Gabi Ben-Dor
Oren Sadot
Ozer Igra *Editors*

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Exploration of Methods in the Exploding Wire Technique for Simulating Large Blasts

E. Nof, O. Ram, E. Kochavi, Gabi Ben-Dor, and Oren Sadot

Introduction

Small-scale modeling of explosive events has become an important tool in the investigation of blast wave-structure interactions. In this approach, a full-scale model is miniaturized and subjected to "gram-scale" explosions from detonated micro-charges. While offering a cheaper, faster, and ultimately more manageable alternative to full-scale field tests, small-scale testing also offers better reliability and accuracy in more complex scenarios where numerical simulations become limited. Nevertheless, small-scale experiments introduce other difficulties due to the reliance on the well-known Cranz-Hopkinson "cube-root" scaling law. This scaling relationship is suitable for self-similar open-field experiments but does not necessarily apply to urban scenarios. Additionally, chemical explosive charges of such small quantities might be susceptible to changes in parameters such as the explosive compound compression strength, the humidity of the explosive and of the surrounding atmosphere, the method of ignition, etc. Logistically, the handling and preparing of the experimental setup with these small chemical explosives requires specially trained personnel and permits. To overcome these challenges, the exploding wire (EW) technique offers an elegant substitute to using small chemical charges in scaled-down modeling.

In the EW method, a thin metal wire is connected to a charged high-capacity electrical capacitor. The stored energy is then discharged in a very short time through the wire, causing it to undergo extremely fast joule heating, melt, and ultimately evaporate without virtually any change in volume. The dense, vaporized metal gas expands rapidly while forming a strong blast wave [1–4]. A complete exploding wire system was constructed and calibrated for simulating small spherical blasts, showing high accuracy and repeatability [5]. However, the system had inherent limitations on the scale of the explosions due to the maximum working conditions of the capacitor and the electrical setup. In the current work, a more complex studied scenario, which also required more intense explosions, called for an expansion of the EW method. The following presents the methodology implemented in developing these capabilities while enhancing the reliability of the overall system.

Methodology

The proliferation of technologically advanced weaponry, particularly non-state groups obtaining short- and mid-range missiles [6], has increased the threat to civilian areas and has fostered a higher construction of safe rooms in many security and residential structures. Usually, these rooms are located well away from the exterior wall of the building, often separated by other rooms in the home. A generic structure consisting of such a configuration was chosen as the model to be investigated in the event of an exterior explosive threat as shown in Fig. 1. All windows and inner doors are left open assuming the worst-case scenario. The safe room's blast-resistant entrance door had to be designed in order to withstand the effect of an 800-kg TNT hemispherical surface burst detonating 15 m from the frontal façade of the building. This specific scenario was chosen following an identical setup in a previous work with well-validated numerical simulations [7].

Since the maximum explosion the EW system could generate was equivalent to a mere 0.06-g TNT, a 1:100 scale-down ratio was chosen for the scenario. According to the Cranz-Hopkinson "cube-root" law, in order to properly simulate this scenario, a 0.8-g TNT explosion should be

E. Nof (✉) • O. Ram • E. Kochavi • G. Ben-Dor • O. Sadot
Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel
e-mail: sorens@bgu.ac.il

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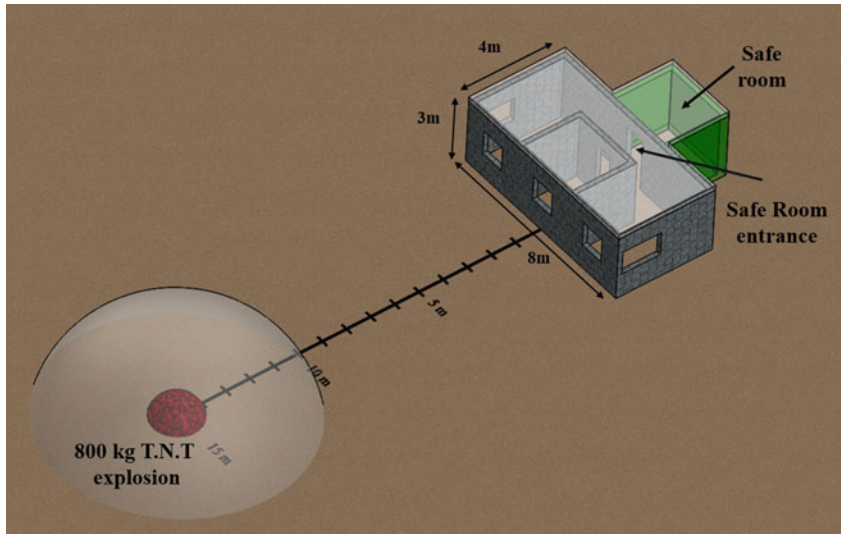

