Explosives Engineering, December 2018, pp. 26-28

Feature

Scaled simulation of the blast effects on structures using lego blocks: A pilot study

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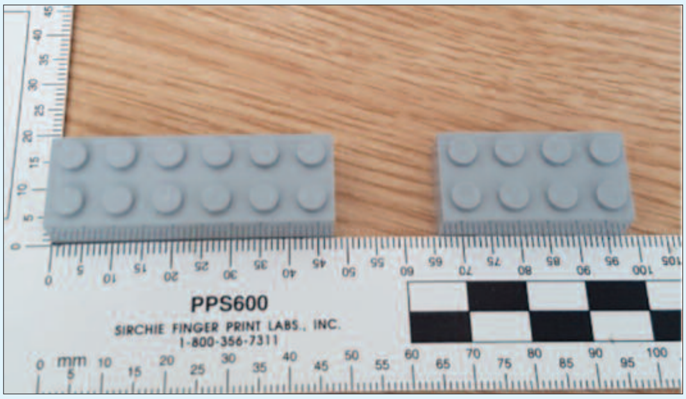
Blast effects on structures is an important topic in this modern age for many practising engineers, including structural engineers designing buildings for safety or weapons engineers attempting to destroy enemy infrastructure. Due to the large costs, time demands, space requirements and expertise required, full scale testing is rarely a feasible approach. As such it is important to be able to effectively model the blast effects on structures. Currently, computer modelling techniques are extensively used, however the results of these models are often difficult to verify, whilst requiring experienced expert users to ensure accurate data.

As it is unfeasible to demonstrate blast effects on structures to students using traditional approaches due to time and cost constraints, the idea of testing instrumented scaled models using materials (LEGO blocks) that are familiar to large portions of the population, readily available and easily assembled, offer a suitable alternative solution. By utilising LEGO blocks, students can design, build and instrument various structural designs. These structures can then be subjected to a blast wave generated from the detonation of a Hydrogen/Hydrogen-Oxygen balloon within a controlled laboratory environment. To date, this approach has been explored throughout literature[1,2] and has proven to yield results in good agreement with large scale testing and computational models. As such, this article details the initial work in developing the technique, the data outputs and the methods of exploitation.

Method

Lego Bricks were supplied in the form of Classic Large Creative Brick Box sets (LEGO 10698) and were purchased from Amazon UK. To reduce complexity, Lego blocks used in construction were limited to 2x4 (Item No: 3001) and 2x6 (Item No: 2456) brick types (Figure 1). Sets purchased were chosen as they provided the best brick to price ratio for the required blocks. Using these blocks,

Figure 1: Lego blocks used in model construction.

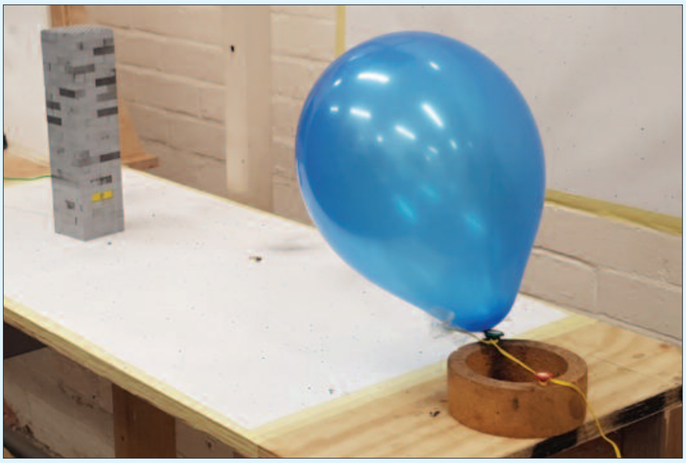


model structures of dimensions 250 x 64 x 64 mm were produced and offset at a given standoff distance to represent an idealised building. Shock events were then generated using two distinct methods; oxygen-hydrogen filled balloons and a shock tube. A total of eight tests were conducted tests for each methods.

Balloons

Party balloons, produced from natural rubber latex were supplied by Amazon UK and filled with an approximate mixture of 50-50% of oxygen-hydrogen. Each fluid was individually injected into the balloon, where mixture naturally occurred. Once filled, balloons were tied off by hand and stored until used. During use, individual balloons were secured to a cork based sample holder using a typical stationary drawing pin. The electric match was then placed in contact with the surface of the balloon, and subsequently detonated using an electronic match. Figure 2 shows a typical experimental arrangement.

