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# Site conditions and site response at Dafnes, W. Greece during Pirgos March 1993 earthquake sequence

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ABSTRACT: This paper describes the results of a preliminary microzonation investigation carried out at the settlement Kalatheika of the village of Dafnes - NW Pelloponese which was partly destroyed during the March 1993 Pirgos earthquake sequence. Almost 40% of the settlement's buildings, all located within the same territory were severe damaged while the rest remained intact. A microtremor survey revealed the unexpected result of de-amplification throughout the affected region suggesting that the damages should be attributed to geotechnical causes. A geophysical survey with a number of exploratory boreholes revealed the existence of swelling soils in the foundation level of damaged houses.

## 1 INTRODUCTION

This study is a part of an integrated microzonation investigation which was carried out at the village of Dafnes, settlement of Kalatheika, located at the NW Peloponnese in W. Greece (Fig.1a).

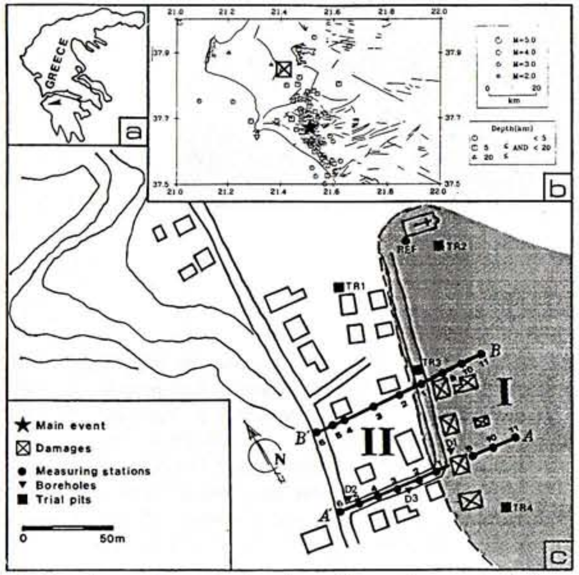


Fig.1 a. Arrow shows the location of the study area. b. Epicentral distribution of the Pirgos earthquake sequence during March 1993. Neotectonic faulting is shown after Lekkas et al 1992.c .Simplified map of the studied area showing the two traverses, the reference station and the measuring stations.

The reason of conducting this investigation was to provide an explanation for the selective concentration of damages within a certain part of the settlement, which occurred during the recent Pirgos March 26, 1993 Ms=5.2 earthquake at an epicentral distance of 25Km (Fig.1b). Fig.1c depicts a topographic sketch of the region under investigation. Within subregion I, all the buildings suffered severe damages whereas similar buildings located in subregion II suffered no damage at all. The damages had the form of shear cracks on masonry walls (Fig.2) and on concrete floors (Fig.3).

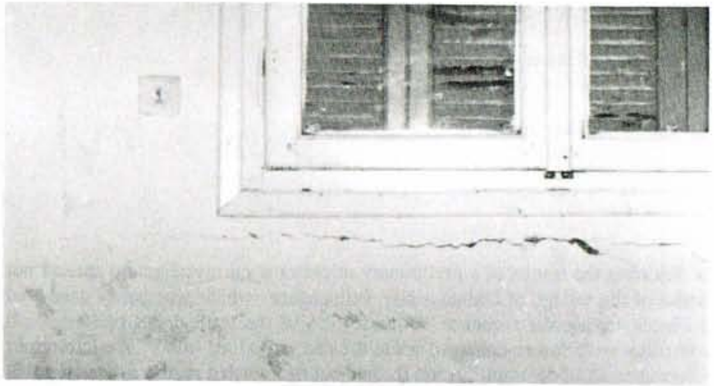

Fig 2. Shear cracks on masonry walls.

