Gruppo Nazionale per la Difesa dai Terremoti

Framework Program 2000-2002

ANNUAL REPORT
- 1ST YEAR -
(2000-2001)

Design and installation of a seismic small scale array as seismic alarm system

Coordinator: Dott. Thomas Braun
(I.N.G.V.-Roma)

Index

---

1. Preface

SInce the project was not approved as proposed at first, but merely as a feasibility study, it was not possible to maintain the scientific activity schedule originally foreseen. In their expert opinion the scientific committee of the GNDT expressed some doubts concerning the successful application of the proposed method to the complex Italian geology. In particular it was noted, that array techniques would not be advantageous compared to a local seismic network.

Following the recommendations of the referees the approved grant was employed for the realisation of a field experiment in order to test the proposed array method under real conditions. For this reason the original subdivision of the project in five tasks was abandoned and substituted by one unique task: "*Installation of a test array*". The purpose of this unique task was to study the respective advantages, limits and conditions of the applicability of the method on the national territory.

2. Installation of a test array

For economical and logistical reasons the installation of the test array was realised together with the field experiment of the GNDT project *"Development and Comparison between Methodologies for the Evaluation of Seismic Hazard in Seismogenic Areas: Application to the Central and Southern Appennines."* (Coordinator: Cocco). In this way the requirements of the two different field campaigns could be unified in one common experiment.

By the way, the seismic campaign was the first test of the new Mobile Acquisition Centre (MAC) of the INGV Mobile Network (fig. 1).

Fig. 1 - Mobile Acquisition Centre of the INGV.

2.1. Choice of the test site

The choice of an appropriate logistical base for the MAC had to come up as well for the array installation itself, as for the successive network configuration. That's why one unique site (☆ star in fig.2) was chosen for both seismic experiments, located on the hills of «Città di Castello», in the vicinity of an *«agriturismo»* called Pratacci di Uppiano" (fig. 3).

The main argument for the decision to chose this panoramic site as logistical base for both experiments was given by the technical requirements of the digital data telemetry, which needs the single transmitter antennas to come into the sight of the MAC. This point was crucial for the successful successive installation of the local network up to 40 km from the MAC. However the perfect site for an seismic array would have been more distant from civilisation, with less topography within the array area. Therefore the final choice represented a compromise between the requirements of the two site surveys.

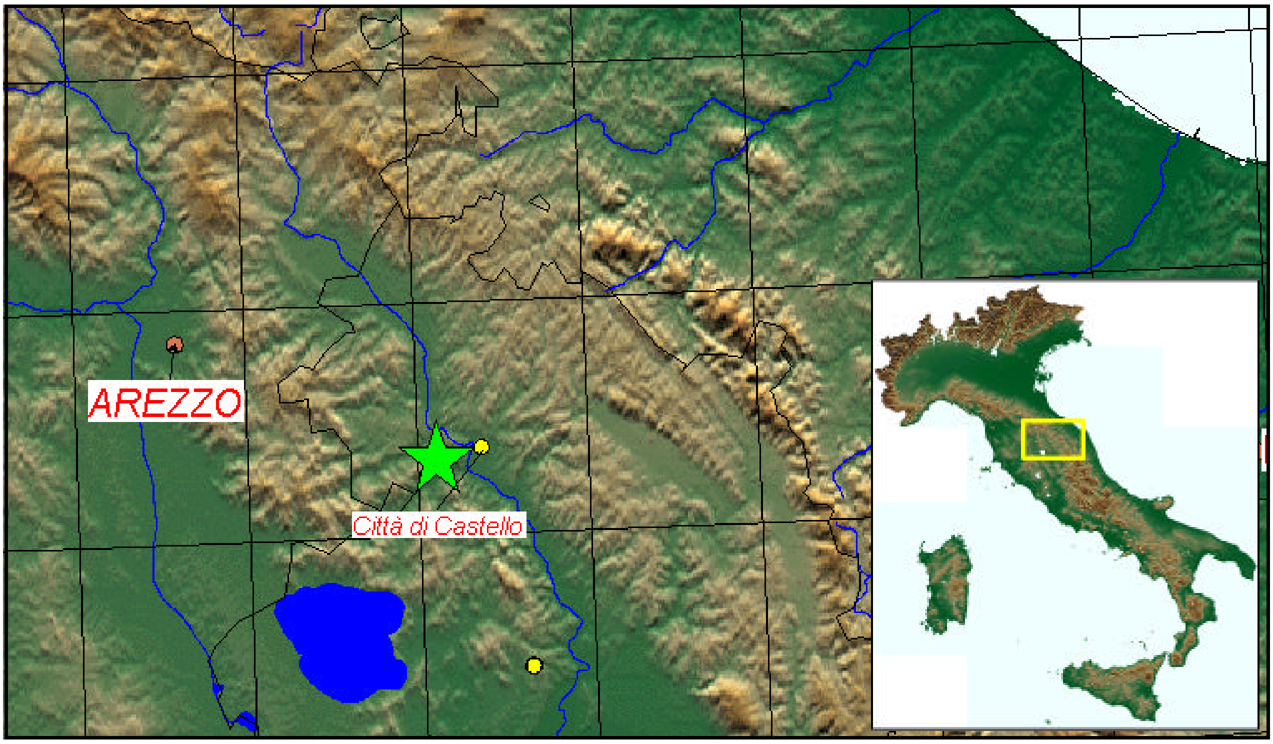

Fig. 2 - Location of the test array site.

2.2. Instrumentation

One of the main hardware requirements for seismic arrays is generally to use instrumentation with identical technical characteristics and to have at one's disposal a central data acquisition with central timing. The INGV's MAC is able to handle the acquisition of 28 channels in real time and was therefore the appropriate instrument for the array experiment.

