ESCUELA DE CONSTRUCCIÓN CIVIL
FACULTAD DE INGENIERÍA
Revista de la Construcción
Journal of Construction

Research Article

An experimental study on the blast responses of hollow core concrete slabs to contact explosions

Sedat Savaş[1], Dursun Bakir[2, *]

[1] Department of Civil Engineering, Firat University, Elazığ (Türkiye), ssavas@firat.edu.tr
[2] Department of Civil Engineering, Firat University, Elazığ (Türkiye), dbakir@firat.edu.tr
*Correspondence: dbakir@firat.edu.tr

Received: 06.08.2021; **Accepted:** 04.10.2022; **Published:** 29.12.2022

Citation: Savas, S., and Bakir, D. (2022). An experimental study on the blast responses of hollow core concrete slabs to contact explosions. Revista de la Construcción. Journal of Construction, 21(3), 587-601. https://doi.org/10.7764/RDLC.21.3.587.

Abstract: Measures taken against preventing damages in structures against explosive load are a popular matter of investigation among researchers. Generally, numerous studies were conducted on reinforcement materials for outer surfaces, reinforcement design, and utilizing fibers produced from various materials. In this study, a hollow-core slab was manufactured with concrete, which had a regular strength, and a design that discharged the explosive energy upon contact explosion via the hollow cores of the slabs and prevented the redirection of the explosive energy to the area below the slabs was investigated. Because the hollow-core slab in the study did not have any lateral reinforcement, the utilization of the tensile strength of the concrete proved advantageous. For this purpose, in the experimental tests of the study, contact explosions were conducted on hollow-core slabs with hollow diameters of 14 cm for each core. Before the explosion tests, the TNT equivalent of 910gr explosive was determined by performing the TNT equivalent tests. In the explosion tests of prepared hollow core concrete slabs, 125 gr, 250 gr, 375 gr, and 500 gr dynamites were used as the explosive materials. In conclusion, the explosive loads that the slabs could withstand were calculated and various slabs with distinctive hollow-core diameters were determined depending on the amount of the explosives.

Keywords: Contact explosion, explosive pressure, hollow-core slab, crater hole, absorption of explosive pressure.

1. Introduction

Explosions are defined as large-scale, rapid, and instant releases of energy. The considerations in the matter of explosions in contact with structures arose the need for improving the strength of structures against impact loads, such as explosive loads, in addition to the dynamic and static loads while designing structures(Houari et al. 2021; Nguyen et al. 2019; Savaş et al. 2021). Within this scope, numerous studies have recently investigated explosive loads and structural elements via various field tests in the literature(Abbas et al. 2019; Al-Shaarbaf, Al-Azzawi, and Abdulsattar 2018; Goswami, Ganesh, and Das 2022; Hanifehzadeh et al. 2021; Liu et al. 2022; Maazoun et al. 2019; Peng et al. 2022; Tarlochan 2021; Wei, Li, and Wu 2020). In such tests, various difficulties emerged due to high economic costs, long preparation periods, risks of damaging data collection tools during tests, and specialized permissions to conduct explosion tests have emerged. Accordingly, these difficulties have resulted in an insufficient number of explosive tests; thus, an insufficient amount of experimental data to analyze the behaviors and responses of materials and structural elements. Most of the comprehensive studies were conducted with military support, which aimed to investigate the protection and safety aspects of the structure in question. Because the structures to be protected have large surface areas, the structural element to be the most impacted by outer loads are slabs. On this matter, researchers classified the tests conducted on slabs into four scenarios. These included excessive damage on the surface despite the high displacement of explosive load by slabs (I), the formation of craters on the outer surface of slabs and lack of any damage on the inner surface (II), the formation of a deep crater on the outer surface and fragmentation and dissipations (such as shrapnel) on the inner surface (III), and penetration of slabs (IV) of those, the last two scenarios are the most destructive ones. Additionally, the last two scenarios cover the undesirable slab behaviors under explosive loads in terms of project design.

The studies that investigated these behaviors with tests conducted on concrete slabs could be divided into two groups. The first group of studies investigated concrete mixtures that could withstand explosive intensity with high strength materials, chemical additives in concrete mixtures by Kristoffersen(Kristoffersen, Hauge, and Børvik 2018), reinforcement replacement(Zhao et al. 2021), and concrete mixtures with fibers(Almustafa and Nehdi 2020; Yang, Zhang, and Liu 2021).The second group of studies investigated increases and decreases in the contact surface with explosive waves for establishing geometric connections by altering plate geometry, thickness, and altering the distance between plates and explosives. Within this framework, the distance problem can be divided into three groups as contact explosion, close-range explosion, and far-range explosion.

The amounts of explosives in contact and close-range explosions are smaller compared to far-range explosions. Therefore, most studies conducted contact and close explosion tests to reduce expenses. Explosion protection structures, safety clearance of explosives, is designed taking into consideration the amount of load criteria. However, structurally, material properties are delicate features for design. In this study, reinforced concrete slabs of different thickness blast analyzes were made with different thicknesses, reinforcement ratios and yield strengths on it. Slab thickness has been found to have significant effects on both the inertia force and flexure resistance. It has been observed that compressive strength is not an important factor besides these factors(Kee, Park, and Seong 2019).

