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Investigation of Soil Amplification in North Cyprus

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Abstract

In this study, soil characteristics were investigated using four well-located earthquakes recorded by six accelerometers located in North Cyprus. The amplification values obtained according to the soil features were mapped in accordance with different frequencies using horizontal to vertical spectral ratio method. The dominant period values of the units below the station locations were calculated in order to prevent the resonance effect of structures under dynamic loads. In general, high amplifications were observed in the low-frequency range in the loose units, while low amplifications were calculated in the compact units. High amplification values were detected at low frequencies in accelerometer stations located above the Quaternary alluvium and gypsum marls in Nicosia. Since the soil dominant period varies from 0.1 s to 0.3 s, structuring between 1 and 3 floors should be avoided in this area. The dominant period values for Erenkoy and Famagusta are 1.1 and 0.6; therefore, structuring between 11 and 6 floors should be refrained, respectively.

Keywords: Soil Amplification, Horizontal to Vertical Spectral Ratio, Soil Dominant Frequency, North Cyprus.

1. Introduction

The movements of the African, Eurasian and Arabian plates direct the tectonics of the island of Cyprus, located in the Alpine-Himalaya earthquake belt (McKenzie, 1972, 1976; Dewey et al., 1986; Le Pichon et al., 1995; McClusky et al., 2000; Ozer and Polat, 2017a, b, c; Ozer et al., 2018). Historical and instrumental records indicate that devastating earthquakes adversely affected Cyprus and resulted in loss of lives and properties (Ambraseys and Finkel, 1987; Ambraseys and Jackson, 1998; Tan et al., 2008). Sixteen devastating earthquakes reported in the historical period with reference to the Mercalli Scale between B.C. 26 and A.D. 1900 are the evidence that the region is under the risk of continuing earthquakes. The amount of energy released during the instrumental seismology period is remarkable (Papadimitriou and Karakostas, 2006; Kadiroglu et al., 2014; AFAD, 2018). From these earthquakes, the cities of Paphos, Salamis and Kition were affected mostly (CGHET, 2018). In the historical period in 1741, the earthquake on the offshore of Rhodes caused structural damages in Cyprus and its surroundings. Following this earthquake, a major earthquake occurred in Antalya in 1743 with a domino effect in which many structures were damaged (Ambraseys and Finkel, 1995). The first devastating earthquake of the instrumental period occurred in 1941. The earthquake with a magnitude of 6.0 caused damages in Famagusta and its vicinity, resulted in loss of several people's lives (Aziz, 1942; Hill, 1948; Galanopoulos and Delibasis, 1965; Ambraseys, 1988). In the 1953 earthquake with the magnitude of 6.1, it was observed that 160 villages were damaged and the landslides triggered by the earthquake caused that loss of some people lives (Galanopoulos and Delibasis, 1965; Pantazis, 1969; Ambraseys, 1988). Cyprus, where no earthquake happened during 43 years, was shaken in 1996 with a 6.2 magnitude earthquake (Mercalli Scale); (Demirtas, 2018). In addition, it was observed that more than 150 aftershocks occurred in the area after an earthquake with the magnitude of 5.8 on August 11, 1999 (AFAD, 2018). Considering this, it is required to be investigated by geotechnical methods whether the places opening to the new settlements are suitable, and then new settlement areas resistant to the earthquake should be built (Mor and Citci, 2007).

One of the most important factors in the

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devastation of earthquakes is the soil amplification. The best example of this situation is that the structures with similar structure quality in the same settlement places differ in their extent of damage due to the soil conditions (Yalcinkaya and Alptekin, 2003; Yalcinkaya, 2005; Yalcinkaya and Alptekin, 2005; Gok et al., 2012). This situation necessitates the earth scientists to examine the local soil features and learn the behavior at the moment of the earthquake. As a result of the studies, the earth scientists realized that the soil was like a strainer and absorbed the earthquake waves in some frequencies while it increased some frequencies (Yalcinkaya and Alptekin, 2003; Yalcinkaya, 2005; Yalcinkaya and Alptekin, 2005). Local soil effects should be achieved using real earthquake records. However, it is also possible to determine the soil conditions in a realistic and practical way using noise recordings (Pamuk et al., 2017a, b; Pamuk et al., 2018a, b, c). The most important reason for this is that the earthquake is the best source for analyzing these dynamic behaviors. The outstanding aspect of this study is the usage of earthquake records. In this study, Horizontal to Vertical Spectral Ratio (HVSR) method (Nakamura, 1989; Lermo and Chavez, 1993) were used in order to determine the soil characteristics of accelerometer station locations using four earthquake recordings in North Cyprus.