Figure 2: Balloon experimental setup.

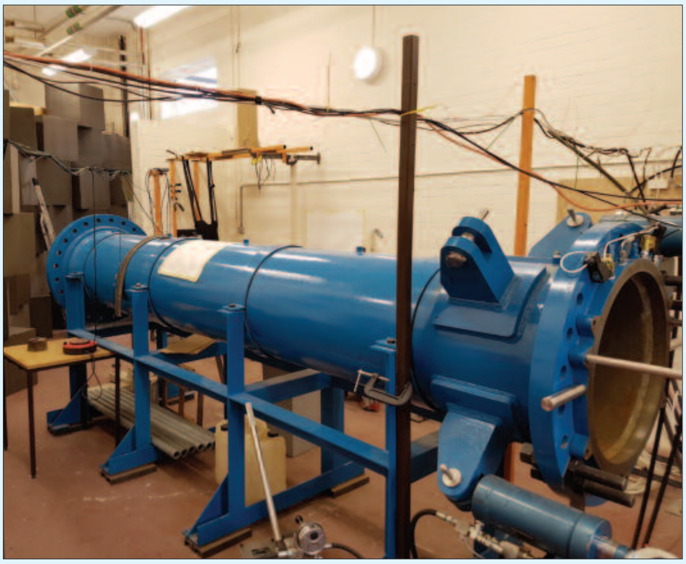


Shock tube

The shock tube comprises of a straight walled tube with external and internal diameters of 600mm and 565mm respectively. The device was 4550mm in length, and comprised of a 4000mm driven chamber, and a 500mm driver chamber separated by a 50mm intermediate chamber (Figure 3). Pressurisation of the driver chamber was achieved using a single diaphragm, located between the intermediate and driven chamber.

Diaphragms were manufactured from 125μm thick Mylar A sheets

Figure 3: Cranfield Shock tube.



supplied by C F supplies. Diaphragms were cut using a metal stencil and sharp blade, fitted with rubber gaskets secured using double-sided tap on both faces, and placed in to position. The system was then pressurised using compressed air until diaphragm rupture occurred, at a mean pressure of 88 ± 2kPa

To measure the loading effects on the represented building structure, a Kistler 603B 0-200 bar pressure gauge was fixed flush in a 3D printed sensor holder **(figure ?).** The sensor holder was shaped as a 2x4 Lego block with a central hole (Ø = 6 mm) and manufactured from Polylactic acid (PLA) using a Prusa I3Mk2S 3D printer with a 0.15mm layer thickness with a 0.4mm nozzle. Following manufacture, samples were visually assessed and tested to ensure interconnectivity with regular Lego blocks and sensor fit. Data was captured using Prosig P8020 coupled with a Kistler 5018 charge amplifier, at a capture frequency of 400 kHz for 1 second. To ensure full capture of the load event, a pre-trigger (set at 30 kPa) was used, with a pre-capture of 0.1 seconds. A Phantom V12-12 camera was also used to record the event (up to 16000 frames per second and 1024 x 768 resolution).

Results

Figure 4 shows example pressure-time histories from balloon-based blast event. Over the different tests, an assortment of peak overpressures were recorded ranging from (mean 192±117), with a time duration between 0.045 – 0.095 ms (mean 0.065±0.025). Typically, an almost instantaneous peak overpressure occurred followed by a negative pressure. This behaviour then repeated approximately 3 to 4 times, but decreasing in magnitude with

Figure 4: Balloon test 8 pressure-time history from balloon based blast event.

