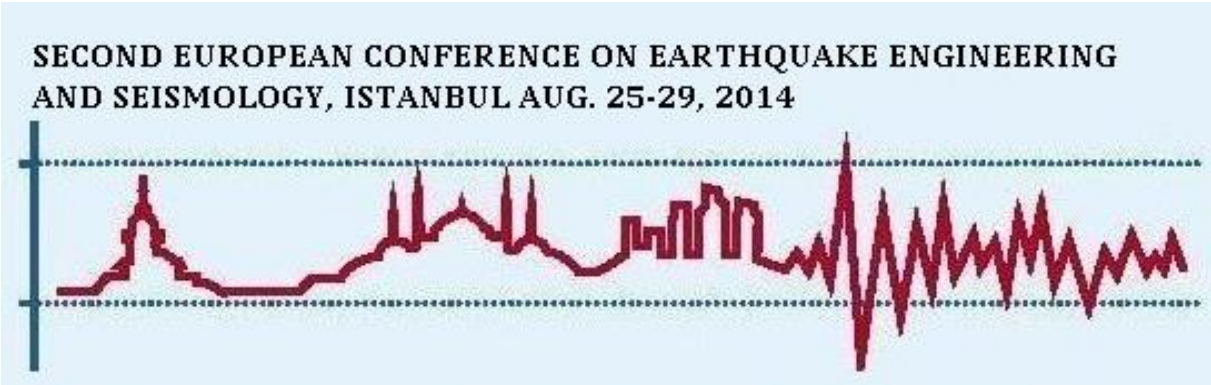

THREE MASSIVE EXPLOSIONS AND SEISMOLOGY
a) Afyonkarahisar (Turkey) Military Ammunition Depot Explosion (2012)
b) Damascus Jamraya (Syria) Military Research Center Explosion (2013)
c) Kırıkkale (Turkey) Gunpowder Depot Explosion (2013)

Fikret KURAN

Depending on the developments in technology and industry, explosions may occur in mines, in petroleum and natural gas pipelines, in factories manufacturing chemicals as well as in military ammunition depots. After being conducted first nuclear test by USA in New Mexico in 1945, numerous number of nuclear bomb tests were conducted and still continuing for military purposes. The latest nuclear test was conducted by North Korea in 2013. During the recent years, large-scale bombing attacks were organized by terrorist groups in the world and in Turkey. It is known that man-made explosions can cause vibrations in the earth's crust like earthquakes. In this study, the origin time, the geographical locations and charge weight of explosives were investigated by using seismological records for the 3 large-scale explosions occurred in the last two years period. These explosions were recorded by different seismic networks. According to the origin time for the explosions, the first one took place in Afyonkarahisar (Turkey) Military Ammunition Depot Explosion in 05.09.2014. In this explosion, 25 soldiers were death. The second explosion took place in May 5, 2013 in Jamraya, which is at the north-west of Damascus, capital of Syria. This explosion was occurred due to air strike to the ammunition depot in the Military Research Center of Syria. The third explosion, which is taken into consideration in this study, is the explosion occurred in the gunpowder depot of Mechanical and Chemical Industry Corporation (MKEK) in Hasandede Town of Kırıkkale in 20.08.2013. Seismograph records of explosion provide a great benefit to investigate accidents or terrorist attacks.

Keywords: Seismology, explosion, origin time, geographical location, charge weight of explosives

INTRODUCTION

Explosions from human activities form vibrations similar to the vibrations of earthquake origin. During the "Cold War" nuclear weapon test explosions were monitored by seismographs and the test location and the size of the weapon were determined by other countries.

Besides the monitoring of nuclear weapon tests, forensic seismology is used in the analysis of many unusual incidents affecting a large part of the public such as terrorist bomb attacks; mine, pipeline and fuel storage explosions and airplane accidents. Some of the events where seismograph recording had been used are as follows: bomb attack to US Federal Building in Oklahoma State in 1995, bomb attack to the US Embassy in Nairobi-Kenya by Al-Kaide Terrorist Organisation in 1998; explosion and sinking of Russian Nuclear Submarine Kursk in the Barents Sea; explosion of the New Mexico Carlsbad natural gas pipeline in US; fuel tank explosion in Buncefield town in United Kingdom in 2004; terrorist attack to airplane PAN-AM Flight No 103 over Lockerbie in Scotland in 1988; explosion and sinking of South Korean Submarine in 2010, explosion of the Novaky

Civil Engineer (MSc), Prime Ministry, General Directorate of Foundations, Ankara, Turkey
email:f.kuran@vgm.gov.tr

ammunition factory in Slovakia in 2007 and Al-Kaide attacks to the Twin Towers of New York World Trade Center on September 11 2001.

In these events sometimes the exact time of the event is important and in other events the location of the event or size of explosion are more important. For example, at the Lockerbie attack the location the airplane was calculated with a tolerance of 300 meters using the seismograph records (Reynolds, 2011). For such events, data obtained from seismograph records immediately following the event could be very important for the planning and management of emergency operations.

Table 1. Magnitudes of Some Man-Made Large And Uncontrolled Explosion Events.

