DISASTER SCIENCE AND ENGINEERING

2018 - Volume: 4 Number: 1
Page: 46-53

Received: Feb 5, 2018 Revised: May 14, 2018 Accepted: Jun 22, 2018

SEISMIC CHARACTERIZATION OF THE BLAST OCCURED IN ISTANBUL (TURKEY) BY THE END OF 2016

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ABSTRACT

On December 10, 2016; two terror originated attacks hit Istanbul, Besiktas at sequential time intervals of 45 seconds shaking the buildings, damaged surrounding structures and caused loss of lives. The first blast was hit with a bomb loaded vehicle moving through the eastern exit of the Vodafone Park stadium. The second attack was occurred after 45 seconds in the western exit of the stadium. These blasts produced seismic signals which were recorded by two broadband instruments ISK and KAVV that are operated by Kandilli Observatory and Earthquake Research Institute Regional Earthquake-Tsunami Monitoring Center (KOERI-RETMC). These explosions were audible up to several kilometers including significant acoustic energy at frequencies higher than 20 Hz. The blasts were analyzed in frequency and time domain to illustrate the attack's frequency characteristics and its amplitudes. The first attack's (car loaded) record in station KAVV's N-S component shows the fundamental peak frequency in 17 Hz at 0.2th second, 12 Hz at station ISK respectively depicting single massive event and energy discharge as well. For the second attack which was a suicide bomber, the results of Short Time Fourier Transform analysis indicate that the energy releases focused both at higher frequencies and involving infrasound at < 20 Hz. Due to amount of bomb, the second blast corresponds to energy discharge at low amplitudes in comparison with the first blast. In addition to that it was detected from the energy estimation that the explosion for the first attack is equivalent to 225.6 kg TNT.
Keywords: blast, Istanbul, spectra, time-frequency domain analysis, Turkey.

1. INTRODUCTION

Energy release during an earthquake or an explosion in the Earth crust could generate seismic waves. The recorded seismic waves at regional distances carry out important information about possible source(s) of the sudden energy release. There are numerous studies discriminating the earthquakes and explosions. Earlier efforts have focused mostly discrimination between earthquakes and (nuclear/chemical) explosions [1-2-3]. However, recent studies related to accidents, sinking of ships bomb explosions [4-5-6-7], meteor approaches, sonic booms [8-9] military operations and understanding the seismic and acoustic sources ranges from meters to kilometers has many military and forensic applications [10-11].

Istanbul, economical and historical capital city of Turkey, has recently been suffered from serious terrorist attacks in last year. It is the most populated city in Turkey with 15 million inhabitants (Figure 1). The last explosion occurred two hours after a Turkish football league match between Besiktas versus Bursaspor at the Vodafone Park. The first blast was hit with a bomb loaded vehicle moving through the eastern exit of the Vodafone Park. The second attack was occurred after 45 seconds after the first one at the western exit of the stadium where the policemen had tried to stop the suicide bomber. 38 people have died and 166 were injured in this terrorist attack because of about 300-400 kg Trinitrotoluene (TNT) bomb [12].

In the studies of [6-7], Ankara and Diyarbakir bomb attacks were investigated, respectively. Even though most of the energy radiated to atmosphere as the healing energy or air blasts, estimated energy

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amount using seismic signals suggest that 1.04×10^7, 4.21×10^7 and 8.16×10^7 joule energy radiated in crust for October 10, 2015; February 17, 2016 and March 13, 2016 attacks, respectively.

In this study, some characteristic features of these events were investigated by performing spectral analysis both in time and frequency domain. The seismic data generated by the explosions recorded by stations ISK and KAVV have been analyzed (Table 1). Analysis of the seismic data has been tried to give an answer to the questions related to properties of the explosion such as frequency content, bomb's monolithic characteristic (one blast or more triggered) and its energy that was released in joule and corresponding TNT amount.

