Firat Univ Jour. of Exp. and Comp. Eng., 1(2), 80-93, 2022

Fırat Üniversitesi Deneysel ve Hesaplamalı Mühendislik Dergisi

Firat University Journal of Experimental and Computational Engineering

A novel design for concrete culverts absorbing explosive energy from homemade explosives

Ev yapımı patlayıcılardan oluşan patlayıcı enerjisini sönümleyen beton büzler için yeni bir tasarım

Sedat SAVAŞ[1], Dursun BAKIR[2*], Muharrem BAŞPINAR[3], Mehmet ÜLKER[4]

[1,2,3]Department of Civil Engineering, Faculty of Engineering, Firat University, Elazig, Turkey.
[4]Department of Civil Engineering, Faculty of Engineering, Turgut Ozal University, Malatya, Turkey.
[1]ssavas@firat.edu.tr, [2]dbakir@firat.edu.tr, [3]muharrem_baspinar@hotmail.com, [4]mulker44@gmail.com

Received: 28.03.2022
Accepted: 12.05.2022
Revision: 07.05.2022
doi: 10.5505/fujece.2022.66376
Research Article

Abstract
With the increasing number of terrorist attacks for the last 40 years, terrorist organizations have devised various attack tactics. One of these tactics is to attack by placing homemade explosives inside culverts that are originally constructed for draining water within road infrastructure. The aim of this study is to enable the absorption of the explosive blast in concrete culverts in face of homemade explosives. For this purpose, concrete culverts that were within three road embankments and road infrastructures were built by projects that were devised according to the American Association of State Highway and Transportation Officials Standards. The experiment was carried out in three stages. tjIn the first one of these culverts, a standard road was built. In the second and third culverts, a system that enabled the installation of secondary culverts above and below primary culverts was devised.In conclusion, it was revealed that the methods developed in the study could enable ithe absorption of the explosive energy of homemade explosives by 60%-80%.

Keywords: Explosion load, Absorption of explosive energy, Concrete culvert, Homemade explosive, Road design against terrorist attacks.

Özet
Son 40 yılda terör saldırılarının artmasıyla birlikte terör örgütleri çeşitli saldırı taktikleri geliştirmiştir. Bu taktiklerden biri, yol altyapısındaki suyu tahliye etmek için yapılmış olan büzlerin içine ev yapımı patlayıcılar yerleştirerek saldırı yapmaktır. Bu çalışmanın amacı, ev yapımı patlayıcılar karşısında beton büzlerdeki patlama enerjisinin sönümlenmesini sağlamaktır. Bu amaçla, Amerikan Devlet Karayolları ve Ulaştırma Yetkilileri Birliği Standartlarına göre tasarlanan projelerle üç yol dolgusu ve yol altyapısı içerisinde yer alan beton büzler hazırlanmıştır. Bu büzlerden ilkinde standart bir yol yapılmıştır. İkinci ve üçüncü büzlerde ise birincil büzlerin üstüne ve altına ikincil büzlerin kurulmasını sağlayan bir sistem geliştirilmiştir. Sonuç olarak, çalışmada geliştirilen yöntemlerin ev yapımı patlayıcıların patlama enerjisinin %60-80 oranında emilmesini sağlayabildiği ortaya koyulmuştur.

Anahtar kelimeler: Patlama yükü, Patlayıcı enerjisinin emilimi, Beton büz, El yapımı patlayıcı, Terrorist saldırılara karşı yol dizaynı.

1. Introduction

The aims of terrorist organizations are always political. These aims can cover changing economic systems and social policies, or spreading a socioeconomic or religious ideology. Common physical damage and destruction to physical properties are primary goals [1] . As events related to terrorist attacks are increased and various types of attacks for smarter operations are developed, transportation systems have been chosen as ideal targets for terrorist organizations [2]. Over transportation systems and related infrastructures, terrorist threats for various destinations, including shopping malls, hotels, and restaurants, have been especially increased for the last 25 years [3].

In Turkey, it has been observed that terrorist organizations have been choosing homemade explosives (HMEs) since 2015. In 2016, when the explosions were at the highest frequency, landmines were used 11 times while HMEs were used 93

*Corresponding author

times. Because HMEs are prepared conveniently, they have become the most commonly adopted method of asymmetrical war today.In most cases, those explosives are manufactured in hidden laboratories. The raw materials of these types of explosives are conveniently obtained, which include urea nitrate, triacetone triperoxide (TATP), and hexamethylene triperoxide diamine (HMTD) [4]. Figure 1 demonstrates HMEs that were planted by terrorist organizations and discovered by law enforcement agencies.

Figure 1. Images of HMEs planted and hidden in culverts [5–7]

Figure 2. Images of damages resulting from explosions [8,9]

In the literature, a study conducted by M. Kristoffersen et al. investigated the explosions of C4 explosives inside a concrete pipe culvert with a 2 m diameter [10]. Furthermore, P. Bonalumi et al. examined the pressure that was created by explosions within culverts by using 10 g and 12 g of explosives [11]. Olarewaju et.al. In their study, 50kg TNT explosive on concrete pipes was modeled numerically, taking into account the ground environment, and its static and dynamic effects were investigated [12]. Olarewaju et.al. In another study they have done, various explosions have been applied numerically in the analysis, design and simulation of underground structures, in a way to withstand the bursting effect of concrete pipes. Explosion inside the concrete pipe, blasting at the standoff distance and open trench explosions were investigated. Considering the concrete and soil parameters with different Young modules, pipe designs were also studied. The effects of thickness variation were also investigated [13]. Mohsen Parviz et.al. Parametric studies were carried out on concrete pipes placed on two different soil types under blast loading. The effects of different parameters such as water, air, soil, pipe and TNT explosive properties were investigated. Arbitrary Lagrange-Eulerian (ALE) method is used in LS-DYNA software. The results of the study revealed that a higher soil density causes a higher pressure and stress transfer on a pipe. Explosion under a lower soil density results in less damage to the pipe [14]. Qichen Tang et.al. A field experimental study of the dynamic response properties of buried pipelines under surface burst load was carried out to investigate the effect of blast load on pipelines located underground. The ground surface peak particle velocity (PPV) above the pipeline was analyzed under blast load with various explosive charges and different detonation distances. In addition, the PPV and peak particle stress (PPS) distribution properties of pipelines under surface bursting were investigated. After the blasts were made, it was revealed that there is a linear relationship between the PPV of the ground surface above the pipeline and the PPV of the buried pipeline. According to the soil functions of the blastings applied in the experiment site, in order to protect the pipeline in surface blasts, it was buried at a depth of 2 m, just above the pipeline. It is emphasized that the PPV of the ground surface should be less than 71.36 cm [15].