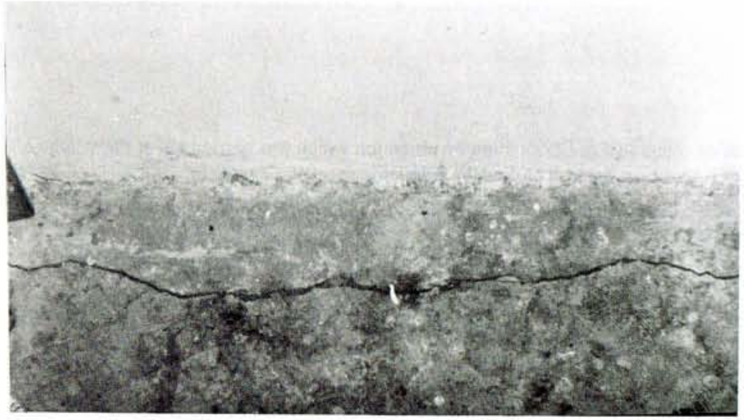

Fig 3. Shear cracks on concrete floors.

1.1 Site of study

The dwellings of both regions I and II were built on 1972 in order to house the inhabitants of the village of Kalathas, which was affected by intensive landslide phenomena. The new houses were single storey structures, with masonry walls, without reinforced concrete elements. They were founded at low depths (0.5-1.0m), on strip footings with a foundation pressure of about 40-50KPa.

Generally the settlement is built on a smooth geomorphological relief, which lies between two hilly undulates. The surface of the area consists mainly of brown-yellowish silty clay to sandy clay, which represents the upper strata of the *Keramidia* formation, mainly consisting of sands to silty clays, which is overlain by the Pleistocene formation of *Kalatha* (coarse grained sands and medium grained sandstones) (Kamberis 1987), (I.G.M.E. 1993). Towards the northern part of subregion I, a layer of stiff grey marly clay was found near the surface, at the foundation level of the church of the settlement, and was used as "base rock" during the microtremor measurements. In the greater study area, no morphotectonic or tectonic evidence was found to indicate the existence of any fault structure.



2 MICROTREMOR INVESTIGATIONS

Current microzonation mapping procedures often call for the generation of complicated mathematical ground-motion models. These models require that expensive geophysical and geological investigations be performed to gather input information (Tselentis et al 1992). A more desirable method of estimating ground motions would be to measure these effects directly.

Such an alternative approach, first introduced by Kanai (1957), involves the use of microtremor or ambient seismic noise to estimate site response. Since then, many researchers have studied microtremor motions in the attempt to gain an understanding of the influence of local basinal geology on ground motions (Lermo et al., 1988; Seo et al., 1989; Field et al., 1990; Morales et al., 1991). However, the relation between geological conditions and vibrational characteristics of microtremors still remains open to discussion. In some cases predominant period is discussed (Ohta et al., 1978), while in others attention is focused on the variation of amplitude (Kagami et al., 1982). The purpose of this part of the research is to evaluate the use of microtremors in understanding the anomalous distribution of damages at the settlement.

2.1 Instrumentation and data acquisition

The ground vibration study was performed using a three component system consisting of three Teledyne S13 sensors ($T_0$=1 sec) and a 12bit digital acquisition system (PDAS) recording at a rate of 100sps. The PDAS contains an anti-aliasing filter with a high-cut value set automatically by the sample rate. A complete system calibration curve is shown in (Fig.4).

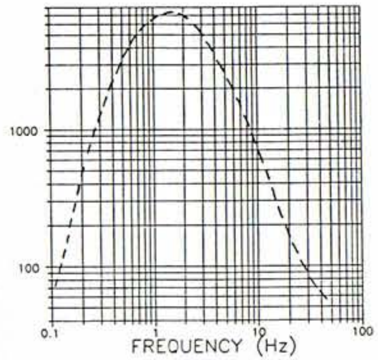


Fig 4. Calibration curve of the recording system.

System noise was measured by replacing the seismometer with an inert dummy load and computing spectra for various gain settings and for the three components. No significant differences were detected and the system's electronics noise remained almost 30dB below the measured seismic noise.