2. INTERPRETATION AND RESULTS

Although the metropolitan is under dense and chaotic structural circumstances, the explosions were recorded by two broadband stations where the locations depicted in Figure 1, Station KAVV has GURALP-CMG 3ESPC broadband sensor model with the DM24 digitizer. At the same time another station ISK has DM24 digitizer with the GURALP-CMG 3T broadband sensor. Both of the record's sampling frequencies are 100 Hz. The recorded signals of the blasts were depicted in Figure 2.

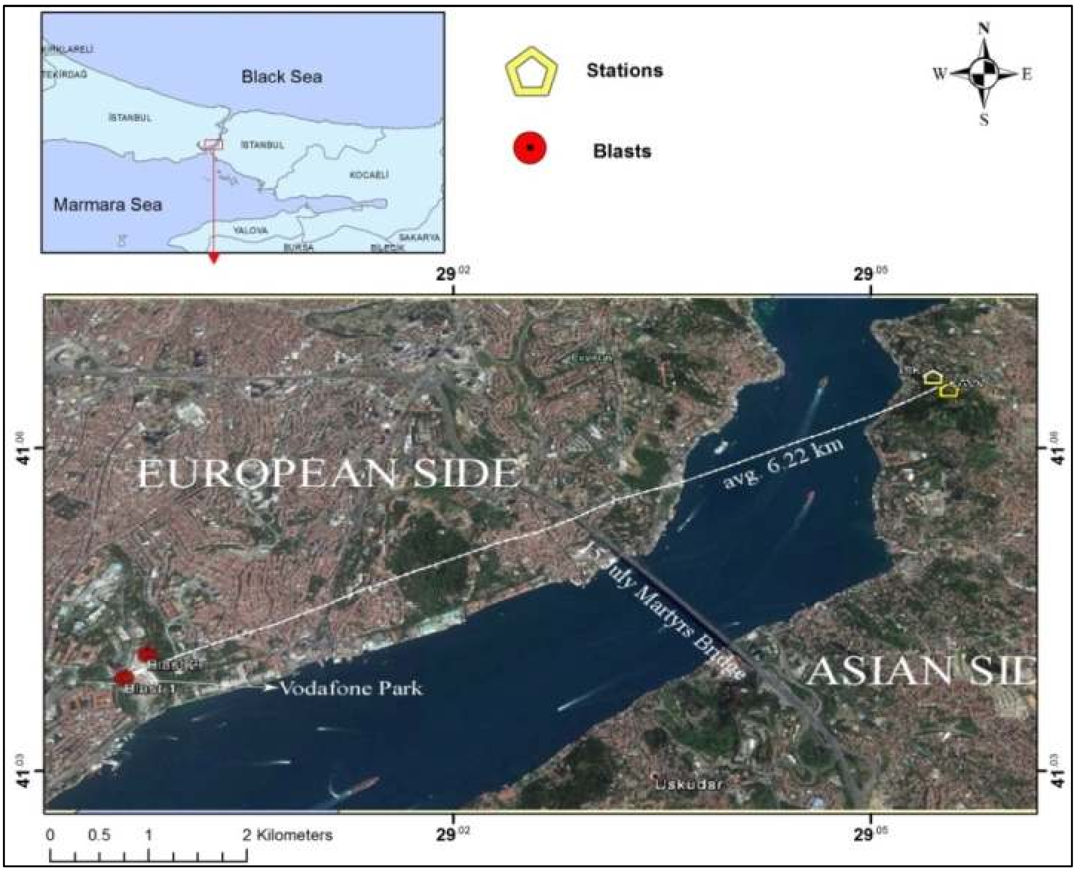

Figure 1. The general view of the location of blasts and earthquake stations. Explosion site is illustrated in red points and seismic stations in yellow pentagon symbols.

Table 1. Information of the blasts investigated and their calculated energy amounts.