Fig. 1 Illustration of the full-scale scenario. A generic one-story building with three windows at its façade, two side windows, and an inside room leading to an entrance to a safe room (not included in the scenario). The building façade is subjected to an 800-kg TNT explosion at a distance of 15 m from the front façade

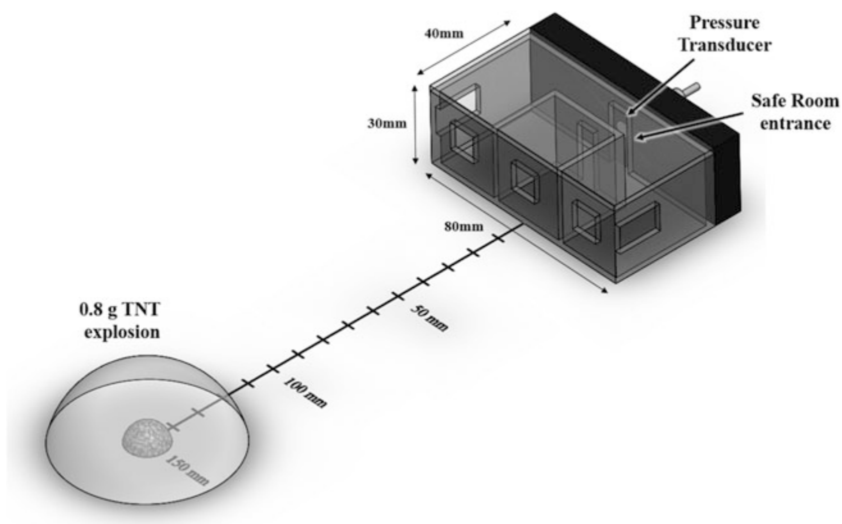

Fig. 2 Illustration of the scaled-down scenario consisting of a 0.8-g TNT explosion 150 mm away from the front façade of a building 80-mm wide, 30-mm high, and 40-mm deep. The small-scale model was constructed from a 2-mm thick polycarbonate sheet machined by CNC

detonated at a distance of 150 mm from the miniature model's façade, as shown in Fig. 2. This ratio was seen as a lower limit for the scaling for practical reasons such as a significantly more tedious miniature model assembly, and more importantly, making the model any smaller rendered mounting diagnostic equipment such as the pressure transducer inside the blast-door entrance to be completely unfeasible. As mentioned earlier, however, the EW system could only generate a maximum 0.06-g TNT explosion, and so a means to amplify the effects on the building had to be created to account for the 0.8-g TNT requirement.

Collimating the blast energy towards the model could be achieved by enclosing the exploding wire in a tunnellike fixture with one end blocked and the other open towards the building façade, thus enhancing the overall loading on the structure. However, introducing such an alteration to the geometry of the problem, particularly the volume in which the blast waves travel, would change more than one parameter. Preliminary testing revealed that one could not hope to achieve both the correct pressure loading profile and the impulse profile as would be produced by a hemispherical explosion. It was therefore decided that simulating the correct impulse profile would take precedence, even at the cost of compromising the shape of the pressure profile. The basis for this decision stems from the fact that the blast door to the safety room reacts primarily to the impulse profile and would be the deciding factor from a defensive standpoint.

The geometry design of the focusing tunnel was developed through a numerical model solved using the commercial code LS-DYNA. The wire was modeled as a cylinder of the length of the real wire and with a radius ten times larger than the real one. The initial energy per unit volume and the density were evenly distributed throughout the cylinder. The density was such that the total weight of the wire in the

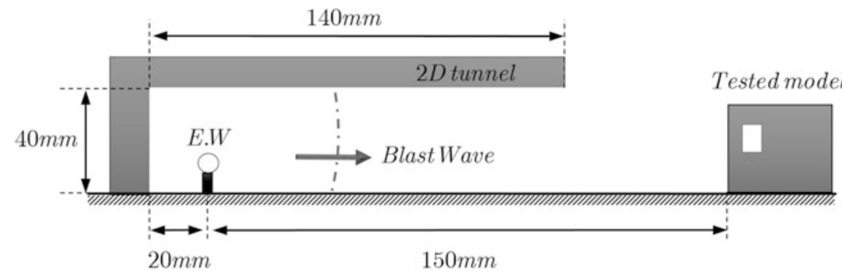

Fig. 3 A schematic illustration of the tunnel used to enhance the loading on the frontal facade of the building. The exact dimension of the tunnel had to be determined by numerical simulations. Different loading will require redesigning the model