In this study, as can be seen in Figures 1 and 2, it was aimed to reduce the potential damages that result from the explosion of HMEs placed inside culverts, which are convenient in terms of costs and camouflages. For this purpose, three techniques were developed. In the first two construction techniques, it is aimed to discharge the explosive energy by building a secondary culvert that is in contact with the primary culvert in a way that is hidden under the road infrastructure. In the third construction technique, it is aimed to install geotextile membranes between each 20-cm ground backfill layers above the culverts during the construction of the road infrastructure. The goal of this technique is to dissipate the explosive load through a wider area on the road surface by preventing the explosion, which was demonstrated in Figure 2, to burst from a certain area of the surface. The ultimate aim of this technique is to dissipate the explosive load throughout a larger area and reduce its impact by the same ratio.

In each test, 50 kg of ammonium nitrate and fuel oil (ANFO) and 3 kg of trinitrotoluene (TNT) with electric detonators, which were manufactured by adopting the manufacturing techniques of terrorist organizations, were placed within culverts and after the necessary compactions were conducted, the explosives were detonated. Each explosion was recorded by three stationary cameras and one camera drone.

The footage obtained from the cameras in the tests was scaled by the image processing technique and the distances that materials traveled due to dislocation from the road by the explosion were measured. The velocity of detonation (VoD) device was used in the measurements of the explosions. The explosions were conducted under the supervision and observation of law enforcement agencies. Additionally, the explosions were conducted by two demolition experts, who were certified in the matter of explosions by legal authorities.

2. Methodology

The locations that are convenient for planting and camouflaging explosives on roads and chosen by terrorist organizations are concrete culverts, which are used in road infrastructures and were demonstrated in Figure 3. Reinforced concrete culverts are commonly used in infrastructures of railways and highways to enable the transfer of water, vehicles of pedestrians. Common types of culverts include slab culverts, arch culverts, pipe culverts, and box culverts [16]. In terms of the interaction between the culvert structure and the soil materials that cover the culvert, the difference in stiffness of the material of the culvert and the surrounding soil is of great importance. This is because a concrete culvert mainly carries the external load on it by its strength [17].

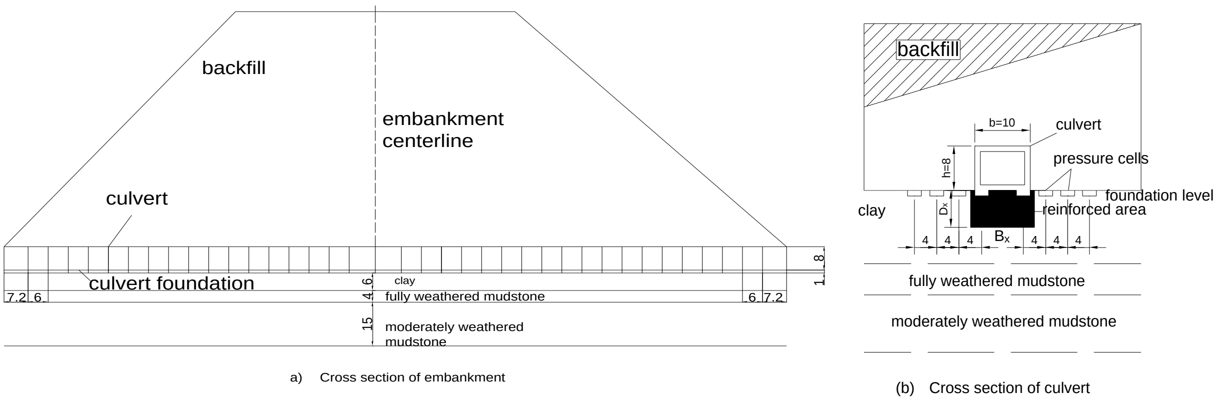


Figure 3. Field layout of the culvert, cross-sections of embankment and culvert

In this study, the pipe concrete type of culverts was used. These types of culverts are manufactured by fabrication and provide convenient transfer and installation as infrastructure components (Figure 4).

Figure 4. Concrete pipe culverts

2.1. Homemade Explosives

In recent years, urea nitrate has been frequently used in manufacturing HME by terrorist organizations due to its convenience and easy accessibility. In most cases, these explosives are manufactured in hidden laboratories. The main component of these explosives is urea nitrate, triacetone triperoxide (TATP), and hexamethylene triperoxide diamine (HMTD) (Figure 5).