#	Station/ Component	Date	Time (TLT)	Distance (km)	Energy (joule)
Blast 1	ISK (E-W)	10.12.2017	19:29:15	6.21	6.4×10^7
	KAVV(E-W)	10.12.2017	19:29:16	6.22	9.4×10^7
Blast 2	ISK (E-W)	10.12.2017	19:29:53	6.21	3.9×10^5
	KAVV(E-W)	10.12.2017	19:29:53	6.22	1.3×10^6

2.1. Time Domain Analysis

The first attack was occurred at 19:29:15 and the second one is at 19:29:55 in Turkish Local Time (TLT). The instrument responses of gathered seismic records were removed based on same digitizer model. The energy released in a blast attenuated in the atmosphere and earth by varying conditions such as acoustic sound waves, ambient noise, etc. So, the peaks on the seismograms are not clearly distinguished for the second blast and 3 seconds time shift was occurred in seismogram (Figure 2).

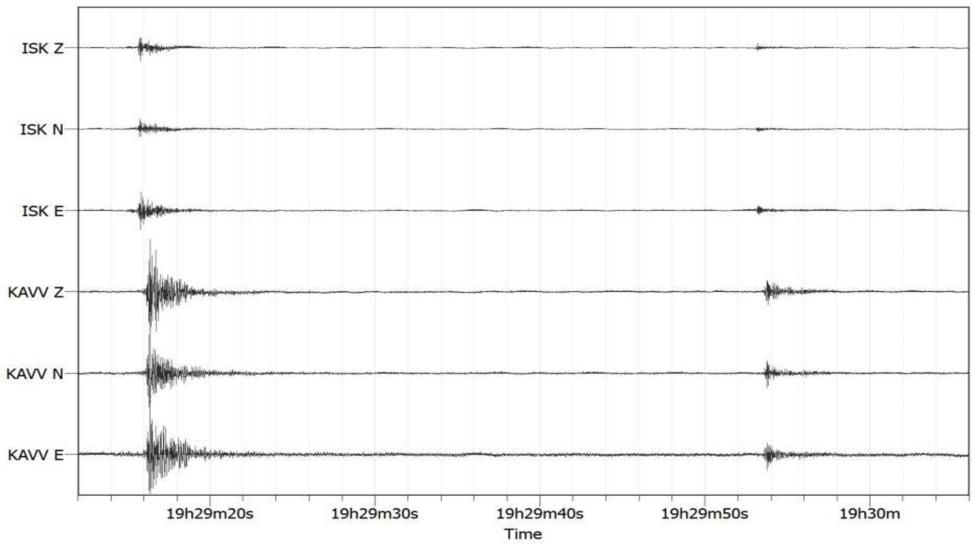

Figure 2. The raw data generated by blasts recorded at station ISK and KAVV.

Correlation between two signals provides the time delay and enhances the frequencies common to the two signals. In Figure 3, the correlation between stations ISK and KAVV were demonstrated. It can be obviously seen that there is a relatively symmetry at time lags due to high similarity between all pairs of signals. Also there is a short delay between these stations generated from acoustic/infrasonic wave travel time which is expected. Therefore, signals can be considered as blasts which originated from particular events.

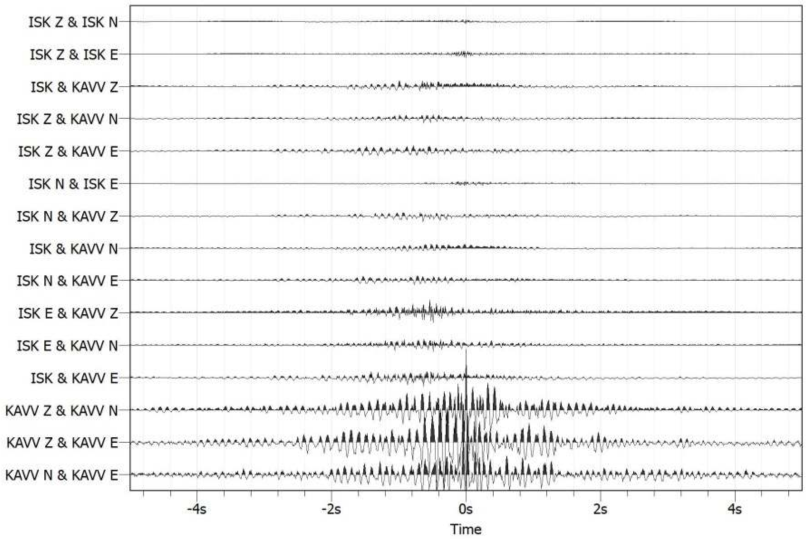

Figure 3. Correlations between all pairs of signals for each station.

