

Two Recent Strong Motion Records from Turkey: Re-Interpretation of Bolu (1999) and Bingöl (2003) Seismograms

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Two major earthquakes in Turkey were recorded in identical buildings at a spacing of three and one-half years in 1999 and 2003, respectively. There was heavy pounding between two buildings of both building complexes where the seismograms were recorded. This paper seeks to inquire whether pounding might have left an imprint on those records.

INTRODUCTION

This paper is motivated by the question of whether a hitherto ignored commonality exists between two strong motion records recovered in Turkey in 1999 and 2003, respectively. The M7.2-earthquake in Düzce on November 12, 1999 caused in Bolu, 21 km away, a peak acceleration of about 0.8 g. This figure remains the highest PGA recorded by the national network in the country to date. Three-and-one-half years later the M6.4 earthquake on May 1, 2003 in the north of Bingöl (900 km east from Bolu) caused a 0.54 g PGA seismogram in that city at a distance of 17 km. This value also is also seemingly an outlier for the experience in Turkey. Both records were made in identical buildings that experienced varying degrees of the same type of damage that was partly caused by pounding between two adjacent buildings at 15-20 m to the sensor.

The national strong ground motion network in Turkey is owned and operated by the General Directorate of Disaster Affairs (GDDA), which is part of the Ministry of Public Works and Settlement (MPWS). The system has been initiated in 1973, but currently it stands only at the very modest total of 140 instruments about evenly divided between analog and digital types. (Another 20 digital instruments are to be located along the Maraş-Antakya route in April to form an array.) Concerns over safety and ease of access, maintenance and phone connection have been the reasons for placing them at basement level of public buildings such as meteorological stations or health clinics. A small number of professionals within GDDA are charged with operating the system. Whenever possible emplacement is also chosen at some suitable spot at the provincial branch buildings of MPWS.

Many of these buildings have been built according to the same custom design because they all fulfill the same public service. While this provides convenience to the Ministry in awarding contracts to contractors for building the same building in many

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different cities, it has become an unwitting guarantor of facing the same type of damage when those buildings as has been the case in at least three major earthquakes during the last 12 years. (The building during the M6.8 earthquake in 1992 in Erzincan did not contain a sensor.)

INFORMATION ABOUT THE BUILDINGS

The MPWS provincial branch buildings are a five-story, reinforced concrete structure with a plan area of 230 square meters. It is essentially rectangular in shape, with three bays both principal directions. The peripheral beams have the unusual depth of 1.2 meters. Seven columns of this structure can be classified as shear walls according to the 1975, Turkish Earthquake Code (TEC) that was applicable when the building was designed. Four of these are oriented in the North-South direction and the other three are L-shaped columns. Dimensions of other columns in addition to amount of longitudinal reinforcement in these members decrease progressively from the lower to the upper stories. On the other hand, dimensions of beams and amount of longitudinal reinforcement in them do not vary with height. Figures 1 and 2 show the buildings in Bolu and Bingöl, respectively.



Figure 1. MPWS Branch Building in Bolu



Figure 2. MPWS Branch Building in Bingöl

A four-story building served by the same staircase (Figure 3) abuts the block seen in these figures, and two other one story buildings are configured in both cities to form a rectangular courtyard. The instrument station is in one of these lower buildings as shown in Figure 4. The sensor in Bingöl was similarly positioned.



Figure 3. Arrangement of Buildings (Bingöl)

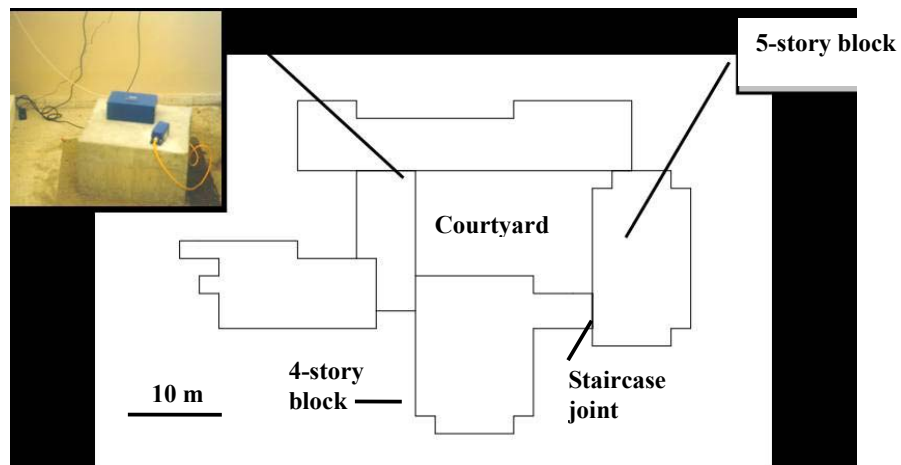


Figure 4. Positions of Sensor and Adjacent Building Blocks (Bolu)

