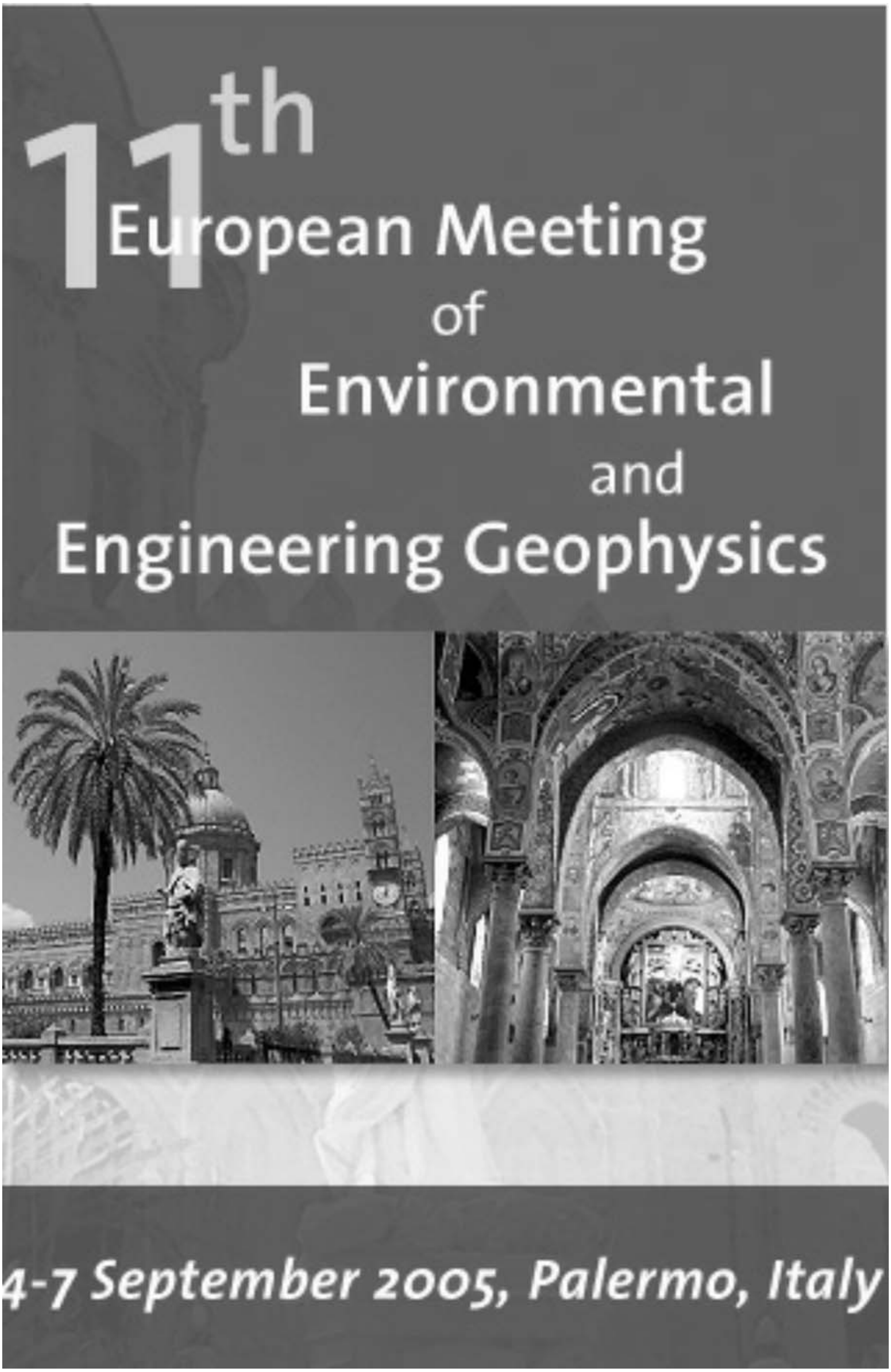
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A041 Use of surface waves for geotechnical characterization of neogene deposits – The Glyfada, Athens case study.

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Abstract

Summary.

The surface waves method was used in this case study as an alternative and efficient tool for geological and geotechnical investigation. The site is located at Glyfada, Athens where neogene formations, mainly composed by clayish layers with intercalations of conglomerates, are present. The results were compared with data from geotechnical investigation and seismic refraction data.