The particle motion of the records belonging to first explosion is indicated elliptical character so it can be approved as Rayleigh waves (Figure 4).

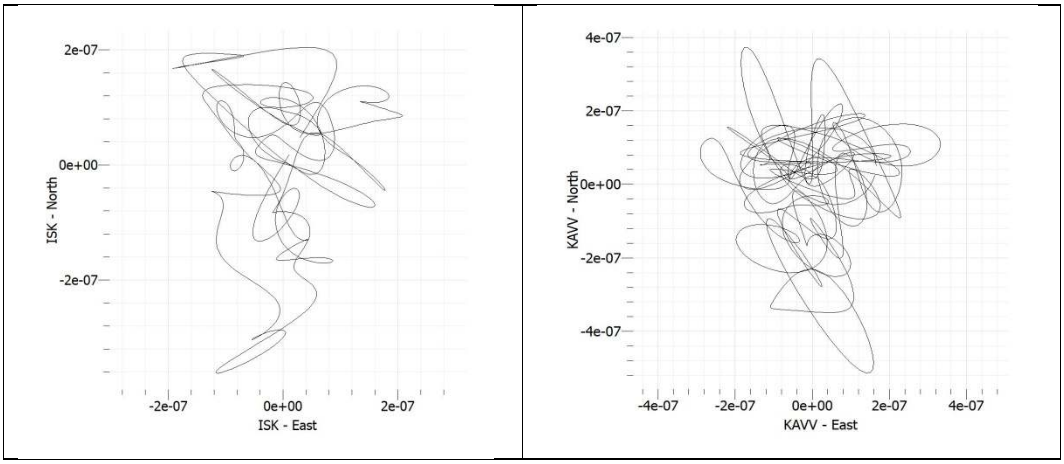

Figure 4. Particle motion analyses for the first explosion recorded at horizontal components of both seismic stations.

2.2. Frequency Domain Analysis

Seismic sources can be identified by using their frequency content. Body and surface waves generated from earthquakes execute low frequency range (0.01-1 Hz) in spectra while explosions generate high frequency (1-1000 Hz) [13].

Frequency analysis of the seismograms has been done by using Short Time Fourier Transform (STFT) and Fourier Transform (FT). STFT allows us to see the changing spectra as a function of time while FT allows seeing the changing amplitude as a function of frequency.

The STFT maps a signal into a two-dimensional function of time and frequency. It provides information about both when and at what frequencies a signal occurs [14-15]. If the chosen window shifts over a time and the windows instantaneous time is represented as "τ" , then STFT is shown as expressed in

Equation 1. In the analysis Gaussian window was performed with the k parameter which controls the frequency resolution at both extremities as 0.005.

$$STFT(\tau,f)=\int_{-\infty}^{+\infty} f(t)g(t-\tau)e^{-i\omega t}dt \qquad (1)$$

According to STFT analysis, the first blast displays more uniform energy release at short times in the range of similar frequencies (12 -17 Hz) due to the amount and properties of the bomb (Figure 5). Although the stations recording the blasts were close about 200 meters apart, the difference between the fundamental frequencies for the first bomb could be originated from topographic effect [16] allied to sediment thickness [17-18]. In Figure 6, it can be obviously seen that the spectrum of the station ISK's N-S component and its corresponded amplitude peaks in time-frequency resultant 3D view.

