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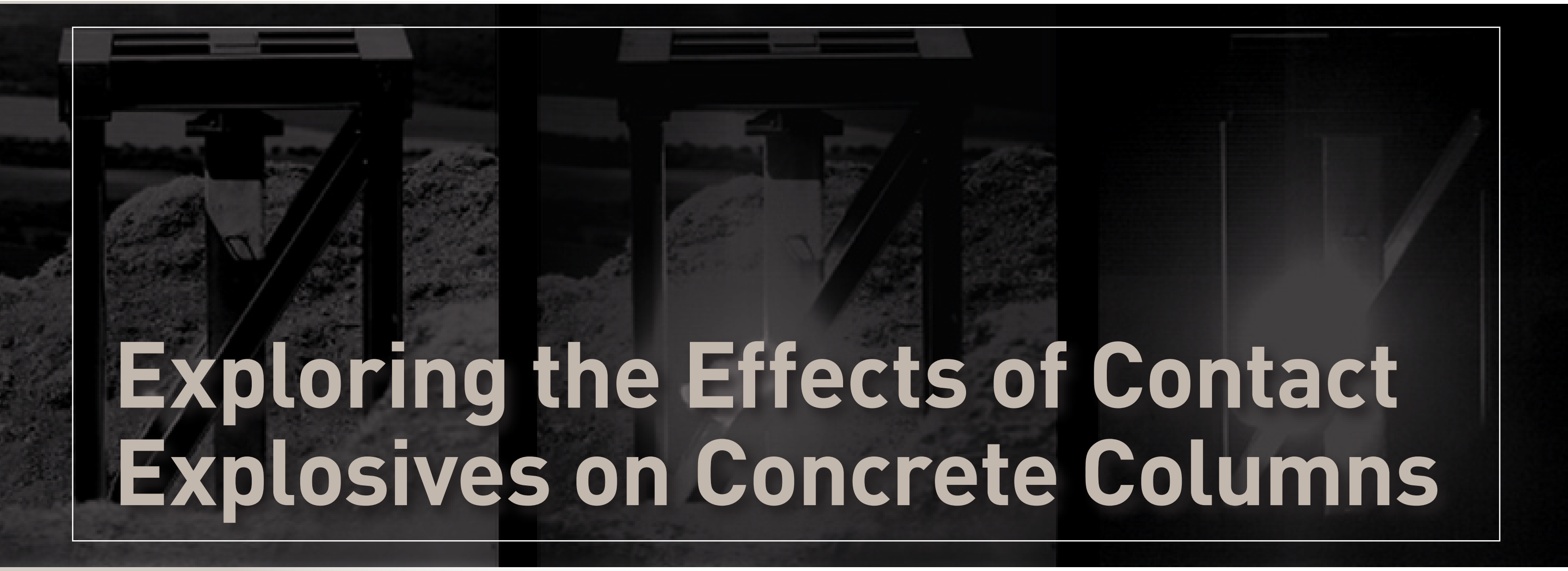
2022
CASE STUDY



Exploring the Effects of Contact Explosives on Concrete Columns

How high-speed imaging is enabling researchers to better understand the damage response of concrete columns subjected to contact explosives — research that has implications for the development of safer building implosion practices.

With more than half of the world population living in urban areas, many government agencies are investing in research projects to improve the safety of city dwellers. One issue that has emerged in the wake of natural disasters is building implosion, a practice that involves the strategic use of explosives to cause a structure to collapse into its footprint, minimizing the physical damage to the surroundings.

Safer building implosion practices require a deeper understanding of how concrete structures dynamically respond to blast shock waves. To this end, David Mejia, a professor at the University of the Armed Forces ESPE in Ecuador, analyzes the damage response of reinforced concrete (RC) columns. "After earthquakes hit Ecuador in 2016, the army had to implode several buildings," he explains. "One of the goals of our research is to learn more about this process, to improve the safety of controlled blasts like this in dense urban areas. For example, what is the minimum amount of explosive material we need to successfully implode a building?"