Introduction.

The test site is located on South – West Attica at the suburb of Glyfada in Athens, Greece. The layout for the acquisition of surface waves data was based on the multistation approach while the processing method was f-k transformation. On the test site a geotechnical investigation was already performed (*Kolaiti E., 2004*). Refraction data acquisition was also performed. The results from surface waves test, refraction test and geotechnical investigation were compared and the outcome is presented in this paper.

Geological setting of the test site and Geotechnical investigation.

The site is located near the coastal zone of South-West Attica at the Glyfada suburb on the outskirts of Athens. The broader area along this coastal zone geologically is composed by Quaternary and Neogene deposits (**figure 1)**. Quaternary formations include coastal deposits of sands and gravels and slope debris of clay and silt with gravels. Neogene deposits include marine faces at their lower parts and successions of lacustrine and terrestrial faces at their upper parts, (*Skylodemou H., 2002*). The test site is located on neogene formations composed by clayish terrestrial deposits. These formations include successions of calcite clay layers with intercalations of conglomerates composed by limestone gravels with clay-calcite cementation material.

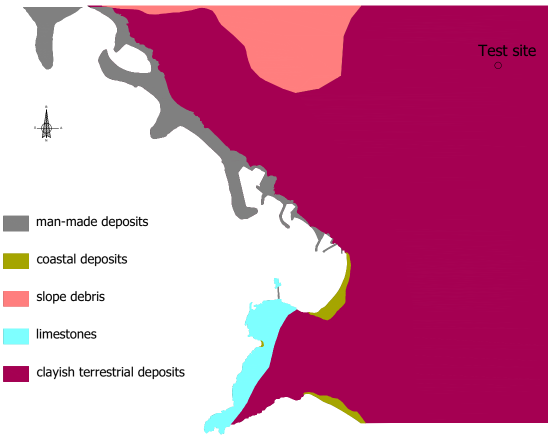

Figure – 1. Geological map of Glyfada suburb.

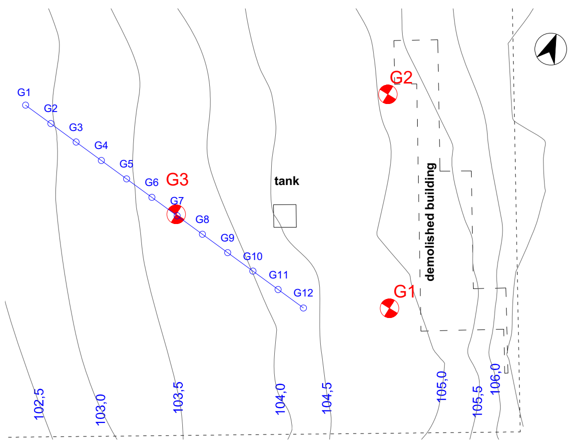

Figure – 2. Topography of test site with borehole positions and refraction line.

The geotechnical investigation included three sampling boreholes G1, G2 and G3 of 15m, 10m and 15m respectively using a rotary drill (**figure 2)**. All three borehole logs reveal similar stratigraphy, composed of a thin layer (0,50m to 0,80m thickness) of superficial weathered materials of clayey sands with a small percentage of gravels. Further below, a conglomerate layer was drilled of

6,70m to 7,80m thickness. It is a strongly to moderate cemented conglomerate, with various degrees of fragmentation as shown by the variation of R.Q.D. At the lower parts of all three boreholes drilled a layer of hard calcite clay with sand with a small percentage of gravels. Field tests included rock quality index measurements (R.Q.D.) of the conglomerate layer and standard penetration test (S.P.T.) of the clayish layer. The inferred geotechnical stratigraphy is presented in **figure 3** (*Kolaiti E., 2004*).

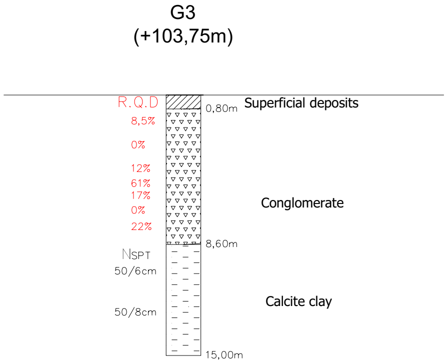

Figure – 3. Test site stratigraphy, (*Kolaiti E., 2004*).