The measurements were performed during the night along two parallel traverses (Fig.1c). Each traverse consisted of 9 measuring stations at a spacing of about 15 m. A reference base station (REF) was positioned at the basement of a nearby church which was founded on stiff soils. For each recording site, a 5-min window was recorded and the base measurements were repeated after every four site measurements.

2.2 Data analysis

Ambient noise within the region is low; absolute amplitudes of $10^{-5}$ to $10^{-4}$ mm/s are typically observed. Fig.5a,c shows 30-second traces recorded at the base at the beginning and at the end of the survey. Although the time-domain character of the noise depicts some variations, the spectra characteristics are persistent as it is seen from the corresponding spectra (Fig.5b,d).

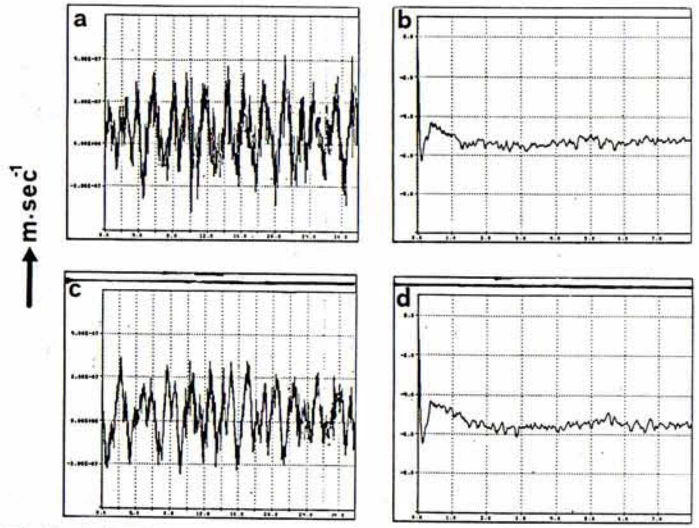


Fig 5. a , b. Thirty seconds microtremor recording at the beginning and at the end of the survey at station REF. c , d. Corresponding spectra.

Average spectra for all the recording sites were computed by dividing the 5-min microtremor signal for a given site into five 1-min subwindows. Each of these series was tapered with a 3-sec Hanning taper and converted to the frequency domain employing an FFT. The five spectra thereby generated were then averaged to obtain a mean spectrum for the corresponding site. Fig.6 shows some of these spectra for the N-S component along the two traverses. Although all of them are somewhat complicated and seem to have many peaks, nevertheless it is possible to find a change of predominant frequencies specially at the N-S component where they start from 0.5Hz at location 11 to about 1.8Hz at location 4 of traverse A. In the spectra of the vertical component no systematic changes were found.

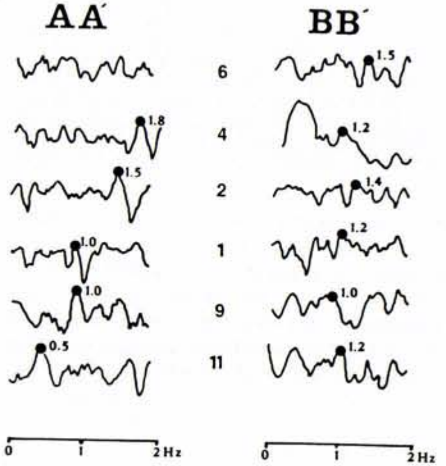


Fig 6 . Spectra for the N-S component at the two traverses (AA', BB')

Next, spectral amplitudes for the three components were normalized by that at the reference site which was observed at the nearest time. The spectral ratio was calculated for every 1-min window and mean values up to 4Hz were computed for all the sites. Fig.7 depicts the obtained spectra ratios while Fig 8a,b