This study aims to examine the structural behavior of concrete gravity dams under bursting loads. For this purpose in Turkey Sarıyar concrete gravity dam reservoir 85 m height (H), the reservoir length of 255 m (3H), 72 m and 7 m upper base width is selected for digital applications. Approximately 13 tons of TNT explosives were applied 20 m from the downstream of the dam. Pressures obtained UFC 3-340-02 standard (UFC 3-340-02 2008) compared with. As a result, it was emphasized from the study that bursting loads should be included in the design of dams(Sevim and Toy 2020). In this study, contact burst experiments with 0 to 6% volume fractions were carried out on steel fiber reinforced concrete.20 gr RDX explosive placed on the surface reduces the crater volume formed on the surface by 80% with a 6% fraction after it is detonated. In this experiment, steel fiber fraction and explosive quantity factors are determinants for determining crater trench volume and crack density(Zhang et al. 2018).

In the current study, it was aimed to protect the slab or absorb the explosive wave by preventing the explosive shockwave to dissipate to the surrounding area rather than reducing the damage to be done on slabs. For this purpose, precast hollow-core slabs were chosen in slab design. Precast hollow-core slabs have been popular structural elements in the field of construction thanks to their utilization under circumstances with large installation spaces and inexpensive installation costs (Zhao et al. 2020). Accordingly, the contact explosions, which cause the greatest damage, were conducted in the tests of this study. In the first step, the explosion resistances of slabs with hollow-core diameters of 14 cm, which were supported from four corners, were measured against contact explosions. In the second step, the tests were conducted when the slabs were in contact with the ground. As a result of the tests, the maximum amount of explosives that could be resisted by the slabs with hollow-core diameters of 14 cm were determined in the contact explosion setup.

The slab with 300x300x30 cm dimensions was placed 0.50 cm away from the explosives, and 1 kg, 2 kg, and 3 kg TNT explosives were detonated. The aim of this study is to measure the diameter and depth of the craters that are formed on slabs and the dissipation of materials on the back surface following explosions. In the study, the measurements could not be conducted in the 3kg TNT explosion. In the 1kg TNT explosion, a crater with a 50cm diameter was formed on the front surface of the slab; however, the slab was not penetrated. On the back surface, damages were observed in an area with a 75cm diameter. In the 2kg TNT explosion, a crater with a diameter of 25cm was created, and damages were observed on both the front and back surfaces(Wang et al. 2008).

Figure 1. Contact explosions and the aftermath of the slabs with 300x300x30 cm dimensions (Wang et al. 2008).

In the other installation conducted with concrete slabs supported from two opposing corners, the compressive resistance of 52MPa RC slabs were installed with upper and lower supports with 6 mm diameters at every interval of 10 mm (dimensions of 750x750x30, 1000x1000x80, 1250x1250x100 mm, Figure 2). Considering the ratio between the distances and amounts of explosives, TNT explosives ranging from 0.13 kg to 0.94 kg were installed in distances ranging from 0.3 m to 0.5 m. The influences of the slab dimensions were evaluated and it was observed that larger specimens were damaged more intensively. Furthermore, the ratios between explosive shock radius and slab dimensions were measured. Common formulas for blast waves and pressures were tested.

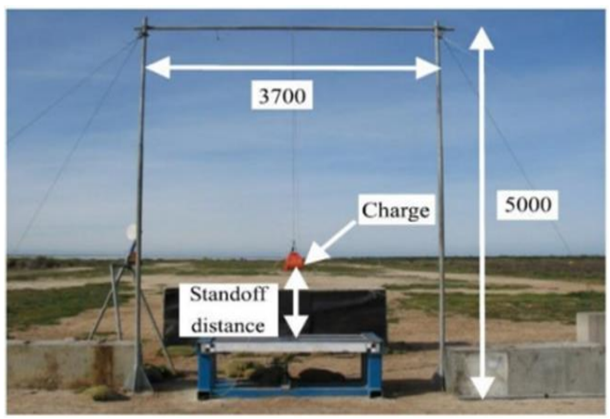

Figure 2. The slab setup with fixed supports on two corners (Hosseinipoor, Gholamrezaei, and Akibarian 2014).

In the study conducted by Foglar(Foglar et al. 2014), the results of field tests on FRC (Fiber Reinforced Concrete) and concrete specimens were presented, which was conducted in the Boletice military training area with the support of the Czech army. The tests were conducted on true-to-scale concrete precast slabs (6x1.5x0.3 m) with various contents, types, and strengths of fibers as well as various concrete strengths. The slabs were loaded with a 25 kg TNT explosive load. The study aimed to investigate the propagations of explosive shockwaves, propagation of cracks below specimens, and final collapse of the specimens in the center of the specimen that was exposed to the explosion (Figure 3). The propagation process of the explosive waves enabled the estimation of shock waves in the air and velocity of debris propagation; however, the attempt of measuring the crack propagation at the top. In the study, it was suggested to design novel triggering systems in future studies.

Figure 3. Concrete precast slab setup (Foglar et al. 2014).

In an experimental study conducted by Jun Liv et al.(Li, Wu, and Hao 2016), it was reported that comprehensive explosive scenarios, which covered contact explosions focusing on structural reactions and damages under the impact of distant or contact explosions based on current design and test practices, were not investigated comprehensively. In Figure4, the researchers conducted performance measurements of concrete slabs built with regular strength concrete and steel wire mesh (wire mesh with 1 mm diameter at every 6 mm interval).