The MAC's instrumentation pool used for the test array consisted of nine 3-component stations, composed by:

- <u>datalogger</u>: Lennartz 5800 (12 bit gain ranging)
- <u>seismometer</u>: Lennartz LE 3D-5s
- <u>time signal</u>: GPS
- <u>power supply</u>: solar panel + battery
- <u>data transmission</u>: digital telemetry unit/antenna
- <u>acquisition system</u>: software developed by INGV, based on Linux system

2.3. Geometry of the test array

The scientific purpose of the field experiment was to test the applicability of array techniques to the inhomogeneous Italian geology. Therefore, the tasks of the feasibility study were twice:

- test of beam forming method itself
- noise correlation analysis

For the latter task the array geometry must be as irregular as possible in order to obtain as many different intersensor distances as possible. The test array was therefore composed of nine 3-components sensors, with respective station-to-station distances between 100 m and 1800 m, installed in a rather irregular geometry as shown in figure 3.

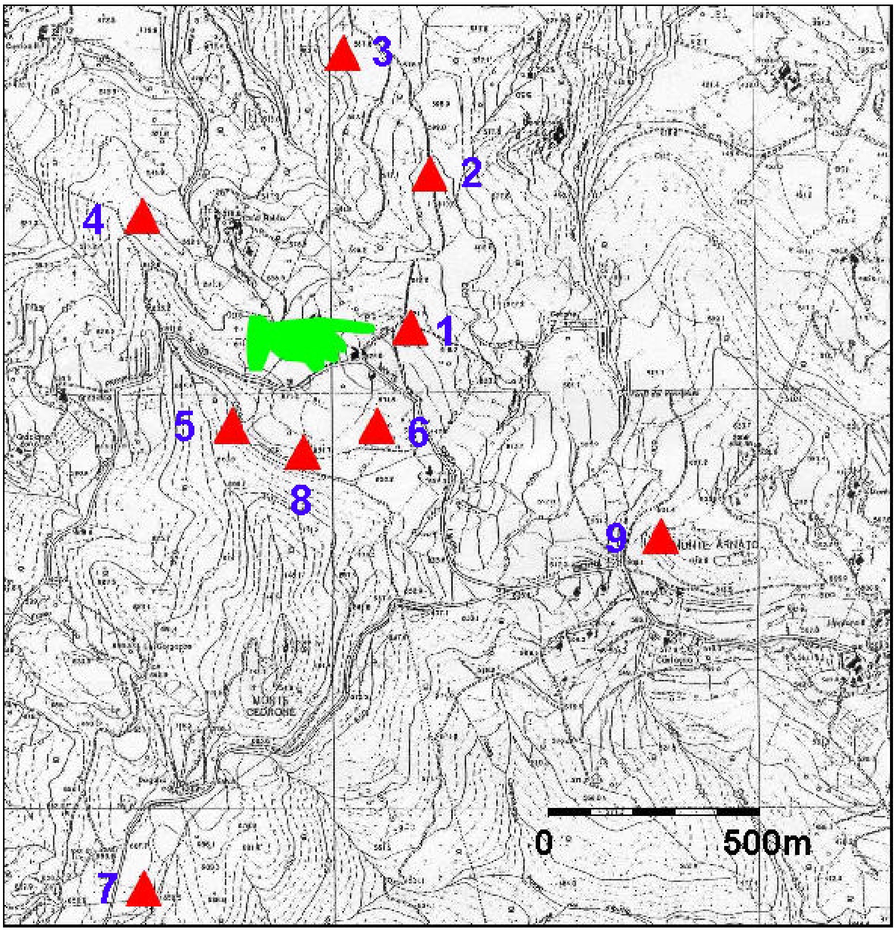

Fig. 3 - Configuration of the test array.

In order to test the first task, the asymmetry of the installed array of fig. 3 was not the perfect configuration for an azimuth-independent detection array. However, it's slight extension in N-S direction, suggested a good azimuth resolution for the seismogenic zone (Central Appennines) situated east of «Città di Castello».

3. Data analysis

3.1. Available data set

As mentioned above, the two tasks to study with the experimental array installation were:

(i) application of beam forming and f-k analysis to local seismic events

(ii) noise correlation analysis

In order to record the appropriate data for computing successfully both tests, the MAC's acquisition characteristics had to be brought on line with the requirements of our two tasks. Since the MAC was not born originally for array applications, continuous real time acquisition of simultaneously nine 3-component stations (27 channels) was not feasible.

Therefore, during the 2 weeks lasting array test (10-24.10.2000) we ran the MAC in it's normal operation mode, namely the "trigger modus". Each single field station triggered locally, and only in the case of 4 coincident trigger reports arriving at the MAC 4, the event was stored on disk. In this way during the first two weeks 18 local events with a magnitude of 1.0 < M < 2.6 were recorded. Fig. 4 (from Cocco, 2001) shows the E-W cross section of the hypocentres determined during the two GNDT field experiments at «Città di Castello» in October 2000. One of the deeper seismic events, emphasised in fig. 4, was subject to the f-k analysis (details see section 3.2).