Event	Date	Time (GMT)	Magnitude
Bomb explosion in the Boeing 747 Airplane over Lockerbie Scotland and the magnitude of the event when the airplane strikes the ground	21.12.1988	------	1.3 (M_L)
Explosion in the Russian Kursk Nuclear Submarine (Two separate explosions)	12.08.2000	07:28:27 07:30:42	1.5 (M_L) 3.5 (M_L)
Al Kaide Attacks on The Twin Towers of The World Trade Center in New York USA (respectively first impact, second impact, collapse of WTC South Tower. and the collapse of WTC North Tower)	11.09.2001	08:46:26 09:02:54 09:59:04 10:28:31	0.9 (M_L) 0.7 (M_L) 2.1 (M_L) 2.3 (M_L)
Explosion in AZF Fertilizer Factory in Toulouse France	21.09.2001	08:17:56	3.4
Buncefield Fuel Storage Explosion in United Kingdom	11.12.2005	06:01:31	2.2 (M_L)
Explosion in Novaky Ammunition Factory in Slovakia (Four separate explosions)	02.03.2007	15:26:24 15:26:53 15:26:55 15:28:05	 0.6 (M_L) 2.2 (M_L)
Explosion in Gerdec Ammuniton storage facility in Albania (Two separate explosions)	15.03.2008	11:10:06 11:29:15	2.9 (M_L) 2.5 (M_L)
Explosion in Porto Rico Catano Petroleum Storage Tanks	23.10.2009	24:21:13	2.8
Sitapura Refinary Explosion in India	29.10.2009	~07:36:00	2.3
Explosion of South Korean Submarine	26.03.2010	12:21.57	2.04 (M_L)
Ammunition Explosion in Evangelos Florakis Military Naval Base in South Cyprus	11.07.2011	02:47:52	3.0 (M_L)
Fertilizer Factory Explosion in US Texas Waco	18.04.2013	00:50:46	2.1 (m_b)

Man-made controlled or uncontrolled explosions sourced seismograph records can be distinguished from earthquake sourced seismograph records. There are large number of scientific studies on differentiating explosion and earthquake seismograph records. Seismograph records of explosions are of shorter duration and display impulsive character. The most important difference between explosions and earthquakes is the amplitude ratio of P and S waves. This P/S ration which is much greater for explosions compared to the earthquakes (Rogers and Koper; Ottemöller and Evers, 2008; Gitterman et al, 2007).

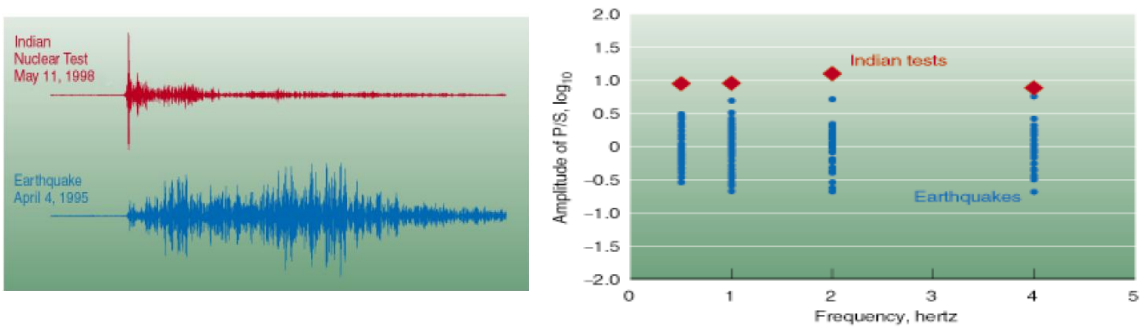

Figure 1. Seismograph records for Nuclear Test and Earthquake and P/S Waves Amplitute Ratios (From J.D., Rogers and K.D., Koper, Military Geology and Combat Engineering Lecture Notes.)

The explosion and the sinking of the South Korean warship (Table 1) in the Yellow Sea is studied by Kim and Gitterman. According to another study by South Korean Military, the explosion is the result of a CHT-02D type torpedo with 250 kg TNT equivalent explosive charge fired by North Korea

(DPRK). According to Kim and Gitterman's study, the most feasible scenario would be that the seismic yield of the South Korean warship under water explosion is a 136 kg TNT yield, corresponding to a seismic magnitude of 2.0 at the detonation depth of about 8 m, taking into account the observed bubble pulse period of 0.99 sec, which is equivalent to a LCM (local land control mine), but not a 250 kg TNT yield corresponding to DPRK's torpedo CHT-02D (Kim and Gitterman, 2013).

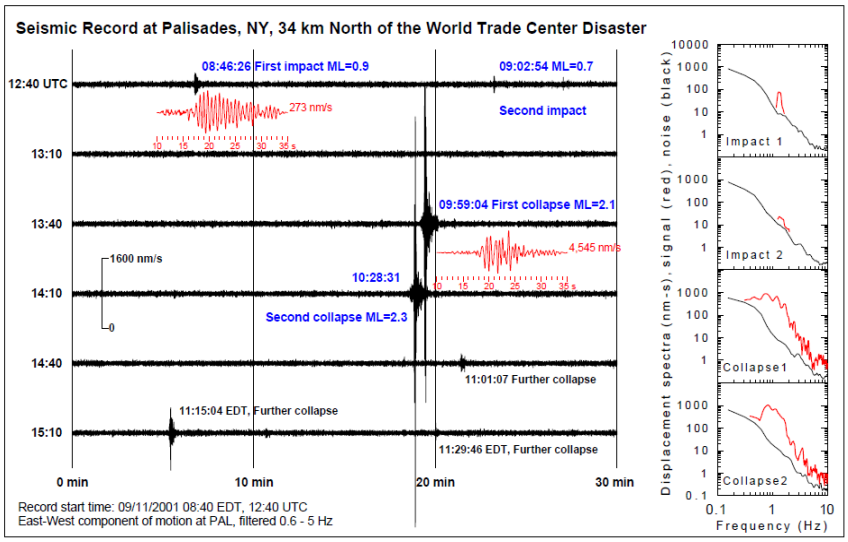

Figure 2. Seismic Record of Al Kaide Attacks on The World Trade Center in New York (from Kim et al, 2001)

THREE MASSIVE UNCONTROLLED EXPLOSIONS

An explosion occurred at the military ammunition depot in Afyonkarahisar on 05.09.2012 resulting loss of life of 25 soldiers. On the same day according to the web site of the Earthquake Department of Disaster and Emergency Management Presidency (AFAD), an earthquake of local magnitude of M_L=2.1 at local time 21:07:55.53 occurred. In Turkey weak motions of earthquakes are monitored by the networks of two different organisations: namely Kandilli Obsevatory and Earhquake Engineering Institute (KOERI) and Earthquake Department of AFAD. KOERI did not report an earthquake on the above mentioned date and time. On the other hand AFAD reported on its website an "earthquake" corresponding to the date and time of explosion with the usual calculations for location (coordinates) and size (magnitude).