Figure 4. Concrete precast slab setup (Foglar et al. 2014).

In a study conducted by B. Luccionia (Luccioni et al. 2018), a series of experimental tests and numeric models were conducted on high-strength fiber-reinforced concrete slabs. In the study, as can be seen in Figure 5, 49 gr, 244 gr, and 488 gr of TNT explosives were detonated from 0.0175 m, 0.2425 m, and 0.2725 m distances, respectively. As a result of the tests, it was determined that the specimens with shorter fibers had higher strengths compared to specimens with the same fiber content both experimentally and numerically.

Figure 5. Explosion tests on high strength fiber reinforced concrete slabs (Luccioni et al. 2018)

In a study conducted by Azer Maazoun(Maazoun et al. 2019), contact explosions were tested on hollow-core slabs with 22x62x8.2 cm dimensions. In the study, 1.5 kg of C4 explosives were detonated from a 50 cm distance. In the tests, micro cracks that occurred in the slabs were presented, and the displacement of the slabs was measured. Following the explosions, the stability of the slabs was not disrupted, and crater holes were not formed.

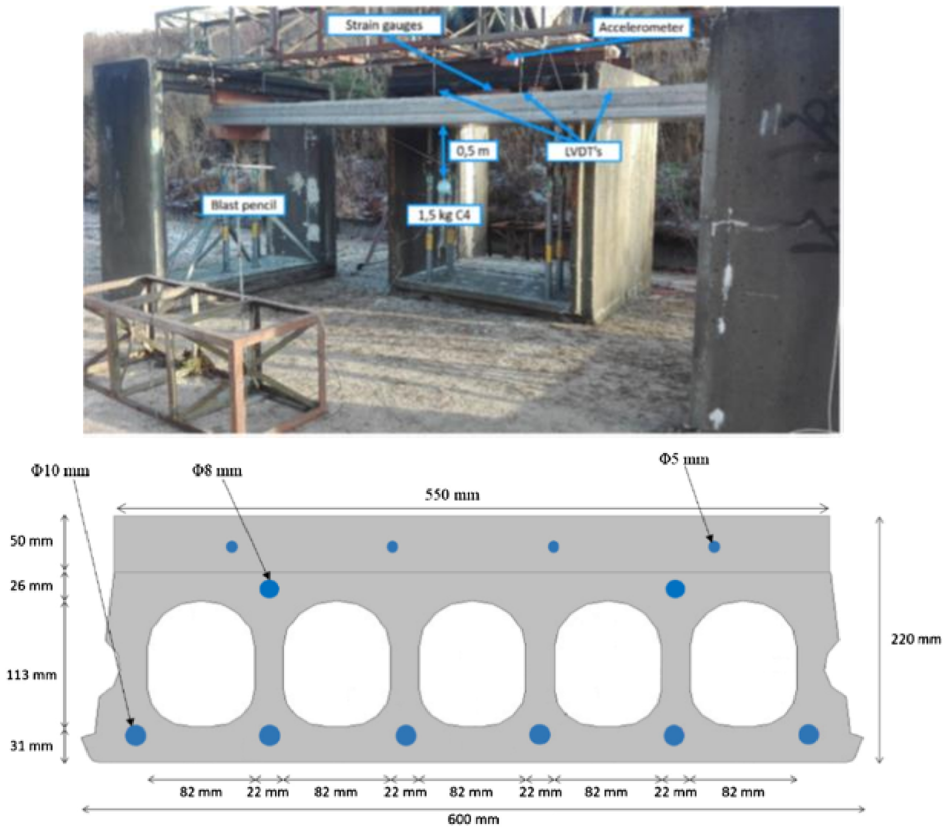

Figure 6. The image of the test setup built in the study by (Maazoun et al. 2019).

2. Materials and methods

In the current study, 12 explosion tests were conducted at various intervals within 5 weeks. In the tests, 125 gr, 250 gr, 375 gr, 500 gr, and 1000 gr of TNG dynamites were used. The tests were conducted on slabs with two different types of supports (Figure8). In the first setup, the slabs were semi-statically supported from four corners. In the second setup, the slabs were placed on the round. Additionally, two different sizes of slabs were used in the study. The experimental tests were conducted in the sand quarry presented in Figure 7. Then, 12 hollow-core slabs were installed in the test field, and the experiments were conducted after the necessary measures were taken.

Figure 7. Image of the testing field and the installation of the specimens.

2.1. *Hollow-core slab specimens*

The design of the RC hollow-core slabs, which were manufactured in a factory that produced prefabricated concrete construction elements, were presented in Figure 8 while the final forms of the slabs after the manufacturing were presented in Figure 9. The type of slab used in the study had a width of 119 cm and a height of 23.5 cm and included 6 hollow cores, each of which had a diameter of 14 cm, and was placed 5 cm away from the sides.