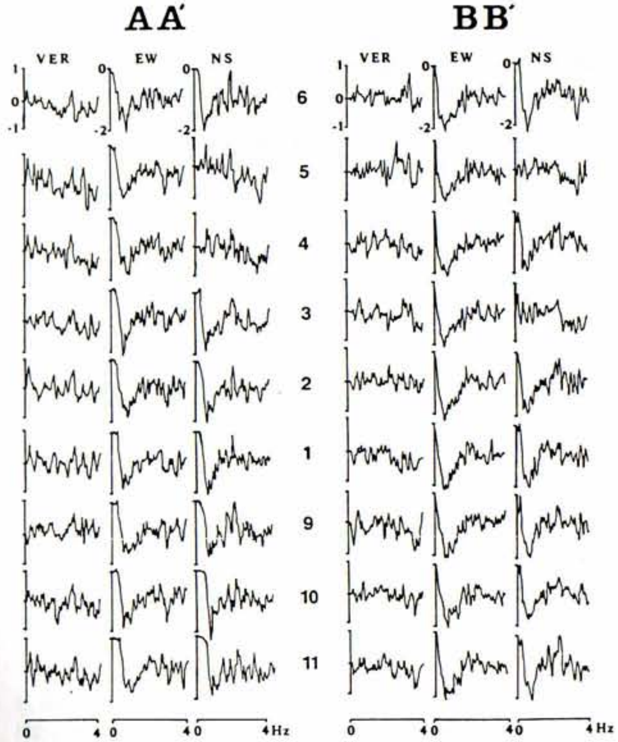


Fig 7. Spectra ratios obtained for the two traverses with respect to the base. Y-axis scaling is applied similarly on all traces as shown on trace 6.

depicts the corresponding amplification factors with respect to reference station (REF) for the three components along the two traverses.

Judging from this diagram we see that an interesting feature is the difference in amplification between the N-S component and the vertical and E-W components. Also a zone defined between sites 11-2 for

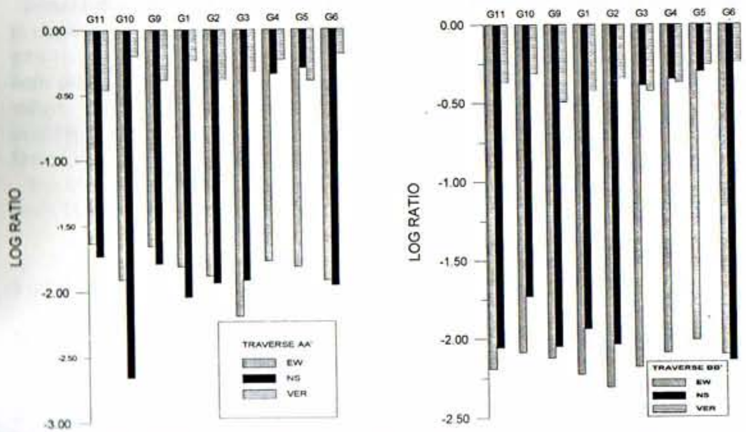


Fig 8. a,b. Amplification factors for the three components, for the two traverses.

traverse BB' and sites 11-3 for traverse AA' depicts considerable deamplification of the ground motion with respect to the reference station REF. This situation contradicts the macroseismic observations since at those locations where there was deamplification the buildings suffered severe damages.

In order to emphasize this phenomenon and reveal any site dependent spectra variations, we also computed spectral ratios with reference to the first site for each traverse (sites 6A and 6B in Fig.1c). The obtained results are depicted in Fig.9 while Fig.10 shows the corresponding amplification factors. Sites 5A, 4A, 3A, 5B and 4B show amplification of the microtremor motions at a frequency band around 0.5Hz with reference to sites 6A and 6B. Sites 10A,9A,1A, and 2A indicate deamplification.

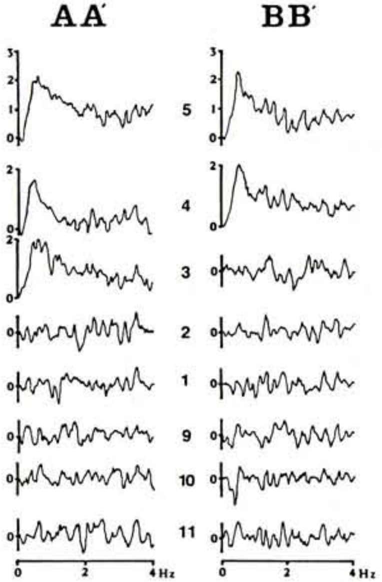


Fig 9. Spectra ratios obtained with respect to sites 6A and 6B for the two traverses.