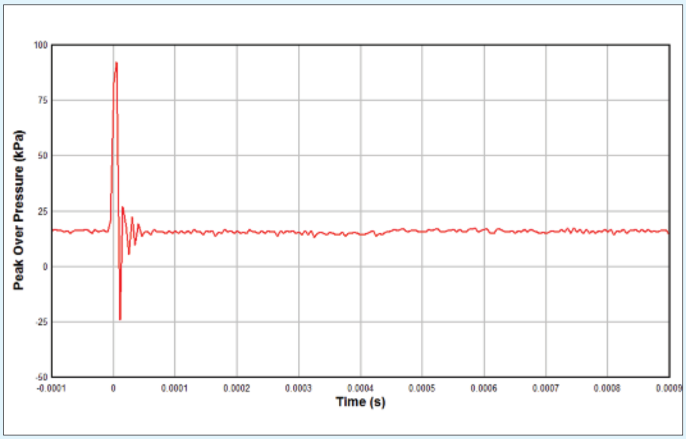
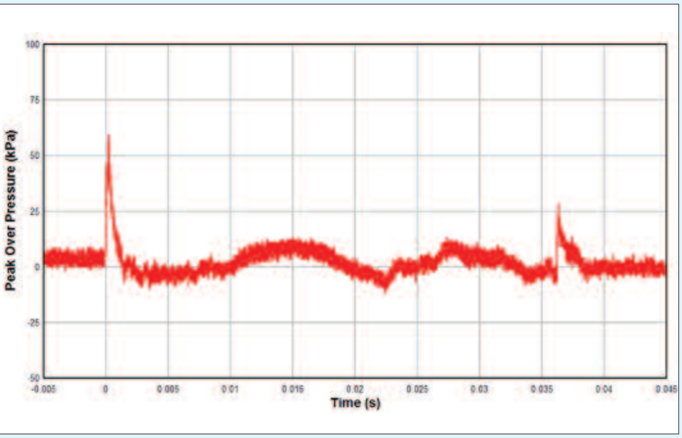


Figure 5: Shock tube test 3 pressure-time history from balloon based blast event.



respect to time. In a number of tests no discernible pressure-time histories were captured (tests 1 – 5) and thus not considered beyond this point. Interestingly, in one test, following the initial peak overpressure event, two later instances were captured approximately 14 ms afterwards. While the cause of this behaviour is currently unknown, the clear shape of the data indicates it is not an out layer event, and thus requires further investigation.

Figure 5 shows example pressure-time histories using the shock-tube. In all tests, an initial Friedlander waveform was exhibited, with maximum peak over-pressures between 28.9 to 62 KPa and an average time duration of 2.95±0.24 ms. A second Friedlander waveform was also shown to occur approximately 36ms later, with approximately half the magnitude of the initial peak-overpressure but same average time duration. Interestingly, the peak pressures reported here were more variant than those reported in other studies using the same method[3]. Variance such reported here is typically caused by premature failure of the Mylar diaphragms, due to pre-existing damage or material defects. To mitigate against such occurrence, a controlled failure mechanism such as scoring of the material or an electronic triggering system could be utilised.

Analysis of HSV found that following balloon detonation, the model experienced some vertical displacement even when adhered to the surfaced. It is suspected that displacement was attributed to Rayleigh waves (shown as surface vibration) traversing along the work surfaced, which as they pass, cause the structure to experience a vertical raise before a fall. In all instances of vertical displacement the whole model moved with no noticeable damage due to a weaker bonding between the model and work surface, opposed to the bonding between Lego blocks.

The shock tube also showed evidence of support surface vibrations, but did not result in vertical displacement. This is suspected to be due to a greater level of adhesion between the model and the support surface. Instead, models experienced interlayer failure between the bottom brick and the one above; a behaviour not demonstrated by the balloon detonations. While the use of interlayer adhesives such as superglue or two part epoxy would strengthen the models, it also limits block reusability, and thus detract from the purpose of this work. Instead to mitigate against interlayer failure, models were rebuilt at a 90° angle, such that the block interlayers were horizontal through the structure and a flat surface maintained towards the direction of loading. No further interlayer failure was observed following redesign.

Interestingly, no shockwave was observed in any HSV following balloon detonations. It is currently unclear if this was due to its absence, obscurity by the flame front, or if it dissipated before reaching the model. It is suspected that dissipation is the probable explanation, as air movement was observed through the spatial domain post detonation. Alternatively, the shock tube produced a number of shockwaves (approximately 340 m/s) events prior to structure impact (Figure 4).

Discussion

Two different methods (oxygen-hydrogen balloon and shock tube) have been explored to investigate the merits of each teaching students about blast loading on structures. Both methods exhibited the ability to induce structural loading but were highly variable in the pressure loading profiles delivered.