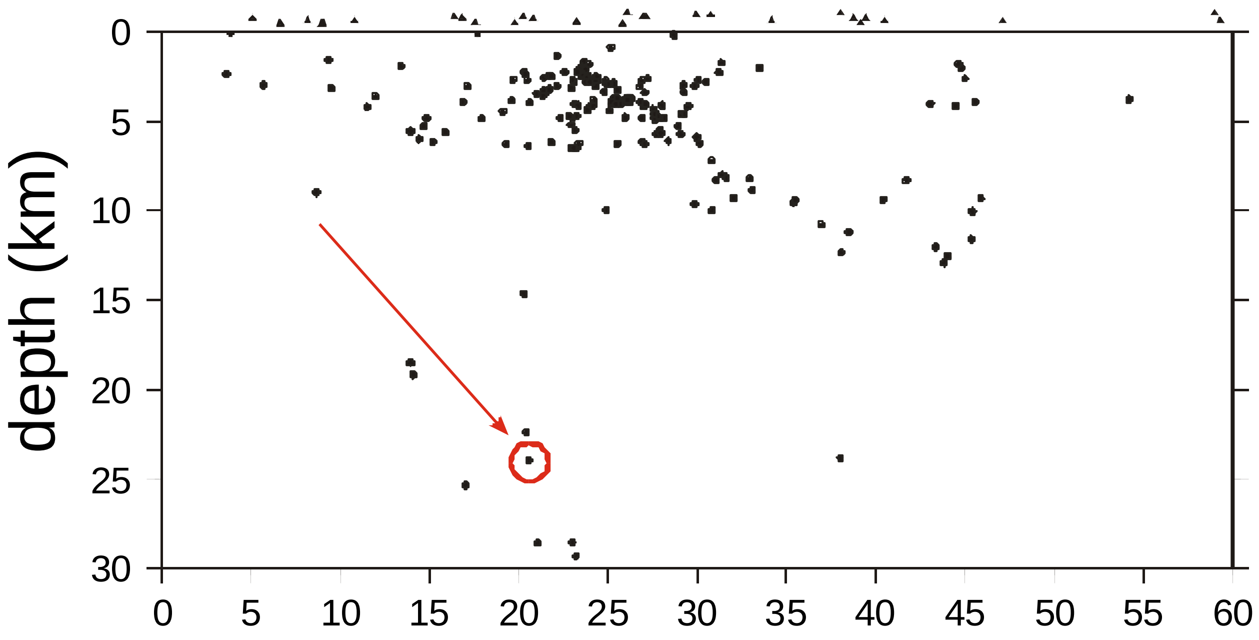

Fig. 4 - E-W cross section (from 0 to 60 km) of the recorded seismicity during the GNDT field experiments at «Città di Castello» in October 2000 (from Cocco, 2001). The array was located at distance 0 km, at the left upper corner. Triangles mark the stations during the local seismic network configuration, the black dots mark the hypocentres.

Concerning the noise correlation analysis, we recorded three times a day 5 min long noise windows (the coincidence parameter at the MAC was set to zero). These noise records were collected for the entire period of the array installation in order to have a statistical significant data set.

3.2. Beam forming and f-k analysis (P-wave)

In order to prove the expected successful application of beam forming and f-k analysis, one representative example will be presented an discussed below.

Fig. 5 shows the nine vertical traces of the seismic event of October 10, 2000, 13:41 GMT, MD=2.5, located by a joint seismic network of mobile local stations and INGV's National Seismic Network at 20 km east from the MAC in a depth of 24 km. (red circle in fig. 4)

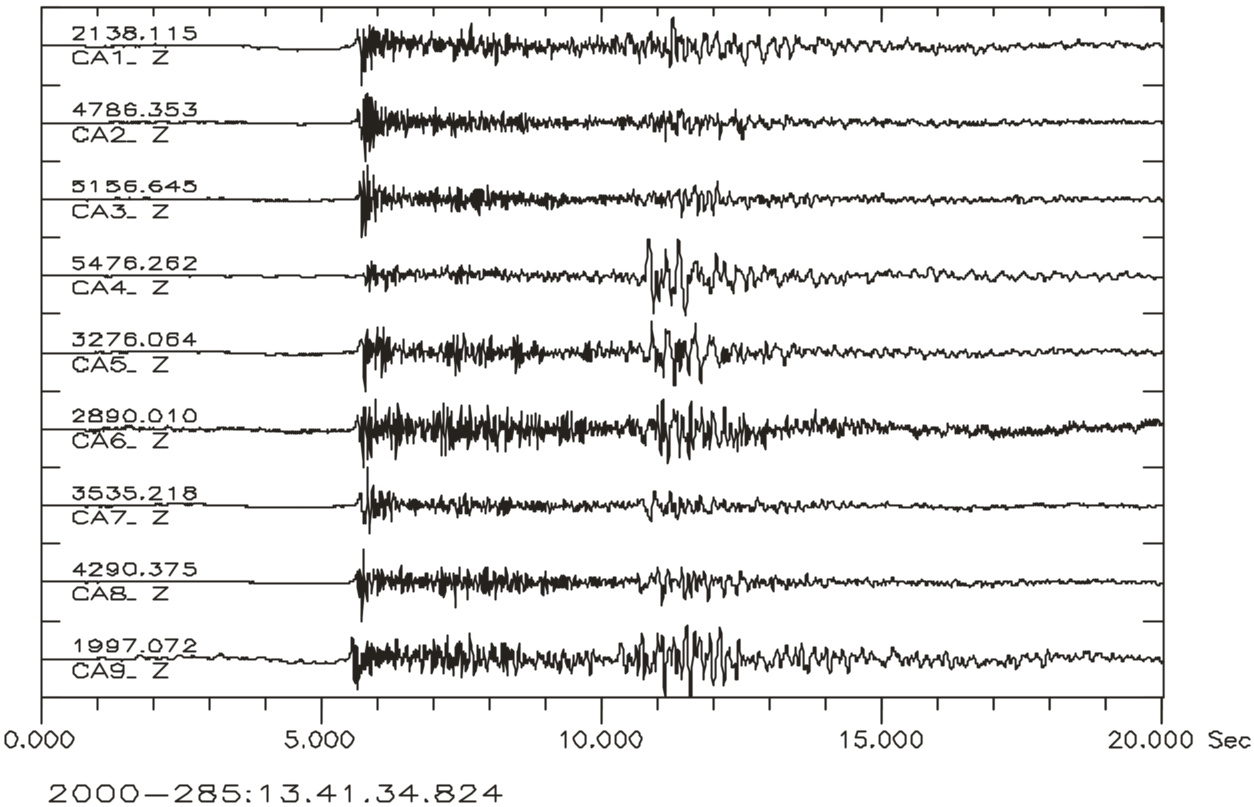

Fig. 5 - Seismic event of October 10, 2000, 13:41 GMT, 20 km E from MAC, in a depth of 24 km Unfiltered seismograms of the test array's nine vertical components.

