SEISMIC DOUBLET ANALYSIS AND APPLICATION IN THE RUPTURE PROCESS: PRELIMINARY RESULTS OF THE RIO-ANTIRRIO REGION (GREECE)

Papadimitriou,P., Makropoulos,K. and Drakopoulos,J.

Department of Geophysics, University of Athens, 157 84 Athens, Greece

A B S T R A C T

We present a method that greatly improves the precision of the estimated P and S waves relative differential times using doublets or triplets microearthquake analysis. The differential times are estimated in time domain using a cross correlation method and then they are compared to those obtained by a standard picking method. The remaining residuals are of the order of 8msec which is approximately 4 times or more the calculated residuals obtained by the standard method. The high resolution of the hypocentral determination and the similarity of the events could be applied on the geometry estimation of the fault plane and the directivity of the earthquake rupture.

ΑΝΑΛΥΣΗ ΔΙΔΥΜΩΝ ΣΕΙΣΜΩΝ ΚΑΙ ΕΦΑΡΜΟΓΗ ΣΤΗ ΣΕΙΣΜΙΚΗ ΔΙΑΡΡΗΞΗ

Παπαδημητρίου,Π., Μακρόπουλος,Κ. και Δρακόπουλος,Ι.

Π Ε Ρ Ι Λ Η Ψ Η

Στη μελέτη αυτή παρουσιάζονται τα πρώτα αποτελέσματα υπολογισμού των χρόνων άφιξης των κυμάτων P και S με μεγάλη ακρίβεια χρησιμοποιώντας τη μέθοδο της ετεροσυσχέτισης και δεδομένα δίδυμων σεισμών. Οι σειρές σεισμικών δονήσεων των οποίων οι κυματομορφές είναι σχεδόν όμοιες ερμηνεύονται σαν γεγονότα που προέρχονται από το ίδιο σεισμικό ρήγμα και ονομάζονται δίδυμοι σεισμοί.

Προκειμένου να διαπιστωθεί η ομοιότητα των κυματομορφών καθώς επίσης και ο προσδιορισμός των διαφορικών χρόνων άφιξης των κυμάτων P και S, εφαρμόζεται η μέθοδος της ετεροσυσχέτισης χρησιμοποιώντας σαν κύριο γεγονός μία σεισμική δόνηση της οποίας το επίκεντρο μπορεί να προσδιορισθεί με ακρίβεια. Οι διαφορικοί χρόνοι υπολογίζονται με μεγάλη ακρίβεια μέσα σ' ένα προεπιλεγμένο κινητό παράθυρο. Η μέθοδος αυτή δίνει τη δυνατότητα προσδιορισμού του επικέντρου με πιθανότητα σφάλματος μερικών δεκάδων μέτρων λόγω συσχετισμού των κορυφών της κυματομορφής.

Η παραπάνω μέθοδος εφαρμόστηκε με επιτυχία σε ψηφιακά δεδομένα που καταγράφηκαν στην περιοχή Ρίου-Αντιρρίου. Η χρησιμοποίηση της προτεινόμενης μεθόδου, για τον προσδιορισμό των επικέντρων, έχει σαν αποτέλεσμα τα υπολογίσιμα χρονικά υπόλοιπα να είναι πολύ μικρότερα από αυτά της κλασσικής μεθόδου. Με το τρόπο αυτό προσδιορίζεται η χωρική κατανομή της σεισμικής πηγής καθώς και το επίπεδο διάρρηξης σε συνδυασμό με το μηχανισμό

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

γένεσης του κύριου γεγονότος.

INTRODUCTION

During the summer of 1991, a dense network of 60 portable digital seismographs was installed for a period of two months (July-August), in the western part of the gulf of Corinth, around the Rio-Antirrio and Aigion region (Greece), and recorded over 5000 events. From this databank we selected a part of microearthquakes containing seismic doublet or triplet signals occurred during the month of July. The seismic activity occurred principally between 0-15km depth and the seismicity appears to be diffused in this region (Rigo et al., 1993). The epicentral locations were computed with the HYPO71 program with an appropriate velocity model and a Vp/Vs ratio 1.80 using Chatelain method. This data set was used to study the resolution power of the cross correlation method for the differential time estimation between the events.

Similar microearthquake recordings are called "doublets" or "triplets" because they are characterised by very similar waveforms. Geller and Mueller (1980) have postulated that these recordings are the expression of the stress release on the same part of the fault. In this case, the source process and the medium properties must be identical (Poupinet et al., 1984). Using doublet analysis, temporal variations could be studied to determine the crustal properties (Got et al., 1990) or spatial variations to determine the earthquake process (Scherbaum and Wendler, 1986; Augliera et al., 1992). In this paper we present preliminary results of the spatial variation doublet analysis in order to study the earthquake process and the geometry estimation of the fault plane.

