Ground Motion Prediction and Eastern U.S. Earthquake Monitoring

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The contracted work includes research in the following aspects (1) developing a method for prediction of ground motion in active fault zone using small earthquake data. (2) setting up stations in northern and western New York to monitor rare but potentially damaging earthquakes.

1) Methods for Prediction of Ground Motion.

We have developed a more direct approach to the ground motion prediction than contained in the original proposal. The method is called Grean's function or the Impulse Response method. The basic idea is that records from small earthquakes can be viewed as an impulse response from a particular source location on the fault to the station, and that large earthquakes can be viewed as a convolution of the impulse response with appropriate source space-time functions. The method has been explained in a paper (Wu, 1978), and is summarized as follows:

There are two main tasks involved in the proposed method, namely, the scaling of displacement from small earthquakes to reduce it to that of a unit excitation and the summation of elementary sources to produce simulated displacement from a large earthquake.

The displacement at a point from a shear dislocation source can be written as,

$$u_i \, (x,t) = \int_{S'} d\bar{x}' \; m_{kj}(x,t') g_{ij,\,k}(x,t;\, x,t') \, dt'$$

where m_{kj} is the moment tensor density and can be expressed as

$$m_{kj} = \mu \left[m_k \, (x') \, S_j \, (x',t') + n_j \, S_k \, (x',t') \right]$$

In these and the following equations, $x = (x_1, x_2, x_3)$ it is time, prime refers to source coordinates, S_j is the dislocation specified at every point on the fault surface S', and $n = (n_1, n_2, n_3)$ is the unit normal to the fault surface, ij is the Green's function representing the displacement in the ith direction due to a point force in the jth direction with (t) as source time function. $G_{ij,k}$ denote differentiation with respect to source coordinates x_k.

Considering an earthquake with source dimension much smaller than the wave length of interest, then the source can be approximated as a point and equation (1) can be written as a convolution integral (Stump and Johnson, 1977):

$$u_i\ (\bar{x},t;\bar{\xi}') = g_{ij,k}\ (\bar{x},t;\bar{\xi}',o) \otimes m_{jk}\ (\bar{\xi},t)$$

where $x - \xi'$ is the source location, and x denotes convolution.

In frequency domain, we can then write

$$U_i(\bar{x},f;\bar{\xi}) = G_{ij,k}\ (\bar{x},f;\bar{\xi})\ M_{jk}\ (\bar{\xi},f)$$

where f = frequency. In the first problem, we need to normalize U_i to that from a unit impulse. This can be approximately obtained by assuming a simple and yet reasonable structure between the source and the receiver to obtain g_{ij} and G_{ij}. Then m_{jk} or M_{jk} can be obtained by trial and error or inversion. In order to obtain M_{jk}, we need at least six components (for example, two three-component stations); but if we can make certain assumptions about the source--in the case of the San Andreas fault in Northern California, pure strike-slip faulting may be assumed--then the number of independent records required can be decreased. The location of the earthquake, however, has to be accurately known, so that earthquakes not on the fault of interest will not be used; thus a conventional seismic network for locating microearthquakes could be used, or if there are enough stations of the kind needed in this work in the area, location can be performed also.

It should be remarked here that the intent of the procedure discussed above is not to fit the seismograms in every detail but to obtain a relative scaling of the sources.

By recording a large number of scale earthquakes from the same fault, a library of U $(X,t;\xi)$ can be established. Because of the non-uniform distribution of small earthquakes, inter-polations have to be made. Hartzell et al. (1978) have demonstrated that theoretical Green's functions can be inter-polated with satisfactory results.

Once the library of the U_i's is established, then the displacement field from a large earthquake can be calculated by using Hartzell et al. (1978):

$$u_i\ (x,t) = \int_{S'} dx'\ S(\bar{x}') \int_{-\infty}^{\infty} u_i(x,t;\ x',t')f(x',t')\ dt'$$

$$\cong \sum_n A_n(x')\ S_n(x')\ u_{in}\ (x,t'\ x',o)\ \ x\ f_n\ (x',t)$$

where A_n = area of the element such that $_n A_n$ equals the total fault area. f(x,' t) and S(x') together specify the source of spatial and temporal variations and inlcude factors such as rupture propagation velocity, variation of displacement along the fault, and stop-and-start nature of the source. By assuming various combinations of S', S(x'), and f(x't'), we can simulate earthquakes of various magnitudes, fault lengths and characteristics. The method is schematically illustrated in figure 5.

This proposed method aims at incorporating correct path and site functions which are difficult to compute theoretically, not knowing the structure precisely nor ways to handle them mathematically, in the calculation of strong ground motion at a site. It will also enable one to calculate the motions from earthquakes with various fault parameters, such as fault length, rupture propagation velocity, amount of slip and the source time function; multiple event type of earthquakes can be simulated also by specifying appropriate S(x) and f(x,t).

Although there has been a large collection of data at large distance ranges recorded on film with velocity transducers, those are not usable for the present purpose because of the lack of precise calibration and the limited dynamic range. The feasibility of recording small accelerations, (down to tens of μg) has been proven (Figure 1), thus this proposed method is within reach. However, the Green's function library for a particular site will take a period of time to collect; if a fault is presently active and populated with small earthquakes, then this method is appropriate.

We have now on loan to us, through the Department of Energy, a collection of San Fernando aftershock data. These are recorded on analog magnetic tapes with two gain ranges, so that both small ($M_L \sim 1$) and larger ($M_L \sim 3$) events are on scale. There are several periods of recording at the Pacoma Dam site. Thus the results of synthesis can be compared to the actual mainshock accelerogram and we can then correlate the source function to obtain better approximation.