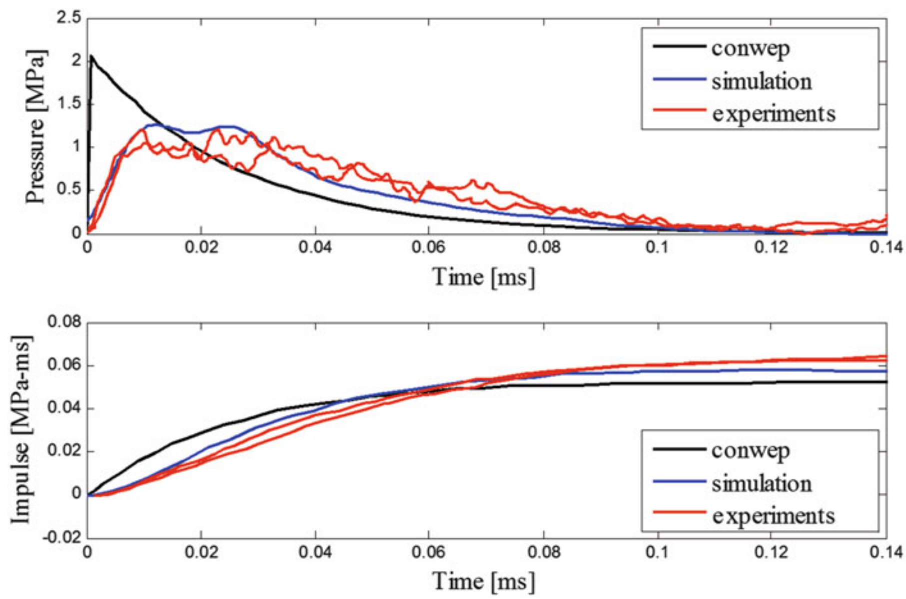

Fig. 4 Reflected pressure and reflected impulse histories measured at 150 mm from the explosion area using the tunnel

model matched the real case. The energy per unit volume had to be calibrated until the pressure history obtained numerically at a distance of 150 mm from the wire agreed with the empirical pressure histories. After the calibration of the explosion in the numerical model, the tunnel was added in the computational model (see Fig. 3).

Once the proper impulse profile from a 0.8-g TNT hemispherical explosion (taken from CONWEP) was achieved using the focusing tunnel in both the simulations and experiments (see Fig. 4), the complete scenario including the miniature building could be introduced and finally compared to the full-scale numerical simulation of the complete scenario.

Results

Figure 4 shows the reflected pressure and impulse profiles produced by a 0.8-g TNT hemispherical surface explosion at a range of 150 mm as computed by CONWEP [8]. These profiles served as the reference to both the collimated experiments and simulations also presented in the same figure. Though the impulse profile was correctly replicated, the pressure profile was smeared and its peak significantly reduced. As mentioned earlier, this compromise was tolerated since the response of the blast-resistant door and the walls are mainly expected to be affected by the impulse of the blast.

Collimating the blast by means of a tunnellike structure proved successful in enhancing the impulse on the structure, and this effect can be explained as follows. Firstly, the additional pressure loading on the building façade is partially caused by secondary reflections generated off of the reflector. These reflected shocks are directed towards the structure façade thereby increasing the head-on pressure. Secondly, the resulted flow field is mainly directed towards the façade, and the added dynamic pressure constitutes the main contribution to the head-on pressure. This compounded effect stems from the combination of the explosion strength, reflector geometry, and the reflector-façade gap distance. Changing any one of these parameters alters the loading, and this modification is difficult to anticipate.

Figure 5 presents results from two groups of experiments. The results in the dashed line are from the numerical simulation of the loading on the blast door in the full-scale scenario with a pure surface blast. The solid lines portray