Inspection of both buildings following the main shocks indicated the occurrence of severe pounding between the 4- and 5-story blocks across the staircase joint that is located at about 20 m away. Once again, the images in Figures 5 and 6 showing the interface as seen from the courtyard are nearly duplicates of one another. Severity of hammering was observed to increase at the higher floor levels to the points of dislodged floor tiles immediately adjacent to the joints. The rating of the overall damage in Bolu was more severe. That building has been condemned to demolition. It is likely that the Bingöl building will be returned to service following retrofit.



Figure 5. Close-up View of Building Joint in Bolu



Figure 6. Close-up View of Building Joint in Bingöl

ACCELERATION SEISMOGRAMS

The distance to the closest visible rupture trace of the Bolu sensor was 21 km. In Bingöl, most geologists agreed that there was no visible faulting as such, so the estimated distance from the observed epicenter was about 15 km. Both sets of seismograms are shown in Figures 7 and 8, respectively.

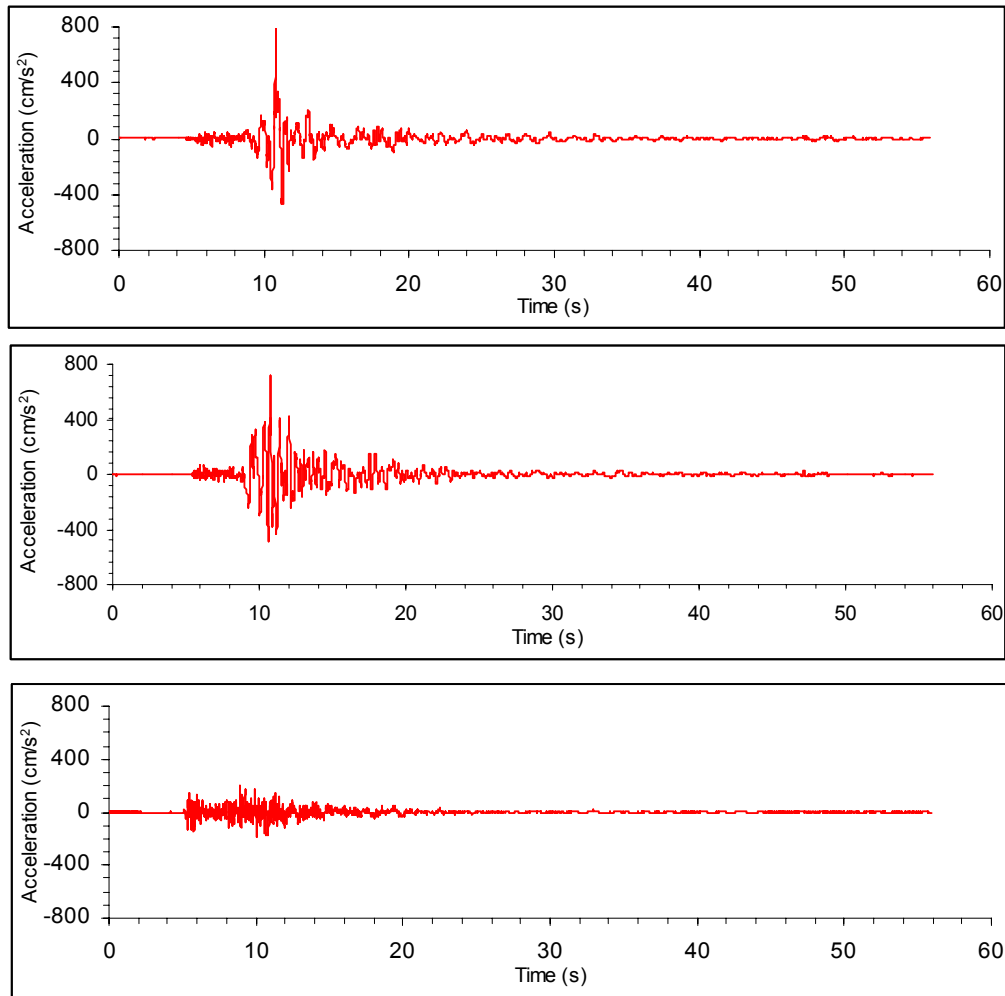


Figure 7. Components of the Bolu Acceleration Seismogram

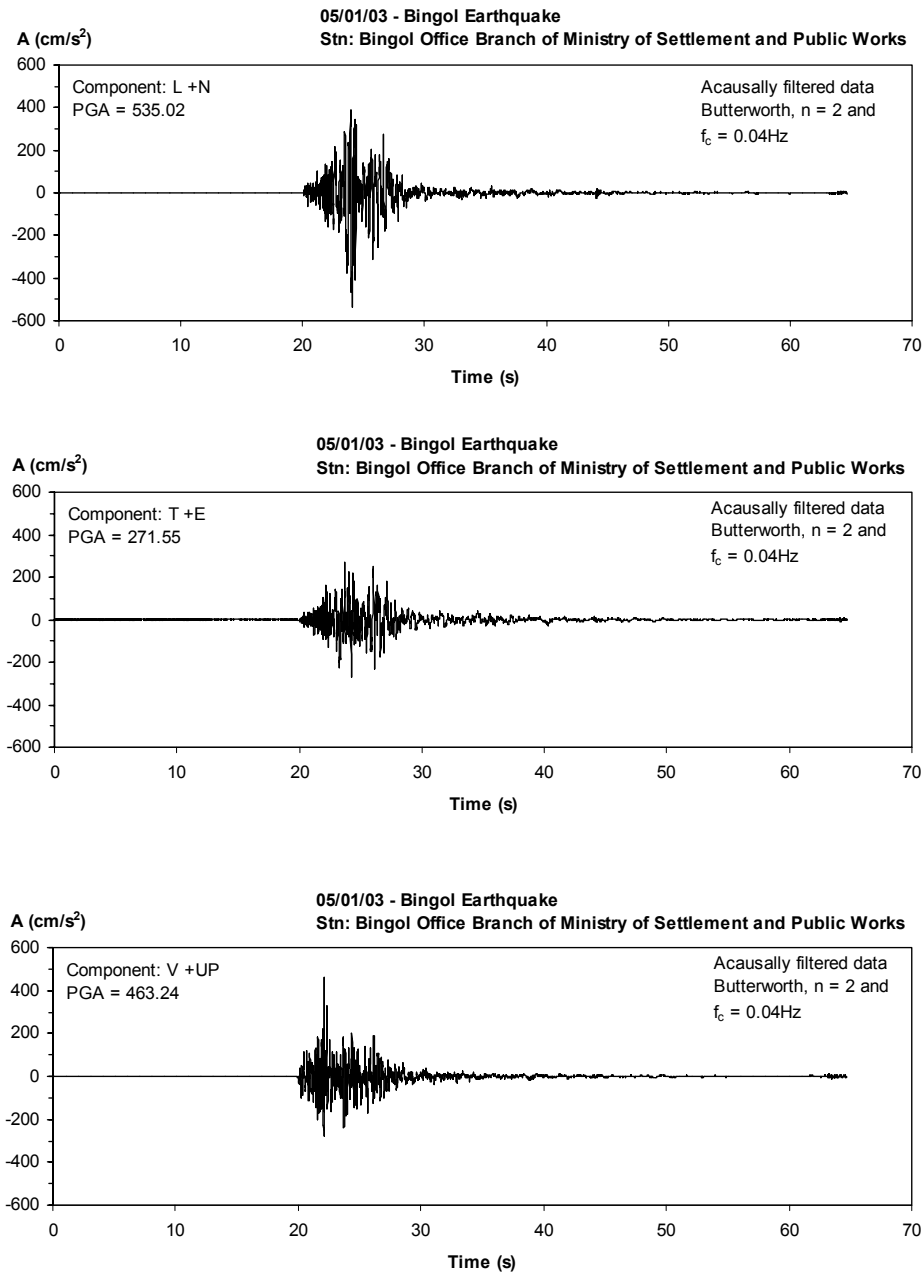


Figure 8. Components of the Bingöl Acceleration Seismogram

Neither accelerogram is accompanied by any other recording within many kilometers, nor are the local site conditions at these stations known well. This paper will seek to establish whether ground transmitted shocks from hammering between two buildings has left subtle traces on these seismograms. The target of establishing unequivocal answers to this question invites speculations that we wish to minimize. Pointers for both accelerograms are reproduced in Tables 1 and 2, respectively. We

show the acceleration and displacement spectra for both in Figures 9 and 10, respectively.

