك توافق واضح بين قيمة الزمن الطبيعي السائد وطبيعة توزيع تربة السطح. يعكس الاختلاف في القيم التنوع الذي تظهره الخارطة الجيوتقنية لانتشار التكشفات الجيولوجية على السطح حيث تم بناء عليه تحديد ثلاث وحدات جيولوجية أساسية لتأثيرات تربة السطح.

1. Introduction

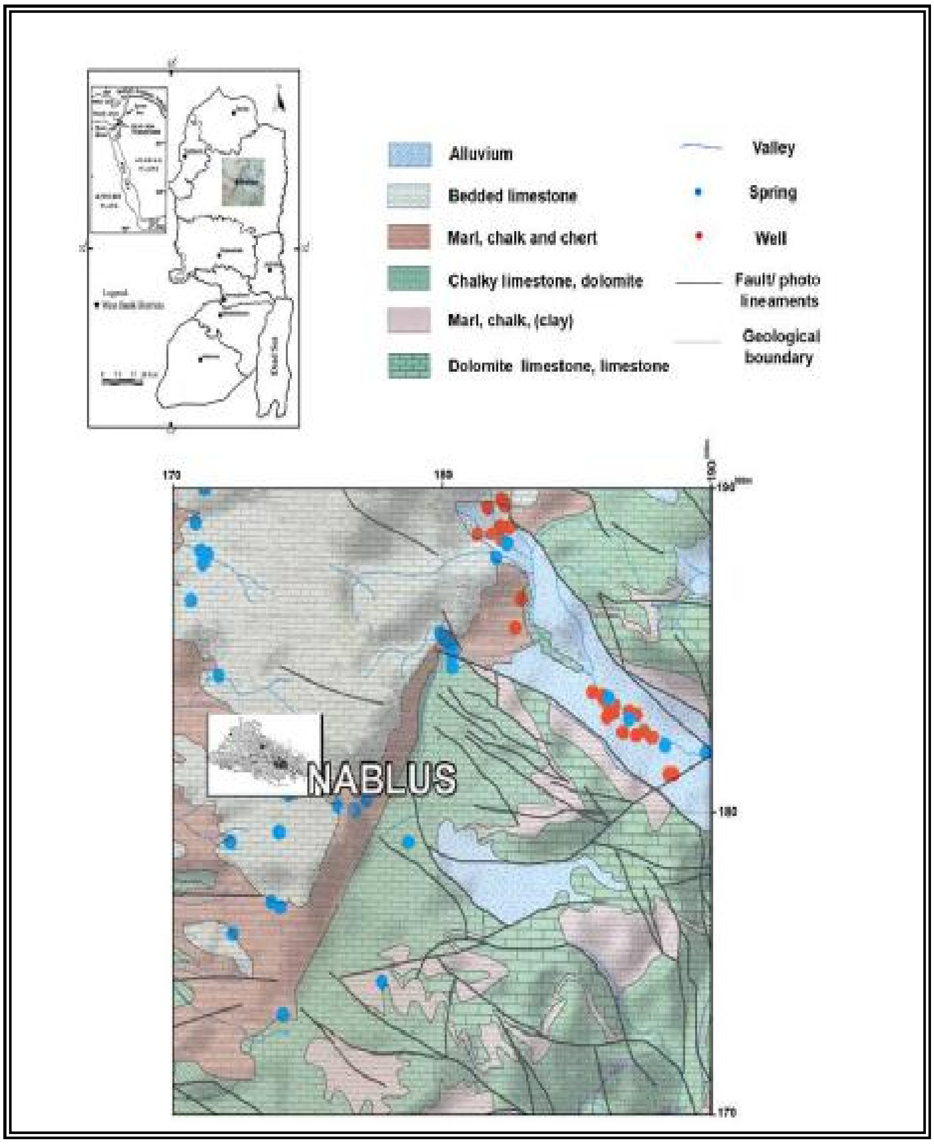
Nablus city is situated in the northern region of West Bank on exposed sequence of deposits mainly consists of carbonates; limestone, dolomite, marl and chalk, also containing other sediments of chert, clay, gravel and some sandstone, with ages ranging from upper Cretaceous to Recent (Fig. 1). The limestone formation is massively bedded at base and becomes increasingly thin towards the top [1]. Deep seismic sounding investigations in Palestine, paleoseismic Studies of historical earthquakes for the past few hundreds years (Fig. 2), and instrumental earthquake monitoring of half a century [2-19] demonstrate that the damaging earthquakes were located along the Dead Sea Rift/Transform fault. These damaging earthquakes caused in several cases severe devastation and many hundreds and sometimes thousands of fatal casualties. Recent earthquake engineering studies reveal that Nablus region has a medium or medium-high level of seismic hazard [20, 21]. Consequently, all available techniques must be used to mitigate the risk of expected large earthquakes that may shake the area.