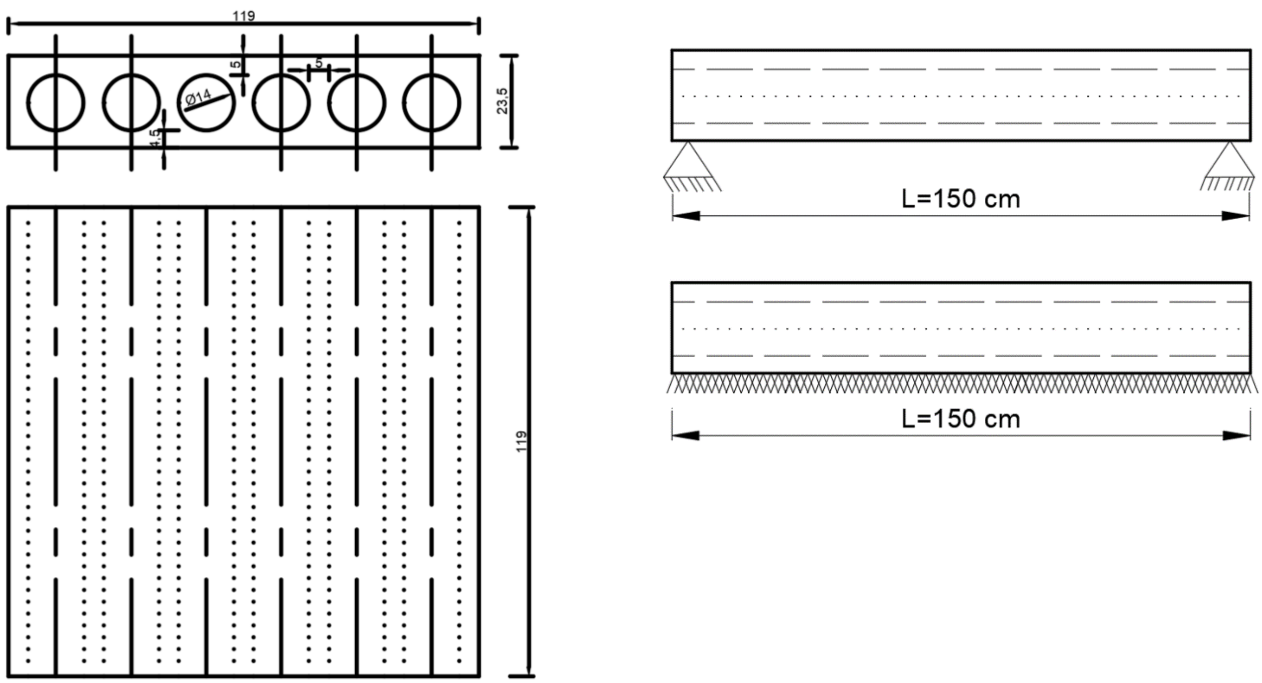

Figure 8. Cross-section presentation of a hollow-core slab and types of supports.

In the tests, slabs with two different widths, 120 cm, and 150 cm, were used. The pressure strength of the concrete was 35 MPa, and the steel rope had a diameter of 3/8" (9.3 / 9.53 mm) and tensile strength of 1860 N/mm2. The steel ropes were used to tighten the frontal lower section of the slabs and were placed on the frontal lower section of the slab in parallel to the hollow plane. The concrete mixture used in the study included 0-5 mm sand, 3-8 mm aggregate, 1-14 medium aggregate, and 14-28 mm large aggregate as well as an amount of cement 440 kg/m3.

Figure 9. Images of hollow-core slabs, hollow-core cross-sections, and prestressing ropes, respectively.

2.2. Explosives

In the study, the explosives used in the study included Nitroglycerin (NG), Trinitroglycerin (TNG), Nitroglyceryl trinitrate (GTN), or the nitroglycerin nitric acid ester, as known as 1,2,3-trinitroxypropane, which are based on dense, colorless, oily, explosive liquid produced by nitrating white fuming nitric acid and glycerin under favorable conditions. Nitroglycerin is majorly used for explosive materials and fuels, such as dynamites(Pawłowski et al. 2017).

Nitroglycerin and its thinners are materials with combustible (flammable) qualities. The explosive quality of nitroglycerin is due to the explosion, and the energy released from the first decay creates a strong pressure wave that ignites and explodes the surrounding fuel. This pressure wave spreads around with a velocity that is 30 times higher than the velocity of sound and consists of a self-sustaining shockwave that results from the sudden pressure, where the separated fuel turns into a white-fuming hot gas. The explosion of nitroglycerin creates gasses that cover a volume that is 1.200 times higher than the first volume at room temperature and pressure. The released heatwave rises to approximately 5000 °C by Kunduraci (Kunduraci 2010). Regardless of pressure and shock, this is different from the current ignition process, which depends on the fuel. The decay concludes with rather higher ratios of released energy to gas moles compared to other explosives, which makes nitroglycerin one of the hottest explosives.

In the study, electric detonators were used as boosters in the explosions. The type of detonator had a diameter of 6 mm and a length of 50 mm. These detonators could be ignited by electricity (magneto or condenser-type igniters), which included a blasting cap with a fuse. These types of capsules, which are manufactured to be used in open quarries with aluminum as an external body material, are used for detonating explosives such as dynamite and similar explosives (Gümüşçü et al. 2016). The velocity of the ignition (detonation) in the dynamite can reach approximately 7500 m/s (Fig10).

Figure 10. Images of the dynamite and the electric detonator used in the tests, respectively.