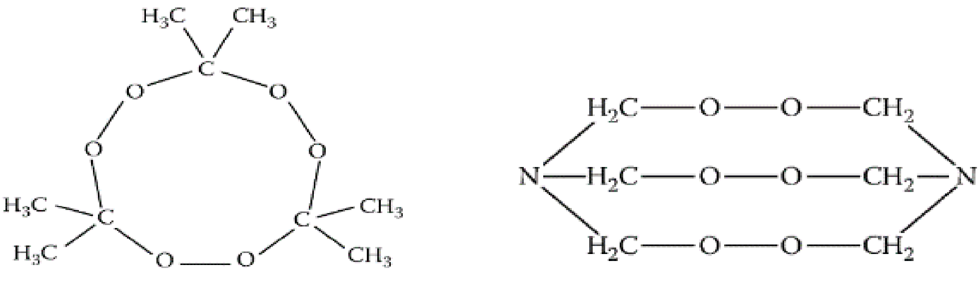


Figure 5. Structural formulae of TATP and HMTD, respectively [18]

Urea nitrate is manufactured by using nitric acid and urea. Urea is a commonly used fertilizer and it is easily accessible. Urea nitrate has never been used as a commercial explosive due to its abrasive qualities. TATP is a product of the combination of hydrogen peroxide and acetone. In recent years, these materials have become popular choices of terrorist organizations worldwide. Mercury fulminate has been a standard main charge in detonators. Although it has not been significantly used commercially, it is regarded as a serious explosive material. The precursors of the explosives in question are commercial products.

2.2. Experimental tests

The study was conducted in a quarry, which was located in the Pütürge District of the City of Malatya in Turkey. The quarry had an altitude of 1200 meters. For the video recordings, 3 stationary cameras and 1 camera drone were used.

Figure 6. Image of the field used for explosions

In the tests, HMEs that were planted inside four culverts under road infrastructures were detonated. For the preparation of these setups, one excavator, two dumper trucks, one loader, one ground compaction vibratory roller were used while one mobile winch and one sprinkler were used for the installation of the culverts (Figure 6). On highways, culverts with various sizes and diameters are used under backfills. Readily manufactured concrete culverts are manufactured in culvert worksites that are organized in suitable places for projects. In the manufacturing process, the culverts are built in steel molds that are manufactured in certain sizes (Figure 7).

Figure 7. The installation process of the culverts

2.3. Planting process of HMEs

The method that was adopted while planting the explosives within culverts was implemented according to the terrorist practices that were reported by the media and law enforcement agencies. In Figure 8, the schematic for planting and compacting the explosives was presented. In terrorist activities, the steps of planting explosives include an initial step of compaction to increase the explosive energy of the culvert that hosts the explosive. Rocks or sandbags are used for these compaction practices. Then, the material, which is referred to as fertilizers in the market, and diesel are mixed and compacted in the 17-kg tin or water cans, or 12-kg gas cylinders to be placed in culverts. In the next step, dynamites and detonation cords are placed in the setup as detonators attached to a cable system that extends to a certain distance outside of the culvert. The amounts of explosives used are given in Table1.Then, the planted explosive is compacted once more with rocks or sandbags and the setup is completed. The explosion is triggered by a remote detonator or extended cables from a faraway place from the culvert during the transit of a vehicle from the road. The process for planting the explosive setup is completed quickly, which prevents third parties from obtaining information about the explosive. This also prevents complete compaction. In this study, we followed the exact steps above one by one while planting the explosive setups.

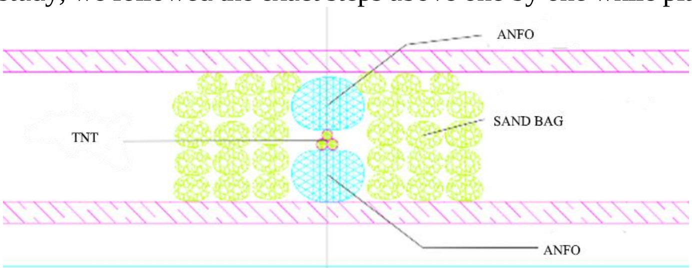


Figure 8. Schematic image of the HME setup

Table 1. Contents of the HMEs in the study

TNT	1.50 kg
ANFO	2 x 25 kg
Electrical Aluminum Capsule	1 set
Electric Cable	250 meters

2.4. The first test setup

In the explosive setup, crushed rock materials within nylon sacks, each weighing 30 kg of rocks with 0-14 mm diameters, were prepared for 21 sacks. 11 sacks were placed before planting the HME while 10 sacks were placed after planting the HME for compaction. In Figure 9, the preparations for planting the explosive setup were presented.

