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Detection, Neutralization, and Destruction: The Limits of Israel's Strategy against Gaza's Tunnels

اكتشاف الأنفاق وتدميرها/ تحييدها: محدودية الاستراتيجية الإسرائيلية تجاه أنفاق غزّة

Abstract: Ever since taking control of the Gaza Strip in 2007, Hamas has heavily invested in underground infrastructure. It has developed a massive tunnel network that it regards as both an economic artery and a geo-strategy that helps withstand any Israeli attack or siege on Gaza. This tunnel network has thus become central to Hamas's defensive strategy in resisting Israel and its superior military force. In turn, Israel has made this tunnel network a major target in each of its wars on the Gaza Strip since 2014. This study seeks to understand Israel's military strategy against the tunnels in Gaza and evaluate its effectiveness. It examines the various Israeli initiatives to tackle the tunnels, including the establishment of special military units, and the use of new technologies to detect, destroy, or neutralize them, outlining the limitations of each of these technologies.

Keywords: The Gaza Strip; Hamas; Israel; Tunnels; Military Technology.

ملخص: منذ سيطرة حركة المقاومة الإسلامية «حماس» على قطاع غزّة في عام 2007، طوّرت شبكة أنفاق ضخمة عُدّت الشريان الاقتصادي لعقدٍ من الزمان، وظلّت بنية جيوستراتيجية تُساهم في مقاومة الحصار والتفوق العسكري الإسرائيلي، وتؤدي دورًا مهمًا أثناء الحروب الإسرائيلية على غزّة حتّى اليوم؛ ما جعل تدمير الأنفاق هدفًا رئيسًا للحروب الإسرائيلية على غزّة منذ حرب عام 2014. تسعى هذه الورقة لفهم الاستراتيجية العسكرية الإسرائيلية في مواجهة أنفاق غزّة وتقييم فاعليتها، من خلال بحث المشاريع والوحدات العسكرية الإسرائيلية لمكافحة الأنفاق، والتقنيات المطوّرة لاكتشافها وتدميرها وتحييدها، ومحدودية هذه التقنيات في حالة غزّة.

كلمات مفتاحية: قطاع غزّة؛ حماس؛ إسرائيل؛ الأنفاق؛ التقنيات العسكرية.

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Introduction

On 7 October 2023, the Izz al-Din al-Qassam Brigades, the military wing of the Palestinian Islamic Resistance Movement (Hamas), launched an attack on Israeli targets, the first of its kind in the history of the Palestinian armed struggle. Dubbing its assault "Operation Al-Aqsa Flood", the Qassam Brigades stormed dozens of Israeli military positions and settlements adjacent to the Gaza Strip, fired 5,500 rockets and shells, neutralized Israeli observation and transmission towers as well as communications and jamming systems, and smashed gaps through the separation wall surrounding the Gaza Strip. It mobilized some 4,500 fighters (3,000 in the assault and 1,500 in support roles) and targeted the Israeli army's Gaza Division in no fewer than 15 positions, and attacked another 10 military installations and guards at 22 kibbutzim. It also expanded beyond the Gaza Division to include the Camp Iftach base near Zikim, the Katsa naval base, the war emergency command centre, the Yad Mordechai kibbutz, the Orem base, the Tselem base, and the Mishmar HaNegev kibbutz.[1]

Israel responded on the same day by launching an operation dubbed "Iron Swords", with the stated aim of removing Hamas from power and destroying the group's military capabilities. On 27 October, after 20 days of intense, unprecedented bombing from the air, land, and sea, the operation expanded into a ground invasion of the Gaza Strip.

Despite inflicting massive destruction via extensive airstrikes, Israel has been unable to defeat Gaza fighters or seriously degrade their combat effectiveness. While they have suffered losses in terms of personnel and capabilities, they were still able to fire missiles at cities within the occupied territory and inflict casualties on Israeli forces during ground battles inside Gaza, attacking military vehicles and soldiers in various parts of the Strip, killing dozens of Israeli soldiers, and wounding hundreds of others.

The Israeli army understands that its greatest challenge since it sent in ground troops has been the underground tunnel network developed by Hamas since it took over the Strip in 2007. These subterranean passageways had already proved their effectiveness during Operation Protective Edge (8 July-26 August 2014), a comprehensive Israeli assault on Gaza. One Israeli soldier who fought Hamas fighters during that battle later remarked: "It was like I was fighting ghosts. You don't see them".[2]

The Israeli army realizes out of experience from previous wars on Gaza that tunnels cannot be tackled through aerial bombardment alone. Rather, a ground intervention of troops capable of conducting underground operations is required.