Assessments of local site conditions and earthquake motion characteristics at the ground surface play a key role in determination of local site effects in geotechnical engineering practice. Seismic microzonation based on subsurface ground conditions is very important to accurately define seismic hazard for a city. It is well documented phenomenon that earthquake ground motion can be amplified by local site conditions [22] arising from a ground-shaking space variability conditioned by lateral heterogeneities present in the vicinity of each site.

Local geology can substantially alter the characteristics of seismic waves. In particular, it has been shown that for unconsolidated deposits, resonant phenomena often appear. For these deposit sites, ground motion amplitude and duration over certain period bands may be several times larger than levels at sites located on rock. Of specific interest is that near-surface impedance contrast, such as those arising from unconsolidated soil and sediments deposits, can significantly affect the frequency-amplitude content and duration of earthquake ground motion. An extreme example of this phenomenon was recently illustrated during the 1985 Mexico earthquake[23].

The main objective of this work to study the local site effects of the near-surface soil in Nablus city based on microtremor measurements, in an attempt of reducing the impact of potential earthquakes in Palestine.

Figure 1: The main outcropping formations in Nablus region [24, 25, and 38].



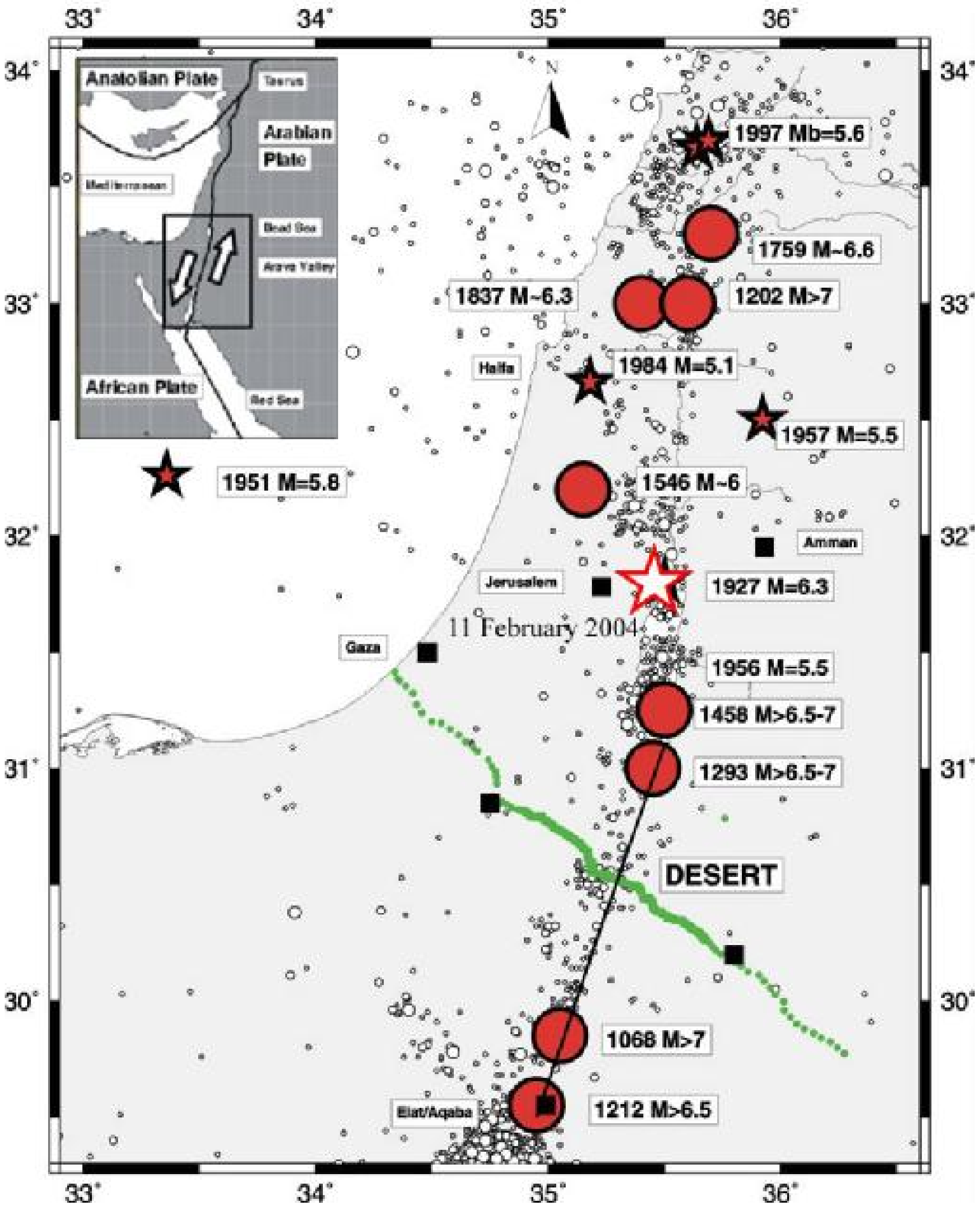


Figure 2: Seismic activity in the Dead Sea Transform region with locations of historical earthquakes [13-19].

3. Geotechnical map