Location and magnitude solution is made using data from 4 seismograph stations: Afyon-Bolvadin (BLV-36.69 km.), Afyon Kızılören (KZIL-63.70 km.), Isparta-Egirdir (BAGO-89.12 km.), Usak-Karahanlı (KHAL-97.42 km.). Average P wave velocity for these stations are 5.4 km/sec. Earthquake solutions using these records at BLV, BAGO and KHAL stations give local magnitudes of M_L:2.6, M_L:2.1 and M_L:2.0 in the same turn. Earthquake is assigned a magnitude of M_L= 2.2 taking the average of the three M_L values. In a later calculation magnitute for BLV station is not considered and the average of the magnitude from BAGO ve KHAL stations is considered the local magnitude of the earthquake is revised as M_L: 2.1. Epicenter coordinates of the earthquake as determined by AFAD and the coordinate of the explosion is plotted on satellite map in Figure 3. It appears that there is difference of 5.2 kilometers distance between the eartquake epicentre and the location of the explosion (Figure 3).

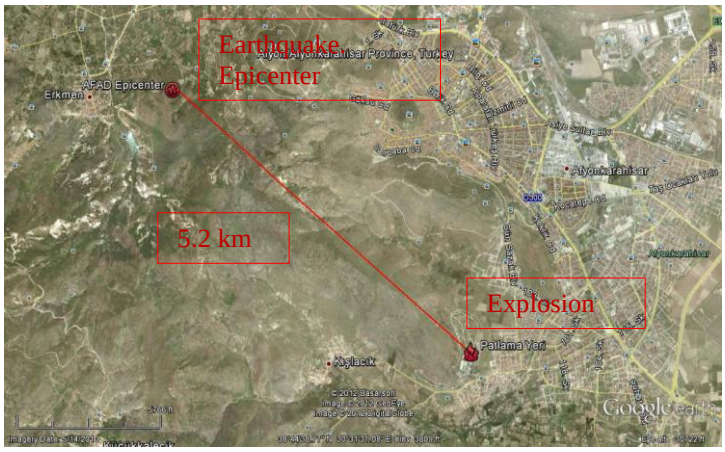

Figure 3. Location of the Explosion in Afyonkarahisar and Epicenter of the Earthquake

An earthquake of local magnitude of M_L:2.1 however close to an explosion site can not be felt by people and can not cause any effect on buildings. An earthquake of such a size would be very difficult to be felt by human beings. It can not cause a spark, loss of balance in people or damages in a structural-non structural parts. Considering the Figure 3 the given earthquake epicentre and the explosion location and the time of occurence of the earthquake and the explosion; the seismograph record is not related to an earthquake, rather it is the vibration of the ground caused by the explosion. This is not a tectonic earthquake, it is an "artificial earthquake" caused by the explosion. The time of the "earthquake" is actually the time at which the explosion occured, which is at 21:07:55.53 with local time.

Second massive explosions took place as a result of the Israel air strike on May 5th 2013 to the Jamraya Military Scientific Research Center located north of Syrian Capital City of Damascus, just outside the City at the skirts of the Mountain Kasyun, and the nearby military ammunition storage facilities. News agencies report that the target of the air strike was the rockets beeing sent to Hezbollah in Lebanon from Iran. According to the news agencies first explosion took place before 02.00 hours at local time, the first explosion was very large, followed by many smaller explosions and the large explosion were felt in the whole Damascus City and shook all the buildings like an earthquake (NBC News, Reuters). According to the Jewish Press the first explosion occurred at 01:50 with local time. European and Mediterranean Seismology Center (EMSC) reported an earthquake at 04.05.2013 and 22:48:46.1 (UTC); which is at 05.05.2013 and 01:48:46.1 with local time with coda magnitude of M_C:3.5. Data for the earthquake in Damascus City were provided by Lebanese National Geophysical Research Center. The coordinates of the event are given as 33.59 N, 36.15 E, focal depth as 19.1 km. Epicenter coordinates reported for the event when plotted on the satellite map and it is found that the distance between the Jamraya Military Scientific Research Center and the earthquake is approximately 8.5 kilometers (Figure 4). The time of occurrence and the location of the earthquake and the explosion indicate that the event given as an "earthquake" is actually the recorded vibrations resulting from the explosion caused by the air strike.

Third massive explosion occurred at the Gunpowder Depot of the Mechanical and Chemical Industry Corporation (MKEK) in Hasandede town close to the Kırıkkale City Center on the date 20.08.2013 with no casualties. Earthquake Department of AFAD reported on the same day on its website an earthquake with a local magnitued of M_L= 2.3 with epicenter at the Kırıkkale City dated 20.08.2103 and at 21:03:03.41 with local time. Location and magnitude solution is made using data from five seismograph stations and following stations are used: Kırıkkale-Delice (DELI-41.00 km.), Kırşehir Çiçekdağı (CDAG-71.86 km.), Kırşehir Center (KIRS-76.63 km.), Aksaray Center (AKSY-124.96 km.) and Bolu Yeniçağa (BCAM-172.11 km.). Based on the arrival times at the stations average P wave velocity is 5.7 km/sec. Local magnitudes as calculated from records for these five stations are as given in the same order as M_L:2.2, M_L:2.4, M_L:2.2, M_L:2.4 ve M_L:2.4. Earthquake magnitude is given as the average of these five stations as M_L: 2.3 (www.deprem.gov.tr). Epicenter coordinates of the event as given by AFAD when plotted on a satellite map indicate a distance of 7.5

kilometers from the site where the explosion took place (Figure 5). Considering the time and the location of the event given as an “earthquake“ and the time and the location of the explosion, the so-called “earthquake” is actually the explosion as itself. Explosion occurred exactly at 21:03:04.41 with local time.