2. Tectonic and Geology

With the African Plate to the south, the Eurasian plate to the north and the Arabian plate to the east, Cyprus is tectonically located in a very active area. The relative separation, collision and parallel movements of these three main plates since the Mesozoic period have caused many geological events in the area. The beginning part of these events is the formation of Cyprus, the Hellenic arc, the Aegean Graben System, the Anatolian Micro plate, the North Anatolian Fault Zone, the East Anatolian Fault Zone, and the Dead Sea Transform Faults. It is possible to observe many Ophiolites in the Eastern Mediterranean, and Troodos Ophiolites are among the best-preserved examples. In the Cyprus Island, it is possible to observe these Ophiolites that occurred on the boundaries of the convergent plate and derived from the oceanic crust (Pantazis, 1969; CGHET, 2018; MOA, 2018).

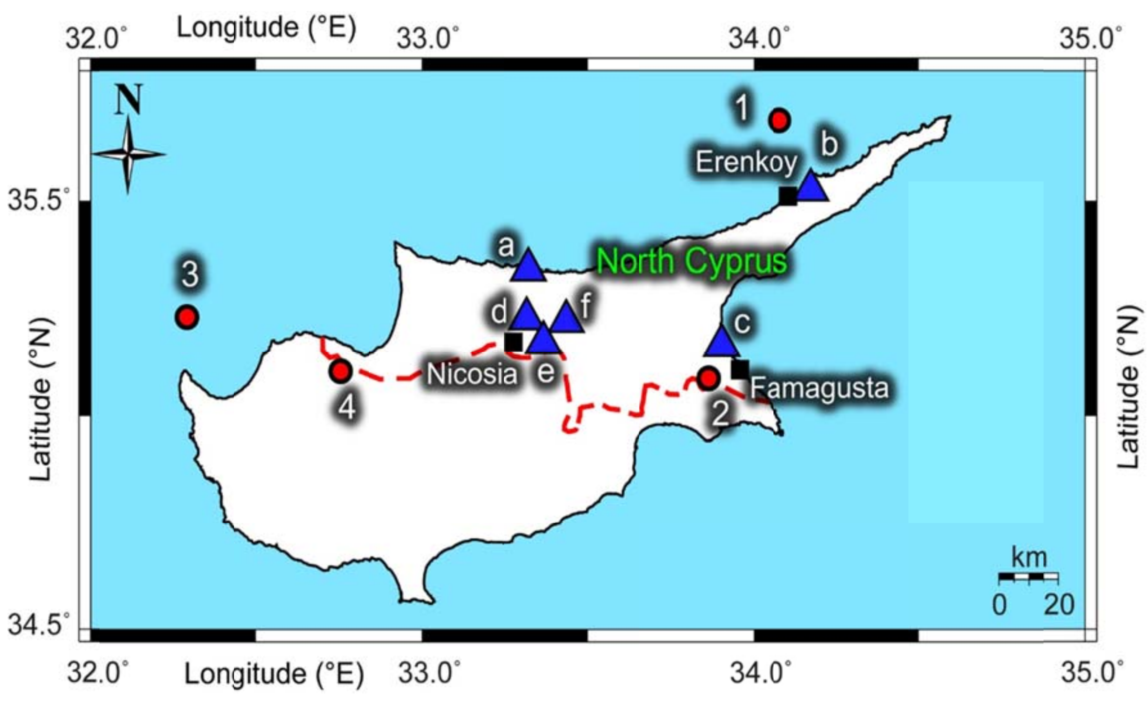

Figure 1. Distribution of selected earthquakes (red circles) and accelerometer stations (blue triangles) in North Cyprus to study the local soil effect. The numbers indicate the earthquake numbers in Table 1.

