Scattering and intrinsic attenuation structure in Central Anatolia, Turkey using BRTR (PS-43) array

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Introduction

• When we look at the past seismological studies in Turkey, we can say that the Central Anatolian region has not been studied as much as western and eastern parts of the Turkey mostly due to its low seismic activity and hazard level compared to other regions.

• However, starting from 2005 Bala earthquake and recent earthquakes that occurred near Ankara and its vicinity show that there is an increase in seismic activity and it might be a good idea to do more research on these areas in order to get a better picture of the crustal structure and the seismic hazard of the region.

• For this purpose the main goal of the study will be obtaining the attenuation structure in the source region of Bala events and along the path from source region to station.

• The study of short-period S-wave propagation in the upper lithosphere is of wide interest for seismological study as well as for engineering purpose.
Bala (Ankara) seismic activity

- On December 2007 there has been two mid-size earthquake occurred in the vicinity of Bala (Ankara). The first event that happened on 20 December has a magnitude Ml=5.7, and the second event occurred one week later on 27 December has a magnitude Ml=5.5.

- The earthquakes was felt strongly in Ankara, Bolu, Kırşehir, Yozgat, Aksaray cities and surrounding villages. Initial reports indicate no people were killed, but the damage were considerably in the villages.

- During this one week there was a lot of aftershocks. BRTR array recorded approximately 1100 aftershocks between 20-28 December 2007. The magnitude range for those aftershocks are changing between 1.5 to 5.0.

- When we look at the aftershocks on the map we see that they are lined up in NW-SE direction. The focal mechanisms of the events are right lateral strike-slip.
Location of Bala Aftershocks
Map of the Seismic stations
Seismic stations to be used for the study (BRTR arrays)

- BRTR is composed of two sub-arrays (Ankara and Keskin)

- The medium-period array with a 40 km diameter located in Ankara and the short-period array with a about 3 km diameter located in Keskin

- Each array has a broadband element located at the middle of the circular geometry.

- Short period vertical instruments (Geotech23900) are installed at depth 30 meters from the surface while medium and broadband instruments (KS54000) are installed at depth 60 meters from surface

- Broadband sensors are operating at 40 sps, short periods 20sp s and medium periods are 4 sps.

- The epicentral distance from Keskin array is about 50 km.
Seismic stations to be used for the study (TUBITAK temporary network)

- TUBITAK has installed a temporary seismic network around Bala (Ankara) in order to collect aftershock data.

- This network consists of 6 short period and 1 bb sensors.

- All of the sensors are 3 channels.

- Signals are recorded with 100 sps sampling rate.

- The distance of the each element from main events are approximately between 15-40 km.
Data Processing/Preparation

- **Data Conversion**

- Since our Keskin SP array data have CCS3.0 format and the Tubitak data have SAC format, conversion between the two data sets is inevitable.

- We converted Keskin array data into the SAC format for now. The conversion process is done with Geotool software which has been developed by IDC/CTBTO. The process is fairly simple.
Coda Normalization
Data Processing/Preparation

• The coda normalization method was applied to a set of the earthquakes observed at distance range between 10 to 65 km.

• Coda and direct S wave level is estimated by root mean square (rms) of the spectral amplitude for a 6-sec time window and a central time at \( t_c = 40 \) sec.

• The waveforms were band pass filtered at the central frequencies 1.0, 3.0, 4.0, 6.0 Hz. Since the two data sets (Keskin array and Tubitak network) have different sampling rates, it is not possible to investigate higher frequencies such as 12, 16, 24 Hz.

• At this point of the study only 50 earthquakes were selected and analyzed,

• The focal depths of the chosen earthquakes are usually shallower than 15 km. Most of the earthquakes have a local magnitude in the range of 2.0 to 3.8
Coda Normalization
Event-Distance Observations

Distribution of distance observations for each event.
The event date is printed at the right and the event ID at the left.
Coda Normalization

Station-Distance Observations

Distribution of distances observations for each station.

Left hand side shows the Station Channel names.
Coda Normalization
Trace envelopes
Coda Normalization
Site Terms
Coda Normalization

$1/Qs$

<table>
<thead>
<tr>
<th>Freq (Hz)</th>
<th>$1/Qs$</th>
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<tr>
<td>3 Hz</td>
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<td>4 Hz</td>
<td>0.0052</td>
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<tr>
<td>6 Hz</td>
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Multiple Laps Time Window (MLTW) Method

- Multiple Lapse Time Window Analysis (MLTW) method is becoming a routine tool in seismic attenuation analysis (see also Sato and Fehler, 1998, p. 189).

- In this method the integrated energy density over three consecutive time windows from the S-wave arrival time is evaluated as a function of source–receiver distance (Fehler et al., 1992; Hoshiba, 1993; Carcole and Sato, 2010).

- The observed energy density is compared with the synthesized one to obtain the seismic albedo, defined as the dimensionless ratio of scattering loss to total attenuation.
Multiple Laps Time Window (MLTW) Method

Measure

scattering coefficient, intrinsic attenuation

Terminology:

\( Q_i^{-1} \) Intrinsic Attenuation
\( Q_s^{-1} \) Scattering Attenuation
\( g \) Scattering Coefficient

\[
g_0 = \frac{1}{4\pi} \int g \, d\Omega = \ell^{-1} = Q_s^{-1} k
\]

Albedo: ratio of scattering to total attenuation

\[
B_0 = \frac{Q_s^{-1}}{Q_i^{-1} + Q_s^{-1}} = \frac{g_0 \beta_0}{g_0 \beta_0 + Q_i^{-1} \omega}
\]
Multiple Laps Time Window (MLTW) Method

- Based on time-domain solution of radiative transfer theory equation
- Analyze Integrated Energy Density vs time and space
- Allows Separation of Scattering and Intrinsic Attenuation

Integrate Energy in Windows whose Times are Referenced to S-wave Arrival Time
Multiple Laps Time Window (MLTW) Method

- Define 3 time windows and integrate energy in these windows

\[ EI_1(f)_{kj} = \rho_0 \int_0^{15s} |\dddot{u}_{kj}(t; f)|^2 dt, \]

\[ EI_2(f)_{kj} = \rho_0 \int_{15s}^{30s} |\dddot{u}_{kj}(t; f)|^2 dt, \]

\[ EI_3(f)_{kj} = \rho_0 \int_{30s}^{100s} |\dddot{u}_{kj}(t; f)|^2 dt \]

- Use Coda Normalization to correct data for station amplification and source size
Multiple Laps Time Window (MLTW) Method

Slope of Integrated Energy Vs Distance for First-Arrival Packet is Proportional to Total Attenuation

Amplitude of Integrated Energy Vs Distance for Late-Arriving Energy is Proportional to Scattering Attenuation
Multiple Laps Time Window (MLTW) Method

Fits to Data Collected in Japan
Multiple Laps Time Window (MLTW) Method

Results Obtained with Multiple Lapse-Time Window Analysis Method

- Total Attenuation
- Albedo
- Scattering Attenuation
- Intrinsic Attenuation

Frequency [Hz]
Multiple Laps Time Window (MLTW) Method
Multiple Laps Time Window (MLTW) Method
Conclusion

• We have applied Coda normalization technique to the data recorded by Keskin Array and Tubitak stations.

• Also Hoshiba’s MLTW method in order to separate scattering and intrinsic attenuation was applied but not completed. Normalized energy plots were calculated but the energy - distance curves will be drawn and $Q_i$ and $Q_s$ will be obtained.

• At this point in the study The estimated $Q_s^{-1}$ values will be compared to other studies in different regions.
References