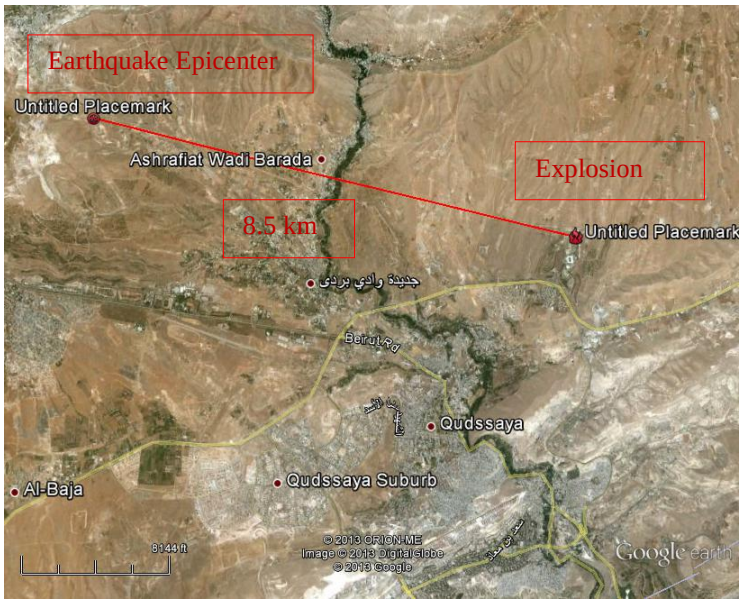

Figure 4. Syria-Damascus Jamraya Military Research Center and Epicenter of the Earthquake

Table 2. Parameters for Artificial Earthquakes

Date	Origin Time	Latitude	Longitude	Epicenter	Depth	Magnitude
05.09.2012	21:07:55.53(LT)	38.7585	30.4962	Afyon-Center	7.00 (km)	2.1 (M_L)*
04.05.2013	22:48:46.1(UTC)	33.59	36.15	Lebanon-Syria Region	19.00 (km)	3.5 (M_c)**
20.08.2013	21:03:03.41(LT)	39.7617	33.5515	Kırıkkale Center	7.04 (km)	2.3 (M_L)*

* AFAD website, ** EMSC website

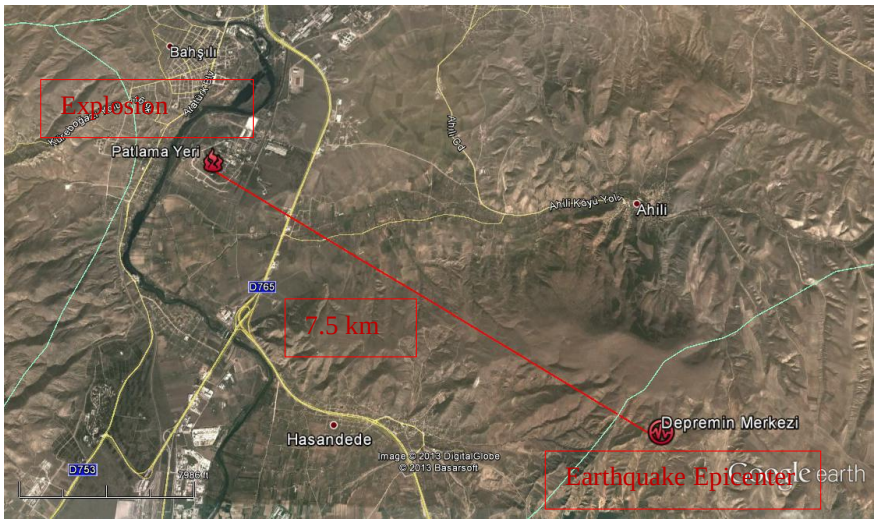

Figure 5. Location of the Explosion in Kırıkkale MKEK Gunpowder Depot and Epicenter of the Earthquake

THE MAGNITUDE AND CHARGE WEIGHT RELATIONSHIPS

The relation between the magnitudes measured or calculated following an explosion and the amount of explosive varies greatly depending on the medium of the explosion whether it is under water, on the ground or in the air. Explosion under the sea with lesser amount of explosives result in larger seismic wave amplitudes as compared to the explosions on land. In other words explosions under sea create larger shaking (Rogers and Koper 2013, Gitterman et al., 2007, Lahr, 1999). Explosion on land is influenced by depth. Explosion on the surface or at a depth indicate different characteristics. Explosion on the surface or at a depth changes the relation between the dissipated seismic energy and the amount of the explosive (Gitterman and Hofstetter, 2012). It is assumed that all the three explosions studied in this paper took place on the ground. Many relatioships between charge weight and magnitude has been developed in US, Russia and Israel. In surface explosions a large part of the energy acts on the surrounding objects and radiate as an airblast in the atmosphere, seismic energy transferred to the ground is reduced. Explosion may create deformations in the surrounding buildings and a crater in the ground (Gitterman and Hofstetter, 2012).

The relation between seismic body wave magnitude and the amount of explosive (Y:kilotons) based on nuclear explosion records in the former Soviet Union is as follows (Khalturin et al., 1998);

$$m_b = 4.45 + 0.75\log(Y) \quad \textbf{(1)}$$

Base on the nuclear tests in USA Nevada the relation in case the explosion is below ground water level and in rock the relation body wave magnitude-explosive weight (kilotons) is given as (Khalturin et al., 1998):

$$m_b = 3.92 + 0.81\log(Y) \quad \textbf{(2)}$$

Khalturin et al. (1998) in their studies for nuclear tests and chemical explosions give the following relation for the upper level of magnitude at given charge weight (tons);

$$M(Y)_{\max} = 2.45 + 0.73\log(Y) \quad \textbf{(3)}$$

Use of this equation provides the estimation of minimum amount explosive needed to calculate corresponding to the resulting magnitute of the event. For underwater explosions, controlled military explosions carried out in the Dead Sea are used to develop Eq.(4) (Gitterman et al., 2007). In this equation M_L and W are local magnitude and charge weight (kg) respectively. Salt content of Dead Sea (33.7 %) and its density is greater then other seas. The explosion tests are also made at greater depths. The following relation is valid for explosions in seas with high salt content, high seawater density and deeper explosions

$$M_L = 0.285 + \log(W) \quad \textbf{(4)}$$

For explosions in seas with usual salt content (around 3 %), and at depths near to sea surface the relation between amount of explosive (kg) and local magnitude Eq.(5) is more applicable (Kim and Gitterman, 2013).