From all the above it is evident that the observed macroseismic anomaly cannot be explained simply as the effect of local site amplification due to variations of surface geology. Neither it can be attributed to any shift of the predominant periods of soils towards the resonant periods of the buildings (estimated to be around 0.05s). In order to investigate the possible causes of this variation of the wave field, further investigations both Geotechnical and Geophysical (Cross-Hole and Down-Hole) were conducted.

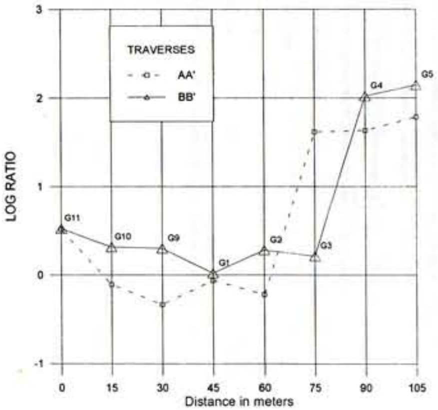


Fig 10. Corresponding amplification factors for the spectra ratios with respect to site 6A and 6B.



## 3 GEOTECHNICAL INVESTIGATIONS

### 3.1 Description of tests

The Geotechnical investigations consisted of:

1. Three exploratory boreholes D1,D2,D3 were drilled to depths of 39.15, 39.50 and 32.15m respectively by the Central Public Works Laboratory. During the advance of the boreholes disturbed, undisturbed (shelby) and semidisturbed samples were obtained.
2. Four trial pits TR1,TR2,TR3 and TR4 with corresponding maximum depths of 3.15, 1.95, 2.60 and 2.25m.
3. In-situ Standard Penetration Tests (S.P.T.) were carried out during the drilling of D1, D2 and D3 at 1.50 to 2.50m intervals, in order to assess the in-situ mechanical characteristics of soils. During the Cross-Hole investigations the S.P.T. device was also used to generate body waves.
4. Measurements of the underground water table, taken at the beginning and at the end of daily drilling.
5. Laboratory tests, including:
   - -classification test according to U.S.C.S.
   - -linear shrinkage (L.S.) tests
   - -organic matter determination (O.M)
   - -natural water content (W.C.) and wet bulk density determination
   - -tests to determine the strength and deformation characteristics of soils such as unconfined compression, unconsolidated undrained triaxial (UU) tests, consolidation (oedometer) tests as well as tests of the estimation of swelling pressure.

### 3.2 Test results

In subregion I (Fig.1c) near the surface the stratigraphy consists of brownish-yellow to greyish-brown clay, with sparse thin gypsum fragments and some calcareous concretions (Unit 1). The thickness of Unit1, is ranging from 0.70 to 2.05m and it is laterally diminishing (at TR2 and TR3). This probably represents the aforementioned upper strata of the *Keramidia* formation. The superficial encountered lithology at TR2 and TR3 is composed of grey, brownish-grey to greenish-grey marly clay, with many calcareous concretions and some brown remnants of lignite (Unit2a). This layer represents the aforementioned *Keramidia* formation and is met also in TR3 and D1 (under Unit1) at depths 1.00 and 3.00m respectively. In Unit 2a an interlayer of dark brown lignite formation (Unit2b) is encountered, with a thickness of about 1.50m. This material includes some gypsum fragments and some very thin sulphate layers and is found only in subregion I, at depths ranging from 1.00 to 3.00m from the surface. At greater depths (about 7.50m) the marly clay of Unit2a, is transforming to clayey marl (Unit2c).