The detection capability of the array depends on the coherence of signal and noise in the frequency band of the P-wave. The beam contains the information, whether the array's main task – the noise suppression in the frequency band of the interesting signal – can be performed successfully.

The single steps for the performed slowness analysis of the P-phase were:

- Bandpass filtering of the traces between 2.0 and 8.0 Hz
- Zoom out a time window of a few seconds near the P-onset (fig. 6)
- Delay-and-sum beam forming for different slownesses and azimuths
- Plot of the results in the f-k plane (fig. 7).

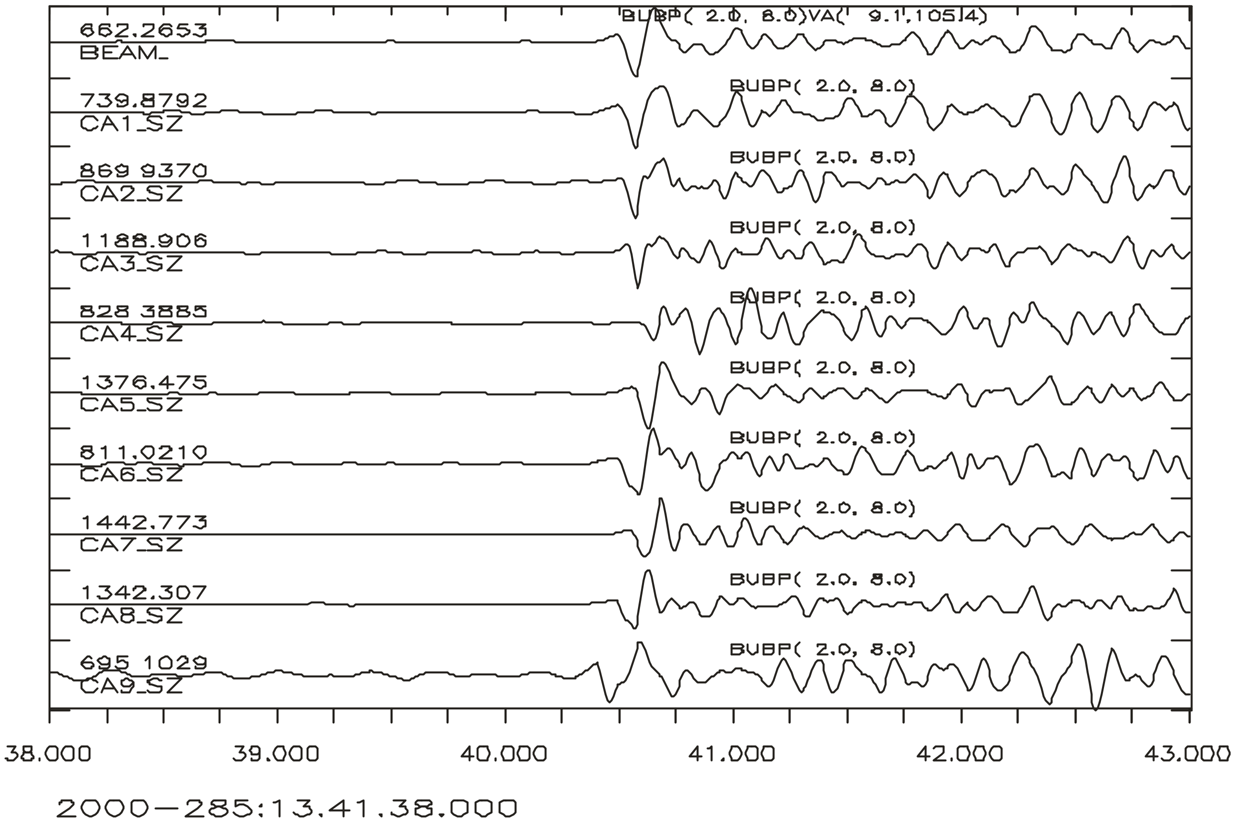

Fig. 6: Seismic event of fig. 5. The traces have been Butterworth-bandbass filtered between 2.0 and 8.0 Hz and zoomed around the P-wave onset. The upper trace shows the resulting beam.

The P-wave of the data example calculated for the recordings of the vertical components showed a clear improvement of the signal noise ratio. First of all the P-wave coda (e.g. trace CA4_SZ in fig. 6) was suppressed significantly.

As can be seen by the f-k plot from fig. 7 the slowness analysis determined for the beam an azimuth of approximately 105°N (ESE from the MAC) and an apparent velocity of about 9.1 km/s. This unusually high value indicated a high incidence angle of the incoming wavefront (approximately 45°), a result caused by the fact that the hypocentre is located diagonally under the array. This result confirmed very well the solution found by the classical hypocentral determination of the above mentioned joint network.