$$M_L = 0.436 + 0.753\log(W) \quad \textbf{(5)}$$

The relation developed in Israel based on controlled explosions in land and in mines and at limited depths is as follows:

$$M_d = -1.42 + 0.99\log(W) \quad \textbf{(6)}$$

In this equation M_d and W are duration magnitude and charge weight (kg) respectively. For land explosions revised from limited surface explosions the following equation is suggested by Gitterman et al., 2007.

$$M_d = -0.2937 + 0.7327\log(W) \quad \textbf{(7)}$$

Eq.(8) between coda magnitude (M_c) and charge weight of explosive (W:kg) is developed from 322 explosions on surface and at depths in USA California and Nevada Test Site. Amount of explosive varies between 25 and 1000000 kilograms. Measured magnitudes are between 0.5 and 3.9 (Brocher, 2003).

$$M_C = 0.31 + 0.50\log(W) \quad \textbf{(8)}$$

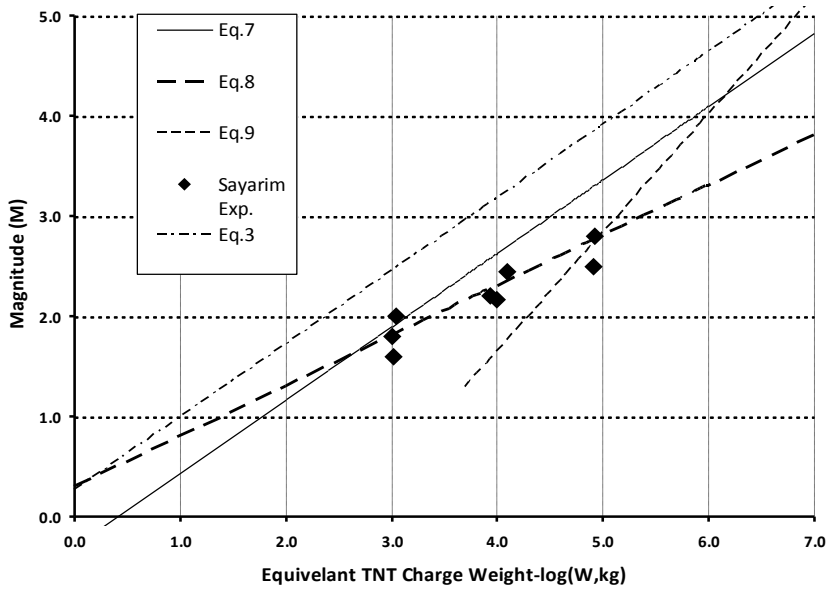

Figure-6. Magnitute-Charge Weight (LogW) Relations

Brocher (2003) developed also the relation between weight of explosive (kg) and coda magnitude using the explosions on the surface and with largest charge weight (between 5385 and 1000000 kg) from among the same 322 explosions (Eq. (9)).

$$M_C = -3.07 + 1.18\log(W) \quad \textbf{(9)}$$

Since the the energy dissipated in surface explosions are transferred to the atmosphere, the location, time and magnitude of the event is determined by infrasound recording instruments besides the seismometers. According to the knowledge of the writer existence and operation of an infrasound station in Turkey is not known. Infrasound stations as a kind of nuclear test monitoring instruments besides the seismograph stations are existing in various locations in the world and the records are collected by The Comprehensive Nuclear-Test-Ban Trearty Organization (CTBTO) in Wien. On the otherhand many countries have their national infrasound recording stations. In 2011 Israel and USA carried out a joint military surface explosion in Sayarim Valley of Negev Desert and 102 ton ANFO (Amonyum Nitrat+Fuel Oil/ 1kg ANFO=0.82 kg TNT) exploded and the explosion is recorded by Mongolia infrasound station approximately 6000 kilometers away. Researchers carried out explosion tests towards development of relations of magnitude and explosive amount using infrasound recordings.

Another method to estimate the amount of explosive is by measurment of the dimensions of the crater as a result of the explosion. Measurement and determination of crater size is possible after the crises medium following an explosion returns to normaly that is the fires are put out and experts have arrived and the medium is suitable for investigation. When the location of the event is undetermined it is not possible to carry out crater investigation. Explosions in the sea, airplane crashing into the sea and the fall meteor are events where craters are not produced. Controlled explosions are carried out by researchers in order to develop amprical relations between explosive amount and crater size. Crater size is affected mostly by depth of the explosion from the ground surface or whether the explosion is on the surface or how high from the surface. Another factor is the geological structure of the ground and whether the ground is dry or wet. Crater diameter is greater in sandy soils compared to cohesive soils while the depth of crater is lesser in sandy soils. In Rusia, Adushkin ve Khristoforov developed the Eq.(10) for the relation between the diameter and depth of crater as a function of amount of explosive after controlled surface explosions in soft soils with very large amount of explosives.

$$D = 2x3.36W^{0.336}; H = 1.78W^{0.316} \quad \textbf{(10)}$$

In this equation D and H are crater diameter (m.) and crater depth (m) respectively. W is TNT equivalent weight of the explosives in tons. In another study by Kinney and Graham using data from 2000 surface explosions Eq.(11) is derived (Gitterman and Hofstetter, 2012; Ambrosini et al, 2004).

$$D = 8W^{1/3} \tag{11}$$

Controlled explosions where explosives are at a certain height above ground surface are carried out to find out crater width and the following relation is derived (Ambrosini et al., 2002). This relationship could be used for the case of terroist bomb attacks using a motor vehicle. Here W is the equivelant weight of TNT in (kg), D crater diameter in meters (m), d height of the explosion above surface level in meters (m).

$$log\frac{D/2}{|d|} = 1.241xlog(\frac{W^{1/3}}{|d|}) - 0.818 \tag{12}$$

Using a web based software and a data bank established by Keith A. Holsapple for collisions and explosions it is possible to calculate TNT equivalent explosive amount depending on the type of explosion and the soil parameters. The data bank is compiled with the information from 1500 explosion and collision events (http://keith.aa.washington.edu./craterdata).