2.3. Contact explosion tests of supported hollow-core slabs

Five blasting tests, 250gr (2), 500gr (2) and 1000gr were carried out on supported slabs. As can be seen in Figure 11, because the initial explosion of a 500-gr and 1000-gr explosive resulted in an excessive amount of damage on the slab, the tests were conducted with 250-gr explosives. In the tests, the 250-gr explosives also divided the slabs into two. In the tests, the explosives were installed in the middle of the slabs and in parallel to hollow-core planes and hollows, which was presented in Figure 12. The purpose of this practice was to redirect the energy resulting from the explosion to discharge from the hollows before contacting the lower surface of the slab. However, in both tests, the slabs were divided into two from the points where the explosives were installed.

Figure 11. Images of supported hollow-core slabs after contact explosions with 500-gr dynamite setups

Following the explosions of 500-gr explosives, the slabs were damaged heavily, and the pre stressing ropes were separated from the slabs. In addition to the cracks, a crater with an ellipsis shape (17x12cm) was formed (Fig11).

Figure 12. Images of supported hollow-core slabs after contact explosions with 250-gr dynamite setups

In the explosions, the slabs were separated into two pieces, and a crater with an ellipsis shape (15x12 cm) was formed. In supported slabs, 250 gr TNG explosive showed the same behavior as 500 gr TNG explosive as shown in figure 12.

2.4. Contact explosion tests of hollow-core slabs placed on the ground

In these tests, the explosives were installed on the middle sections of the slabs, on hollow cores, and in parallel to the hollow-core plane, which was demonstrated in Figure 13.

Figure 13. Images of the installation of the slabs and the explosives on slabs in the field.

As can be seen in Figure 13, the hole beneath the slab is in direct contact with the lower surface of the slab and the ground. In the tests, due to the collapsing of the supported slabs, it was aimed to redirect the explosive energy through the slab gap and to release it from the hollow cores. In the tests, a total of 7 explosions were conducted, which covered a single explosion for 125-gr explosives, two explosions for 250-gr explosives, two explosions for 375-gr explosives, and two explosions for 500-gr explosives.

Figure 14. Contact explosions of 125-gr explosives on slabs placed on the ground

As can be seen in Figure 14, the 125-gr explosive created a crater hole with a diameter of 9 cm on the upper surface of the slab. This hole was formed on the 25cm² area from the upper section of the slab. This damage formed on the upper surface of the slab did not affect the lower and lateral surfaces of the slab. The next test was conducted by doubling the amounts of explosives, and the tests were conducted with the 250-gr explosive setup, which was demonstrated in Figure 15.

Figure 15. Contact explosions of 125-gr explosives on slabs placed on the ground

In this setup, two contact explosions were conducted. In both tests, crater holes with an average diameter of 11 cm were formed. These holes were formed on the 11cm width from the upper section of the slab. These damages that occurred on the upper sections of the hollows did not affect the lower and lateral surfaces of the hollows. In the test, it was ensured that the explosive energy was absorbed by draining it. Except for the penetration in the upper section of the slab, no damage was created, and the 375-gr explosive test setup was implemented for the next test.

Figure 16. Contact explosions of 375-gr explosives on slabs placed on the ground.

In this setup, two contact explosions were conducted. In the first test, the slab width was 120 cm while the slab with a width of 150 cm was used in the second test. In tests conducted on the slab with 120-cm width, a 13x17 cm crater hole was formed due to the explosions; however, the upper surface of the slabs was cracked throughout the hollow plane. No damages were observed on the other areas, sides of hollows, or lower surfaces. In the second test, the test was conducted on the slab with a width of 150 cm. As a result, a 12x17 cm crater hole was formed. The other areas of the slab were not damaged, and no crack was formed on the slab.

According to these results, it was concluded that the limits of energy absorption were reached at these tests. Then, the amounts of explosives were increased to 500 gr to test the limits of slab strength and hollow drainage in contact explosions.

Figure 17. Contact explosions of 500-gr explosives on slabs placed on the ground

In these tests, the slabs were separated into two and three pieces, which was presented in Figure 17. As a result of the tests, a 16x25 cm crater hole with an ellipsis face was formed, and the slab was cracked from the upper and lower sections. In conclusion, the 500-gr explosive setup disrupted the stability of the slab, which resulted in a transmission of the explosive energy to the rear side of the plate and a failed absorption.

3. Experimental results and analysis

3.1. Analysis of the explosion pressure within hollow cores

The explosive material used in the study, $C_3H_5(ONO_2)_3$ is a colorless, oily, and dense explosive liquid, which is obtained by nitrating Trinitroglycerin (TNG) with glycerin. Because it contains nitric acid inside, the explosion creates white fumes.

Figure 18. Propagation of the explosives during the tests

Table 1. Properties of the hollow cores (L=120 cm)

Hollow area	153.93cm²
Pipe volume	18000cm³
Hollow pressure area(Fig.19)	1200cm²
Tensile strength of concrete	5MPa
Pressure in the pipe	≥600000N

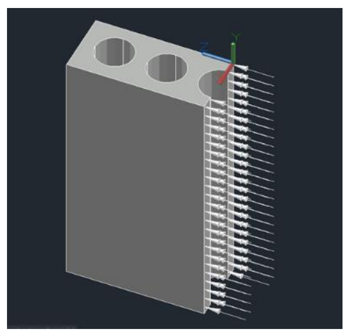

Figure 19. Hollow-core pressure distribution

The equivalent of TNT was read with the help of Ps0 incident pressure sensors by detonating a 910g TNG explosive at a standoff distance of 3.2 m, by referring to the logarithmic graph (Fig20) of the UFC Free air explosion depending on the scaling factor (UFC 3-340-02 2008). Here, table2 data is obtained by calculating the Z scaling value read in Fig20 with the equation 1. TNT equivalence coefficient was calculated by dividing the weight of TNT calculated in Table 2 by the weight of the TNG explosive (equation 2).