This study analyses Israel's military strategy toward the tunnels in the Gaza Strip, exploring the methods and technologies the Israeli army uses to locate and destroy or neutralize them, and the limits of these methods. It also examines how Israel's strategy has evolved since Operation Cast Lead (27 December 2008 to 18 January 2009), when it enacted a far-reaching incursion into the territory, and made the destruction of this vital Palestinian infrastructure its topmost priority.

Israeli Initiatives for Tackling the Tunnels

Israel has introduced several initiatives to try and tackle Palestinian tunnels. In August 2014, the Israeli army announced that it was developing the "Iron Spade", the underground equivalent of its Iron Dome rocket

[1] This was declared in a video message by the al-Qassam Brigades spokesman Abu Obaidah on 12 October 2023, five days after the operation. See: Alaraby TV, "Kalimat al-Nāṭiq al-Rasmi Bi-Ism Katāʾib al-Qassām ʿAbū ʿUbaydaʾ Ḥawl Mujrayāt Maʿrakat #Ṭūfān_al-Aqṣā," *X*, 12/10/2023, accessed on 29/1/2024, at: http://tinyurl.com/28ntfm5e

[2] "'Like fighting ghosts': The challenge the IDF faces in destroying Hamas's tunnels," *The Times of Israel*, 28/10/2023, accessed on 28/1/2024, at: http://tinyurl.com/skcfy4n6

defence system. The Iron Spade aims to detect tunnel digging operations via sensors designed to detect underground excavations and cavities, which would then be destroyed using a new generation of robots.[3]

At the beginning of 2016, the Israeli Ministry of Defence began implementing the first construction phase of a barrier against offensive tunnels in the Gaza Strip, a series of engineering works dubbed "Zohar Hadrom" (Glow of the South).[4] The barrier, stretching the entire 65-kilometer border of the territory and completed in 2018 with a price tag exceeding $1 billion, was implemented in three stages: an underground concrete barrier, a six-meter wall, and surveillance and sensory systems to monitor activity both above and below ground.[5] In 2016, the Israeli army set up a technological laboratory to detect and locate tunnels. The lab is dedicated to field research, scanning, and monitoring underground cavities and improving existing technologies. The army claimed in April 2018 that the system had "detected and thwarted" five tunnels.[6]

Further, the Israeli Combat Engineering Corps set up dedicated forces for underground warfare. The most prominent of these is the Yahalom unit, which specializes, among other things, in detecting, evacuating, and destroying tunnels, demolishing and blowing up buildings, handling and neutralizing explosives, building explosive devices and bombs, clearing complex minefields. After the 2014 war, the unit was reorganized, and two additional sub-units were added to it. Now it includes five sub-units specialized in disposing explosive ordnance, the Sayfan unit specialized in dealing with non-conventional weapons, the Yael unit for engineering reconnaissance, and the Samur unit, which focuses on tunnel warfare.

Since 2016, the Yahalom unit has gradually expanded from 400 to 900 fighters experienced in complex military engineering missions.[7] This expansion came in response to the challenges the unit had faced in Operation Protective Edge, such as delays in destroying newly discovered tunnels.[8] Thus, the number of personnel specialized in dealing with tunnels in the 2023-2024 Gaza war has thus doubled since the 2014 war.

Within the Yahalom unit, the Yael and Samur sub-units are the most important when it comes to tunnel warfare. The Yael sub-unit operates under the command of the Gaza Division, and is charged with the tasks of locating, mapping, and destroying offensive tunnels, in addition to integrating ground data with intelligence and technological data to create unified operational plans. The Samur sub-unit tackles weapons caches and tunnels, while also specializes in underground combat detecting and destroying tunnels. Its personnel receive extensive training on working in tunnels, including communications and breathing systems,[9] as well as on operating tunnel exploration robots, detonating bombs, and using trained military dogs to detect explosives and attack fighters.