PERFORMING THE BLAST TESTS

While the effects of many explosion types on RC columns have already been researched, there is a general lack of data on columns subjected to contact explosive charges, which are designed to transmit very intense pressure loads to a localized region of the column. This is where Mejia's research comes in, as it seeks to reproduce the damage caused by the combined effects of contact explosives and axial loading. The study also takes into account variables like the compressive strength of the concrete, as well as various arrangements of the transverse reinforcement steel bars within the column.

Mejia and his team tested 33 specimens of RC columns that were manufactured according to Building Code Requirements for Structural Concrete (ACI 318S-11) — "all with different mechanical properties and cross sections," Meija says. They also built a large structural frame to support each column during the blast. Once they placed the column into the frame, they applied an axial load to it using a hydraulic jack. After the blast, the researchers checked the remaining pressure using a hydraulic jack pressure gauge. "The remaining pressure was one of the parameters that helped us determine if the column collapsed," Meija explains. "For example, if the gauge had a value of 0 megapascals, then the specimen lost 100 percent of its load carrying capacity and could be considered collapsed."

The structural frame, and the frame with a concrete column inside it.

For the contact explosives, Meija and his team used pentolite 50/50 — a mixture of 50 percent pentaerythritol tetranitrate (PETN) and 50 percent trinitrotoluene (TNT) — and attached each conical-shaped charge to the middle of the column. After the blast, they made a 3D scan of what was left of the column and processed the data in computer graphics software, measuring the exposed length of longitudinal reinforcement, the deformation of central longitudinal steel and the percentage of concrete fragmentation.

Attaching a conical-shaped explosive to the column.

"If the pressure gauge had a value that was different from 0 megapascals, we couldn't infer the level of damage to the column," Meija says. "That's why we had to complement this information with the effects of the blast on the column's concrete core and longitudinal steel bars. Together, this information enabled us to define the level of damage."

ADDING THE HIGH-SPEED ELEMENT

As part of his experimental trials, Mejia used high-speed imaging equipment, a Phantom v2512 camera, which the team installed in a trench 30 meters away from the explosions. The camera was armored by bulletproof glass on the front side and an explosive orientation disposal (EOD) ballistics shield on the top side, protecting it from any concrete fragments from the blast waves.

The Phantom v2512 high-speed camera, positioned 30 meters from the blast tests.

Mejia adjusted the camera's field of view, resolution and focal length to maximize image quality. Specifically, the team set the recording speed to 75,000 frames per second (fps) and filmed the blast at 512 x 512 resolution with an exposure time of 13.33 microseconds (μs).

PHANTOM: A SUPERIOR CHOICE FOR EXPLOSIVES TESTING

The Phantom v2512 is a powerful one-megapixel digital high-speed camera capable of capturing over 25,000 fps at full 1280 x 800 resolution — and 1,000,000 fps at reduced resolutions with the export-controlled FAST option. Beyond its ability to balance fast frame rates and resolution, the camera combines several advanced features that make it a superior choice for imaging difficult phenomena like explosions. These features include:

- A proprietary CMOS sensor with 28-micron pixel size and 12-bit depth.
- 25 gigapixels (Gpx) of throughput.
- Features that mitigate the bright light inherent in explosives testing. For example, the camera has a minimum exposure time of 1 μs — and 265 nanoseconds with the FAST option — as well as Extreme Dynamic Range.
- High image quality for capturing shock wave and fragmentation details.
- Up to 288 GB of memory, to capture the aftereffects of the explosion.
- A sturdy, all-metal body for withstanding harsh situations in the field.

