

observation because Rayleigh-type seismic surface waves should be strong in the vertical and radial directions, and weak in the transverse direction, as is the case for station BRNJ shown in Figure B-3. This is an interesting propagation effect due to strongly contrasting properties of shallow rock layers along the wave propagation path between the WTC and PAL which is nearly parallel to the Hudson River. Lateral refraction is caused by contrasting shallow rock layers at the boundary between high-velocity crystalline metamorphic rocks of the Manhattan prong and low-velocity Triassic rocks of the Newark basin (Anderson and Dorman 1973). When the wave leaving the source at the WTC site enters the rock underlying the Hudson River, much of its energy can be trapped in a wave guide along the river in the form of a lens or tube and undergo multiple lateral refractions along its passage. Hence, there are several distinct criteria for characterizing seismic waves generated at the WTC site and observed at stations around New York City. These criteria are:

- seismic surface waves generated at the WTC site and observed at PAL have stronger EW-components than vertical- or NS-components (Figure B-3);
- seismic surface waves, mainly of the Rayleigh type, travel at about 2.4 km/s between the WTC site and stations in the region, and the surface waves arrive first at station PAL, followed by BRNJ, GPD, TBR and so on, as listed in Table B-1 (Figure B-4); and
- no clear *P* or *S* wave arrivals are observed due to the vertical force nature of the sources at WTC (Figures B-3 and B-4).

B.5 SEISMIC SIGNALS FROM THE WTC 7 COLLAPSE

East-west and vertical component seismic records from five stations around New York City, filtered to pass signals below 5 Hz, are plotted in Figure B-5 for the time during the collapse of WTC 7. As before, *Rg* indicates the arrival of the seismic surface wave of the Rayleigh type which propagated with a speed of 2.4 km/s. *Pg* and *Sg* indicate *P*- and *S*-wave estimated arrival times from the WTC site using a velocity model for the region (these wave arrivals were not detectable). The Rayleigh waves were quite weak and difficult to discern clearly at most of the stations. Nevertheless, *Rg* waves at PAL, BRNJ, TBR and ARNY were stronger than the background noise in Figure B-5.

Three-component records at PAL associated with the WTC 7 building collapse are shown in Figure B-6 (including frequencies up to 10 Hz). The event origin time, based on the arrival of the Rayleigh type of shear wave *Rg* on the BHE component, was estimated to occur at 17:20:42 EDT with an uncertainty of ± 4 s. Notice that the seismic signal strengthens at about 21.5 s, following the initial *Rg* wave arrival at 14.5 s. A *P*-wave from the Fox Islands earthquake (event #17) would have arrived about 11 s after *Rg*, and would have had nearly equal amplitude and duration on both the N-S (middle trace of Figure B-6) and E-W (lower trace) components of the seismic signal. Since the N-S component is small in Figure B-6 (compared to the amplitude of *Rg*), that the signal beginning at 21.5 s is likely due to the sustained period of collapse of WTC 7.

The WTC 7 building collapse was observed to have two distinct phases. First, an internal structural failure occurred which led to the observed east penthouse movement, when it sank below the roofline. Second, the entire building began to collapse about 7 s later, when the roofline and building exterior were observed to start moving downward. The first phase resulted in interior debris falling to the lower floors of WTC 7 on the east side, which transmitted impact loads to the foundation. The debris fell over several