Figure 9. The preparation process for planting the first test setup

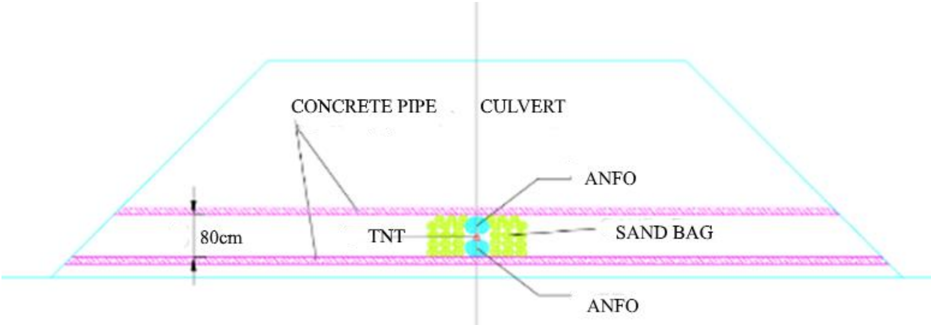


Figure 10. Cross-section image of the first test setup

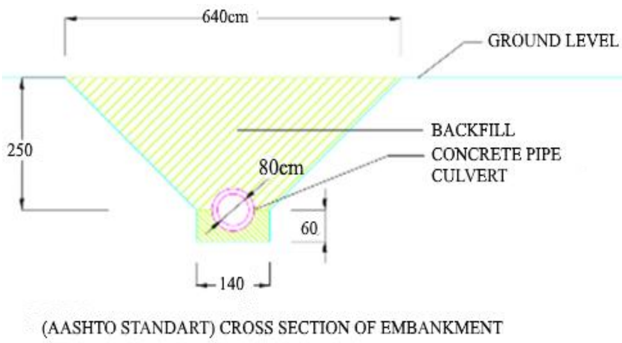
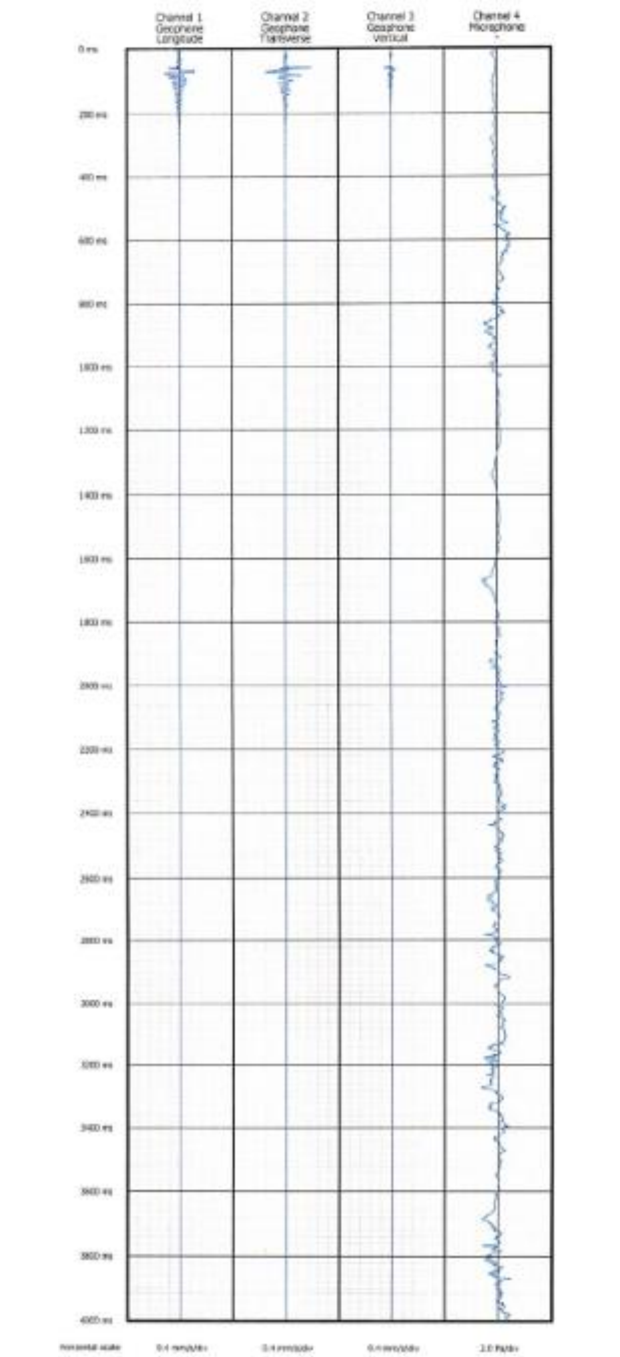


Figure 11. Cross-section image of the standard road

The schematic presentations of the HME setups in Figures 10 and 11 are in the middle of the road's axis. To reduce the impact of the explosive blast, sandbags were placed on the sides of the HME setup. The goal of placing sandbags on the sides of the explosive setup is to ensure compaction and redirect the explosive blast over the road. In other words, the goal is to prevent the explosive blast from discharging through the sides of the culvert. In Figure 12, the images of the explosions and the crater holes that were formed after the explosions were presented. The wave speed and sound measurement data of this explosion were presented in Table 2.

Table 2. Data summary of System 1



Date:	21-07-2019	**Serial number:**	5111
Time:	14:39:28	**Calibration date:**	21-11-12
Note:	System one		
Peak values			
Channel:1	**Channel:2**	**Channel:3**	**Channel:4**
3.14 mm/s	2.26 mm/s	2.89 mm/s	OvR!148.8 dB
Vector Sum:	4.27 mm/s-272.0 ms		