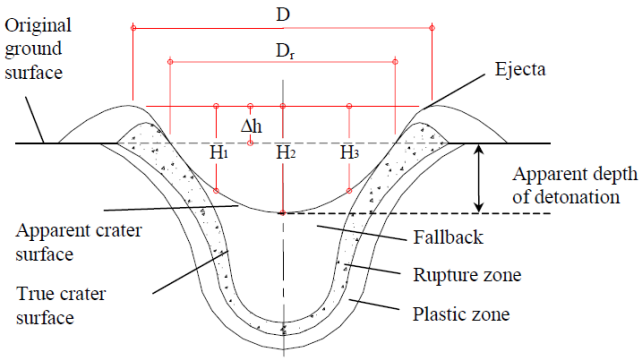

Figure 7. Crater Geometry and Definations (from Ambrosini at al, 2004)

YIELD ESTIMATION FROM SEISMOGRAPH RECORDS OF THE THREE LARGE EXPLOSIONS

As a result of the three massive explosions given in this study with detailed information, "artificial earthquakes" occured, magnitudes were given as if they were tectonic earthquakes by seismological institutions. As presented in Table 1 "artificial earthquakes" occur in many lage explosions. As the seismograph and strong ground motion records of these three explosions were not available to the author of the paper the number of explosions for each event could not be evaluated in this study. As there is no information available to the author about the crater geometry following the explosions, any evaluation based on crater geometry could not be carried out as well. Magnitudes calculated from the seismograph records of these three events considered as earthquakes are for the largest explosion which occurred during the events. As seen from Table 1, there could be more than one explosion in the similar events. News agencies reported a set of many smaller explosions following the largest explosion in Damascus. The author does not have any information about the number of explosions following the initial explosion in the Afyonkarahisar and Kırıkkale events. To determine the number of consequent explosions based on testimony of the witnesses of the event is not very reliable. Observers in a controlled explosion using 102 tons of ANFO and the witnesses from the USA Oklahoma Federal Bulding Explosion said that they had heard two distinct explosions due to secondary shock effect however in both case there had been only one explosion (Gitterman and Hofstetter, 2012; Rogers and Koper). Therefore the best and the true way to determine the number of explosion is through the analysis of seismograph, accelereograph and/or infrasound records.

All the three explosions occurred on land and on the surface. Eq.(7), Eq.(8) and Eq.(9) are more representative of these events (Table 3). In another study by the author TNT equivalent weight of the explosion at the Afyonkarahisar ammunition depot were calculated using equation Eq. (7) (Kuran, 2013). Eq.(8) for the charge weight and the magnitude is in good aggrement with the results from controlled surface explosions carried out at Sayarim Valley in Negev Desert in Israel. In these tests maximum charge size of explosive is 102 tons of ANFO (Amoniyum Nitrate + Fuel Oil) had been used. In other explosions military explosives and/or ANFO had been used. Use of Eq.(8) for controlled explosions with measured magnitudes more than 3.0 gives more amount of explosives than known charge weight. Using of Eq.(9) for controlled explosions with measured magnitudes more than 3.0 gives more closer amounts of explosives to the actually used amount of explosives. For these reason in the evaluation of explosions in Afyonkarahisar and Kırıkkale Eq.(8), for the explosion in Damascus Eq.(9) has been used.

According to the Eq.(8) in the Afyonkarahisar explosion the equivalent TNT weight is 3800 kg for the local magnitude 2.1, calculated from the weak motion record as given by AFAD. In the first report by AFAD using the three stations the magnitude of the event were given as M_L=2.2. In the second analysis using from two station the magnitude is given as M_L=2.1. Local magnitudes from three stations were 2.6, 2,1 and 2.0, respectively and standart deviation is large. The average local magnitude is M_L=2.23. Changes in reported magnitudes effect largely the amount of explosives involved in the event. If the magnitude of the event is taken as the average of the three seismograms and using Eq. (8) the TNT equivalent amount of explosives is calculated as 7000 kilograms. At the time of the explosion there were various types of hand granedes in the ammunition storage facility. The type of hand granedes were DM 41 (offensive), M26 (offensive), Mk44 (deffensive), M14 (thermit incendiary), M7CS (lachrymatory) ve MKE Mod 56 (defensive) and the total number of hand granades were 117900 according to Brown (2013). Mk II type hand granede contain 0.125 lb (0.057 kg) TNT (http://munitionsresponsepartners.com). If all the ammunition in the depot were of MK II type hand granades, 7000 kg equivalent TNT corresponds to 125000 handgranades. M26 type handgranades contain 0.164 kg explosive. Assuming that on the average the types of handgranades present in the facility contains 0.100 kg, 7000 kg of TNT corresponds to 70000 handgranades. The amount of explosive calculated from the magnitude of the event and the number of handgrandes present in the facility at the time of the explosion is in good agreement. Using the records of the of the ammunition depot and their types a more accurate calculation could be made.