There are four main geological zones in Cyprus. These zones from North to South are the Keryneia Terrane, the Circum Troodos Sedimentary Succession, the Troodos Ophiolite complex and the Mamonia Terrane. In the North of Cyprus that is the study area, there are the Keryneia Terrane (KT) and the Circum Troodos Sedimentary Succession (CTSS) zones. The KT constitutes a steep mountain chain from the plains with altitudes ranging from 800 to 1024 meters. The KT consists of complex sedimentary units and a limited number of metamorphic-magmatic rocks from Permian to the present. The allochthonous formations, known as the Kythrea formations inside the KT, are pushed southward along the younger autochtonous sea sediments. The Kalogrea-Ardana Flysch unconformably overlies on Kythrea formation, which is presented by a series of Miocene sandstones, siltstones and marls on both sides of the Pentadaktylos Mountain Range. The autochthonous sedimentary units cover the Keryneia Terrane and Troodos Terrane areas. The volcaniclastics, melanges, marls, cherts and limestones are the examples of them. The Lefkara formation is presented by the yellowish colored marls and pebbles. The Kalavasos formation consists of gypsum marls. A new period of sedimentation occurred with the re-bounding of the Atlantic Ocean and the Mediterranean Sea. The Nicosia formation containing sandstones and marls was first subsided. The Fanglomerate formation formed during the glacial period consists of crumbs, sand and clastic sedimentaries (CGHET, 2018; MOA, 2018) (Fig. 2).

3. Data and Method

Four earthquakes recorded by six accelerometers were used in order to understand the soil characteristics of the stations located in North Cyprus. The magnitudes of the selected earthquakes are larger than 3.0 and their depth varies between 25 km and 46 km (Table 1). All accelerometers consist of CMG-5TDs.

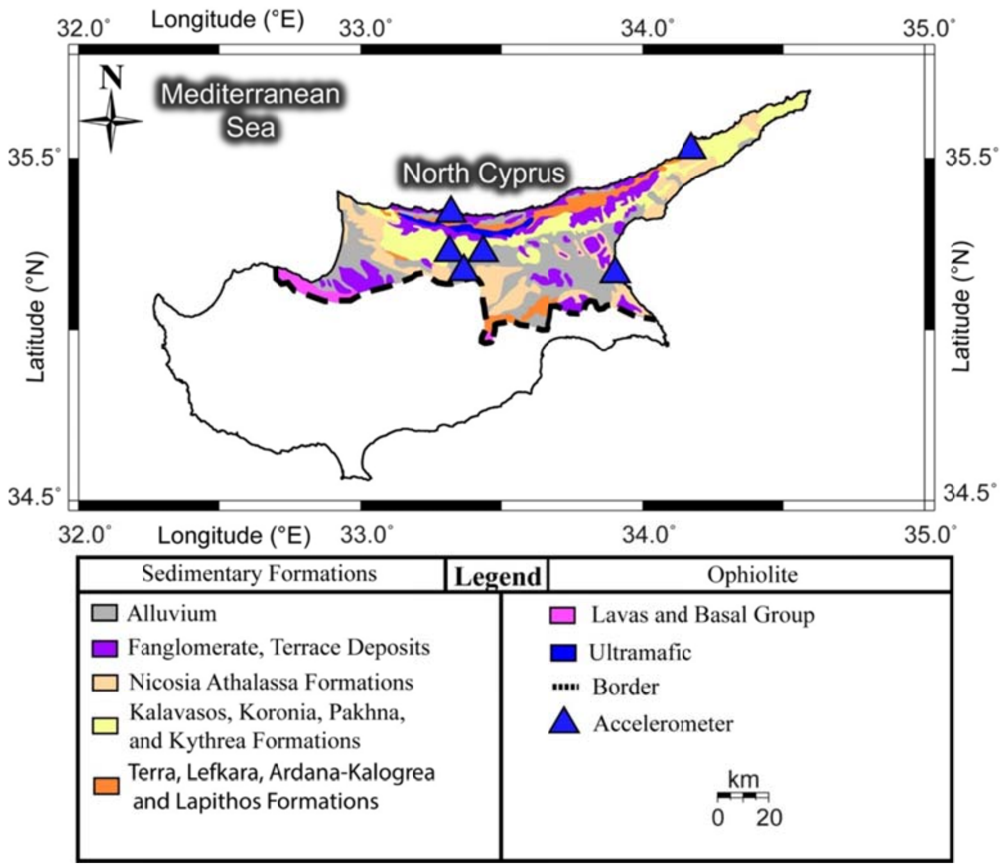

Figure 2. Simplified geological map of North Cyprus (Pantazis, 1969; CGHET, 2018; MOA, 2018). The seismic stations used in this study are represented by blue triangles.