Table 1. Ground Motion Parameters for Bolu

Component	PGA (cm/s ²)	PGV (cm/s)	PGD (cm)	EPA (cm/s ²)	AI (cm/s)	t _{eff} (s)	PGV/PGA (s)
N10E	739	58	40	582	-	12.8	0.078
E10S	806	67	21	463	-	12.5	0.083
UP	196	25	22	146			0.127

Table 2. Ground Motion Parameters for Bingöl

Component	PGA (cm/s ²)	PGV (cm/s)	PGD (cm)	EPA (cm/s ²)	AI (cm/s)	t _{eff} (s)	PGV/PGA (s)
N10E	535.3	36.1	26.6	441.2	192.2	4.58	0.067
E10S	271.5	22.1	10.1	253.1	79.5	6.90	0.081
UP	463.3	13.6	8.5				0.029

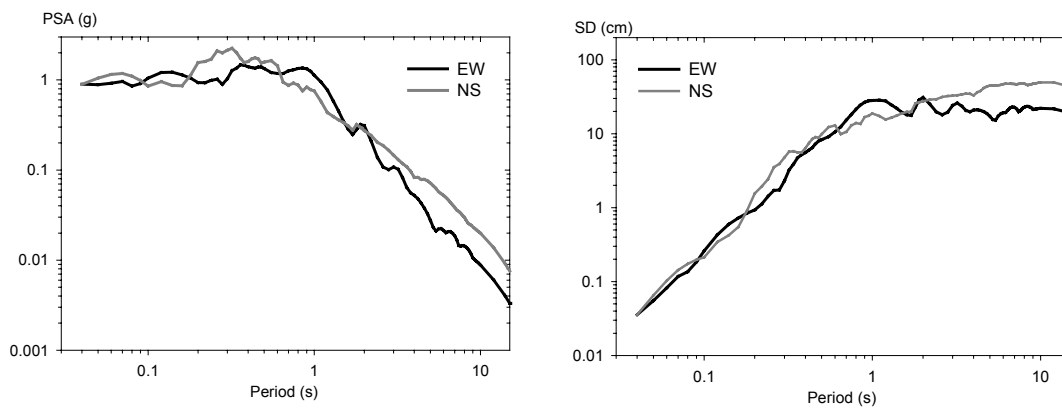


Figure 9. Bolu Spectra

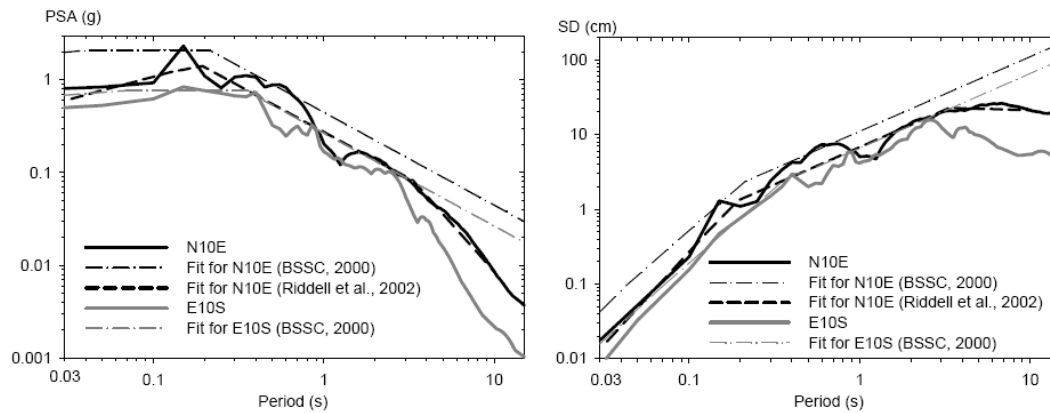


Figure 10. Bingöl Spectra

PARTICLE MOTIONS IN BINGÖL

It is reasonable to expect that, if any building impact affected the ground motions in Figure 8, this would leave an imprint on the particle motions. The accelerations are rich in high frequency components, and successive integrations for velocity and displacement traces would lead to increasingly more long period representations. Combining the two horizontal components into a single hodogram yields the particle motion trace in Figure 11 which is drawn only for the time interval between 20-25 s when impact was most likely to have occurred.