The city of Nablus is located in high slopes mountainous region, with altitudes ranging from 580 m to 940 m, and wide valley in the city center. The rapid development of Nablus city in recent years has lead to increased demand on land use. Geologically the study area is mainly constituted by Tertiary and Quaternary sediments of gravel deposits and clay sediments cover the central part of Nablus city and form the main surface soil layer at the eastern and western parts (Fig. 3). The existence geotechnical map [24] that could be used as support for the planning in new areas (construction of buildings, roads, tunnels, etc.) was developed to fulfill the essential requirements of simple and fast access to geotechnical information regarding allowable bearing capacity, potential swelling and shrinkage, sliding and cavities. In the current study, all available boreholes measurements and seismic refraction data [25-28] were used to modify geotechnical information on the near-surface of the entire valley (Fig. 3). Geotechnical investigation for Nablus Commercial Complex, carried out in the city center, encountered thickness soft clay and valley deposits to a depth of 16 m [28], whereas the thickness of clay soil cover determined from seismic data in the eastern side is between 7-5 m. On the other hand, geotechnical borehole data showed thin soil cover with 0.5-1.5 m thickness distributed at small scale sites in the western part of the city containing weathered material of marl and clay sediments.

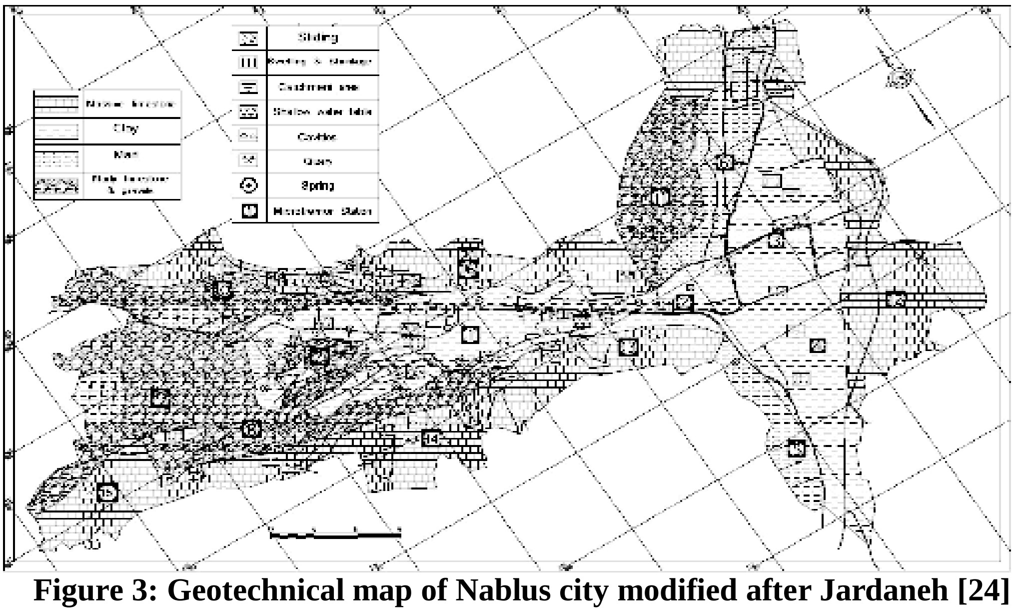


Figure 3: Geotechnical map of Nablus city modified after Jardaneh [24] with the locations of the microtremor stations distributed at different sites of geological formations.