Seismic refraction tests.

Two different refraction tests were performed using arrays, sited along the same line, deployed in a way that borehole G3 would be in its middle. Twelve geophones with a spacing of 5m and two different impulsive sources were used. The first source was a 5Kgr sledgehammer on a metal plate and it was used for the determination of P-waves arrivals. The second source was an S-wave source and it was used for the determination of S-wave arrivals. The sources were positioned on both sides of the arrays at 2,5m from the nearest geophones (**figure 2)**. Time arrivals for P-waves and S-waves were calculated and time arrival – distance figures were constructed for P and S waves and their corresponding models (**figure 4**). Calculation of P and S waves enable an estimation of Poisson's ratio for the subsurface layers.

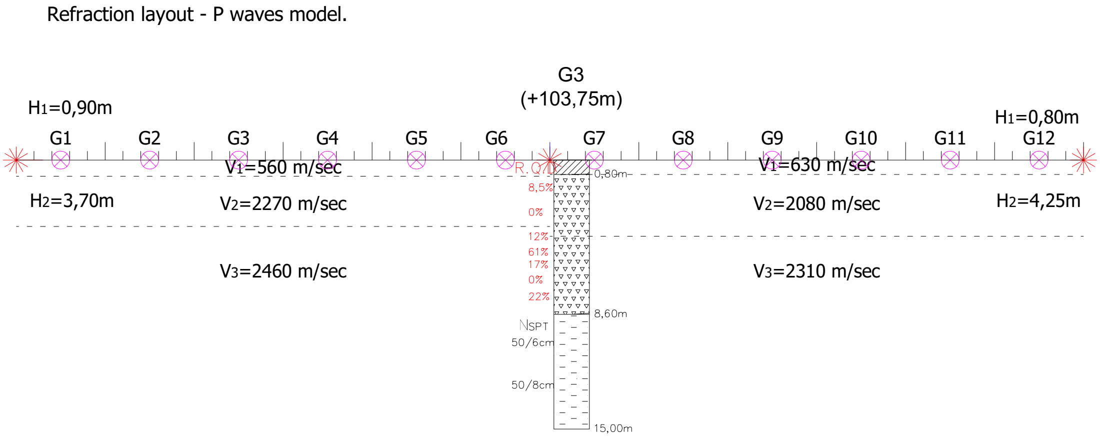

Figure – 4. Refraction P-wave model.

Surface waves test.

The surface wave test was performed using multistation array of 24 vertical geophones with a spacing of 1m along the same line as seismic refraction tests. The source was a 5Kgr sledgehammer on a metal plate and was positioned at both sides of the array at distances of 10m, 15m and 20m. Data were acquired with a Smartseis device. Considerations were taken to ensure a high signal to noise ratio by stacking the data. Surface waves records were further processed by using the S.W.A.T. code of *Strobbia C.* and *Dall'ara A.* (2002) on MATLAB environment. Pre-processing checking of data quality was performed by calculation of coherence function and f-x spectrum. Using S.W.A.T. code time – offset (t-x) data were transformed to frequency – wavenumber (f-k) domain using 2D FFT. Experimental dispersion curves of phase velocities of Rayleigh waves as a function of frequency were obtained in the f-k domain by automatic search of energy maxima for each frequency (*Strobbia C., 2002*). Characteristic f-k spectrum and dispersion curve for one of the tests are presented in **figure 5**.