Soil amplifications and dominant frequencies were determined at the station locations with the horizontal to vertical spectral ratio (HVSR) method (Nakamura, 1989; Lermo and Chavez-Garcia, 1993). The earthquake records were digitized with 0.01 sec intervals. Two seconds before and 8 seconds after the earthquake were used while the earthquake records were being windowed. The trend of data was removed and a 10% operator cosine filter was used to minimize the Gibbs effect. Quality factor was determined as 40 with the algorithm of Konno and Ohmachi (1998). The data was transformed from time to frequency with the Fast Fourier Transform. These steps were performed by using GEOPSY software (Sesame, 2004). The main principle on which HVSR method is based, leans on the assumption that local soil effects are not observed in the seismic records of the vertical component as opposed to the horizontal component. For this reason, it is thought that the ratio of the horizontal component to the vertical component gives information about the soil properties. The soil dominant frequency and the soil amplification values of the areas representing the soil features under the stations used with this method can be calculated easily.

The determination of soil dominant frequencies (f) is very important in terms of calculating the resonance effect. The resonance is the condition that the natural period of the soil (T) is the same as the planned construction. In such a case, the vibration value of the structure under dynamic loads reaches to a maximum value, and a destructive force is applied to the structure. This forces the structure to ruin. In the design of the structure, the period values of the floor and the structure must be calculated meticulously and these values should not be allowed to overlap (Ates, 2016). Many empirical correlations have been developed for the calculation of the resonance state. Basically, resonance can be calculated using relation (1) and (2) for the period calculation according to the number of layers (N) (Hays, 1986).

$$T=1/f \tag{1}$$

$$N=10\times T \tag{2}$$

4. Results

The HVSR results of six seismic stations in the study area are presented in Figure 3. Frequencies greater than 0.5 Hz have been taken into consideration since the accelerometer stations do not produce successful results at frequencies less than 0.5 Hz. In the NEHRP (Rodriguez et al., 2001) and JRA (Zhao et al., 2006) generated from the soil classification tables by using earthquake data, the calculations were completed at 10 Hz, since the frequencies greater than 10 Hz were considered as A-class rock ground (Rodriguez et al., 2001; Zhao et al., 2006; Gok et al., 2012). In the general evaluation of the HVSR curves, it is observed that the soil dominant frequency in North Cyprus acceleration station locations varies between 0.75 Hz and 1.50 Hz, and the soil amplification values vary from 2 to 3. The soil dominant frequency and amplification values in station-a located above the fanglomerate unit consisting of clastic deposits such as gravel, sand and silt were calculated as 0.90 Hz and 1.5, respectively. The soil dominant frequency and amplification values in station b located above the Nicosia formation consisting of sandstones and marls were calculated as 0.90 Hz and 1.4. There is a similar image in the curves obtained at stations c and e on the alluvium.

Table 1. Parameters of selected earthquakes.

Earthquake Number	Longitude (°)	Latitude (°)	Depth (km)	Magnitude
1	33.8650	35.0866	46.59	3.0
2	32.6675	35.1320	25.13	3.0
3	33.8685	34.8861	43.43	3.7
4	32.2910	35.2295	37.64	3.5

The soil dominant frequencies at stations c and e were computed as 1.75 Hz and 3 Hz; the soil amplification values were reckoned as 2.5 and 2.25, respectively. The amplification values at stations d and f consisting of gypsum marls were observed as a rising curve gradually. The soil dominant frequencies of these stations were calculated as 8.5 Hz and 7.0 Hz; the amplification values were figured out as 2.5 and 1.6, respectively. Increases in the amplitude of the soil amplification towards high frequencies were observed in stations d and F, which were located in a more compact unit than other stations. The highest amplification values observed in low frequencies were observed in station c and d locations above the alluvium sediments.