Table 3. Equivalent TNT Yield For the Three Massive Explosions

EVENT	Magnitude	EQ.7 (kg)	EQ.8 (kg)	EQ.9 (kg)
Afyonkarahisar Military Ammunition Depot Explosion	2.1 (M_L) 2.23* (M_L)	1 849 2 782	**3 802** **6 918**	24 063 31 012
Damascus Syria, Cemraya Military Research Center and Ammunition Depot Explosion	3.5 (M_C)	150 556	2 398 833	**369 655**
Kırıkkale MKE Gunpowder Factory Gunpowder Depot Explosion	2.3 (M_L)	3 467	**9 550**	35 551

*Average of the calculated magnitudes from the three seismograph stations of AFAD

The amount of ammunition destroyed bay Israel air raid to Damascus military installation is found as 370000 kg (370 tons) using Eq.(9). Considering the other explosions following the first explosion, the total amount of ammunition destroyed by the air raid would be much greater.

On the other hand in the MKEK event in Kırıkkale the TNT equivalent of the exploded gunpowder is calculated as 9500 kg using Eq.(8). 1 kg of TNT is equivalent to 0.60 kg of gunpowder (Reza et al.,2013, www.nctc.gov). Thus the exploded gunpowder is calculated 16000 kilograms.

The explosions in Afyonkarahisar and Kırıkkale are very close to inhabited areas in fact they are right in the outskirts of the cities. In order to prevent possible loss of life and property from large explosions these kinds of explosives and ammunition storage depot should at a safe distance from inhabited areas and main arteries. To prevent damage to human beings from the shock wave of the explosion and to prevent glass window breakage the required minimum distance is given by Eq.(13) (United Nations, Safer Guide, 2013).

$$R_0 = 130W^{1/3} \quad \textbf{(13)}$$

In this equation, R_0 and W are safe distance (meter) and charge weight of explosive (kg) respectively. Eq (13) gives "safety" distance for Afyonkarahisar event as 2.5 km (20 km2) for an explosive amount of 7000 kg (TNT equivalent) and 2.0 km(12.6 km2) for an explosive amount of 3800 kg (TNT equivalent). The similar safety distance for the case of Kırıkkale Event is 2.8 km (24.6 km^2 area) and for the case of Damascus event as 9.3 km. (272 km^2'area) Explosive yield calculation based on crater sizes could not be made as there were no information on crater geometry. Infrasound records could also be used to evalute the explosion if they had been available. Considering the size of the three explosives and the experiemetal studies of infrasound records it would be highly probable that the explosions were recorded even by very distant infrasound stations. A search for the infrasound records of these events should be made. These events could also be recorded by nearby ground acceleration recorders.

Figure 8. Afyonkarahisar Military Ammunition Depots and Settled Area

CONCLUSION

In this study, the origin time, the geographical locations and charge weight of explosives were investigated by using seismogram records for the 3 large-scale explosions occurred in the last two year period. All the three explosions created "artificial earthquakes". However seismological institutions reported the events as tectonical (fault related events) earthquakes. In the Afyonkarahisar explosion, there is a distance of 5.2 kilometers between epicenter of the so-called "earthquake" and the location of the explosion. Time and the epicenter of the two events indicate that they were infact the same events. The Explosion on the date 05.09.2012 created an artificial earthquake of local magnitude of 2.1 at local time of 21:07:55.53, while the time of the explosion is given as 21:15 by the authorities. Depending on the variation of the magnitude of the seismic event as reported above it is calculated that the TNT equivalent of 3800 to 7000 kg explosive involved in the explosion.

The explosion event in Damascus was the result of the air raid by Israel on the date 05.05.2013 at the local hour of 01:48:46.1. The explosion caused by air strike created an artificial seismic event with a coda magnitude of 3.5. There is a 8.5 kilometers distance between the reported epicenter of the seismic event and the location of the military facility where the air raid was targeted. In the largest explosion following the air strike ammunition with TNT equivalent of 370 tons were destroyed.

The Kırıkkale MKEK gunpowder explosion event occurred on the date of 20.08.2013 at the local time of 21:03:03.41 causing an artificial seismic event of local magnitude 2.3. It is reported that by the authorities the explosion took place at 21:00 hours at night. There is a distance of 7.5 km between the epicenter of the seismic event reported by AFAD and the actual location of the gunpowder explosion. It is calculated that an explosive with an amount of equivalent to 9500 kg TNT (16000 kg gunpowder) exploded.

Based on the amount of explosives involved in the explosions in terms of equivalent TNT amounts, the size of the Kırıkkale explosion is 1.35 times greater than the Afyonkarahisar explosion.

On the other hand the Damascus explosion due to Israel air strike is 53 times larger than the Afyonkarahisar explosion and 39 times larger than Kırıkkale explosion.

Production and storage facilities for explosives should be at safer distances from inhabited areas to prevent loss of life and property in case of accidental explosions. Depending on the equivalent TNT amounts involved in the explosions the diameters of the effected areas calculated as 2.0-2.5 kilometers for Afyonkarahisar, 2.8 kilometers for Kırıkkale and 9.3 kilometers for Damascus events.

The equations used to estimate the size of the explosive materials involved in the explosions are usefull for a prelimanary estmation of the size of the events. Equations for the relation between magnitude and the size of the explosive materials would surely contain some margin of error. Besides small variations in the reported magnitutes of the events may create large variations in the amount of explosives involved in the event. Different seismological centers may report different magnitudes for the same seismic events. The events reported as earthquakes by AFAD and EMSC were in fact artificial seismic events caused by explosions. The exact geographical location (coordinates) of the three events is known. The depths of these "artificial seismic events" are 0.00 kilometers since they are surface explosions. For this reason the epicenter and magnitude solutions for these events should be made again cosidering as "explosions." Following the explosion during emergency period, data on the exact location, time of occurrence, the number of repeats and the size of the event, would be useful for emergency management operations and forensic investigations.

REFERENCES

The author would like to thank Mr. Nejat Bayülke for their contribution.