4. Nakamura's Technique

The estimation of site response is crucial in microzonation studies for earthquake engineering purposes. Such estimation may come from [29]: (a) recordings of earthquakes or explosions; (b) theoretical computations; (c) Microtremor measurements. The best experimental procedure for determining the site response of a particular location is based on the measure of ground motion at different sites as mentioned in (a), therefore, it would be necessary to observe the ground motion during an actual event. This can be done, using either strong or weak motion, by direct comparison of a sediment site to a reference located on bedrock [23, 30] by means of the corresponding spectral ratio. To achieve site response surveys in a reasonable period of time, this approach is practical only in regions such as Japan or California for example. It is therefore desirable to develop alternative methods of characterizing site amplification in high noise urban environments and regions, like Palestine, where the level of seismicity is moderate however the potential for a large event is significant. Approach (b) for specific site involves determining the physical properties of the local setting by conducting borehole and seismic profile studies. Consequently, measured parameters can be used in theoretical models to predict site response [31]. The main disadvantage of this method is the high cost and time consumed in conduction the geotechnical or geophysical surveys. The application of microtremor measurements, alternative (c), in estimating site response is a reasonable one because the method is inexpensive and fast.

The main challenge to determine site amplification characteristics from ambient noise is the removal of source effects. This is often achieved by dividing the sediment site spectra by that observed at a bedrock site [32]. An Alternative method to remove source effects was proposed by [33]. The site response estimated is obtained since it only requires records from a single three-component station deployed at the site of interest an does not need a reference seismogram measured at the substratum bedrock.

As introduced by Nakamura [33], the technique was intended to assess S-wave amplification from microtremor measurements. There are four components of spectral amplitudes involved in this one- layer problem, namely, the horizontal components of motion at the surface and bottom of the sedimentary layer, referred as $H_s(f)$ and $H_b(f)$, respectively; and the vertical components of motion at surface and bottom, correspondingly denoted as $V_s(f)$ and $V_b(f)$. The prime objective of Nakamura's technique is to isolate the amplification effect suffered by horizontal components of substratum motion. In order to do this, he first constructs the theoretical borehole ratios that are widely regarded as the most reliable transfer function estimates for horizontal and vertical components, as given below, respectively:

$$S_h = \frac{H_s}{H_b} and \qquad (1)$$

$$S_v = \frac{V_s}{V_b} \qquad (2)$$

With these two ratios Nakamura constructs an additional transfer function S_t which gives formally the factor by which the horizontal ratio exceeds the vertical one:

$$S_t = \frac{S_h}{S_v} = \frac{H_s / H_b}{V_s / V_b} or \qquad (3)$$

$$S_t = \frac{H_x / V_s}{H_b / V_b} \qquad (4)$$

5. Microtremor Observations and Analysis

Site conditions play a major role in establishing the damage potential of incoming seismic waves from major earthquake. There are several small amplitude vibrations which appear on surrounding ground surface. Vibrations that have small periods, less than 1 sec, are currently called microtremors [34]. The origin of microtremors is probably due to traffic vehicles, heavy machinery facilities, household appliances and so that are not related to earthquakes; however, small waves propagate from artificial sources surrounding daily life.

In an attempt to develop an elementary and simple microzoning of Nablus city, an ultimate region for seismic hazard in Palestine, microtremor measurements were recorded at 16 sites mainly in urban areas (Fig. 3). The distribution of the recording stations was selected upon the variations in the geology as well in the topography, where points have been measured on rock cover of limestone (mountain areas), while other points selected to be on soft clay soil and on moderate sediments (marly limestone and gravels). Because microtremor spectra can be affected by near sources, the measurements were made during the daytime, when the contaminating effects of traffic and industrial noise were significant.