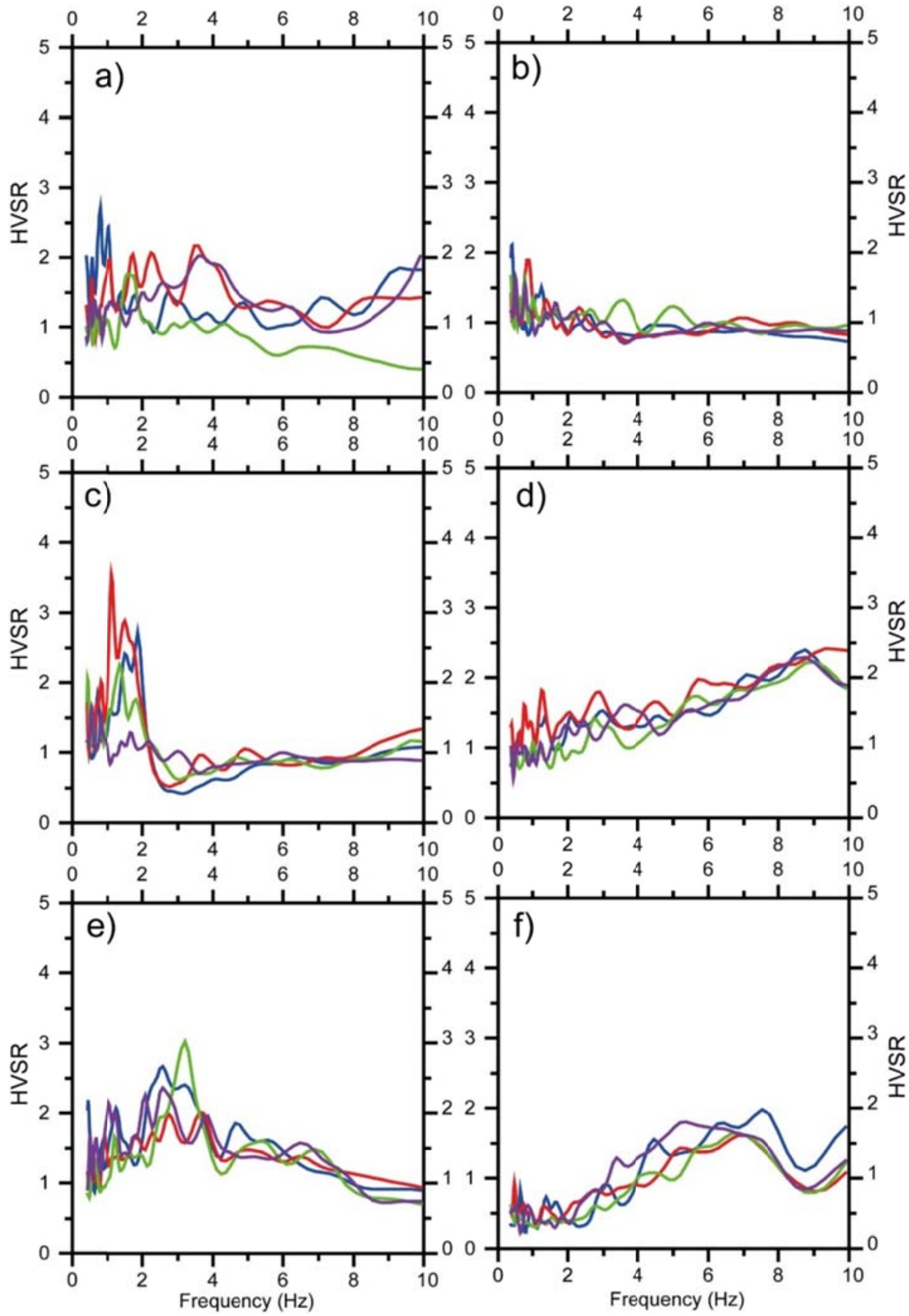

Figure 3. Amplification functions obtained by HVSR method of the accelerometer stations set up on station A, B, C, D, E and F. Each different color curve represents the amplification functions of different earthquakes.