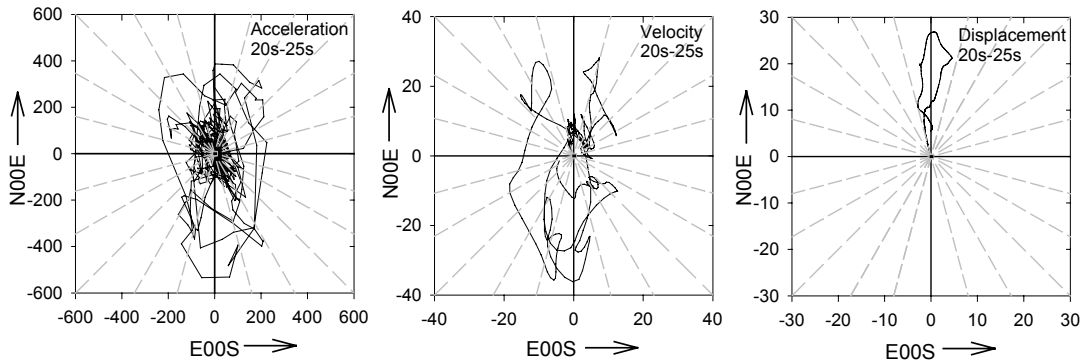


Figure 11. Hodograms of the Horizontal Components

The hodograms are shown for the main pulse of motion, and all three types of motions - acceleration, velocity, and displacement - show a polarization in the north-south direction. This is more-or-less the direction to the cluster of epicenters reported for this earthquake, and is about 58 degrees from the fault strike. We would have thought that the predominate S-wave motion from a vertical strike-slip fault would be oriented transverse to the direction of wave propagation, and thus we expected the S-wave motion to be polarized almost 90 degrees to the observed polarization. We think that the features in the observations that we at first took to be peculiar are in fact natural consequences of the fault-station geometry and the proximity of the station to the fault. It is clear from both sets of hodograms that the polarization is not a maximum in the fault normal direction, as has been suggested by some researchers [e.g. Somerville et al., 1997]. Others studies have also found that the peak motions near faults are not necessarily in the fault normal direction [Akkar and Gülkan, 2002; Howard et al., 2003].

We have examined also the traces of the accelerograms in the direction where pounding may have occurred. Figure 12 contains a blow-up for the Bingöl record at about 23 s where it appears a sharp return interfered with the reversal of motion. It is conjectural to state that this contravenes the oscillatory nature of the ground motion because no other reference motion exists.