ANALYSIS METHOD AND RESULTS

Figure 1a shows a typical triplet seismogram recorded on one trace. To process these signals we divided the whole seismogram in three parts by a moving window technique, in order to obtain three individual traces A, B and C (figure 1b). The first microearthquake (event A) was chosen as a master event, located by the use of standard method (the arrival times of P and S waves are estimated by picking and the hypocentre location is estimated by the HYPO71 program). For each time step and for every pair of events, the cross-correlation function was calculated, in time domain, for the estimation of the traces similarity and the determination of each trace the time delay with respect to the master event.

The cross-correlation is a measure of the similarity between two traces. One trace is shifted step by step with respect to the second one and the corresponding values of the two traces are multiplied together. Then the products are summed to give the value of the cross-correlation. The cross-correlation of two data sets x(t) and y(t) is defined as:

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

$$\Phi_{xy}(\tau) = \sum_{n} x_n y_{n+\tau}$$

where τ is the displacement of the y(t) relative to x(t). When the two traces are nearly the same the products will usually be positive (by moving the second trace to the left with respect to the first trace) and hence the cross-correlation becomes large. When the two traces are not similar, some of the products will be positive and some of them negative, and hence the sum will become small. In this work the cross-correlation function is normalised in order to define the maximum values between +1 and -1 (+1 indicates identical traces and -1 indicates that one of the traces is inverted). In this case the normalised cross-correlation is defined as:

$$\Phi_{xy}(\tau)_{norm} = \frac{\Phi_{xy}(\tau)}{\sqrt{\Phi_{xx}(0)\,\Phi_{yy}(0)}}$$

$$\text{where} \quad \Phi_{xx}(0) = \sum_{n} x_n^2, \quad \text{and} \quad \Phi_{yy}(0) = \sum_{n} y_n^2$$

The analysis was applied on a limited part of the signal (few seconds) around the selected seismic phase (P or S). In figure 1c we indicate by "win" the duration in seconds of the selected window of the signal. The selected part of the signal was shifted step by step with respect to the master one and the maximum of the correlation function defines the similarity of the traces versus the time delay (figure 1d).

This method is very important for small epicentral distance (the S-phase is contaminated by P-wave coda) or when the traces are noised. The time delay between the two events is usually determined with a precision comparable to the sampling rate. It is possible to overcome this restriction by the application of an interpolation between the cross-correlation values. With this technique, the time precision is significantly better than the digitisation rate (Poupinet et al., 1984).

Using standard techniques for phase readings we calculate the hypocentres of the events A, B and C (the event A has been located using five P and four S phases; the event B with three P and three S phases; the event C with six P and six S phases). The spatial distribution of the hypocentres shows no evidence of align clustering and the travel time residuals, calculated be HYPO71, in some cases are greater than 0.10 sec. These results may be attributed to the velocity structure, to the noise or to the anisotropic effects (the Sn and Se arrival times are not identical).

Considering the event A as a master event, we have performed the determination of the arrival times P and S for the events B and C, by the cross-correlation method, using three available digital stations (ELAI, PANO, MALA). To calculate the arrival times P and S for each station we add the differential time, estimated by the cross-correlation method, to the corresponding arrival time of the master event. Then the events B and C have