Tel Aviv company Roboteam has developed robots for deployment in tunnels operations, including the ultra-light, throwable Individual Robotic Intelligence System (IRIS) "throwbot", a reconnaissance robot capable of autonomously moving within tunnels and transmitting images using sensors that detect objects and people. There are also robots capable of locating and detonating booby traps using sensors and special equipment. They are similar to the US Marine Corps' autonomous ground vehicle, the Gladiator,

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[3] "Israel to Develop 'Iron Spade' to Counter Hamas," *Alarabiya*, 17/8/2014, accessed on 20/5/2020, at: https://tinyurl.com/yckks25h

[4] Meaning Israeli settlements close to the Gaza Strip.

[5] Omer Dostri, "The Buildup of Forces for IDF Underground Warfare," *Scholarship*, The Jerusalem Institute for Strategy and Security, 15 January 2019, p. 5, accessed on 31/10/2023, at: https://tinyurl.com/53v8xw5h

[6] "Technological Laboratory for Tunnel Detection and Location," *Israel Defense Forces*, 15/4/2018, accessed on 31/10/2023, at: https://tinyurl.com/ypk5sukw

[7] "Yahalom Unit," *Israel Defense Forces*, 28/12/2021, accessed on 31/10/2023, at: https://tinyurl.com/4tr54t6t; "This is the IDF's Plan to Combat Hamas Terror Tunnels," *Israel Defense Forces*, 27/11/2016, accessed on 31/10/2023, at: https://tinyurl.com/3k7p9whj

[8] Raphael D. Marcus, "Learning 'under Fire': Israel's Improvised Military Adaptation to Hamas Tunnel Warfare," *Journal of Strategic Studies*, vol. 42, no. 3-4 (2019), pp. 358-359.

[9] Yiftah S. Shapir & Gal Perel, "Subterranean Warfare: A New-Old Challenge," in: Anat Kurz & Shlomo Brom (eds.), *The Lessons of Operation Protective Edge* (Tel Aviv: Institute for National Security Studies, 2014), p. 55.

which contains sensors and a 7.62 mm automatic weapon. The Israeli army further uses trained military dogs from the Oketz unit to sniff out explosives, locate entrances, and attack armed individuals.[10]

The growing threat posed by tunnels prompted then Gaza Division Commander Yehuda Fox to set up in June 2018 a specialized underground combat unit consisting of a laboratory and two sub-units. The laboratory is known as "The Brain", and its team includes experts from the Ministry of Defence, geologists, intelligence officers, and military and civilian advisors. The two sub-units are part of the Gaza Division's two regional brigades (northern and southern), and they are charged with locating and destroying combat tunnels as well as coordinating intelligence information and transferring it to the field. Each sub-unit includes two sections: an engineering force specialized in underground reconnaissance, and a section made up of fighters trained in using special technologies.[11]

The 2023-2024 Gaza war has tested Israel's ability to tackle the tunnels, first and foremost, through the "smart" border wall, which had already proved unable to prevent Palestinian infiltrations over the past two years, and was then totally overrun by Hamas on 7 October.[12] Nor has the wall succeeded in preventing the spread of tunnels designed to infiltrate Israel. For example, the Israeli army announced on 17 December 2023 that it had discovered an al-Qassam Brigade tunnel, the largest of its kind, extending some four kilometres from the Jabalia district to an area inside the occupied territories near the Erez crossing. The tunnel was 50 meters deep and spacious enough to allow cars to pass through.[13]

Israel's current war has also demonstrated the limited combat effectiveness of the Yahalom unit despite its advanced training. Many of its personnel have been already killed in the 2023-2024 Gaza war, including its deputy commander.[14] Soldiers in the unit rely heavily on robots and police dogs when dealing with tunnels, and are reluctant to enter or fight inside the tunnels themselves. According to one testimony, they even used a young man from Gaza as a human shield, forcing him to wear an explosive belt and a GoPro camera, wrapping a rope around his waist, and coercing him to enter a tunnel, knowing that the explosive belt would be detonated if the camera detected Palestinian fighters.[15]

Tunnel Detection Techniques

Detection is Israel's first challenge in its campaign against tunnels in Gaza. The Israeli army uses various techniques for this purpose, including excavations and sending in cameras or robots to infiltrate locations suspected of having tunnels. The army has long relied on traditional intelligence-gathering methods, primarily the recruitment of collaborators, whom Hamas has deterred in recent years through its Al-Majd security apparatus.