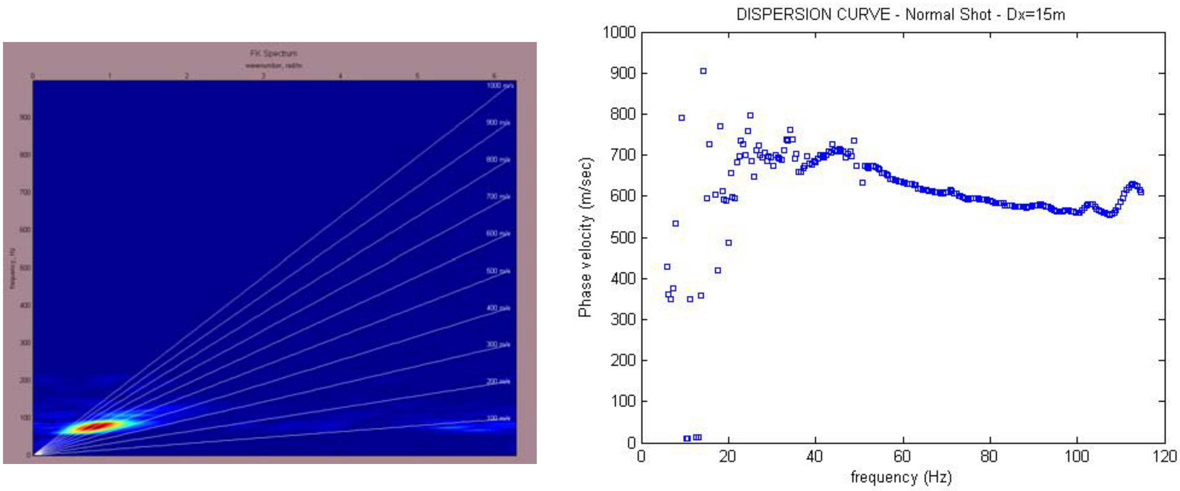

Figure – 5. Characteristic f-k spectrum and dispersion curve (test with 15m distance between source – geophone).

The inversion of the dispersion curves was performed by using the MATLAB code developed by *Rix.* and *Lai.* (2001) which solves the nonlinear inverse problem of estimating the shear wave velocity profile given a surface wave dispersion curve and associated uncertainties, which are assumed to represent the fundamental mode of propagation. Due to constrains concerning the thickness and the number of the model layers, apposed by the inversion algorithm, a discretization of the subsurface was chosen in accordance with the loss of resolution with depth as well as with the resolution limits dictated by the acquisition layout (geophone spacing of 1m and distances to the source). For the model parameters with a lesser influence to the surface waves propagation, were chosen a priori data from geotechnical investigation for the density and from seismic refraction for Poisson's ratio. Characteristic final model and its fitting to the dispersion curve is presented in **figure 6**. In order to check the validity of fundamental mode dominance the final models of the inversion were used as an input to the multimodal forward modeling code as shown in **figure 7** (*Strobbia, 2004*).

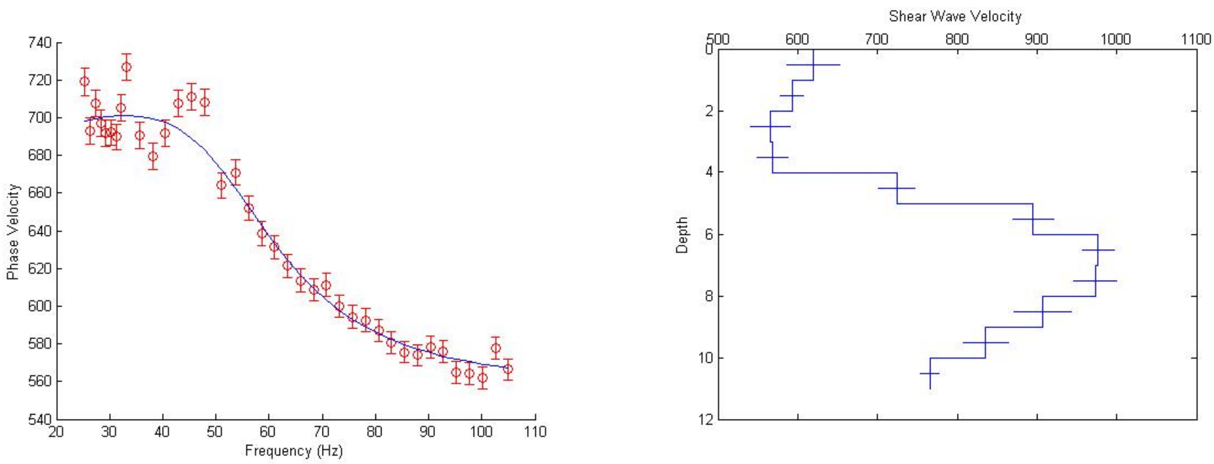

Figure – 6. Final model and its fitting to the dispersion curve (test with 15m distance between source – geophone).

Discussion - Conclusions.