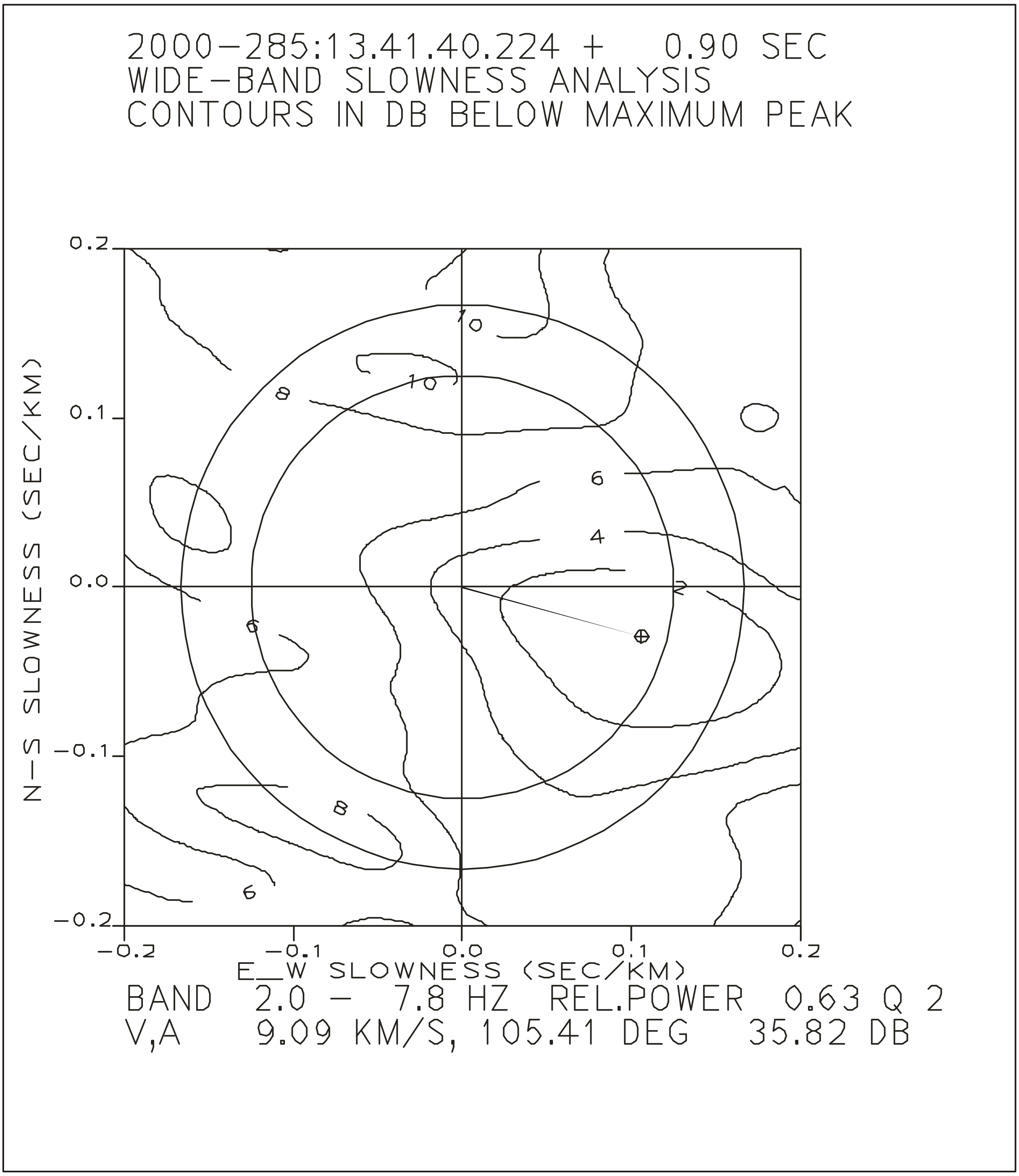

Fig. 7 - Slowness analysis for the beam calculated for the nine bandpass filtered vertical array component (see fig. 5, 6). An unambigous maximum is found for an apparent velocity of 9.09 km/sec in an azimuth of 105.41° (ESE).

3.3. Beam forming and f-k analysis (S-wave)

An innovative aspect of the experimental array installation was the intention to try beam forming even for the S-wave. During the site survey the array stations were not equipped with the classical 1 s vertical seismometers, but with 5 s 3-component seismometers – the perfect starting conditions for an attempt.

Since this was not one of the main scientific goals of the original proposal, this task has to be studied in future in more detail. However, the first encouraging results are shortly here presented.