The Israeli Air Force also uses reconnaissance aircraft to monitor suspected digging sites or trucks suspected of transporting soil from such sites. However, this method has almost never succeeded in

[10] "Robots and Attack Dogs: What Israel Brings to Tunnel Combat," *The National News*, 31/10/2023, accessed on 1/11/2023, at: https://tinyurl.com/mrxv4ybj

[11] Dostri, pp. 4-5.

[12] On the combat effectiveness of Palestinian militants' infiltration operations from Gaza and the evolution of their tactics against the Israeli barrier, see: Yara Nassar, "Khalf Khuṭūṭ al-ʿAduw: al-Fāʿiliyyah al-Qitāliyyah li-ʿAmaliyyāt Tasallul Katāʾib al-Qassām fī Qiṭāʿ Ghazzah," *Strategic Papers*, no. 13, Arab Center for Research and Policy Studies, 8 January 2024, accessed on 18/1/2024, at: http://tinyurl.com/2dcas9ej

[13] Dov Lieber, "Israeli Military Reveals Tunnel It Says Hamas Built for Large-Scale Attack," *The Wall Street Journal*, 17/12/2023, accessed on 18/12/2023, at: https://tinyurl.com/2b7xjskp

[14] "IDF announces deaths of 2 soldiers, raising Gaza ground op toll to 131," *The Times of Israel*, 19/12/2023, accessed on 19/12/2023, at: https://tinyurl.com/3b4c933d

[15] Abeer Ayyoub, "Israel-Palestine war: Palestinian says soldiers sent him into Hamas tunnel strapped with bombs," *Middle East Eye*, 15/12/2023, accessed 19/12/2023, at: https://tinyurl.com/2jvcxpav

discovering tunnels themselves, as tunnel entrances are dug within enclosed spaces (buildings, agricultural greenhouses, and so on).[16] It is also difficult to locate the exits of offensive tunnels used for infiltrating Israel, because the final few metres leading to the exit are usually only dug immediately before executing the attack.

This situation has pushed Israel to adopt and develop various other technologies to detect tunnels, including Ground Penetrating Radar, capable of underground exploration to a limited depth; geophones, a type of motion detector that detects digging sounds; traditional seismic sensor devices; and certain techniques used in oil and gas exploration, such as controlled detonations to detect echoes, which can then be analysed to locate underground cavities. After one tunnel opening is found, army technicians also use the "purple hair" technique to find other exits for the same tunnel network. Israeli soldiers do this by throwing a smoke bomb into the tunnel then monitoring the surrounding area for pillars of purple smoke, rising like strands of hair, which helps locate other nodes connected to the entrance in question.

Israel has used these various technologies in its anti-tunnel efforts, such as the Iron Shovel and Zohar Hadrom projects, as well as deploying them through specialized companies within the Israeli army's combat engineering corps. Yet there are various shortcomings associated with each of these technologies. For instance, Ground Penetrating Radar is ineffective against heterogenous soils comprising sand, clay, and rock, and could be impeded by walls and other underground remains. Geophones are not effective at detecting completed tunnels. Controlled detonations to detect echoes are of limited accuracy compared to their use in oil and gas exploration. Traditional seismic sensors get interrupted by vibrations from road traffic, interfere with heavy agricultural equipment, only target tunnels up to 20-30 meters deep, and are ineffective in sandy soil, which muffles the sound of digging operations. Finally, the purple hair technique requires locating and accessing at least one tunnel entrance first and is ineffective if other tunnel entrances are closed or far away.[17]

The new technologies that Israel has developed and used to destroy and/or control the Gaza tunnels have had limited success for six reasons:

1. They are mainly aimed at detecting uncompleted tunnels still under excavation;
2. They target tunnels of limited depth and are unable to reach deeper or multi-layered passages;
3. They specifically target offensive tunnels built for infiltrations into occupied territories, and are unable to reach tunnels within Gaza except during extensive ground incursions;
4. The sandy nature of the soil in the Gaza Strip muffles the sound of drilling and hinders the work of sensors, unlike the rocky soil in northern Palestine and on the border with Lebanon;
5. Detecting tunnels requires knowing where their entrances are but detection of a tunnel entrance does not necessarily reveal its path, which may wind or branch into more than one tunnel, with multiple entrances and exits;
6. The scanning techniques mentioned above require soldiers on the ground capable of operating large and unwieldy devices in exposed areas, placing them at risk of being targeted by snipers, artillery, shells, or booby traps.