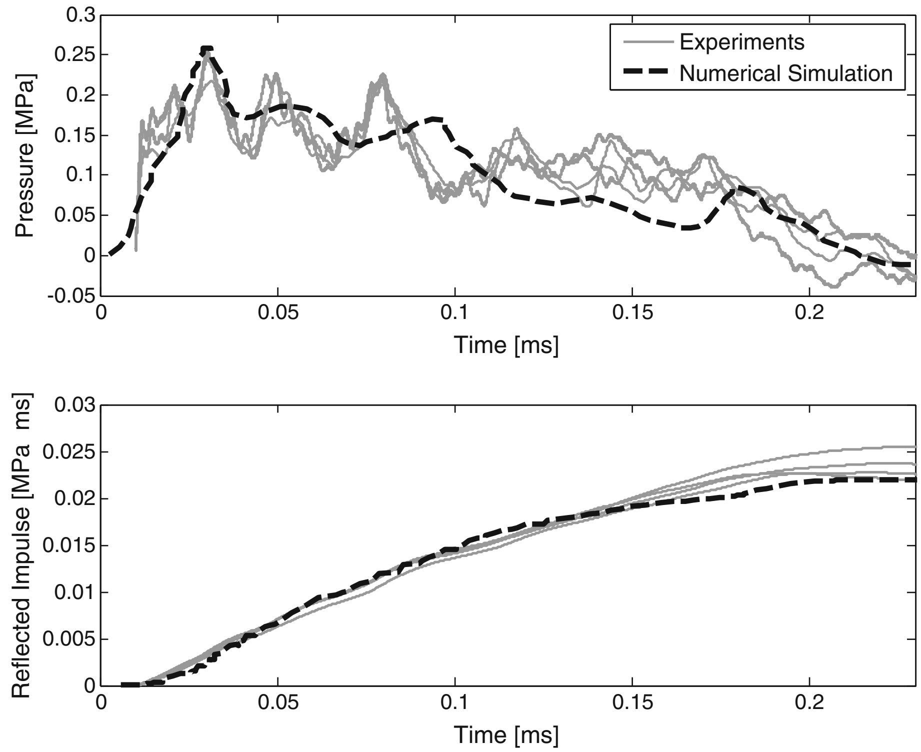

Fig. 5 Comparison between the reflected pressure and reflected impulse histories recorded in the numerical simulation predictions and exploding wire experiments after a scale-up of the latter according to the cube-root scaling law

the scaled-up (by the same ratio) results from repeated experiments of the small-scale scenario using the exploding wire and collimating tunnel and measured on the blast-door entrance at the back of the miniature building. Numerical simulations of the full-scale model were performed using MSC/Dytran commercial software. The numerical model was validated with full-scale experiments and was found to be in good agreement [7]. The results show an excellent agreement between the numerical and experimental results both in reflected pressure and impulse. The experiments were repeated several times in order to ensure that the results are repeatable. These results show that the method used to simulate the blast loading provides a very good tool to predict the loading on the safe-room entrance under the limitations of the scenario's conditions.

Recalling that in the calibration process the impulse was chosen as the determining parameter, it might seem surprising that the pressure profile matches as well. An explanation might be found in the fact that the incident shock wave entering the building gets diffracted and the overpressure profile measured gets "smeared" inside the building. The pressure buildup on the safe-room entrance is achieved by a series of waves rather than one, and since the impulse is retained, the pressure profile must be very similar.

Conclusions

A methodology to simulate large explosion loadings on buildings in a laboratory small scale was presented. The blast wave was created using the exploding wire technique that does not yield a strong enough blast to simulate the desired 800-kg TNT explosion detonated 15 m from a building façade. The model dimensions were arbitrarily chosen to be 1:100 which meant that a 0.8-g TNT equivalent had to be generated, while a free-field wire explosion yielded a mere 0.06-g TNT equivalent. To enhance the loading provided by the exploding wire, a tunnel was used to channel the blast towards the building. It was shown that this method cannot generate the correct loading on the building façade both in pressure and impulse. Faced with this restriction, it was chosen to optimize the tunnel dimensions to match the required impulse. The tunnel dimensions were calculated using a numerical simulation.

Once calibrated, the tunnel was built and tested against the numerical prediction which showed that the impulse loading on the building's façade is similar in both cases. The small-scale structure was manufactured and was subjected to the blast.

After scaling up the small-scale EW results, it was shown that inside the structure, on an entrance to a safe room, both the measured reflected impulse and pressure agreed very well with the numerical predictions. This showed that the impulse at the building façade should be chosen as the determining loading parameter for the tunnel dimension calculation. Due to the numerous diffractions of the shock inside the structure, the pressure measured on the safe-room entrance was also found to be similar to that obtained by numerical simulation in our specific geometry.

References

1. Grinenko, A., Efimov, S., Fedotov, A., Krasik, Y.E., Schnitzer, I.: Efficiency of the shock wave generation caused by underwater electrical wire explosion. J. Appl. Phys. **100** (2006). doi: 10.1063/1.2395603
2. Bennett, F.D.: Energy partition in the exploding wire phenomena. Phys. Fluid. **1**, 515 (1958). doi:10.1063/1.1724375
3. Bennett, F.D.: Shock-producing mechanisms for exploding wires. Phys. Fluid. **5**, 891 (1962). doi:10.1063/1.1706704
4. Bennett, F.D.: Cylindrical shock waves from exploding wires. Phys. Fluid. **1**, 347 (1958). doi:10.1063/1.1705893
5. Ram, O., Sadot, O.: Implementation of the exploding wire technique to study blast-wave-structure interaction. Exp. Fluid. **53**, 1335–1345 (2012). doi:10.1007/s00348-012-1339-8
6. Zohar, E.: The arming of non-state actors in the Gaza Strip and Sinai Peninsula. Aust. J. Int. 37–41 (2015). doi:10.1080/10357718.2014.988206
7. Ostraich, B., Kivity, Y., Anteby, I., Sadot, O., Ben-Dor, G.: Load assessment on safe rooms' doors report. Shock Tube Laboratory, Protective Technologies R&D Center, Faculty of Engineering Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel (2009) (in Hebrew)
8. Hyde, D.: CONWEP, conventional weapons effects program. (1991)