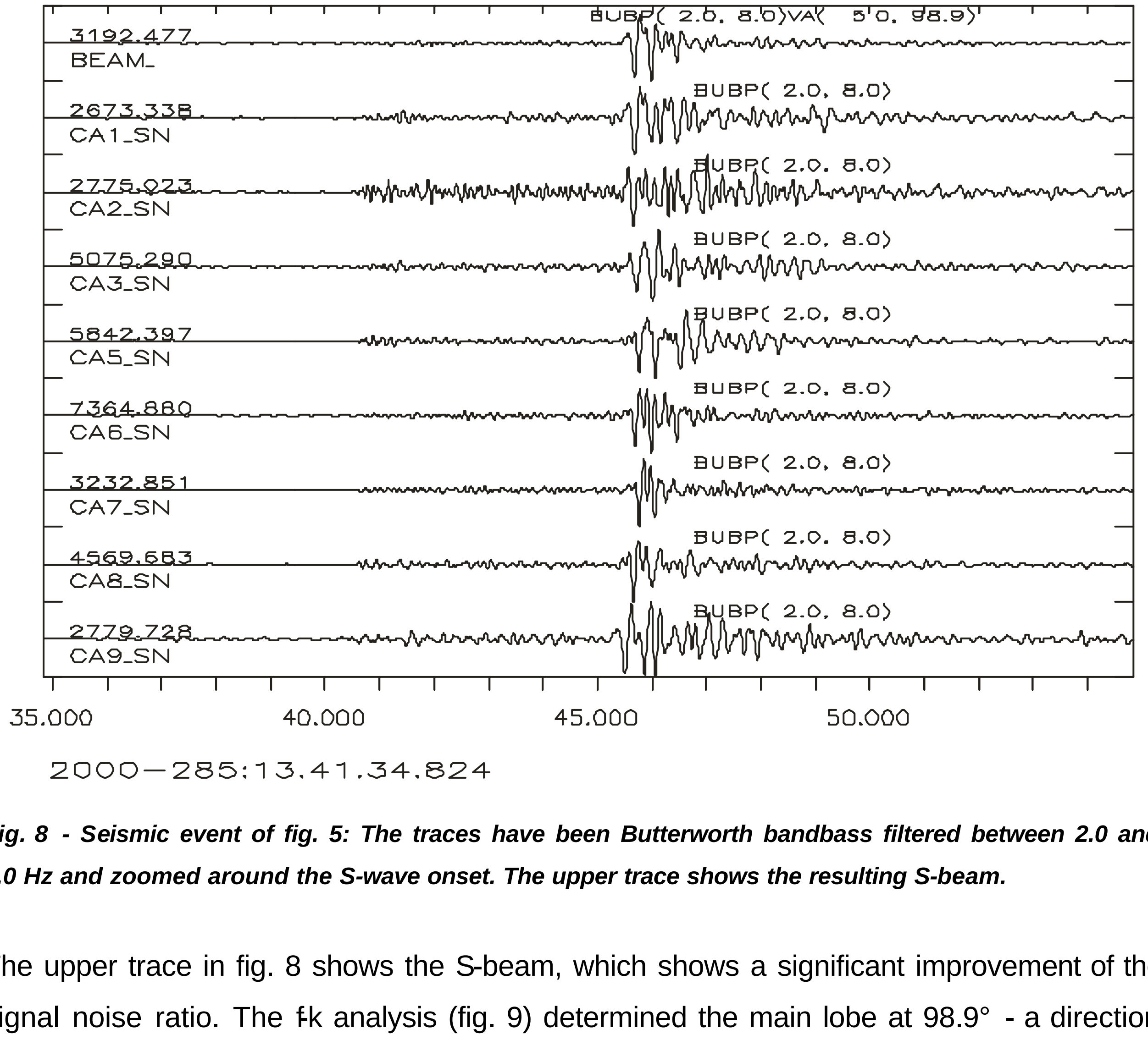

Fig. 8 - Seismic event of fig. 5: The traces have been Butterworth bandbass filtered between 2.0 and 8.0 Hz and zoomed around the S-wave onset. The upper trace shows the resulting S-beam.

The upper trace in fig. 8 shows the S-beam, which shows a significant improvement of the signal noise ratio. The f-k analysis (fig. 9) determined the main lobe at 98.9° - a direction comparable to the respective P-wave plot. The apparent velocity amounts to the relatively high value of 5 km/s, compatible to the location of the hypocentre, mentioned before.