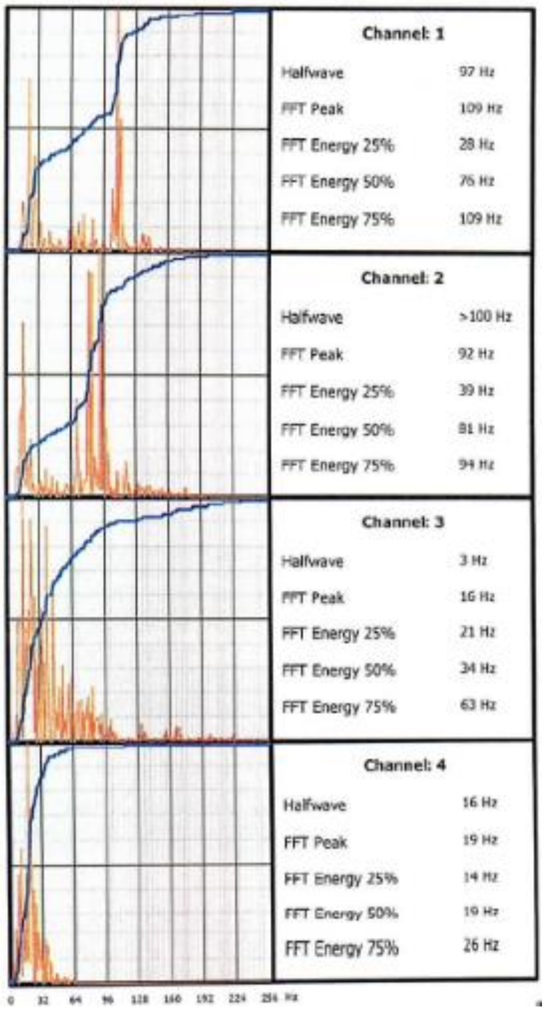
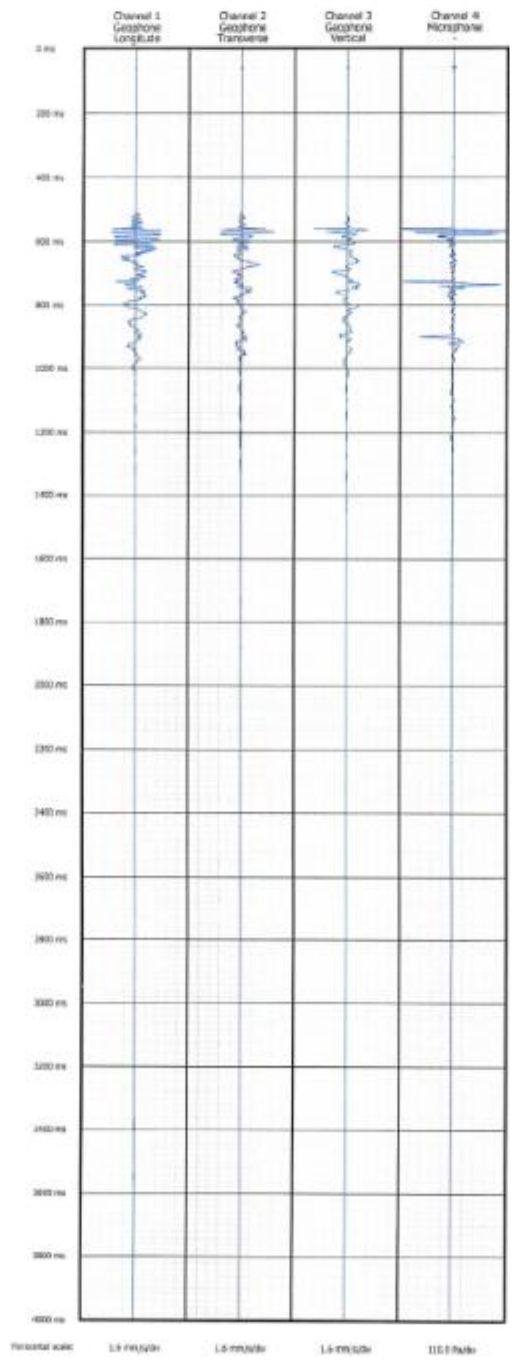


Figure 12. The explosion of the first step and the images of the aftermath

2.7. The third and fourth test setups

The explosive setup was prepared in a way to ensure a single explosion by combining two explosive setups. The third setup was prepared in a way that an 80-cm culvert (5 embedded pieces of culverts, 2 m each) was placed below and a 60-cm culvert (7 embedded pieces of culverts, 1.5 m each) was placed above. The fourth setup was prepared in a way that an 80-cm culvert (5 embedded pieces of culverts, 2 m each) was placed above and a 60-cm culvert (7 embedded pieces of culverts, 1.5 m each) was placed below. The third and fourth explosive setups were detonated by the demolition expert. The wave speed and sound measurement data of this explosion were presented in Table 3 and Table 4.

Table 3. Data summary of System 3



Date:	**21-07-2019**	**Serial number:**	5111
Time:	**16:53:14**	**Calibration date:**	21-11-12
Note:	**System four**		
Peak values			
Channel:1	**Channel:2**	**Channel:3**	**Channel:4**
3.97 mm/s	**5.01 mm/s**	**5.28 mm/s**	OvR!148.8dB
Vector Sum:	**1.09 mm/s-59.6 ms**		