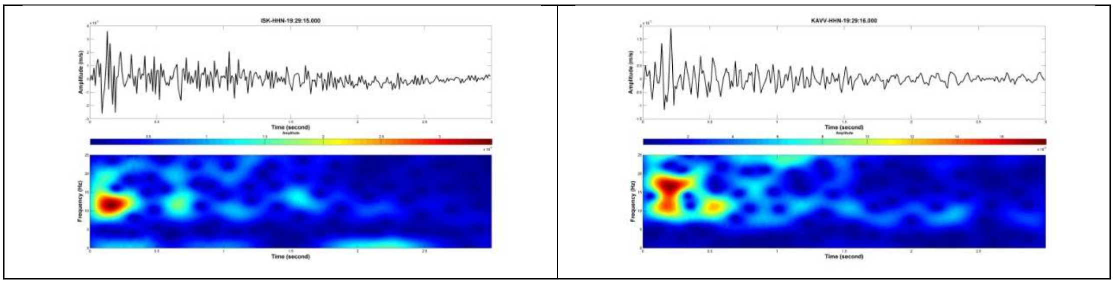

Figure 5. STFT analysis of the first blast recorded at both station.

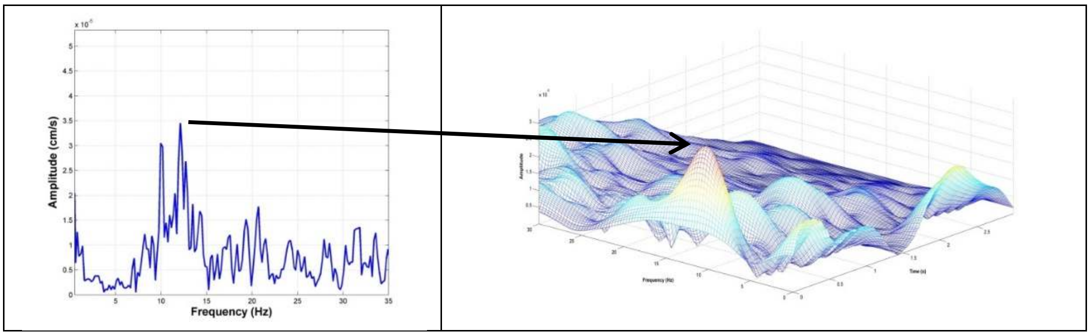

Figure 6. The spectrum of station ISK's N-S component of the first blast and corresponding 3D spectrogram.

However, the second blast displays more scattered characteristic and less amplitudes at different frequencies due to the bomb amount compared to the first attack (Figure 7). For the second attack which was a suicide bomber, the results of short time Fourier analysis indicate that the energy releases focused at higher frequencies around 15-25 Hz regarding less amplitudes due to amount of bomb. Additionally, it shows not only one massive event but also a complicated explosion (Figure 7).

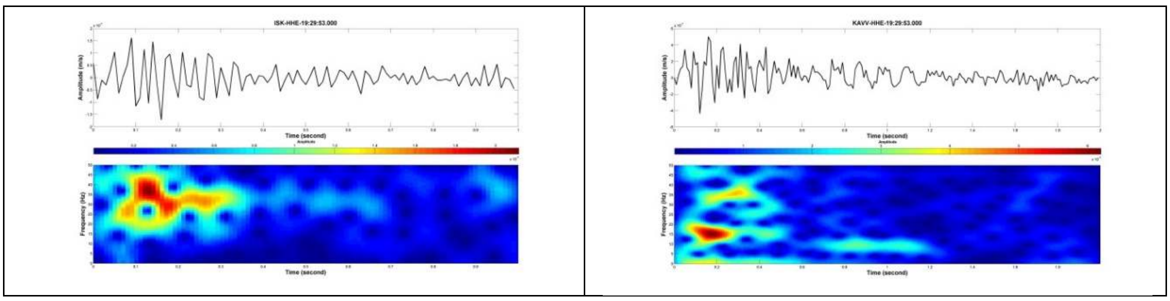

Figure 7. STFT analysis of the second blast recorded at both station.