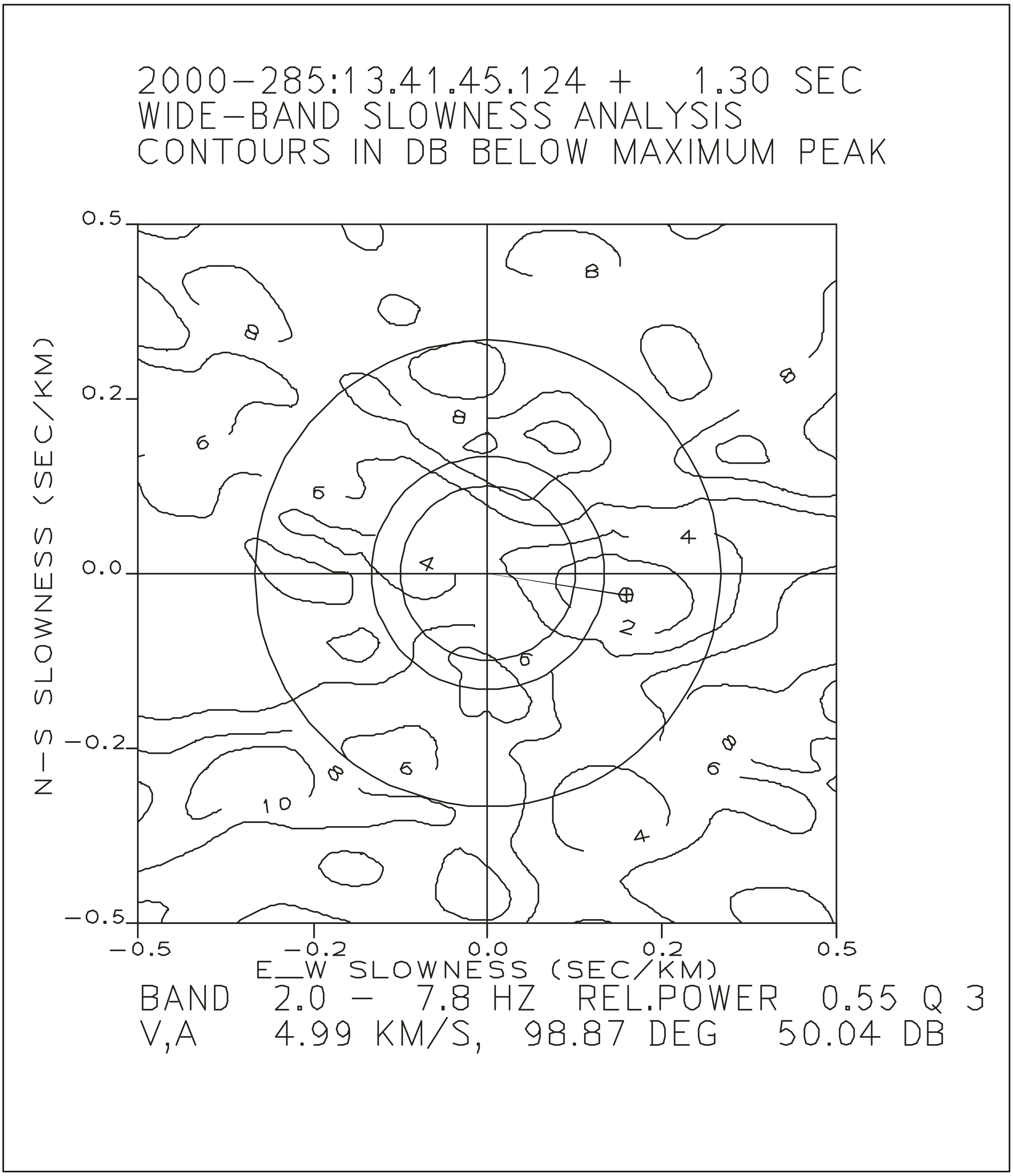

Fig. 9 - Slowness analysis for the beam calculated for the nine bandpass filtered N-S array component (see fig. 5, 6). An unambigous maximum is found for an apparent velocity of 4.99 km/sec in an azimuth of 98.87° (ESE).

3.4. Noise correlation

In order quantify the array gain cross correlation values have to be computed for all combination of sensor pairs of the experimental configuration. In the present case of nine stations this comprises 36 different pairs of sensors.

The respective cross correlation values for were calculated after narrow filtering the noise samples. The following two plots show the cross correlation value as a function of interstation distance, calculated for 30 sec of noise data, from different periods.

Fig, 10 shows the result for the 0.5 – 1.0 Hz filtering.

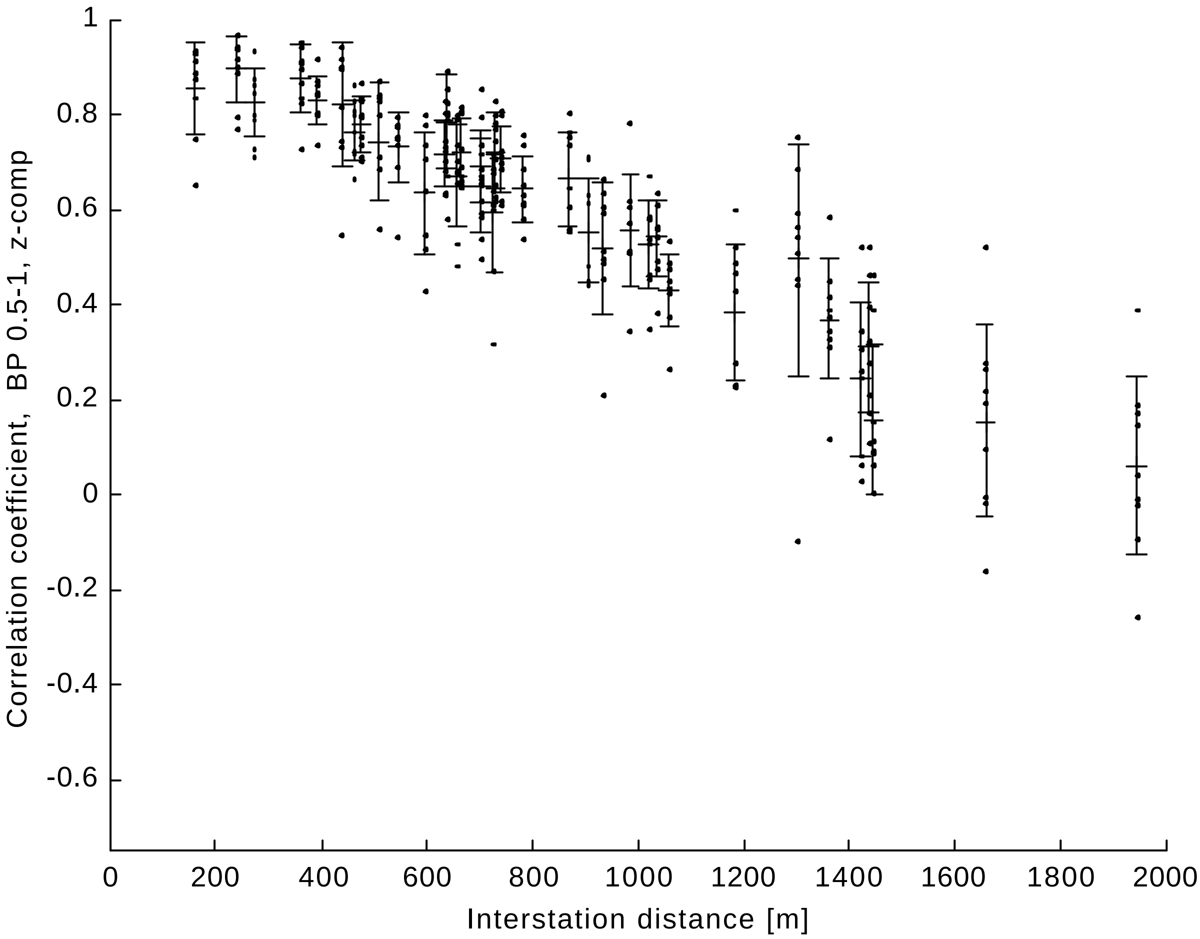

Fig. 10 - Variation of the cross correlation values with distance, calculated for noise data filtered between 0.5 and 1.0 Hz.