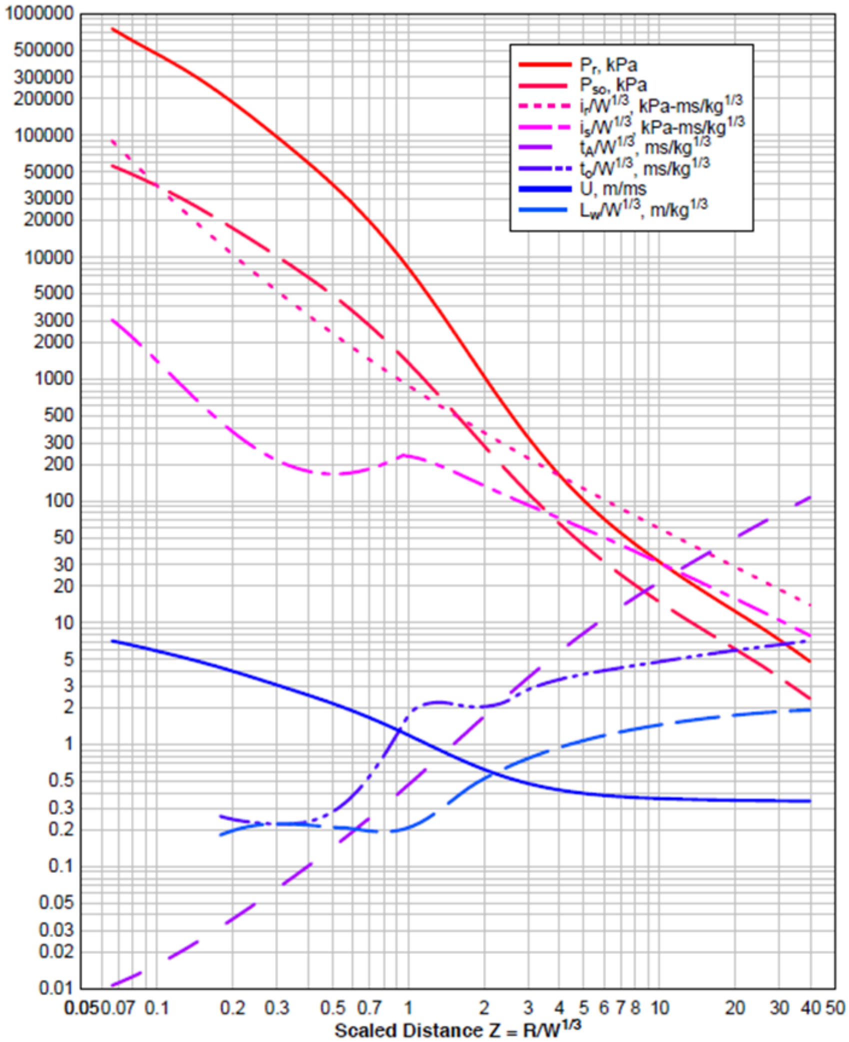

Figure 20. Logarithmic graph of free air explosion with scaling factor

$$\boldsymbol{Z} = \frac{R}{W^{1/3}} \tag{1}$$

Table 2. Pressure sensor values of the explosion test

SENSOR	Max Pressure		Min Pressure		Z	W
	Time (sn)	Pressure (N/m^2)	Time (sn)	Pressure (N/m^2)	(m/kg$^{(1/3)}$)	(kg)
	8.590098	52924	8.594297	-11795,8	3.866359	0.570274

$$\frac{W_{TNT}}{W_{Explosive}} = \frac{0,57}{0,91} = 0,63 \tag{2}$$

The explosive used corresponds to 63% efficiency of TNT.

4. Conclusions and comments

Twelve explosions were conducted within the framework of the study. The number of tests was limited by determining the maximum amount of explosives that could be absorbed by the slabs. In conclusion, the following results were discovered.

1. In the supported slabs tests, where there were hollow under the slabs, the slabs failed to resist the contact explosions. To eliminate this matter, the slabs should be reinforced with transverse reinforcement materials in addition to pre stressing ropes installed in parallel to the hollow plane.
2. The hollow diameter of 14 cm can resist the 375-gram of a dynamite explosion. Greater amounts of explosive than this amount results in the collapse of the system upon contact explosion.
3. When the 375 grams of explosives were used on slabs with 120 cm widths, cracks were formed on the system; however, when the widths of the slabs were increased (150cm), no cracks were formed. This indicated the effects of tensile strengths of concrete and slab dimensions.
4. The tests conducted in this study indicated that the hollow-core slabs, which are in contact with the ground or various types of structures, are the most appropriate and economically viable solutions to be used as structural elements to protect structures that may encounter explosive loads thanks to their ability to absorb the explosive energy under circumstances such as contact explosions.