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

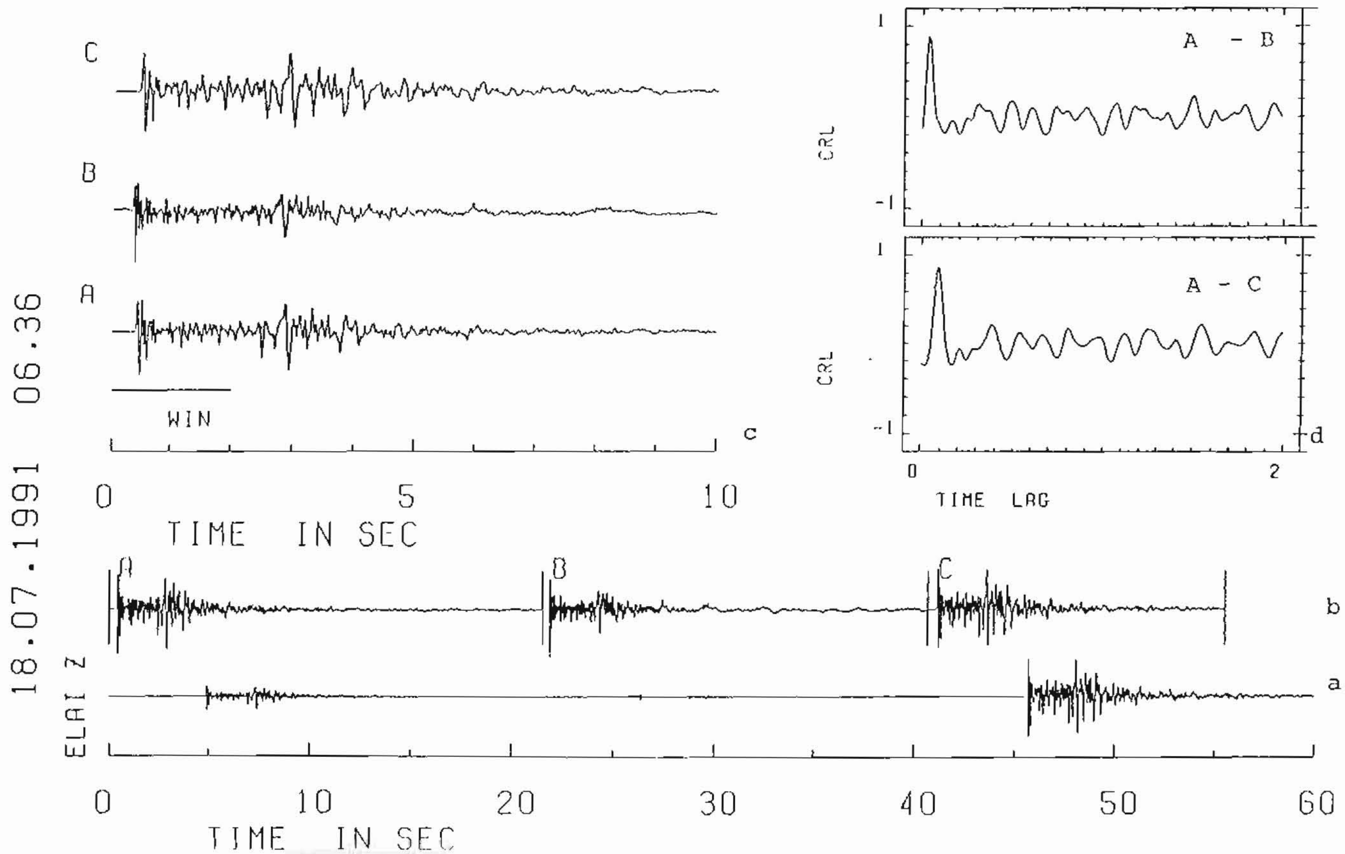

Fig.1. a) Example of triplet signal: Vertical trace corresponding to the digital ELAI. **b)** The whole trace is divided in three parts A,B, and C. c) The selected part of the signal is indicated by "win". **d)** Cross correlation as a function of time delay between the master event A and the traces B and C.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