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[16] Eado Hecht, "The Tunnels in Gaza," Testimony before the UN Commission of Inquiry on the 2014 Gaza Conflict (February 2015), accessed on 2/1/2023, at: https://tinyurl.com/5dye8xjk

[17] See: Raphael S. Cohen et al., *From Cast Lead to Protective Edge: Lessons from Israel's Wars in Gaza* (Santa Monica: RAND, 2017), pp. 99-100; Ian Slesinger, "A cartography of the unknowable: Technology, territory and subterranean agencies in Israel's management of the Gaza tunnels," *Geopolitics*, vol. 25, no. 1 (2020), p. 33; Adam Goldman, Helene Cooper & Justin Scheck, "Gaza's Tunnels Loom Large for Israel's Ground Forces," *The New York Times*, 28/10/2023, accessed on 31/10/2023, at: https://tinyurl.com/yek5scf7

Technologies for Tunnel Destruction and Neutralization

Modern armies typically rely on airstrikes to destroy tunnels. While they are unable to reach tunnels deep underground, such strikes are able to destroy or at least close tunnel openings leading to the surface, rendering the underground infrastructure useless. However, this does not necessarily succeed on a tactical level, especially if there is a lack of intelligence about the locations of the tunnels, and if the targeted areas are built up and are densely populated.

This is certainly the case in Gaza, where Israeli air raids have left massive destruction without causing serious damage to Palestinian combat infrastructure. Israeli forces have struck more than 11000-12000 targets inside Gaza[18] in less than one month into the 2023-2024 Gaza war,[19] and claim that they have targeted more than 15 thousand military targets. Yet as in previous assaults between 2008 and 2021, air power alone cannot achieve Israel's stated mission, and defensive tunnels continue to play a decisive role in the battle, as do "missile launchers", which are hidden inside tunnels and used for firing rockets.

Therefore, once a tunnel is discovered, and before resorting to ground technologies to destroy/neutralize it, military excavators and bulldozers are used to disable any booby traps or devices that could injure or kill soldiers, help to map its layout, and dig canals through which destructive agents such as bombs or floodwater can be delivered. Then the army uses various techniques to destroy the tunnels beyond repair or at least neutralize their battle effectiveness.

The various technologies that Israel has used to destroy or neutralize tunnels have been entirely imported from the US. Those delivered by air involve dropping heavy bombs such as "bunker busters" and thermobaric bombs on suspected tunnel sites, while those operated from ground level involve destroying the tunnel with kinetic drilling, flooding it with bulk emulsion explosives (a type of industrial explosive primarily used in mining, quarrying, and construction), water dumping, and Sponge Bombs.

Bunker buster bombs penetrate deep into the ground and have a high explosive destruction capacity targeting the toughest fortifications and tunnel structures, whether these are made of pure metal or a metal-concrete mix. Such bombs come in two types. The first has a single explosive head and a fuse to delay the explosion, so that the bomb is not simply detonated by the impact of landing. Rather, the bomb's weight allows it to penetrate the ground before exploding. The second type consists of two bombs and a small device that creates a hole and penetrates deep into the ground so the main charge can then detonate, causing the greatest possible amount of destruction.[20]

Bunker buster munitions used by Israel include the GBU-39 small-diameter guided bomb, which weighs 129 kg and can penetrate a meter of concrete, the GBU-28, which weighs 2,300 kg and can penetrate up to 30 meters of fortifications, and the MK-84 unguided bomb, which can penetrate three meters of concrete and reach 11 meters into the ground. The US first used the latter against tunnels during the

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[18] See: "'The Gospel': how Israel uses AI to select bombing targets in Gaza," *The Guardian*, 1/12/2023, accessed on 29/1/2024, at: http://tinyurl.com/ysbzw57h; "Israel Has Struck More Than 11,000 Terror Targets in Gaza," *FDD*, 1/11/2023, accessed on 29/1/2024, at: http://tinyurl.com/4tn975yv; Geoff Brumfiel, "Israel is using an AI system to find targets in Gaza. Experts say it's just the start," *NPR*, 14/12/2023, accessed on 29/1/2024, at: http://tinyurl.com/yy69ta65

[19] It should be mentioned that this number is absurd by the standards of military analysis. Any analyst who accepts that Gaza contains this staggering number of targets is either willfully suspending disbelief that the Israeli Air Force has completely lost its professionalism and morality and is blindly bombing civilian homes as part of an extermination plan, or believes that Hamas has operational combat capabilities of a vast magnitude. Israel itself does not have a comparable number of worthwhile military targets. Creating an airstrike target list of this length in an area that can be flown over in less than ten minutes is pure planning folly and a diversion of technology away from its intended purpose. Were the air force to impose its monopoly and the stronger party to dominate the skies, targeting such a vast number of objectives becomes a cover for mass killing that cannot be measured by standards of military effectiveness.