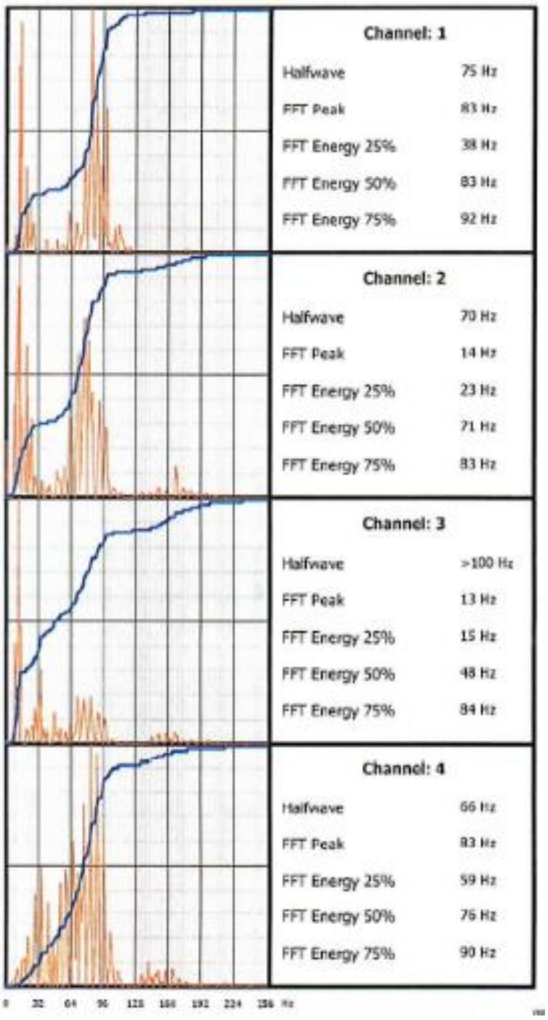
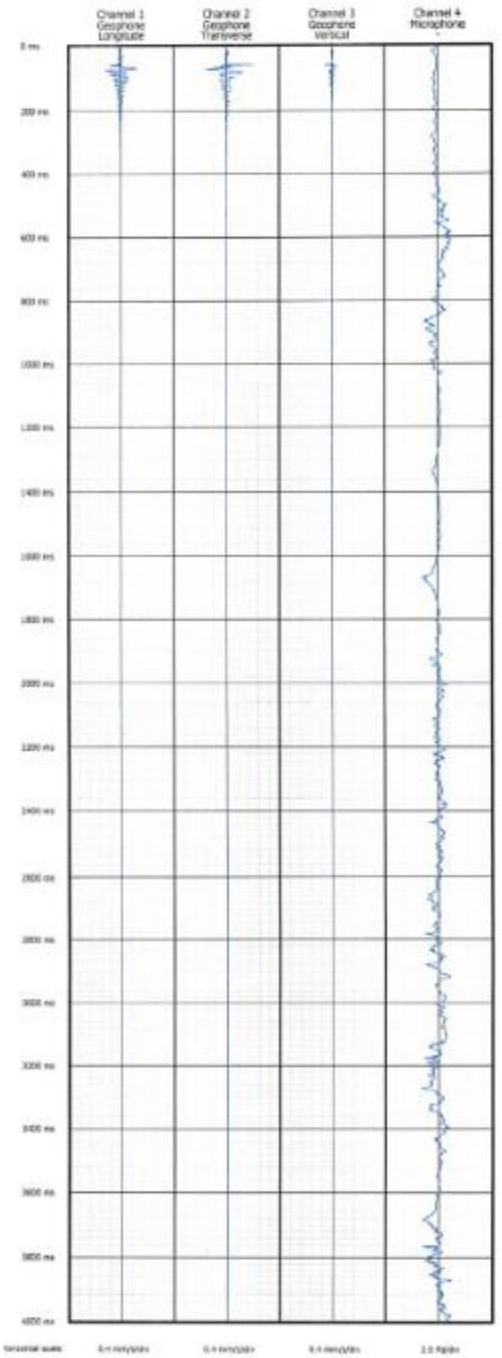


Table 4. Data summary of System 4



Date:	21-07-2019	**Serial number:**	5111
Time:	12:31:57	**Calibration date:**	21-11-12
Note:	System three		
Peak values			
Channel:1	**Channel:2**	**Channel:3**	**Channel:4**
0.62 mm/s	1.01 mm/s	0.27 mm/s	3.3Pa104.4dB
Vector Sum:	1.09 mm/s-59.6 ms		

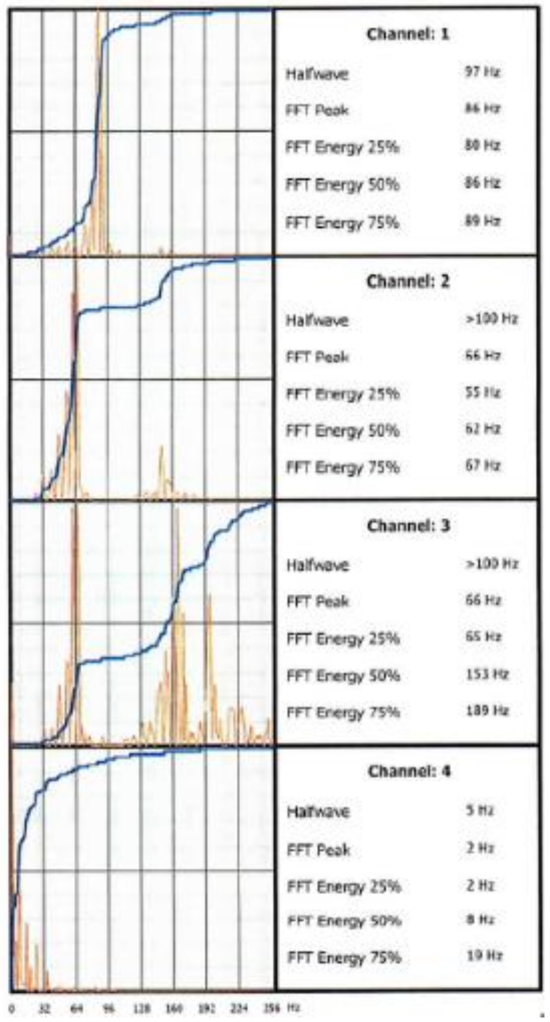
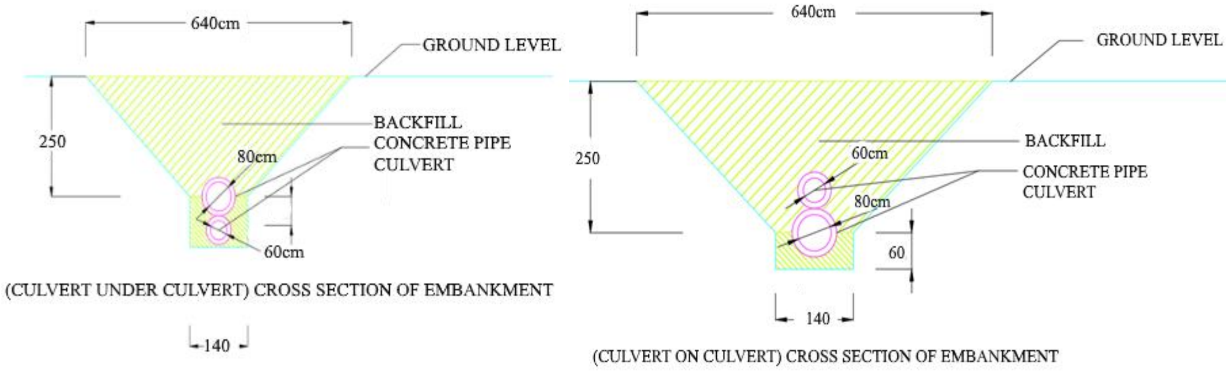