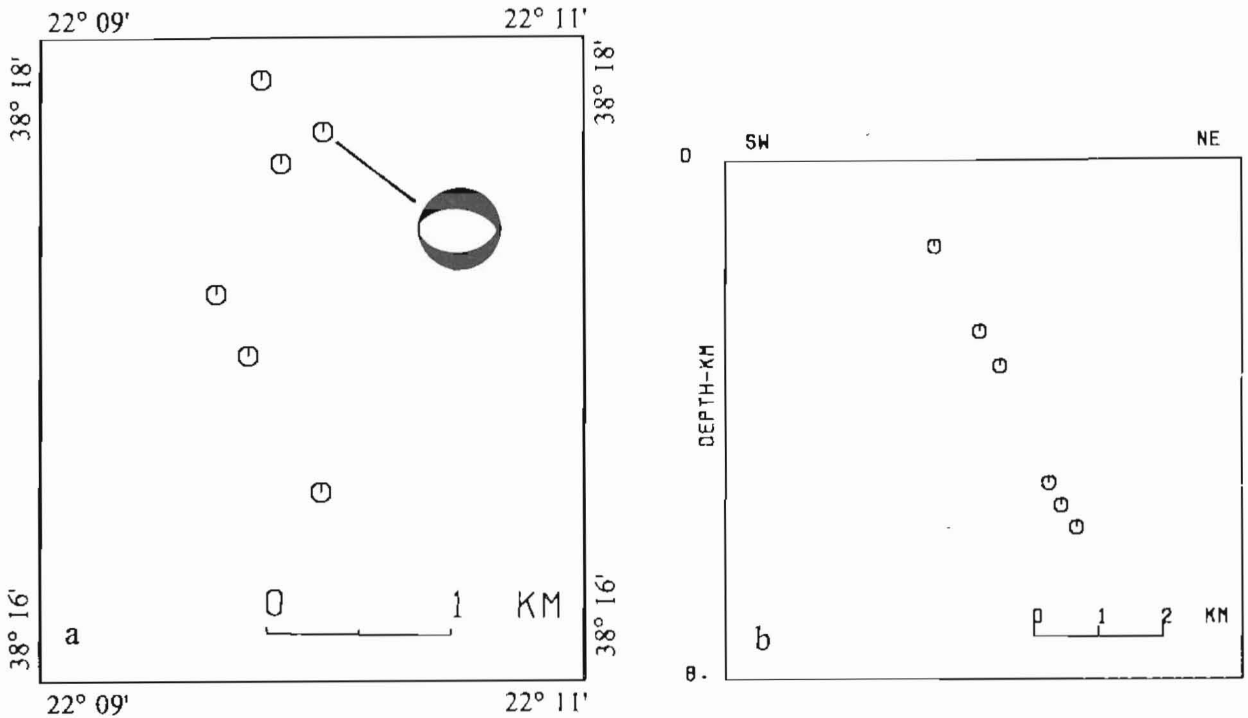

Fig.2. a) Epicentral location map of the six events and focal mechanism of the master event. b) Vertical cross section in N 10° direction.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

been relocated with respect to the master event. The time differences presented in Table 1 are minimum because we have chosen the S arrival times of the eastern component (which is faster than the northern one) thus they are closer to the values calculated by the cross-correlation method.

Table 1. The arrival time of P and S waves using standard methods and cross correlation method is indicated, for each event.

			Arrival Times				
Station			Standard		Cross-Correlation		
			P	S		P	S
ELAI	event A	910718 06:36	39.54	41.38		39.54	41.38
	event B	60.95	62.58		60.95	62.79	
	event C	80.27	82.13		80.29	82.13	
PANO	event A		39.98	42.24		39.98	42.24
	event B	61.40	63.67		61.38	63.64	
	event C	80.73	83.02		80.73	83.00	
MALA	event A		40.70	43.36		40.70	43.36
	event B	62.16	64.88		62.11	64.77	
	event C	81.44	84.15		81.46	84.13	

The above methodology was applied on five events. Figure 2a presents the location of these events as well as the epicentre of the master event and the corresponding focal mechanism which represents normal fault trending E-W. Figure 2b shows the vertical cross section across the cluster striking in N10° direction. The spatial distribution of the hypocentres shows clearly a plane dipping to the north direction at an angle of about 60°. The nodal planes of the fault plane solution are striking in E-W direction. According to the spatial distribution of the triplets we conclude that the most probable fault plane is the plane striking NE-SW and dipping to the north. As far as the source propagation is concerned there is no evidence of the directivity of the earthquake process observed in this application.

CONCLUSIONS

The analysis of the seismological data collected during the summer 1991, shows that the main seismic activity is around the city of Aigion (Rigo et al., 1993). Cross-sections across this cluster, where the seismicity and the focal mechanism are projected on the vertical plane, shows no clear structure in this region. This fact provides the necessity to apply more power techniques in order to identify the active parts of the faults. The cross correlation method of the doublet analysis can provide seismic readings of a high precision and the recognition of the events similarity can be proved by the normalised cross-correlation.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

Applying this method it becomes possible to determine the spatial distribution geometry and then to discriminate the active part of a fault as well as the fault plane from the auxiliary of the focal mechanism. Finally, this method can be used to determine the source propagation or to recognise different clusters in a seismic area.

REFERENCES

Augleria,P., Cattaneo,M. and Eva C., (1992). Seismic doublet analysis: Test of methods and application in North-Western Italy. General assembly of ESC, Praha, 1992.

Geller,R.J. and Mueller,C.S., (1980). Four similar earthquakes in central California. Geophys. Res. Lett., 7, 821-824.

Got,J.L., Poupinet,G., Frechet,J., (1990). Changes in source and site effects compared to coda Q^{-1} temporal variations using microearthquake doublets in California. Pageoph, 134, 195-228.

Poupinet,G., Ellsworth,W.L., Frechet,J., (1984). Monitoring velocity variations in the crust using earthquake doublets: An application to the Calaveras fault, California. J. Geophys. Res., 89, 5719-5731.

Scherbaum,F. and Wendler,J., (1986). Cross specral analysis of Swabian Jura (SW Germany) three-component micro-earthquake recordings. J. Geophys. ,60, 157-166.

Rigo,A., Lyon-Caen,H., Armijo,R., Bernard,P., Makropoulos,K., Papadimitriou,P. and Deschamps,A., (1993). Fault plane solutions of microearthquakes and tectonics analysis in the Western part of the gulf of Corinth (Greece). (2nd congress of the Hellenic Geophysical Union), (this volume).

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.