The amplification values calculated by HVSR method for six stations were mapped for different frequencies (Figure 4). It was observed that the soil amplification values at 0.5 Hz varied from 1 to 2. At 2.5 Hz, it can be interpreted that the amplification values in Nicosia and its surroundings have increased relatively. In the examination of soil amplification values at high frequencies, it is observed that there is a decrease in the amplification values from Nicosia to Erenkoy at 5 Hz and 10 Hz.

5. Conclusions

In this study, conducted for the purpose of determining the soil amplification and dominant frequency properties of the settlement area of North Cyprus, it was observed that the amplification values around Nicosia were relatively high. The most important reason for this situation is that the city is mostly built on loose units. However, soil amplifications at low frequencies are not to be feared in terms of seismic risk. In general, high amplifications were observed in the low-frequency range in the loose units, while low amplifications were calculated in the compact units. In order to reduce earthquake damages and losses, the amplification values determined at low frequencies are especially important in Nicosia and its surroundings. The soil dominant periods should be taken into account in order to prevent the resonance effect of the structures under dynamic loads in the settlement area. In general, since the soil dominant frequency varies from 3.0 Hz to 7.0 Hz (T=0.1-0.3 s) in Nicosia and its surroundings, structuring between 1 and 3 floors should be avoided. The soil dominant period produced for Erenkoy is 1.1 s, this value indicates roughly that 11 floors structuring should not be allowed in the area. The soil dominant frequency for Famagusta is 1.75 Hz (T=0.6) and 6 floors structuring should be prevented. In order to increase the accuracy and sensitivity of these results, the analysis of the earthquakes will be carried on with more earthquakes at an appropriate number and quality in the future.

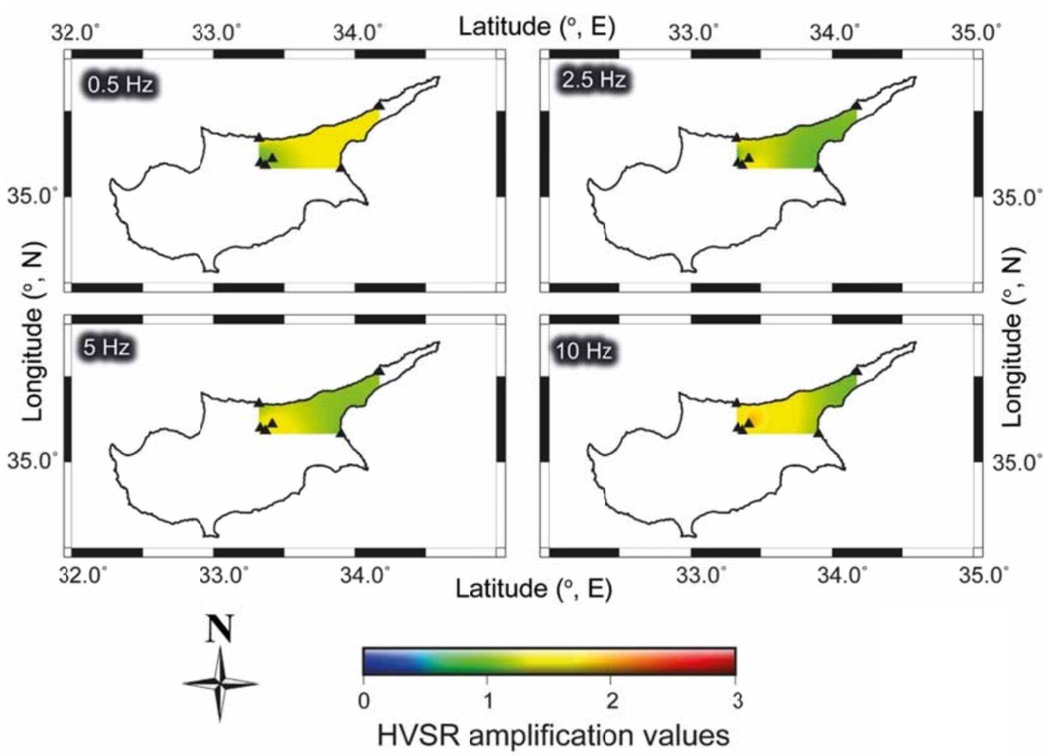

Figure 4. HVSR amplification values according to different frequencies.

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