2) Monitoring Eastern U.S. earthquakes.

a) Three stations have been established in the vicinity of Massena, N.Y., the Site of a 1944 magnitude, six earthquake. Figure 1 shows the sites of these stations with respect to the seismicity in NE U.S. in the last five years. One station is at the bottom of the Long Sault dam; it is an extremely quiet site. The two other stations are away from the Saint Lawrence shore, one near Potsdam and one in Nicholville.

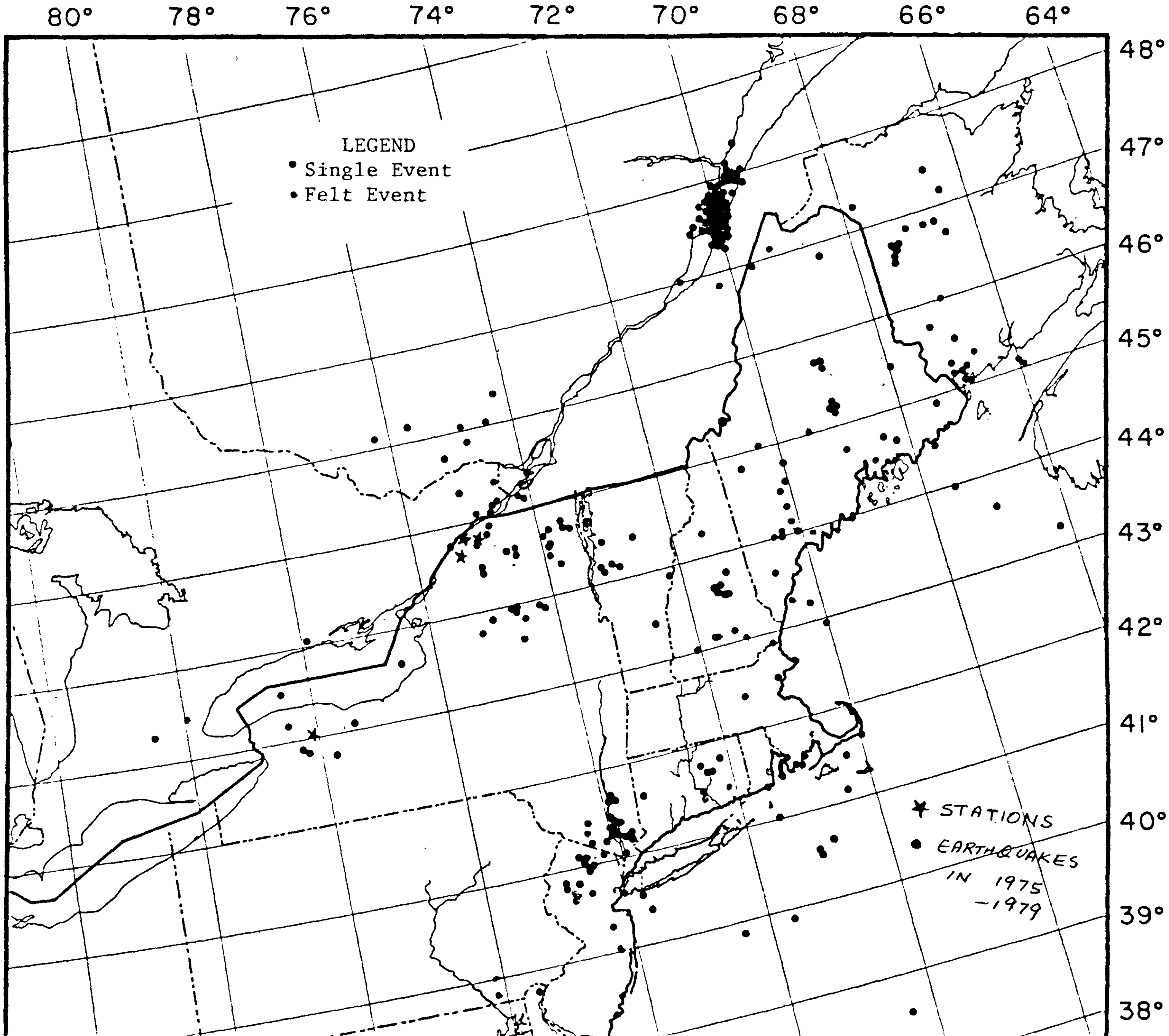
One station has been installed and tested in Alexander, N.Y. near the site of 1939 earthquake (M = 5.6).

After six months of testing at all the above stations, we have chosen the appropriate parameter setting for each site. The site at Long Sault is very quiet and it is likely that we shall be able to detect earthquakes as small as M=2.3 within a radius of 10 kilometers or more.

Terra Technology DCS-302 and its force-balanced accelerometers are used at all the stations. They are found to be operating properly after the initial adjustments. We have taken care not to exchange printed circuit boards and have calibrated each system with the Terra Technology SMR-104 system.

With National Science Foundation Funds, we have established the data processing facilities for the data tapes. They are being interfaced and programmed at the moment. With these facilities, we shall be ready to monitor mainshocks and certainly the aftershocks of any possible eastern U.S. earthquakes and process the data for public use.

3) A field experiment was carried out after the August 6, 1979 Coyote Lake earthquake ($M = 5.9$). We have established a station in Gilroy (#6), and one station near the Coyote dam. The Coyote dam site was found to be noisy and was withdrawn after two days. The Gilroy #6 station has been intensely monitored for ten days. During that period (August 15 to August 25, 1979), all the $M > 2.0$ earthquakes, with no exception, were recorded distinctly. The records all included the triggering P waves. If we were able to get to the site earlier, we would have had enough data to perform the synthesis described in (1).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LEGEND
Single Event
Felt Event
STATIONS
EARTHQUAKES
IN 1975
-1979

figure 1