Table 3. Results of explosions (unsupported)

Explosive weight (gr)	TNT Weight (gr)	Tensile concrete of strength (MPa)	Length (mm)	Thickness (mm)	Hollow diameter (mm)	Load (N)	Damage status
250	158	5	1200	100	140	600000	Success
375	236	5	1200	100	140	750000	Fail
375	236	5	1500	100	140	750000	Success
500	315	5	1500	100	140	750000	Fail

As can be seen in Table 3,
-While the stability of the structure was deteriorated in an explosion with 1000 gr explosive weight, it was not specified because there was no damage to the slabs in 125 gr explosive.
-In the sample with a slabs length of 120 cm, 375 g of explosive resulted in large cracks. The explosion on the 120 cm long specimen caused micro cracks to appear throughout the hollow plane of the sample.
-In comparison to the explosion of the same weight in the 120 cm sample, lesser cracks were produced when 375 gr of explosive was detonated in a 150 cm slab. It has been noted that if the explosive weight is too great, the structure's stability would be compromised.
-On the other hand, in 500 gr explosive, the stability of the structure deteriorated and the sample was divided into several pieces.

As a result, the 150 cm long sample released the bursting energy without disturbing the stability of the 375 gr explosive sample. In other words, when evaluated according to the sample size, 1m of the sample can drain 250gr of explosive. Fractures started above 600000 N which is the limit load of 750000N/1.5m=500000N/m and stopped at 750000N load. In conclusion, cracks were formed when loads of 600000 N, which was the limit, were exceeded while the cracks were stopped at 750000 N load.

At larger cross-sections and explosive weights by using the same ratio, the amounts of explosives that could be absorbed by hollows with larger dimensions can be calculated. In future studies, slabs that include hollow cores with larger diameters can be tested for energy drainage.

Author contributions: Savas and Bakır: conceptualization, methodology, formal analysis, visualization, writing –review& editing, supervision.

Funding: not applicable.

Acknowledgments: This study was conducted within the scope of the Scientific and Technological Research Council of Turkey (TUBITAK). We gratefully acknowledge the financial support provided by TUBITAK to the Research Project 219M392.

Conflicts of interest: the authors declare that they have no conflict of interest

References

Abbas, Asim, Mohammad Adil, Naveed Ahmad, and Izaz Ahmad. 2019. "Behavior of Reinforced Concrete Sandwiched Panels (RCSPs) under Blast Load." *Engineering Structures* 181(August 2018):476–90. doi: 10.1016/j.engstruct.2018.12.051.

Al-Shaarbaf, Ihsan A., Adel A. Al-Azzawi, and Radhwan Abdulsattar. 2018. "A State of the Art Review on Hollow Core Slabs." *ARPN Journal of Engineering and Applied Sciences* 13(9):3240–45.

Almustafa, M. K., and M. L. Nehdi. 2020. "Machine Learning Model for Predicting Structural Response of RC Slabs Exposed to Blast Loading." *Engineering Structures* 221(September 2019):111109. doi: 10.1016/j.engstruct.2020.111109.

Foglar, M., J. Pachman, V. Pelikan, R. Hájek, M. Künzel, and M. Kovar. 2014. "The Structural Response of a Reinforced Concrete Specimen Subjected to Adjacent Blast Loading." *WIT Transactions on the Built Environment* 141(September 2013):171–79. doi: 10.2495/SUSI140151.

Goswami, Abhiroop, Thiagarajan Ganesh, and Satadru Das. 2022. "International Journal of Impact Engineering RC Structures Subjected to Combined Blast and Fragment Impact Loading : A State-of-the-Art Review on the Present and the Future Outlook." *International Journal of Impact Engineering* 170(July 2021):104355. doi: 10.1016/j.ijimpeng.2022.104355.

Gümüşçü, Mehmet, Ayşe Cebe, Abdullah Erdinç, and Sinan Uyanık. 2016. "Characteristics of Explosives Used for Civilian Purposes, Their Effects on the Environment and Measures." *Dicle University Journal of the Institute of Natural and Applied Science* 5(2):81–91.

Hanifehzadeh, Mohammad, Hadi Aryan, Bora Gencturk, and Dovlet Akyniyazov. 2021. "Structural Response of Steel Jacket-UHPC Retrofitted Reinforced Concrete Columns under Blast Loading." *Materials* 14(6):1521. doi: 10.3390/ma14061521.

Hosseinipoor, S. N. M. .., R. Gholamrezaei, and M. Akibarian. 2014. "Study of Explosive Resistance Scaling on Reinforced Concrete Slab under Loading, under Free-Air Burst Blast." *Indian J.Sci.Res* 1(2):650–59.

Houari, A., M. Mokhtari, A. S. Bouchikhi, A. Polat, and K. Madani. 2021. "Using Finite Element Analysis to Predict the Damage in FGM-3D Notched Plate under Tensile Load; Different Geometric Concept." *Engineering Structures* 237(January):112160. doi: 10.1016/j.engstruct.2021.112160.

Kee, Jung Hun, Jong Yil Park, and Joo Hyun Seong. 2019. "Effect of One Way Reinforced Concrete Slab Characteristics on Structural Response under Blast Loading." *Advances in Concrete Construction* 8(4):277–83.

Kristoffersen, Martin, Knut Ove Hauge, and Tore Børvik. 2018. "Blast Loading of Concrete Pipes Using C-4 Charges." *Proceedings* 2(8):428. doi: 10.3390/icem18-05292.