[20] Urooba Jamal & Alex Gatopoulos, "'Israel Doesn't Care about Collateral Damage': Bunker Busters Used in Gaza," *Aljazeera*, 9/10/2023, accessed on 6/11/2023, at: https://tinyurl.com/yeuawxns

Vietnam War. Israel used it during the wars of 2014 and 2021, during which the bomb caused indiscriminate civilian deaths more than it destroyed tunnels.[21] However, these bombs are ineffective for tunnels deeper than 30 metres, and they only destroy part of the tunnel vertically without necessarily neutralizing the rest, especially tunnels with multiple entrances and branches.

Thermobaric bombs, also known as vacuum bombs, have a circular explosive force with a radius of about 300 meters. They consist of a solid fuel munition and two explosive charges, and unlike traditional explosives that consist of an oxidized mixture of fuel, they use the atmospheric oxygen at the target site. When a thermobaric bomb reaches its target, an initial explosive charge detonates, opening a canister that disperses an explosive fuel as a cloud of vapour, which penetrates defences and openings. The second charge then detonates and ignites this cloud, generating a massive fireball and blast wave that also creates negative pressure, sucking oxygen out of the air around the explosion. This increases the ability of thermobaric bombs to loosen the foundations of targeted buildings or tunnels and thus cause them to collapse, compared to conventional bombs that only destroy the target from the side of the explosion, rather than from all sides. As the air around the explosion is emptied of oxygen, and due to the high temperature generated, this type of bomb also kills those inside the tunnel or the blast radius, through suffocation and/or burning. However, its dependence on the oxygen present in the vicinity makes it unsuitable for use underwater, at high altitudes, and in bad weather conditions.[22] Further, these bombs are banned internationally.

The kinetic excavation technique involves dropping Joint Direct Attack Munitions (JDAM), with delayed detonation fuses, at regular intervals along the length of a tunnel to destroy it. However, experience has demonstrated the difficulty of adjusting the munitions to explode at the correct depth, and the resulting debris hinders the work of tunnel detection and identification. In the same way, "Emulsa" water-gel explosives may be used to destroy the tunnel, but destroying the average tunnel requires flooding it with between 9-11 tons of this material and securing it for a long period,[23] which also demands the presence of ground forces.

The same is true of the method of flooding tunnels with cement or water, which requires a long time and large quantities of water. Indeed, the Israeli army installed huge seawater pumps near Gaza's Al-Shati refugee camp and other sites in the Strip in mid-November 2023. The process of pumping water to flood the tunnels began on 13 December 2023 and was expected to take several weeks and about one million cubic meters of seawater, according to Israeli estimates.[24] While it could force fighters out of the ground and pollute groundwater and soil, it would not destroy the advanced concrete tunnels.

Unlike the previous technologies, sponge bombs do not destroy tunnels, but rather attempt to neutralize the danger they pose to soldiers conducting ground incursions. They contain two chemicals separated by a mechanism that disappears when the bomb is activated. The chemicals combine to form a solid, spongy substance that blocks tunnel openings and is difficult to remove. However, to deploy this method effectively, Israeli forces must find all the entrances of the tunnel network, a near-impossible task in the case of defensive tunnels with multiple exits both inside and outside buildings. Moreover, these bombs

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[21] "Fuelling Conflict: Foreign Arms Supplies to Israel/Gaza," *Amnesty International* (February 2009), accessed on 27/11/2023, at: https://tinyurl.com/y5abz45y; Mohammed Omer, "Gaza Outraged at Israel's Use of GBU-28 Missile," *Middle East Eye*, 12/2/2015, accessed on 27/11/2023, at: https://tinyurl.com/bddmdk6v; "US Must Monitor Use of US Weapons in Gaza," *Amnesty International*, accessed on 27/11/2023, at: https://tinyurl.com/5auskxsh

[22] Anna E. Wildegger-Gaissmaier, "Aspects of Thermobaric Weaponry," *Military Technology*, vol. 28, no. 6 (2004), pp. 125-130.