The data acquisition system is composed of a three-component high-sensitive seismometer, which has a natural period of 1 second, and a digital recorder (laptop personal computer). The system was used to record the horizontal and the vertical components of microtremors in each selected point. The site effects have been investigated by taking measurements of ambient noise collected by short period seismic station and making the spectral analysis using the packages programs [35]: SDA software for data acquisition and SEISPECT for data analysis. A time window of fifteen minutes was made for each observation and the signals were Fourier transformed and smoothed using a 0.3 Hz window (Fig. 4). Subsequently Nakamura's technique was applied, obtaining the predominant period at each site (Table 1). From the microtremor measurements and the data analysis, spectral ratio results have been also obtained (Fig. 5).

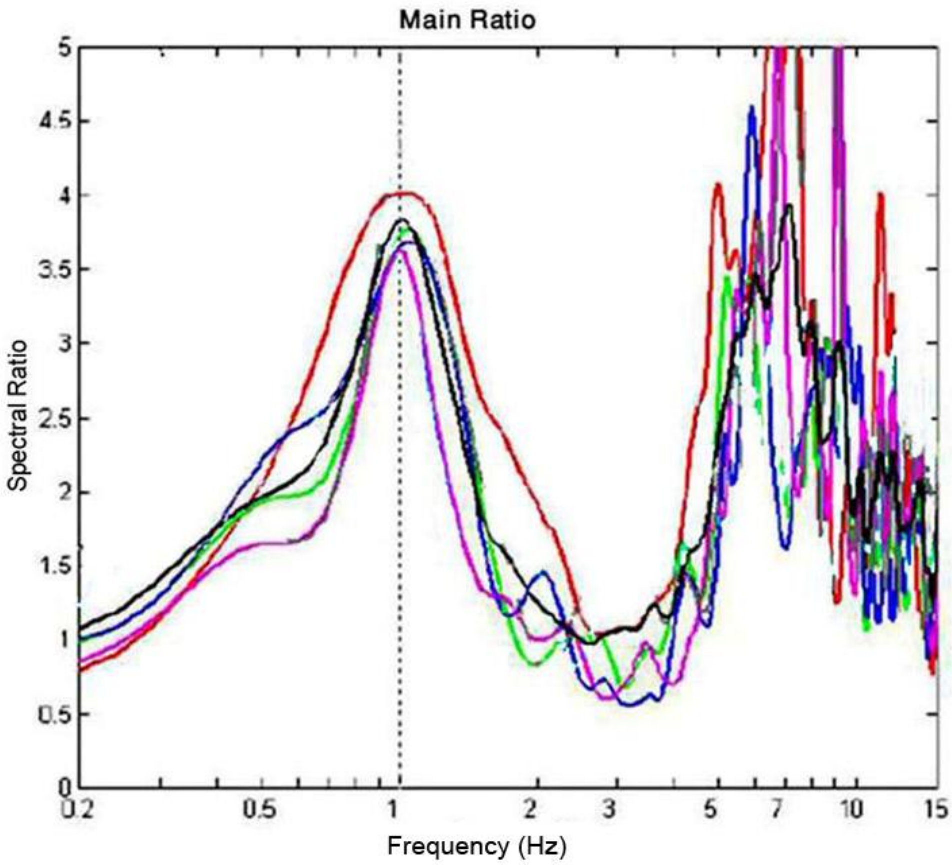


Figure 4: Spectral ratio for site 1.