REFERENCES

Ambrosini RD, Luccioni BM, Danesi RF, Riera JD, Rocha MM (2002), "Size of Craters Produced by Explosive Charges," *Shock Waves*, Vol.12, pp . 69-78

Ambrosini D, Luccioni B, Danesi R (2004) "Influence of the Soil Properties on Craters Produced by Explosions on The Soil Surface," *Mecanica Compitacional*, Vol.XXIII, Bariloche, Argentina, November 571-590,

Bonner J, Waxler R, Gitterman Y, Hofstetter R (2013), "Seismo-Acoustic Energy Partitioning at Near Source and Local Distances from the 2011 Sayarim Explosions in The Negev Desert Israel", *Bulletin of The Seismological Society of America*, Vol.103, No:2A, pp.741-758

Brocher TM (2003), "Detonation Charge Size Versus Coda Magnitude Relations in California and Nevada," *Bulletin of The Seismological Society of America*, Vol.3, No:5, pp. 2089-2015

Brown S (2013), Reducing the Likelihood of Unplanned Explosions at Munition Sites (UEMS)", Meeting of Experts on CCW Protocol V, NATO Support Agency (NSPA), 10-12 April, Geneva, Switzerland

Cerenna L, Le Pichon A, Green DN, Mialle P (2009), "The Buncefield Explosion: a Benchmark for Infrasound Analysis across Central Europe", *Geophys. J. Int*. No:177, pp. 491-508, 2009

Gitterman Y and Hofstetter R (2012) "GT0 Explosion Sources for IMS Infrasound Calibrations: Charge Design and Yield Estimation from Near-Source Observation," *Pure and Applied Geophysics*, Published online, 06 September

Gitterman Y, Given J, Coyne J, Zerbo L, Hofstetter R (2011), "Large-Scale Explosion Source at Sayarim-Israel for Infrasound Calibration of The International Monitoring System" S&T2011, Vienna, Austria, 8-10 June

Gitterman Y, Pinsky V, Hofstetter A (2007), Seismic Energy Generation and Partitioning into Various front Different Seismic Sources in the Middle East Region", *Israel Air Force Researh Laboratory*, Final Report, September

Gitterman Y, Pinsky V, Hofstetter A (2005), Using Ground Truth Explosion for Studying Seismic Energy Generation and Partitioning into Various Regional Phases," *27th Seismic Research Review: Ground-Based Nuclear Explosion Monitoring Technologies*, Ranco Mirage, California-USA, 20-22 September

Gitterman Y (2002), "Implications of the Dead Sea Experiment Results for Analysis of Seismic Recordings of The Submarine Kursk Explosions", *Seismological Research Letters*, Vol.73, No:1, pp. 14-24

United Nations, Safer Guide (2013), International Ammunition Technical Guideline, IATG.01.80

Khalturin IV, Rautian TG, Richards PG (1998), "The Seismic Signal Stregth of Chemical Explosion" *Bullettin of The Seismological Society of America*, Vol.88, No:6, pp. 1511-1524, December

Kim SG and Gitterman Y (2013), "Underwater Explosion (UWE) Analysis of the ROKS Cheonan Incident", *Pure Applied Geopysics*, Vol.170, pp:547-560

Kim WY, Syskes LR, Armigate JH, Xie JK, Jacob KH, Richards P, West M, Waldhauser F, Armbruster J, Seeber L, Du WX, Lam AL (2001) "Seismic Waves Generated by Aircraft Impacts and Buildings Collapses at World Trade Center New York City," *American Geophysical Union*, Vol.82,No:47,pp. 565-571,November

Koper KD, Wallace TC, Aster RC (2003), "Seismic Recordings of the Carlsbad, New Mexico Pipeline Explosion of 19 August 2000" *Bullettin of the Seismological Society of America* Vol.93, No:4,pp.1427-1432

Koper KD and Wallace TC (2001), "Forensic Seismology and the Sinking of the Kursk," *American Geophysical Union*, Vol.82, No:4, pp.45-46

Koper KD, Wallace TC, Hollnack D (1999), "Seismic Analysis of the 7 August 1998 Truck Bomb Blast at the American Embassy in Nairobi-Kenya" *Sesimological Research Letters*, Vol.70, No:5,pp.512-521

Kristekova M, Moczo P, Labak P, Cipciar A, Fojtikova L, Madaras J, Kristek J (2008), "Time-Frequency Analysis of Explosions in the Ammunition Factory in Novaky Slovakia", *Bulletin of The Seismological Society of America*, Vol.98, No:5, pp.2507-2516

Kuran F (2013),"5 September 2012 Afyonkarahisar Military Ammunition Depot Explosion and Forensic Seismology," *Yapı Dünyası Dergisi*, Vol:199-200-201, pp. 8-14 (in Turkish)

Lahr J (1999), "Table top Earthquakes," *Open-file Report*, U.S. Geological Survey

Mishra KB, Wehrstedt KD, Krebs H (2012), "Lessons Learned from Recent Fuel Storage Fires", *11th International Conference on Combustion and Energy Utilization*, May 09-13, Coimbra, Portugal

Mihelic B (2013) "Unplanned Explosions at Munitions Sites (UEMS)," The 6th Workshop of the South East Europe Regional Approach to Stockpile Reduction (RASR) of Conventional Weapons and Munition Initiative", 3-5 March, Bled, Slovenia

Ottemöller L and Evers G (2008), "Seismo-Acoustic Analysis of the Buncefield Oil Depot Explosion in The UK, 2005 December 11," *Geophysics Journal*, 172, pp. 1123-1134

Reynolds JM (2011), "An Introduction to Applied and Environmental Geophsics", Second Edition, Wiley-Blackwell Press

Reza A, Ibrahim Z, Vaitekunas T (2013),"Investigation and Anaylsis of an Explosion at the GOEX Black Powder Manufacturing Facility," *Chemical Engineering Transactions*, Vol:31

Rogers JD and Koper KD, "Military Geology and Combat Engineering Lecture Notes" Department of Geological Sciences and Engineering, Missouri Universty of Science and Technology, USA

www.emsc-csem.org (EMSC)

www.deprem.gov.tr (AFAD)

http://keith.aa.washington.edu/craterdata

www.koeri.boun.edu.tr (KOERI)

http://munitionsresponsepartners.com

www.nctc.gov, (National Counterterrorism Center-USA)