Seismology and physics of the Earth's interior in Croatia, 1991–1994

Report to the International Association of Seismology and Physics of the Earth's Interior of the International Union of Geodesy and Geophysics

The research related to the earthquake seismology and physics of the Earth's interior in Croatia is carried out by a group of 10 seismologists (3 Ph.D., 6 M.Sc. and 1 B.Sc.) at the Andrija Mohorovičić Geophysical Institute of the Faculty of Science, University of Zagreb. Besides scientific activities they are involved in teaching at the undergraduate and postgraduate levels. The seismographic network of Croatia, consisting of 5 permanent and a number of temporary stations, as well as of 15 accelerographs, is managed by the Seismological Service of the Republic of Croatia, which is organized within the Institute. The staff of the Service was able to keep uninterrupted operation of most of the seismological stations during the past war-time years, although some instruments were lost or destroyed (in Dubrovnik, Knin, Orah and Branjina).

The scientific interest of Croatian seismologists ranged from local to the world-wide seismicity. The earthquakes that occurred in Croatia and neighbouring regions in the period 1989–1992 were analysed by Herak D. et al. (1991) and Markušić et al. (1994). Altogether 1549 earthquakes were located and the resulting catalogue was found to be complete for the magnitudes $M \geq 3.0$. Macroseismic investigations confirmed that seismic energy is more efficiently absorbed perpendicularly to the Dinaric belt than along it. The largest events that occurred in the period were the Kamešnica Mt. earthquake (I_0 = VII–VIII °MSK) and two Dinara Mt. earthquakes (M = 5.6 and M = 5.5). Their fault plane solutions are similar and compatible with the stress field in the NNE–SSW direction, as obtained by other investigations. This is not the case with the fault-plane solution for the Knin earthquake of 1986 that was obtained by Herak and Jukić (1993). Their results show the stress roughly perpendicular to the direction mentioned above, thus indicating strong local stress field deformation probably caused by geological structures there.

The rich seismological archives of the Andrija Mohorovičić Geophysical Institute enable investigation of significant historical earthquakes all over the world. Allegretti et al. (1994) and Herak et al. (1994) analysed the record of the great San Francisco earthquake of 1906 as obtained on the undamped Vicentini seismograph in Zagreb. They were able to recover P- and surface waves ground motion amplitudes in Zagreb by considering Reid's friction

induced nonlinear damping, and explained peculiarities of the P-wave train in terms of the rupture process at the source. The magnitudes obtained agree well with those published for other European stations.

The problems related to digitizing old seismograms were discussed in Grabrovec and Allegretti (1994).

The coda waves of local earthquakes in the Dinarides were analysed by Herak (1991) who observed that in the region studied coda Q increases both with frequency and lapse time. If $Q_c(t) = Q_0(t)\, f^{n(t)}$, where f is the frequency and t the lapse time, then for $30 < t < 130$ s Q_0 increases from 45 to 275 while n decreases from 1.0 to 0.6.

A large data set of earthquake phases arrival times was used to invert for the velocity structure of the crust and upper mantle in the circum-Adriatic region (Herak and Herak, 1995). The velocities obtained in general agree well with the previously reported ones, with the most important exception of the area of central part of External Dinarides where the P-wave velocity in the upper crust is higher than elsewhere, while the Pn velocity is lower than that determined by DSS. The use of new models together with station corrections significantly improved the locations of earthquake hypocentres, and the Pn and Sn residuals correlated well with the residual undulations of the Mohorovičić discontinuity.

The velocity of head waves refracted on the top of the mantle in the Dinarides region, was studied also by Markušić (1991), who found the velocities in the range 7.85–8.46 km/s, with the mean of 8.09 km/s.

Considerable attention has been paid also to the problem of earthquake quantification. Trifunac and Herak (1992) have compared M_L^{SM} – the magnitude obtained on the basis of strong-motion records, and the local magnitude at several stations in order to calibrate the amplitude-distance attenuation relations used in local magnitude definitions. This more accurate magnitude determination for regional networks will hopefully improve the reliability of quick estimation of strong motion amplitudes in the epicentral regions of destructive earthquakes.

Herak and Herak (1993) have addressed the distance dependence of the surface wave magnitude Ms. They have shown that the use of the internationally adopted »Moscow-Prague« formula yields values significantly dependent on the epicentral distance of the reporting station, that can lead to errors exceeding 0.5 magnitude units. They used 5514 M_S readings to propose the new calibrating function for 20 s Rayleigh waves in which the amplitudes decrease almost linearly with distance, in agreement with results of theoretical studies.

In the field of seismometry an effort has been made (Sović, 1993) to construct a prototype of the laser interferometer transducer, which was used to measure displacement of strong ground motion. The resolution of 355 nm

was achieved, and the transducer should be able to record without saturation the ground motion caused by earthquakes in the range of 4 magnitude units.

The role of two great Croatian scientists – Andrija Mohorovičić and Gjuro Pilar – in development of geophysics in Croatia, was reviewed by Skoko (1993) and Skoko and Prelogović (1994), respectively. Although the main Mohorovičić's contribution to seismology – the proof of existence of the discontinuity between the crust and the mantle – is generally known, there are his other activities and results that are of no less importance. Some of them are: prediction of the features of the deep earthquakes' seismograms in 1909, method of the seismograph friction determination, the exponential law relating the depth and the wave velocity. Gjuro Pilar's contribution to seismology consisted mainly of macroseismic observations and studies following the Đakovo earthquake sequence in 1884. He considered the local intensity based on elongated isoseismals, influence of soil condition, response of structures to the seismic forces and seismic hazard assessment (seismic recurrence as a »periodic trouble«).

In conclusion we may state that Croatian seismologists succeeded in maintaining high scientific and professional quality of work, in spite of difficulties brought about by war. They were active in several international cooperation programs and have presented the results of their research in 15 scientific papers.

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