Figure 13. Images of explosions of the third and fourth test setups

Figure 14. Measurements of the crater holes that were formed after the explosions



a) Culvert under culvert

b) Culvert on culvert

Figure 15. Cross-section of the culvert systems below(a)-above(b) the culvert

4. Conclusion

One of the main methods practiced by terrorist organizations in transportation routes that have sabotage risks is planting explosive materials in culverts that are originally constructed for discharging water. These structures are hard to check visually and they are constructed with thin-walled materials such as concrete culverts. Another goal of choosing concrete culverts is that they are small structures, which enable better compaction and less energy loss in addition to being suitable for lower amounts of explosives. Furthermore, the possibility of planting the explosive setup by a single individual makes these culverts a common choice. When the literature studies are examined;

- Experimentally applied blasting for this type of work is almost nonexistent.
- In the existing studies, experiments were carried out on how many meters deep the pipelines should be placed from the ground.
- As a design, it has been applied as changing the thicknesses and dimensions on type projects.

This study is different from the studies on this subject in the literature. It is thought that it will give important ideas for new designs. In this study, a field study of a full-scale explosion, which was conducted exactly according to terrorist practices, was conducted. The concrete culvert that was analyzed had a diameter of 80 cm. For the explosive material used in the study, 50 kg of ANFO, 1.5 kg of dynamite (3 pieces), and electric detonators were used. For the tests, 3 roads that met the standards were constructed. The practices that were conducted in the study were presented below (Table5).

Table 5. Test setup and the eruptions resulting from explosions

Test Setup	Specification	Aim of Analysis	Explosives	Eruptions
1st Setup	2.5 m of backfill	impact of explosives	50 kg	430 cm
2rd Setup	Secondary culvert with 60 cm diameter below primary culvert with 80 cm diameter and 2.5 m of backfill	impact of explosives in the secondary culvert setup below the primary culvert	50 kg	210 cm
3th Setup	Secondary culvert with 60 cm diameter above primary culvert with 80 cm diameter and 2.5 m of backfill	impact of explosives in the secondary culvert setup above the primary culvert	50 kg	165 cm

Figure 16. Eruptions in the first setup

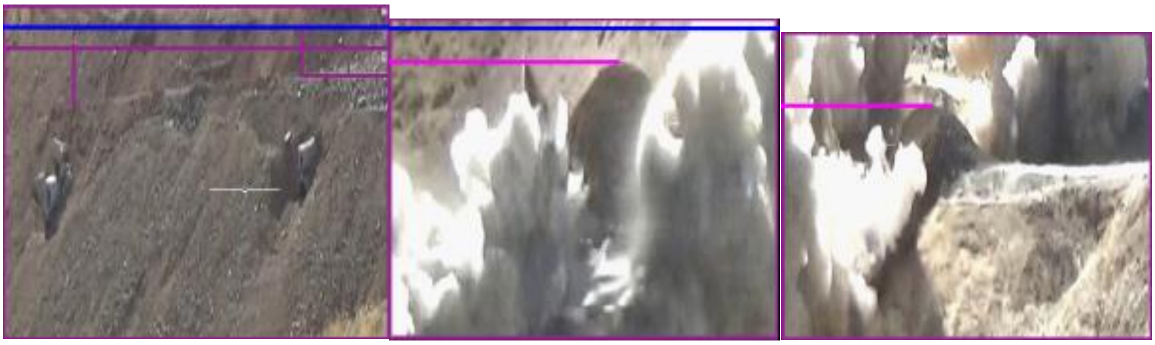


Figure 17. Eruptions in the third and fourth setups

As a result of the tests in the study, when the results were compared with the typical cross-sections, the largest eruptions were observed in the road with geotextile membrane installation, which was followed by the cross-section of the road with a 60 cm secondary culvert below an 80 cm primary culvert and the road with a 60 cm secondary culvert above an 80 cm primary culvert, respectively (Table 6). In the footage recorded by the stationary cameras, the measurements were conducted by comparing the culverts before and after explosions to designate the eruptions during explosions. When the explosions were ranked according to the crater holes that were created as a result of the explosions, the following rankings were obtained.

Table 6. Crater formation

Measurements of the crater holes that were formed after the explosions				
standard road	50 kg	TNT	150 cm	High Damage
the road with geotextile membrane installation	50 kg	TNT	45 cm	Low Damage
backfill above a culvert with 80 cm diameter	50 kg	TNT	65cm	Low Damage
backfill above a culvert with 60 cm diameter	50 kg	TNT	70 cm	Low Damage
General evolation	50 kg	TNT	60 cm	Low Damage

In these tests, 3 pieces of Riogel Troner (38x3870) cartridge Rionel ms capsules were used in the detonations and the cartridges were measured during the detonations in terms of their VoD values within groups of three in the open. When the cartridges were cut to examine their densities, it was observed that the products were turned into sponge-like structures while maintaining their forms. In the analyses, the VoD value was measure as 3826.70 m/s.

Energy of 1 kg of TNT = 0.238845896627 x 4.184 x 106 j=1000 kCal (1)

The relative activity factor of ANFO is 0.42 TNT, which is equal to 420 kCal energy. The amount of ANFO used in the study was 50 kg, which was calculated as the following.