Kunduraci, Melike. 2010. "The Investigation of the Cu(II) Complexes Including Both Azido and Nitro Groups Using Thermal Analisis Methods." Ankara University.

Li, Jun, Chengqing Wu, and Hong Hao. 2016. "Spallation of Reinforced Concrete Slabs under Contact Explosion." *2016 2nd Asian Conference on Defence Technology, ACDT 2016* 42–45. doi: 10.1109/ACDT.2016.7437641.

Liu, Kun, Li Ke, Yanyan Sha, Guangming Wu, Peng Wang, and Zili Wang. 2022. "Dynamic Response of Laser-Welded Corrugated Sandwich Panels Subjected to Plane Blast Wave." *International Journal of Impact Engineering* 164(July 2021). doi: 10.1016/j.ijimpeng.2022.104203.

Luccioni, B., F. Isla, R. Codina, D. Ambrosini, R. Zerbino, G. Giaccio, and M. C. Torrijos. 2018. "Experimental and Numerical Analysis of Blast Response of High Strength Fiber Reinforced Concrete Slabs." *Engineering Structures* 175(October 2017):113–22. doi: 10.1016/j.engstruct.2018.08.016.

Maazoun, Azer, Stijn Matthys, Bachir Belkassem, David Lecompte, and John Vantomme. 2019. "Blast Response of Retrofitted Reinforced Concrete Hollow Core Slabs under a Close Distance Explosion." *Engineering Structures* 191(April):447–59. doi: 10.1016/j.engstruct.2019.04.068.

Nguyen, Hoang, Xuan Nam Bui, Quang Hieu Tran, and Hossein Moayedi. 2019. "Predicting Blast-Induced Peak Particle Velocity Using BGAMs, ANN and SVM: A Case Study at the Nui Beo Open-Pit Coal Mine in Vietnam." *Environmental Earth Sciences* 78(15):1–14. doi: 10.1007/s12665-019-8491-x.

Pawłowski, Wojciech, Łukasz Matyjasek, Katarzyna Cieślak, and Monika Karpińska. 2017. "Contamination with Explosives in Analytical Laboratory Procedure." *Forensic Science International* 281:13–17. doi: 10.1016/j.forsciint.2017.10.018.

Peng, Q., D. Y. Zhou, H. Wu, L. L. Ma, and Q. Fang. 2022. "Experimental and Numerical Studies on Dynamic Behaviors of RC Slabs under Long-Duration near-Planar Explosion Loadings." *International Journal of Impact Engineering* 160(September 2021). doi: 10.1016/j.ijimpeng.2021.104085.

Savaş, S., M. Ulker, S. Turgut, and D. Bakir. 2021. "Determination of Energy Damping upon Impact Load in Reinforced Concrete Sandwich Plates with Different Core Geometries." *Scientia Iranica* 28(6A):3082–91. doi: 10.24200/sci.2021.56554.5165.

Sevim, Baris, and Ahmet Tugrul Toy. 2020. "Structural Response of Concrete Gravity Dams under Blast Loads." *Advances in Concrete Construction* 9(5):503–10.

Tarlochan, Faris. 2021. "Sandwich Structures for Energy Absorption Applications: A Review." *Materials* 14(16). doi: 10.3390/ma14164731.

UFC 3-340-02. 2008. "Structures to Resist the Effects of Accidental Explosions,." *U.S. Army Corporations of Engineers*.

Wang, Fang, Yew Kong, Mark Wan, Oi Yi, Karen Chong, Chee Hiong Lim, Edwin Tze, and Meng Lim. 2008. "Reinforced Concrete Slab Subjected to Close-in Explosion." *LS-DYNA Anewnderforum. Bamgerg* (July):21–28.

Wei, Jie, Jun Li, and Chengqing Wu. 2020. "Behaviour of Hollow-Core and Steel Wire Mesh Reinforced Ultra-High Performance Concrete Columns under Lateral Impact Loading." *International Journal of Impact Engineering* 146(September):103726. doi: 10.1016/j.ijimpeng.2020.103726.

Yang, Dapeng, Bei Zhang, and Guojun Liu. 2021. "Experimental Study on Spall Resistance of Steel-Fiber Reinforced Concrete Slab Subjected to Explosion." *International Journal of Concrete Structures and Materials* 15(1). doi: 10.1186/s40069-021-00459-8.

Zhang, Yongliang, Kai Zhao, Yongchi Li, Jincai Gu, Zhongbao Ye, and Jian Ma. 2018. "Study on the Local Damage of SFRC with Different Fraction under Contact Blast Loading." *Computers and Concrete, An International Journal* 22(1):63–70.

Zhao, Chunfeng, Xin Ye, Kaicheng He, and Avinash Gautam. 2020. "Numerical Study and Theoretical Analysis on Blast Resistance of Fabricated Concrete Slab." *Journal of Building Engineering* 32(May 2019):101760. doi: 10.1016/j.jobe.2020.101760.

Zhao, Xiaohua, Gaohui Wang, Wenbo Lu, Guangdong Yang, Ming Chen, and Peng Yan. 2021. "Experimental Investigation of RC Slabs under Air and Underwater Contact Explosions." *European Journal of Environmental and Civil Engineering* 25(1):190–204. doi: 10.1080/19648189.2018.1528892.