In subregion II (Fig.1c) near the surface the soil consists of brown to brownish-yellow silty, sand clay to clayey sand (Unit1), with an approximate thickness of 9.0m. Unit1 is underlain by grey, brownish-grey to greenish-grey marly clay to claey marl (Unit2c). The variations of physical soil properties of both subregions are shown in Table1. Table 2, depicts the variations of mechanical properties ($N_{SPT}$ values, undrained shear strength Cv, unconfined compression strength $q_u$, compressibility ratio $C_c$, swelling pressure S.P.) is given, as well as the variation of dynamic characteristics, (Cross-Hole and Down-Hole) test results Vs

The level of the water table in subregion I, is found at a depth of 9.0m and in subregion II it varies from 9 to 11m (from E to W). The ground surface is considered as reference level.

## 4 GEOPHYSICAL INVESTIGATIONS

In order to determine seismic velocities and confirm the results of the Geotechnical tests, special Geophysical investigations were performed

The Cross-Hole technique was applied according to A.S.T.M (1988) in boreholes D2 and D3 at maximum depths of 38.45 and 29.2m respectively. At each Cross-Hole test site, two boreholes have been advanced at a given in between distance S (D2D2'=4.30m and D3D3'=3.90m) one for the seismic source (D2',D3') and the other for the transducer (D2,D3).

Table 1: Variation of physical properties.

| Region | Layer | Gravel | Sand | Sieve No 200 | $W_L$ | $I_P$ | U.S.C.S | W.C | W.B.D | O.M | L.S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | % | % | % | % | | % | KN/m$^3$ | % | % |
| I | Unit1 | 0 | 0-14 | 86<br>98 | 57.0<br>83.5 | 34.0<br>52.5 | CH | 24.9<br>29.3 | 19.7<br>20.4 | | 17.9 |
| I | Unit2a | 0 | 0-6 | 94<br>100 | 58.0<br>93.0 | 35.0<br>63.0 | CH | 21.0<br>24.3 | 20.6<br>21.3 | | 13.9<br>18.0 |
| I | Unit2b | 0-1 | 4-42 | 57<br>96 | 52.0<br>79.8 | 24.3<br>46.8 | CH,OH | 37.6<br>38.9 | 18.2<br>18.4 | 7.4<br>10.6 | 10.7<br>14.0 |
| I | Unit2c | 0-2 | 1-51 | 49<br>99 | 25.3<br>64.0 | 9.3<br>39.0 | CL,CH<br>(SM,ML) | 13.5<br>20.7 | 21.5<br>23.1 | | 5.3<br>6.8 |
| II | Unit1 | 0-8 | 6-56 | 44<br>94 | 22.4<br>55.7 | 9.4<br>34.7 | CL,(SC)<br>(CH) | 16.9<br>23.8 | 19.4<br>21.4 | | 3.5<br>4.1 |
| II | Unit2a | 0-6 | 0-75 | 19<br>100 | 22.0<br>70.3 | 9.0<br>45.3 | CL,CH,<br>ML,(SM) | 13.3<br>22.3 | 20.7<br>22.6 | | 3.8<br>10.3 |

Table 2: Variation of mechanical and dynamic characteristics.

| Region | Layer | $N_{SPT}$ | $q_u$ KPa | Cu KPa | $C_c$ KPa | S.P. KPa | $V_s$ m/sec |
|---|---|---|---|---|---|---|---|
| I | Unit1 | 9 | | 177 | 0.197 | 130-200 | |
| I | Unit2a | 31-46 | 423 | 268 | 0.136 | 125-325 | |
| I | Unit2b | | | 110 | | 40 | |
| I | Unit2c | 50/5->50 | 465-886 | | | | |
| II | Unit1 | 9-50/15 | 50-228 | 62-350 | 0.100-0.135 | ~ 0-30 | 160-336 |
| II | Unit2c | 50/10->50 | 216-936 | | | | 269-506 |

The Down-Hole technique was applied in borehole D1 at maximum depth of 37.30m and at a distance S=4.30m from the source. Horizontally polarised shear waves generated by reversible horizontal mechanical impacts, on a massive iron beam of a total weight of about 100Kg. During the Down-Hole measurements, borehole D1 is considered as a receipt borehole (Auld 1977). The locations of both special Geophysical tests are depicted in Fig.1c.