[23] Cohen et al., p. 101.

[24] Nancy A. Youssef, Warren P. Strobel & Gordon Lubold, "Israel Weighs Plan to Flood Gaza Tunnels With Seawater," *The Wall Street Journal*, 4/12/2023, accessed on 5/12/2023, at: https://tinyurl.com/5a933p4b; Nancy A. Youssef, Michael R. GordonFollow & Dov Lieber, "Israel Begins Pumping Seawater Into Hamas's Gaza Tunnels," *The Wall Street Journal*, 13/12/2023, accessed on 13/12/2023, at: http://tinyurl.com/68s3heaz

pose a danger to their operators; some Israeli soldiers have lost their sight when using them.[25] Furthermore, rather than destroying tunnels, they simply block their entrances.

In addition to these techniques, the Israeli army uses various methods targeting individuals inside the tunnels. Israeli military protocol generally prohibits regular ground forces from entering tunnels to avoid the risk of being killed or captured. Therefore, to fight Palestinian fighters underground, the army resorts to sniffer dogs, robots, oxygen withdrawal, and the use of chemical weapons such as nerve gas, which temporarily paralyses people. In addition, Israel resorts to long sieges aimed to cut food supplies on Hamas leaders and fighters, and the fuel necessary to operate the generators providing lighting and ventilation underground, which could force them up to the surface.

The Limits of Israeli Anti-Tunnel Technologies

The processes of destroying or neutralizing tunnels are not necessarily easier than the processes of detecting or locating them. Although bunker busters and thermal bombs are the most effective technologies at destroying tunnels, they are debilitated by Gaza's geography, where multi-layered tunnels of varying depths are located in a highly dense urban area of less than 365 km^2. Conversely, this means that Israel's bombing of buildings above ground impedes its efforts to expose or destroy tunnels, as piles of rubble provide additional fortification to the tunnel network. Interconnected operational tunnels underneath urban areas also give Palestinian fighters the freedom of movement and allow them to carry out defensive attacks against military vehicles and ground forces, using sniper rifles, grenades, explosive devices, and armour-piercing shells.

Moreover, the capacity of these bombs to destroy tunnels is hindered by the engineering of the tunnels themselves, especially logistical tunnels used for the purposes of command and control, internal supply deliveries, and movement of personnel. These tunnels are dug deep underground to avoid detection and bombing, and except for the rooms branching off from them, are narrow, averaging just one meter in width and two in height. They are built by installing successive concrete wall pieces and arches that are prefabricated using concrete moulds, making them more solid and impeding the ability of attacking forces to storm them. Given that the tunnels vary in size, depth, and materials used in their construction, and given their location in urban or open areas, kinetic excavation and flooding with Emulsa explosives or water are also impractical methods. The fact is that each tunnel located by Israeli forces requires individual treatment. Moreover, the effectiveness of Israeli methods of detecting or destroying tunnels is weakened by the ongoing military and operational development of Hamas. The group has not only gained experience from previous Israeli wars on Gaza, but has also benefited from tunnel technologies used in other countries for civilian purposes, such as sewage networks, mine tunnels, and transportation.

Hamas also makes effective use of Open-Source Intelligence (OSINT) which it gathers on the occupying army[26] in order to develop its own offensive tactics and means of defence. Through OSINT, Hamas acquired information related to weaponry, units of the IDF, forces' deployment, drilling mechanisms, training activities, the Israeli mindset, and various aspects of the Israeli society. One example of OSINT's use is a broadcast produced by Hamas's Military Intelligence Department, in which selected segments from Israeli media on topics of interest for Hamas were reviewed with Arabic translation. A broadcast dated 7 April 2008, which was about 17 minutes long, opened with information indicating that the "IDF believed

[25] Dominic Nicholls, "'Sponge bombs' are Israel's new secret weapon to block Hamas tunnels," *The Telegraph*, 25/10/2023, accessed on 10/12/2023, at: https://tinyurl.com/mstbkz98

[26] Netanel Flamer, "'The Enemy Teaches Us How to Operate': Palestinian Hamas Use of Open Source Intelligence (OSINT) in its Intelligence Warfare against Israel (1987-2012)," *Intelligence and National Security*, 2023, pp. 1171-1188.

that the next battle in Gaza would feature substantial subterranean combat and was therefore training for such combat. Next, the broadcast showed a segment on this topic from Channel 10 in which IDF training was documented".[27] Similarly, Hamas has utilized OSINT to develop its tunnel infrastructure. For instance, by learning that Israel forbids its soldiers from entering tunnels, and instead sends robots or military dogs, Hamas has accommodated its subterranean combat methods and was able to exert maneuvering techniques.