The balloons variability stemmed from the manufacture of the

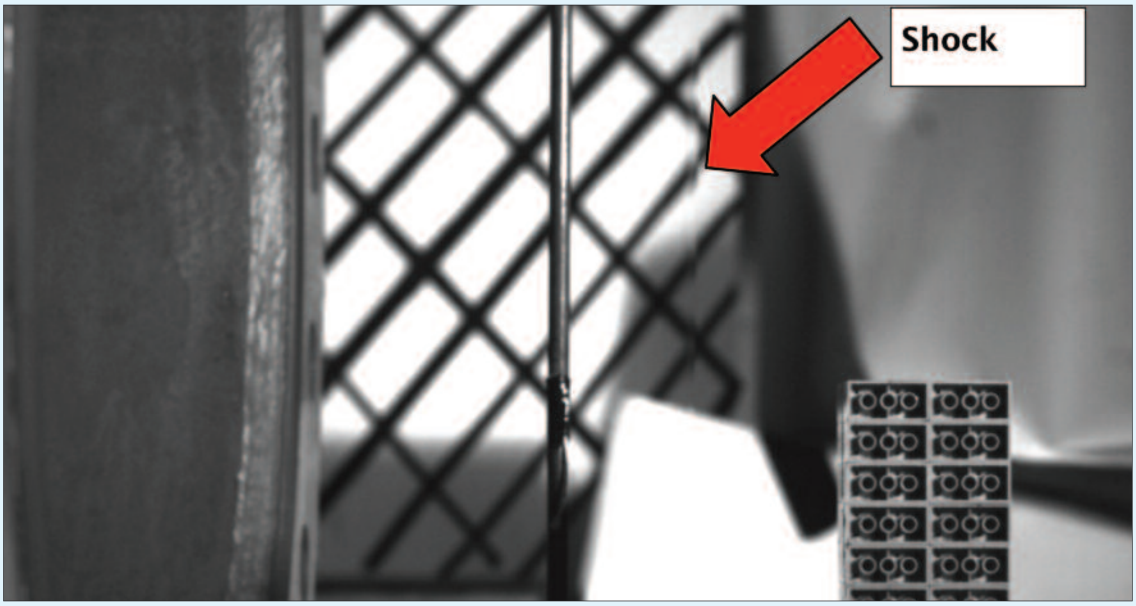


Figure 6: Shock front generated by shock tube

balloons. Variability could be reduced by manufacturing a rig that controls the flow rate of both fluids while pre-mixing prior to injection into the balloon. Such an approach however would not mitigate against the balloons prematurely bursting. The shock tube variability was a product of premature diaphragm failure likely caused by defects within the Mylar material inducing early material failure. By introducing a failure triggering mechanisms such as a hotwire such variability can be eliminated.

Overall only the shock tube demonstrated loading behaviour comparable with free air explosions, as the balloons loading time duration were too small. Analysis of the shock tube data using CONWEP, indicated that the mean loading profiles are equivalent to a 300g hemispherical TNT charge being detonated at 5.1m standoff, or a 600g TNT spherical charge detonated at 5.2m standoff. While this data is below most structural damage likely to be encountered, modification of the shock tube enables varying pressures and time durations, to be explored. However one must be aware that overmatching the model will induce structural damage to the model, which fails to replicate real world structural materials.

While this limits the usability of such a method as a teaching tool in terms of structural damage, this method still have potential to teach topics such as blast mitigating effects of blast walls (and associated parameters) and blast wave transmission of shockwaves in internal blasts. Furthermore, the shock tube was the only method to repeatedly demonstrate a shockwave and its structural interaction via high speed video. While not paramount, the ability to show students how shockwaves travel, and thus interact with objects is favourable, as it visually reinforces taught theory.

A key strength of the balloon detonation is the ability for quick manufacture and ease of procurement of the required components. Alternatively, the shock tube is specialist equipment with greater financial costs and space requirements. The shock tube also has additional limitations in its greater set up times and the requirement of specialist operational training.

One of the key limitations of this work is that, while it enables the teaching of blast interaction on structures, to make work more accessible outside of HE academic institutes, cheaper methods of data acquisition need to be developed.

Conclusions

Two different methods (oxygen-hydrogen balloon and shock tube) have been explored to investigate the merits of each teaching students about blast loading on structures. Both methods exhibited the ability to induce structural loading but were variable in the pressure loading profiles delivered. Only the shock tube demonstrated loading behaviour comparable with free air explosions, with a mean loading profile equivalent to a 300g hemispherical TNT charge detonated at 5.1m standoff, or a 600g TNT spherical charge detonated at 5.2m standoff.

When a model structure was overmatched, model structural damage occurred which differed to real world structural materials. While this limits the usability of such a method as a teaching tool in terms of structural damage, this method still have potential to teach topics such as blast mitigating effects of blast walls (and associated parameters) and blast wave transmission of shockwaves in internal blasts.

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2018-12-01