The respective plot for 1-2 Hz filtered noise sample is shown in fig. 11.

Due to the loss of coherence the cross correlation values decrease with increasing distance. For example for the 1-2 Hz filtering the cross correlation values reduce to zero within a distance of 500 m and then reach negative values up to approximately 1000 m.

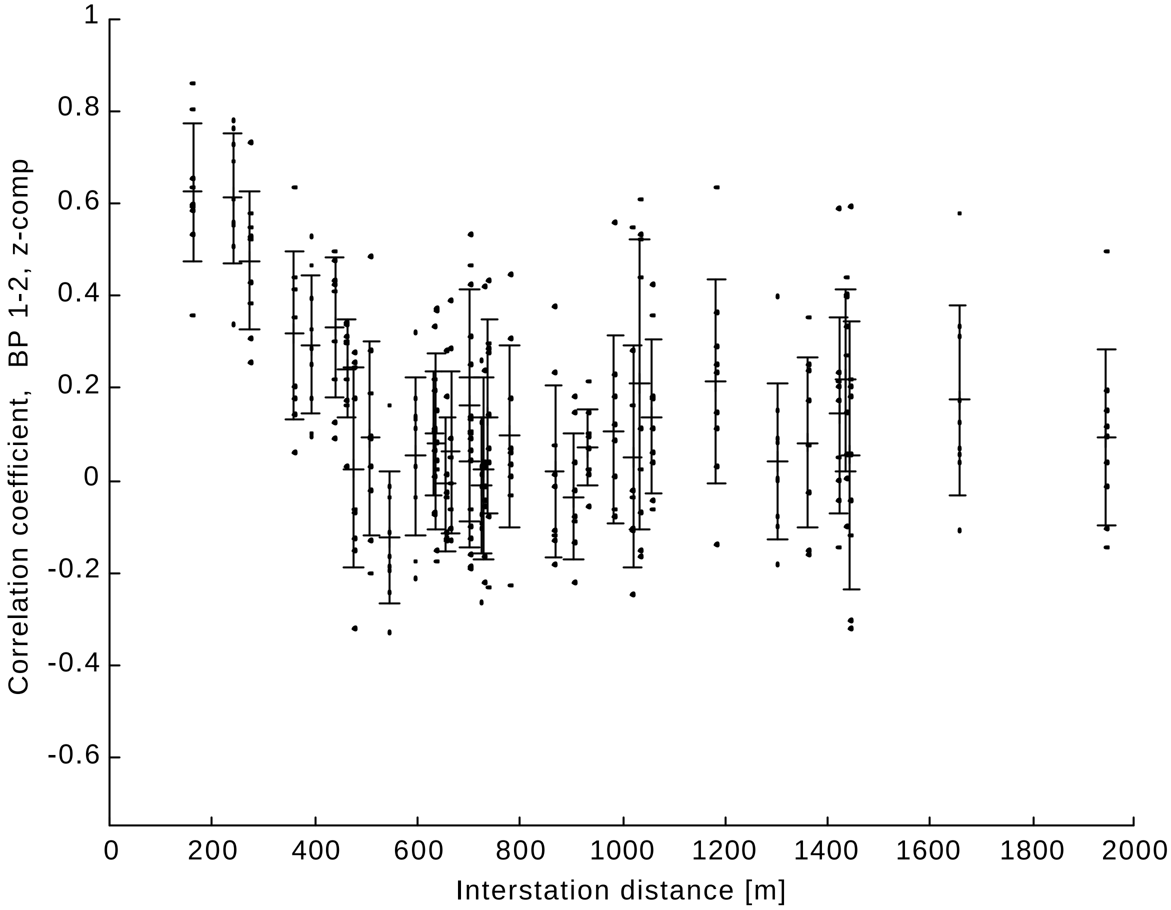

Fig. 11 - Variation of the cross correlation values with distance, calculated for noise data filtered between 1.0 and 2.0 Hz.

Due to topographic limits of the array site it was not possible to redeploy some of the sensors. Therefore possible directional dependencies are not considered statistically in the plot.

4. Conclusions and outlook

Even if the present project was approved only as a feasibility study, the assigned grant of € 10.000 allowed - thanks to the logistic support during the experimental array installation by M. Cocco (and coworkers) in the framework of the GNDT project – to perform a first successful test of the applicability of the proposed method.

It did not allow to realise a unique dedicated field experiment at a real possible future array site. This shortage could be one worthwile reason for a further financing, beyond the 1st year.

One of the main advantages of a seismic array is it's capability to monitor the seismicity in relatively a large area with a low number of sensors - a scientific goal that normally can be reached only by a network consisting of a manifold of stations than employed by an array.

Purpose of the present feasibility study was to test the applicability of array methods to the complex Italian geology.

The main result of the present report is, that in spite of the modest site conditions, beam forming including f-k analysis could be applied successfully, even if the selected site was not the perfect one for a possible future fix installation of a small scale array.

However, the data set obtained during the experimental site survey permits a more detailed study. Especially the following tasks should be worked out in more detail:

- Study of the capabilities of the S-wave beam forming and extension .
- Extended data analysis of the noise correlation, especially for the horizontal components.
- Test of new advanced and innovative technical solutions for the logistical and technical realisation of continuous real time data transmission.

5. References

BRAUN, T, R.M. AZZARA, E. BOSCHI, M. CATTANEO & J. SCHWEITZER (2001): Initial results from an experimental small aperture installation in Umbria (Italy). Meet. German Geophysical Association Union, DGG-Frankfurt..

COCCO M. (2001): 1. Report of GNDT project: Development and Comparison between Methodologies for the Evaluation of Seismic Hazard in Seismogenic Areas: Application to the Central and Southern Appennines."