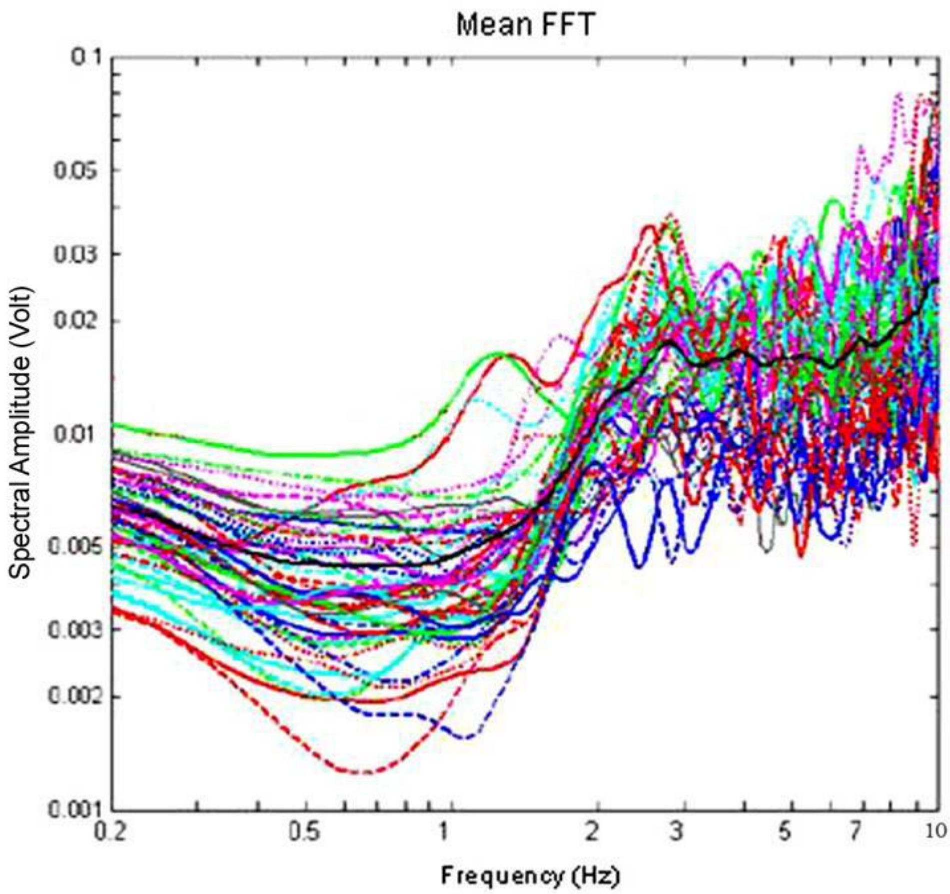
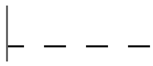
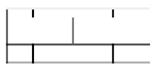


Figure 5: Spectral amplitude for site 8.

The Predominant periods obtained varied from 1.114 sec in the central part of the city, where the thickness of fluvial deposits and very soft clay soil is about 15 m to 0.548 sec on bedrock outcrops of mainly massive limestone at the mountainous areas, whereas to the west in the marly limestone zone (medium soil site) the predominant period ranges between 0.679- 0.751 sec. In general, the longer period correspond to the soft soil zones and the shorter ones can be observed in hard and middle hard soil zones, please see Table 1 and Fig. 3.

Table 1: Results list of dominant frequencies and natural periods, see also Fig. 3.

Station Nr.	Dominant Frequency Hz	Predominant period sec	Typical lithology	Sediments description and soil units	
1	0.897	1.114		Clay & Marl	***Soft soil***
2	0.903	1.107			
3	0.952	1.050			
4	1.001	0.999			
5	1.010	0.990			
6	1.015	0.985			
7	1.331	0.751		Marly limestone & gravels	***Middle hard soil***
8	1.340	0.746			
9	1.457	0.686			
10	1.472	0.679			
11	1.531	0.653			
12	1.824	0.548		Massive limestone	***Hard rock***
13	1.808	0.553			
14	1.818	0.550			
15	1.795	0.557			
16	1.811	0.552			

6. Concluding Remarks

Theoretical investigations and experimental studies [36-40] have shown that Nakamura's method [33] successfully identified the fundamental resonant frequency; a relevant data for the assessment of local site effects. The soil conditions of Nablus city are adjusted to apply Nakamura's method. In the hard rock area and in the middle hard soil zone of Nablus city, the shortest predominant periods ranging between 0.55 sec and 0.65 sec were determined. In the center of the city, a sediment-filled Valley, and in the developed urban area in the eastern part of Nablus city the longest predominant periods with values larger than 1 sec have been found.

Among the three soil units areas based on local geology effects proposed in this study for the city of Nablus, the soft clay presents the worst soil condition for seismic hazard. Furthermore, geomorphologic data point out that large landslide may occur by slope failure in hill zone sites with steep slopes of clay and marl sediments [37].

The findings of this study showed that there is a clear relation between the predominant period values estimated with Nakamura's method and near-surface soil effects in Nablus city, since the smallest predominant period values of soil are observed in mountain landform zones and the larger ones are in the soft clay sediments and valley deposit plain landform sites. This is also in good agreement with the reported obvious difference of intensity grades felt in the different parts of Nablus city during the past and recent seismic activity in Palestine [20]. Thus, microtremor measurements will be a very useful tool to obtain a relevant feature of ground motion behavior in case of new urban planning areas, which is strongly related with the seismic hazard distribution of the Palestinian regions.

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