Indeed, Gaza's tunnel network has become long and complex, designed to take into account new technologies to locate and destroy them. These defensive features include holes at tunnel entrances to prevent liquid explosives or water from spreading through the network, ventilation holes within tunnels to enable toxic gases to escape, and safe rooms alongside tunnels where fighters can take refuge. Tunnels are also divided into segments by iron doors, which play an important role in blocking gas transmission, dulling the force of explosions, and obstructing invading Israeli forces, robots, or dogs.[28] In addition, the tunnels are now well-equipped with the basic necessities of life, such as food supplies, water, power generators, and ventilation, enabling Palestinian fighters to endure a long war and siege.

Conclusion

The tunnels have been the major military target in the Israeli wars on the Gaza Strip since the 2014 war, during which Israeli Prime Minister Benjamin Netanyahu explained that the goal of the ground operation was to destroy the tunnel network.[29] He announced the same goal during the 2021 war. But Israel has continued to find it hard to detect and completely destroy the tunnels, despite launching no fewer than seven military operations over the last nine years.[30]

This raises doubts over Israel's ability to destroy the subterranean infrastructure of resistance in Gaza at all. Given that tunnels are hidden, Israeli military planners struggle to determine the area from which the threat emanates, identify targets, and set time frames for operations against them. This knowledge gap means that the goal of destroying the tunnels is unrealistic.

During its various military operations against the Gaza Strip, the Israeli army has relied primarily on aerial bombardment, aiming to destroy as much of the tunnel network as possible. However, these strikes are only able to destroy or damage shallow tunnels and block the entrances of some others. This does little to help Israeli forces map out the tunnel network. On the contrary, such a strategy may be an obstacle to the methods described above for detecting or destroying the tunnel network, as vast masses of rubble represent additional fortification for the tunnels and hinder efforts to search for them. The strategy is also costly in terms of Israeli public opinion, given the large number of Israeli prisoners currently being held within the tunnels. Around 60 of them had already been killed as a result of Israeli bombing by November 4 last year, according to the Al-Qassam Brigades.

Unless it takes complete control of the entire Gaza Strip for an extended period, Israel will not be able to defuse this strategic threat. All the technologies and techniques it uses for detecting and locating tunnels require a prolonged presence of personnel on the ground.

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[27] Ibid., p. 1177.

[28] Rami Ahmed, "Anfāq al-Muqāwama al-Filasṭīniyya wa-Taʾthīrahā ʿalā al-Iḥtilāl al-Isrāʾīlī," *Dirāsāt Siyāsiyya*, Egyptian Institute for Studies, 25 February 2020, pp. 30-31, accessed on 1/11/2023, at: https://tinyurl.com/2yk3yzyp

[29] "Netanyahu: Gaza op Will Expand until Quiet Guaranteed," *The Times of Israel*, 21/7/2014, accessed on 31/10/2023, at: https://tinyurl.com/28snkjwd

[30] These operations are as follows: Protective Edge (8 July 8 – 26 August 2014), Magma of the Full Moon (3-6 May 2019), Dawn Cry (12-14 November 2019), Guardian of the Walls (10-21 May 2021), Breaking Dawn (5-7 August 2022), Shield and Arrow (9-13 May 2023), and Iron Swords (7 October 2023 – time of publication). For more information on the Israeli military operations in the Gaza Strip, see: Majd Abuamer & Wadee Alarabeed, "The Israeli War on Palestinian Islamic Jihad: Unity of the Arenas Battle and its Strategic Implications," *Strategic Papers*, no. 6, Arab Center for Research and Policy Studies, 19 September 2022, pp. 6-7, accessed on 1/11/2023, at: https://tinyurl.com/5n8jw7nb

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