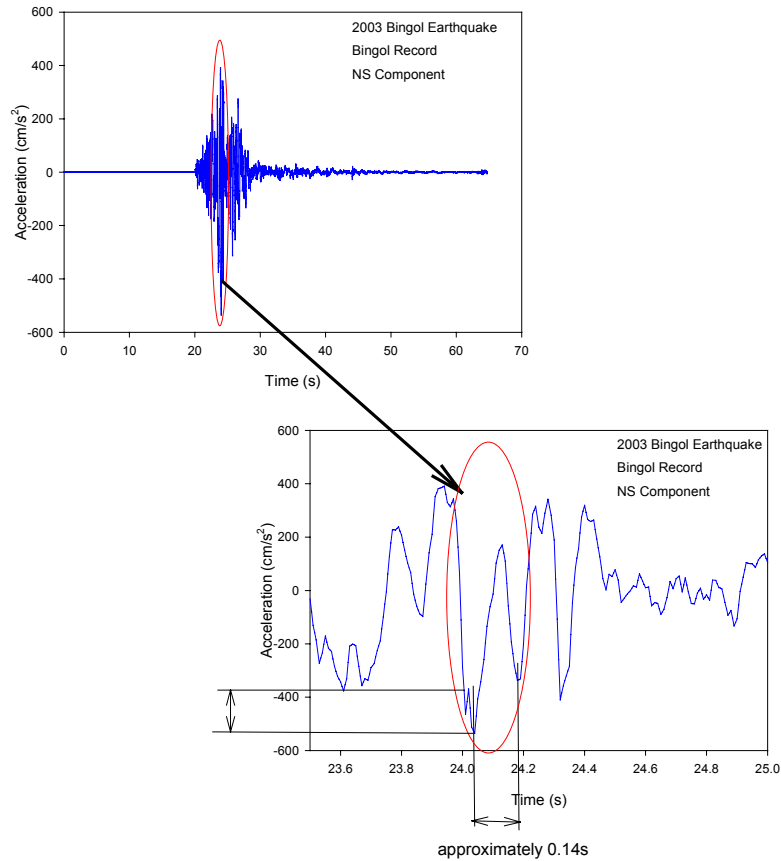


Figure 12. Enlarged Part of the Bingöl Record

GROUND MOTIONS

The peak acceleration from the Bingöl record is unusually large. There are various ways to show this but our conclusion is based primarily on the comparison of peak accelerations to those predicted using data from other earthquakes. The equations of Abrahamson and Silva [1997], Ambraseys and Douglas [2002], Boore et al. [1997], Campbell [1997, 2000], Gülkan and Kalkan [2002], and Sadigh et al. [1997] yield median PGA values ranging between 0.18 g and 0.29 g for a fault distance of about 9 km. The 84th percentiles range between 0.28 g and 0.49 g for the same distance (the PGA values have been adjusted for differences in site response between the average rock site for the equations above and the Bingöl site by using the factors of Boore et al., 1997, with a 30 m-average shear-wave velocity in the equations of 520 m/sec). The observed motion of 0.55 g is well above the 84th percentile predictions. It is not just the peak acceleration that is high - the response spectra over a wide range of periods are larger than median motions from prediction equations, with the spectrum for the N10E component exceeding the 84th percentile for periods surrounding large peaks at 0.15 seconds and 0.6 seconds. The difficulty seems to lie in distributing the complexity amongst the various possibilities.

Why are the motions so large, particularly for the N10E component? Many factors can play a simultaneous role in enhancing motion, and it is well-known that ground motion has significant variability that is not easy to assign to a single cause [e.g. Boore, 2004]. We discuss several possibilities here, with an emphasis on the peak acceleration. The peak acceleration is strongly related to a large, narrow-band peak in the Fourier amplitude spectrum, centered at 6.5 Hz for Bingöl (Figure 13).

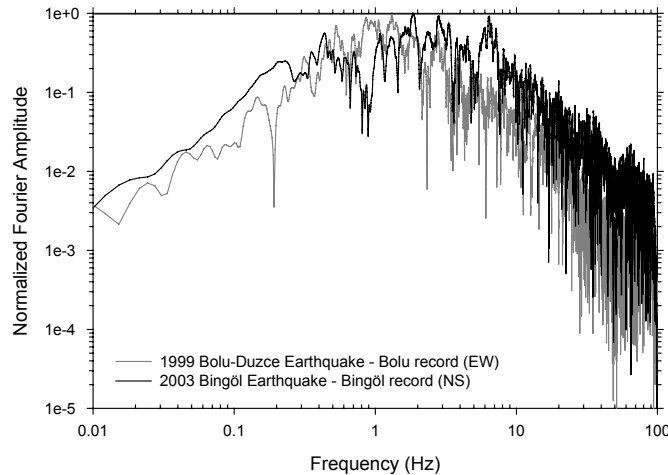


Figure 13. Normalized Fourier Spectra for Bolu and Bingöl Records

Severe pounding between the two mid-rise office buildings was observed immediately after the main shock; the location of this pounding is indicated in Figures 4-6. As noted earlier similar pounding had been observed on the same type of buildings at Bolu during the 12 November 1999 Düzce **M**7.2 earthquake (with a peak acceleration of 0.82 g). Both peaks on the acceleration traces appear to be short duration. Is it just a coincidence that the large peak accelerations also occurred near buildings that pounded against one another, or are the large peak accelerations a result of the pounding? It is hard to come to a conclusion one way or another without a detailed analysis of the amplitude and frequency content expected from the pounding of buildings, so we leave this possibility as a conjecture, and will not pursue it further.

It is well known that fault rupture toward a station can enhance ground motions (an effect termed “directivity”). Although directivity probably played a part in enhancing the Bingöl motions, we think it was not the only important factor. The enhanced motions at relatively short periods might also be used to argue against the importance of directivity, as Somerville et al. [1997, with a revision by Abrahamson, 2000] find that directivity is only important for periods exceeding 0.6 s. But Boatwright and Boore [1982] found clear evidence that peak acceleration can be strongly influenced by directivity.