The spectra of the records were also investigated and compared with their respective ambient noise spectra in Figure 8. It could be seen that amplitude levels for blasts are higher than the background noise starting around from 5 Hz.

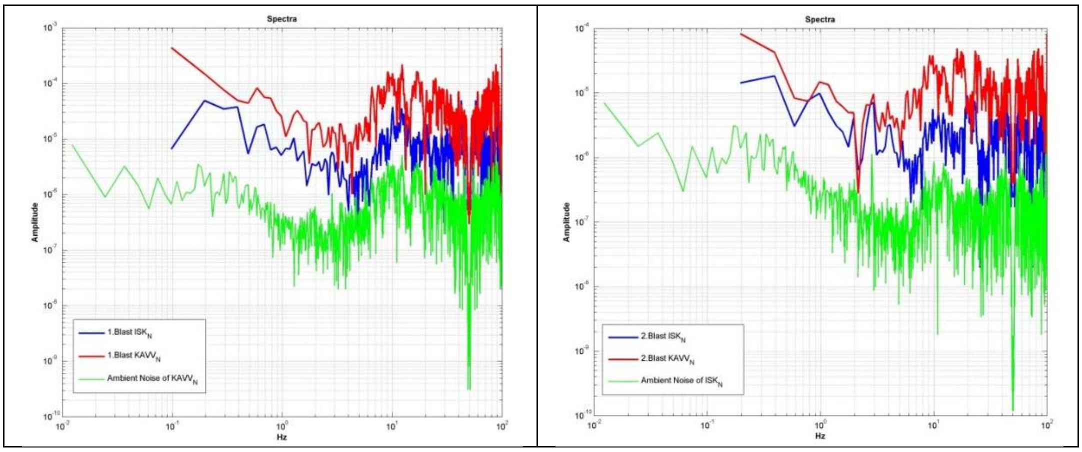

Figure 8. Fourier Spectra for both blasts in all recording stations. The first blast is displayed in left side and the second blast is shown in the right side of the figure.

Calculation of radiated seismic energy from these terrorist attacks contains some difficulties due to scattered energy. In the case that was investigated for this study, the most of energy generated from these blasts is radiated to air.

The radiated seismic energy, E_s, is calculated by following [13-19]. They expressed in units of joules and defined in Equation 2.

$$E_s = 4 \times \pi \times \rho \times C \times R^2 \times (I_{1+} I_{2+} I_3) \quad (2)$$

where ρ is the density of the rock at the source (kg/m^3), R is the distance from source to receiver (m), C is the P-or S-wave velocity (m/s), and I is the integral of squared velocity for an each component of the seismogram (m^2/s^2/Hz). Even though most of energy radiated to atmosphere as the healing energy, calculating energy amount using seismic signals suggest that 9.4×10^7 was calculated for the first attack 1.3×10^6 for the second attack in joule that energy radiated in crust. The station KAVV's E-W components were considered in calculations because of the dominant retrograde motion mentioned in Figure 4; so the first blast is equivalent to nearly 225.6 kg TNT and the second blast is equivalent to nearly 18.3 kg TNT.

3. CONCLUSION

Analysis of the recorded seismic signals show that first blast could generate enough radiated energy and single massive explosion due to much amount explosive materials while second one could not yield a considerable energy and significant time frequency anomaly carried by suicide bombers. Particle motion analysis of seismogram indicates that retrograde elliptical in plane of propagation is dominant means that they are Rayleigh waves so the energy calculations was made according to E-W components.

These analyses which are expected to be promising for forensic seismology in Turkey and provide an insight look detecting and characterizing seismic and acoustic sources from the blasts.

ACKNOWLEDGEMENTS

Authors would like to thank Kandilli Observatory and Earthquake Research Institute Regional Earthquake-Tsunami Monitoring Center for sharing the data.

This study is prepared and improved from the paper presented at the 4th International Conference on Earthquake Engineering and Seismology (4ICEES).

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