The correlation of Shear Cross-Hole velocity Vs, versus depth at sites D2 and D3 are presented in Fig.11.

## 5 DISCUSSION

The evaluation of the microtremor data, revealed that the anomalous concentration of damages in subregion I of the settlement cannot be attributed to the local site amplification of soil spectra or to resonance phenomena.

The presence of a lignite layer of about 1.50m thickness, at a depth of about 2.00m can possibly explain the de-amplification of response spectra in subregion I, but not the selective damages there, during the Pirgos earthquake of March 23, 1993. These destructions must be attributed to other Geotechnical causes.

From the strength and deformation characteristics of soils of Unit 1 in both subregions, it was concluded that there was no problem concerning bearing capacity failure or settlements.

In subregions I and II, soils of Unit1 showed different behaviour, concerning the swelling potential. The surface formations of subregion II (up to 9.0m depth) are classified as CL and showed very low swelling potential (swelling pressures, 0-30KPa). In subregion I, the corresponding surface layer (up to 3.0m depth), is characterised as CH and showed a significant swelling potential (swelling pressures, 125-325 KPa).

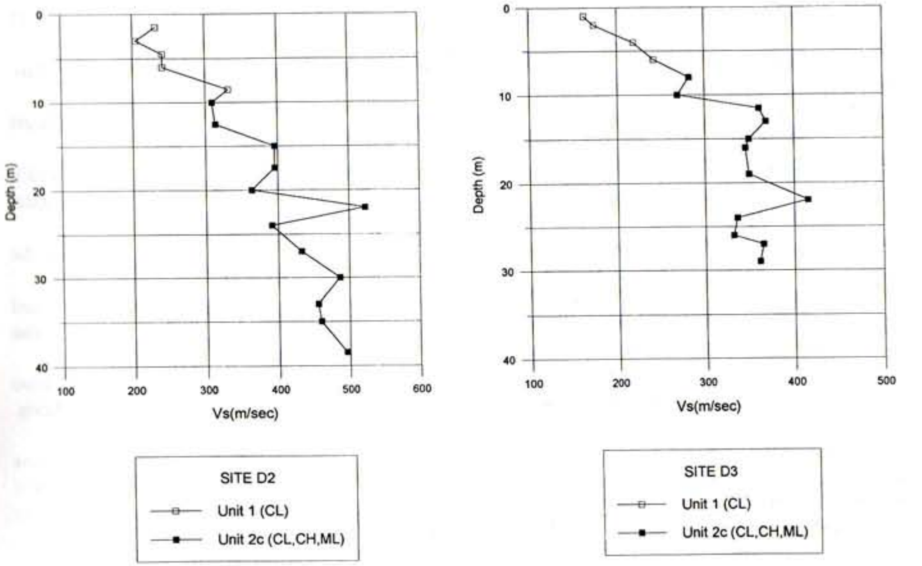

Fig 11. The Cross - Hole test results for sites D2 and D3.

Taking into consideration that the swellin pressures (125 to 325 KPa) are much higher than the corresponding foundation pressures of the houses (40-50KPa), swelling phenomena are very probable in subregion I.

As a result of previous swelling and shrinkage cycles of the foundation soil, there were stresses accumulated in the masonry elements of the buildings. This had not led to breaks of the walls and floors before the earthquake, although some hair cracks had been already noticed. With the earthquake action stresses increased considerably and failures took place, manifested by widening of existing cracks and the formation of new ones (Fig.2.3)

## CONCLUSIONS

This investigation has attempted to explain the causes of a macroseismic anomaly observed at the Kalatheika settlement of the village of Dafnes-W.Greece, during the Pirgos March 26, 1993 earthquake sequence. The fact that the microtremor amplitude spectra indicated de-amplification and the absence of resonance phenomena, suggests that the observed anomaly could be attributed to geotechnical causes. This is verified by the existence of swelling soils in the foundation level of the damaged houses.

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