

Evaluating the performance and accuracy of blast gauge systems compared to pencil gauges in blast environments: A comparative study

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ABSTRACT: Blast Traumatic Brain Injury (bTBI) is a major concern in modern warfare, with 383,947 cases reported between 2000 and 2018. Soldiers with bTBI face severe health declines, emphasizing the need for proper classification and treatment. This study examines blast wave propagation using full-scale experiments with 1 kg charges at different heights of burst (HoB). Findings show that as HoB increases, incident overpressure decreases by 38%, while impulse remains stable due to rarefaction waves. The results highlight the importance of sensor selection and blast analysis, aiding in protective equipment development and improving numerical models for blast mitigation strategies.

1 INTRODUCTION

The detonation of an explosive charge generates shock waves that primarily affect gas-filled organs such as the lungs, middle ear, and gastrointestinal tract due to differential pressure exerted on tissues [1]. The severity of resulting injuries depends on factors such as the type of explosive, detonation environment, and the individual's proximity to the blast source. In military settings, the extensive use of improvised explosive devices (IEDs) presents a significant challenge, as their unpredictable blast waves expose personnel to multiple injury mechanisms simultaneously. During Operation Enduring Freedom, IEDs were responsible for up to 60% of U.S. military fatalities, highlighting the need for effective injury mitigation strategies [2]. While controlled environments often follow the Friedlander waveform, real-world blast events are affected by environmental structures that alter blast wave propagation, making injuries more severe and unpredictable. Previous studies, such as those by Pandelani and Wium (2018) [3], focused on scaled experiments with 300 g charges, but their applicability to real-world conditions was limited. To address this, the present study expands research with full-scale experiments using 1 kg spherical charges at different heights of burst (HoB). By analyzing incident and reflected pressures, impulse profiles, and wave dynamics through side-on pressure probes and blast gauge sensors (BGS), this study enhances the understanding of blast exposure.

2 METHODS

The tests involved detonating a small, free-in-air spherical charge over a flat concrete surface at a distance of 2 m from the BTD. The detonator was inserted into the top of the charge. The 1 kg charge was positioned at three different heights, referred to as the height of burst (HoB); namely 220 mm, 440 mm and 880 mm measured from the ground to the bottom of the spherical charge. A total of 9 tests, as summarised in Table 1, were performed.

Table 1. Experimental parameters.

Test series	HoB [mm]	Explosive material	Charge mass [kg]	Number of test repetitions
1	220	PE4	1	3
2	440	PE4	1	3
3	880	PE4	1	3

Three quartz free-field ICP blast pressure pencil probes (pencil sensors) type 137A22 from PCB Piezotronics, was used to measure the side-on pressure at the same distance from the charge. The blast gauges were mounted at the same measuring point as the ICP pencil probes as shown in Figure 1.

All the pressure sensors were evenly distributed about the charge at 90° at a standoff distance of 2 m.

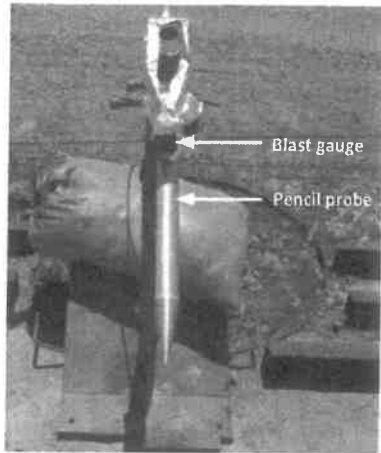


Figure 1. Blast gauge and pencil probe.

3 EXPERIMENTAL RESULTS

The pencil probes, three side-on incident pressures were measured from different positions as per schematic in Figure 2.

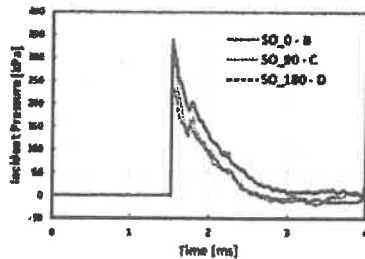


Figure 2. Pencil probe incident pressure profiles for 1 kg PE4 at 220 mm.

The blast gauge sensors (BGS) incident pressure measurements are shown in Figure 3.

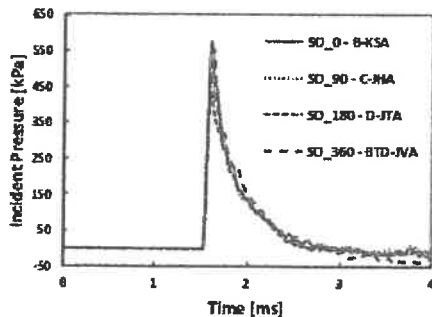


Figure 3. Incident pressure results for 1 kg PE4 at HoB = 220 mm.

4 DISCUSSION

Understanding blast-body interaction dynamics is crucial for assessing injury risks and improving protective measures. Experimental results from side-on pressure probes and blast gauge sensors (BGS) reveal that blast wave behaviour is significantly influenced by the height of burst (HoB), affecting incident and reflected pressures, impulse, and shockwave interactions. Measurements showed that as HoB increased from 220 mm to 880 mm, incident pressure decreased by 38%, aligning with blast wave theory. While peak pressures declined, impulse remained relatively constant due to rarefaction waves extending the blast wave's positive phase. BGS consistently recorded higher pressures than pencil probes, likely due to sensor response differences, with incident pressures reaching 525 ± 28 kPa for BGS versus 341 ± 21 kPa for pencil probes at 220 mm HoB. Impulse values also varied, with BGS capturing higher-frequency components, leading to slightly higher readings across different HoBs. Both sensors exhibited similar trends, though BGS had a slower response time, recording a time to peak of 0.07 ms compared to 0.015 ms for the pencil probe at 880 mm HoB. Despite these differences, both sensor types effectively captured second reflected waves, confirming their reliability in complex blast scenarios. These findings underscore the importance of sensor selection, accurate impulse calculations, and the consideration of rarefaction effects in blast wave modelling.

5 CONCLUSION

The study shows that variations in HoB significantly influence incident pressure and impulse, with rarefaction waves extending blast wave duration. Pencil probes and blast gauge sensors provided consistent data, though response times differed. Findings highlight the importance of sensor selection, accurate impulse calculations, and rarefaction effects in blast modeling for improved structural protection.

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