50 x 420 = 21000 kCal (2)

Here, the VoD value for the ANFO was calculated as 3800 m/s. In theory, 1 kg of TNT produces 70 kPa of pressure within 1 meter. When these values are adapted to ANFO, 30 kPa creates 30 x 50 = 1500 kPa of pressure as the totality of the explosive. This equals 150 tons of pressure per square meter. In the current study, when the area of effect was regarded as 20 cm, this value increases logarithmically. However, because the aim of the study was to simulate terrorist activities exactly in the same way, the compaction practices were not conducted extensively. Therefore, certain amounts of energy were still discharged from the sides of the culverts. This caused certain pieces of culverts to hurtle 200-250 meters away from the explosion site. The distances of hurtling were particularly further in the typical cross-sections of the setups with secondary culverts above and below primary culverts.

5. Discussion

For the results of the tests above, two different types of evaluations were conducted. In the first one, the upsurges over culverts during the explosions were evaluated while in the second one, the crater holes that were formed after the explosions were evaluated. According to these evaluations, the installation of secondary culverts below culverts and geotextile membrane installations should be among the typical cross-sections that can be adopted for absorbing explosive energies. Because the tests in the study demanded high financial costs, the number of tests was limited. However, it was believed that the results were sufficient to devise a general idea about the explosion mechanics in question. In typical cross-sections of the setups with secondary culverts below and above primary culverts, the explosive energies were diverted to the sides of the roads rather than over the roads thanks to the secondary culverts. Accordingly, these two techniques can be implemented for the roads to be built in regions that are under terrorist threats.

6. Acknowledgements

This study was conducted with the help of the Firat University Scientific Research Projects Units (FUBAP Project No: MF.18.26), the Malatya Municipality. We are grateful for their financial and technical support.

7. Author Contribution Statement

In this study, Author 1 contributed to the creation of the idea, the design and the literature review, the evaluation of the results obtained, the procurement of the materials used and the analysis of the results; Author 2 contributed to the creation of the idea, spelling, the procurement of the materials used, reviewing the results and checking the paper for content. Author 3 contributed to the creation of the idea, preparation of experimental setups; Author 4 contributed to the checking the article in terms of content and and literature review.

8. Ethics Committee Approval and Conflict of Interest

There is no need for an ethics committee approval in the prepared article. There is no conflict of interest with any person/institution in the prepared article.

9. References

[1] Almogy G, Rivkind AI. "Terror in the 21st century: milestones and prospects-part I". *Current Problems in Surgery*, 44(9), 496–554, 2007.

[2] Khanmohamadi M, Bagheri M, Khademi N, Ghannadpour SF. "A security vulnerability analysis model for dangerous goods transportation by rail-Case study: Chlorine transportation in Texas-Illinois". *Safety Science*, 110, 230–241, 2018

[3] Elias W, Albert G, Shiftan Y. "Travel behavior in the face of surface transportation terror threats". *Transport Policy*, 28, 114–122, 2013.

[4] Beveridge A. *Forensic Investigation of Explosions*. second edition. New York, USA, CRC press, 2011.

[5] Milliyet. "Silvan'da yine faciadan dönüldü". https://www.milliyet.com.tr/yerel-haberler/diyarbakir/silvan-da-yine-faciadan-donuldu-11124018 (21.12.2015).

[6] Haberler. "Menfez altına yerleştirilmiş 225kilogram Amonyum Nitrat imha edildi". https://www.haberler.com/guncel/mardin-de-menfez-altina-yerlestirilmis-225-8465444-haberi/ (24.05.2016)

[7] Vatan. "İşte PKK tünelleri". https://www.gazetevatan.com/arsiv/galeri-iste-pkk-tunelleri-1525795(16.01.2017).

[8] Habertürk. "Bitlis'te 350 kilogram patlayıcı imha edildi". https://www.haberturk.com/yerel-haberler/haber/11768348-bitliste-350-kilogram-patlayici-imha edildi (29.04.2017).

[9] Yenişafak." Eruh'ta el yapımı patlayıcı ile saldırısı: 5 korucu yaralı". https://www.yenisafak.com/video-galeri/gundem/eruhta-el-yapimi-patlayici-ile-saldirisi-5-korucu-yarali-2106952 (28.08.2016).

[10] Kristoffersen M, Hauge K.O, Børvik T. "Blast loading of concrete pipes using C-4 charges". *Multidisciplinary Digital Publishing Institute Proceedings*, 2(8),428,2018.

[11] Bonalumi P, Colombo M, Prisco MD. "Internal explosions in embedded concrete". *Applied Mechanics and Materials*, 82, 452–457,2011.

[12] Olarewaju AJ, Rao NSVK, Mannan MA. "Blast effects on underground pipes". *Electronic Journal of Geotechnical Engineering*, 15, 1–14, 2010.

[13] Olarewaju AJ, Rao NSV, Mannan MA. "Guidelines for the design of buried pipes to resist effects of internal explosion, open trench and underground blasts". E*lectronic Journal of Geotechnical Engineering*, 15, 1–13, 2010.

[14] Parviz M, Aminnejad B, Fiouz A. "Numerical simulation of dynamic response of water in buried pipeline under explosion". *KSCE Journal of Civil Engineering*, 21(7), 2798–2806, 2017.

[15] Tang Q, Jiang N, Yao Y, Zhou C, Wu T. "Experimental investigation on response characteristics of buried pipelines under surface explosion load". *International Journal of Pressure Vessels and Piping*, 183, 104101,

2020.
[16] Chen B, Sun L. "The impact of soil properties on the structural integrity of high-fill reinforced concrete culverts". *Computers and Geotechnics*, 52 , 46–53,2013.
[17] Kolisoja P, Kalliainen A. "Modelling of plastic culvert and road embankment ınteraction in 3D", *Procedia Engineering*, 143, 427–434, 2016.
[18] Marr AJ, Groves DM. " Ion mobılıty spectrometry of peroxıde explosıves tatp and HMTD". I*nternational Journal for Ion Mobility Spectrometr*y, 59–63, 2003.