Another possible mechanism for enhancing the ground motions is local site amplification. If the high-amplitude, narrow spectral peak at 6.5 Hz were due to site response rather than building pounding or source complexity, we would expect to see it on aftershock records. To investigate this possibility, we computed Fourier spectra for 59 aftershock time series obtained from the same instrument that recorded the main shock. All aftershock records have PGA values of less than 0.01g, magnitudes in

the range $3.0 < M < 4.2$, and epicentral distances, R , in the range $5 \text{ km} < R < 31 \text{ km}$. We focused on the N10E component of the motion in pursuit of explaining the high-amplification spectral amplitudes on that component during the main shock. We compare the average spectra from the 59 aftershock records to the main shock spectrum, for the N10E component, in Figure 14, again using log and linear scaling for the ordinate to help judge the comparison of the various curves. For purposes of comparing the shapes, the aftershock spectra have been amplified to equal the peak spectral amplitude of the main shock motion. Also shown in Figure 12 are simulated Fourier spectral amplitudes from the stochastic method of Boore [2003], for three values of the stress parameter (and site amplifications for $VS(30) = 806 \text{ m/sec}$, using adjustments of the Boore and Joyner [1997] generic amplifications based on the velocity dependence given by Boore et al. [1997]). The simulations are shown to provide “base” spectral shapes that account for difference in average ground-motion spectra for the main shock and the much smaller aftershocks.

Because of the interaction of source corner frequency and local attenuation, the simulated aftershock spectrums have a broad peak in the frequency range within which the narrow-band spectral amplification occurs. Any local site response will appear as local amplifications riding on the broader peak. The mean aftershock spectrum has a local spectral peak at 7.4 Hz, which is slightly higher frequency than the 6.45 Hz spectral peak for the main shock. We also note that the spectrum in Figure 14 contains a number of peaks; although it is dangerous to single out just one of them, the ones at 6.45 and 7.4 Hz are the most prominent peaks in the spectra and probably strongly control the peak accelerations. If a site effect, the difference in peak frequencies for the main shock and the mean aftershock could be due to nonlinear soil response. Of course, the spectral peaks could also be due to source or path effects, and the similarity in frequency could be a coincidence. If the peak frequency changes with earthquake location, which is not at all unusual, then averaging over many events should smooth out any sharp spectral peaks due to non-local effects, unless all the aftershocks occur in the same location.

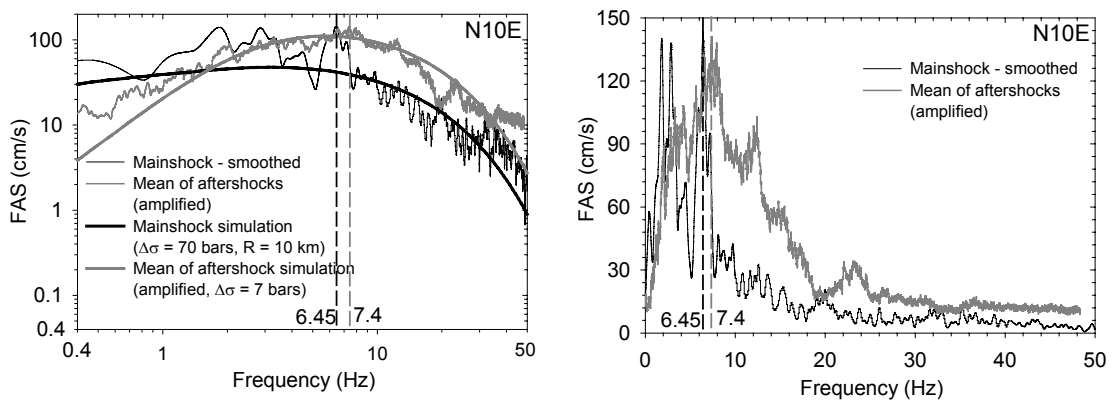


Figure 14. Aftershock data for the arithmetic mean of 59 after shock events: Bingöl

CONCLUSIONS

In summary, we think a combination of factors contributed to the large ground motions, with various effects playing more or less important roles for various ranges of ground-motion frequencies. These effects include pedestal response, building pounding nearby, radiation pattern peculiar to both events, rupture directivity (much more likely in Bolu than in Bingöl), and site response. Among these possibilities, building collision and the site response seems to be more reasonable than the others but there exists little corroborative evidence for elevating either to the position of primary cause.

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