The presence of the conglomerate formation at the site, above the hard calcite clay layer posed the question of the ability to compare the R.Q.D. parameter variation with depth versus Vs variation, as the fragmentation of the rock formation influence the propagation of seismic waves. In order to make this comparison a model was created using data from the geotechnical investigation and the seismic refraction test. This model was used as input to the forward modeling code and its result compared with the experimental dispersion curves. To construct this model a formula relating R.Q.D. with seismic velocities by *Deree* et al. (1967) was used:

$$\left(\frac{V_{SITE}}{V_{INTACT}}\right)^2 \times 100\% = RQD\,.$$

The value of intact conglomerate has a mean value of 2500m/sec inferred from statistical analysis of Vs values measured at laboratory specimens of conglomerates from many sites in Greece (*Bourounis, 1997*). The calcite clay layer was modeled using an empirical formula correlating S.P.T. with Vs by *Kaletziotis et. al. (1992)* for cohesive soils of the Greek area was used:

$$V_S = 76{,}55 \times N_{60}^{\;0{,}445}$$

Seismic velocities for the superficial weathered materials derived from seismic refraction data and a value of 450m/sec for Vs was chosen to represent parts of conglomerate with 0% R.Q.D. The outcome of the forward modeling code for this model is presented in **figure 8**.

This case study showed that the experimental dispersion curves were reasonably compared not only with S.P.T. values, but also with R.Q.D. values. Final models from the inversion of dispersion curves gave variations that can be attributed to the variation of the degree of fragmentation of the conglomerate with depth. These models gave a crude fit to the data mainly because of the limitations of the inversion algorithm. Even though, a clear view of velocity inversions due to fragmentation was possible. In conclusion, surface waves method proved to be an alternative tool for geological and geotechnical investigation, overcoming the limitation of seismic refraction method (like inversion of velocities with depth) and providing data comparable to the findings of the investigation boreholes.

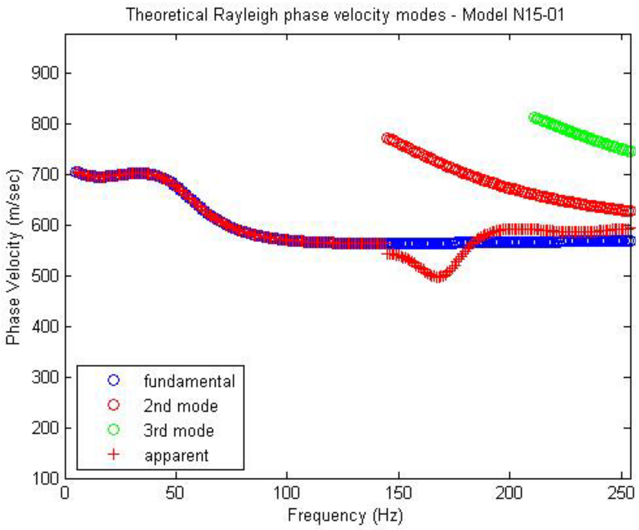

Figure – 7. Results from forward modeling for one of the final models of inversion. The theoretical apparent curve (red cross) lays on the theoretical fundamental mode curve.

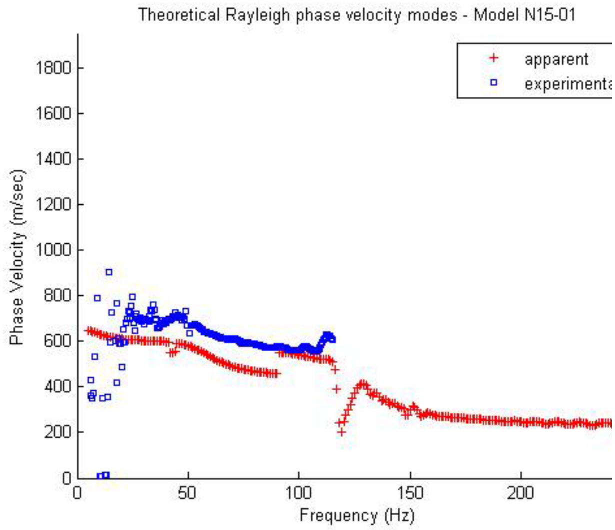

Figure – 8. Comparison between experimental dispersion curve and theoretical apparent dispersion curve of the model base on data from geotechnical investigation (mainly RQD, SPT) and refraction data.

Acknowledgements

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