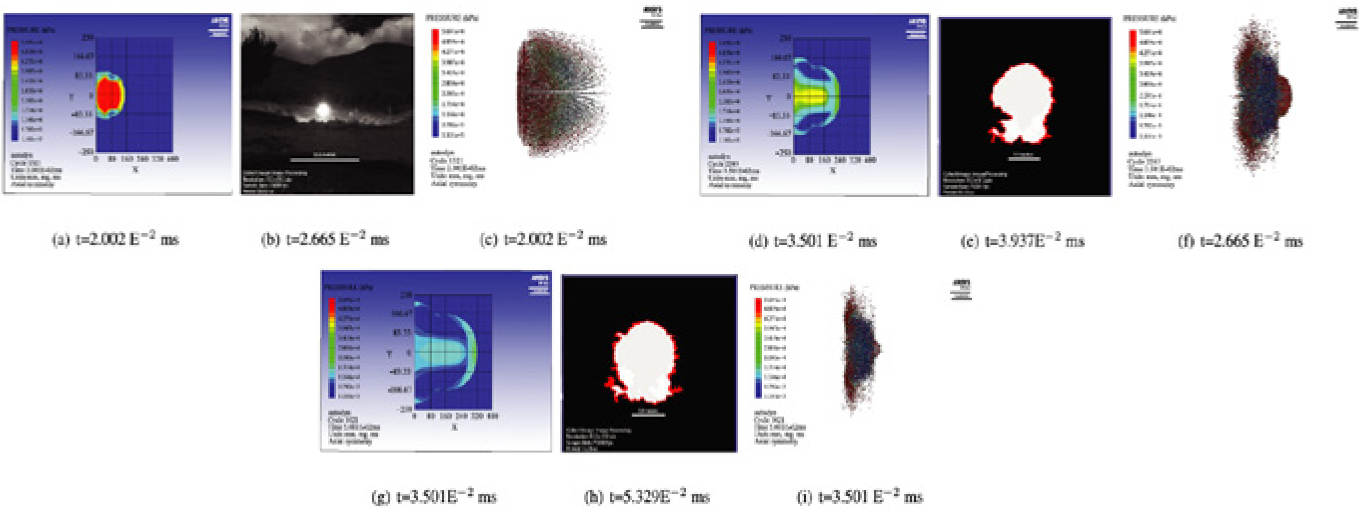
EXPLORING EXTREME DYNAMIC RANGE

Recording high-quality video of extremely luminous events, such as welding, explosions, combustion and ballistic impacts, is no easy task. To overcome these challenges, high-speed camera users will typically opt for shorter exposure times or stopped-down apertures to prevent oversaturation in the bright areas of an image. These adjustments, however, often compromise the features in the non-luminous, surrounding areas of the event, forcing the background details within the shot to become darker and less visible.

In some cases, shining additional light onto the scene can yield effective images of the bright event. However, this outcome is difficult to achieve since the number of scattered photons — provided by the lighting — should be on the order of the number of emitted photons emanating from the event, making it difficult to achieve quality images especially for events with large fields of view.

One way to address these problems is to implement Extreme Dynamic Range (EDR), a sensor-level feature found on select Phantom cameras that offers a way to have a dynamic exposure per pixel. To summarize, if during the frame integration (or image capture) process a pixel value is above a given threshold — 600 counts, for example — after a given time, EDR will reset to a shorter exposure time for the remaining integration. Therefore, the darker pixels will have a relatively longer exposure time compared to the brighter pixels, which the EDR feature resets to a lower user-defined exposure value. In the end, the process extends an image's dynamic range by keeping the exposure time relatively long in the darker areas and relatively short in the brighter areas of an image.

Meija initially wanted to use high-speed Schlieren imaging to directly observe the damage sequence of the columns. "However, smoke and large dust clouds produced too much noise, blocking our target," the researcher says. "The camera did capture the fireball, the expansion and compression of gas and the concrete fragmentation process, enabling us to observe the propagation of the shock wave. Using numerical calculations, we could then demonstrate that the blast nonuniformly expands through the surrounding air."



The numerical and experimental results for a conical charge of 150 grams of pentolite, demonstrating that the shock wave nonuniformly expands through the surrounding air. First, the shock wave adopts a vertical ellipse contour until 2 x 10 E2 milliseconds (ms), after which it adopts a symmetric jellyfish dome-type profile.

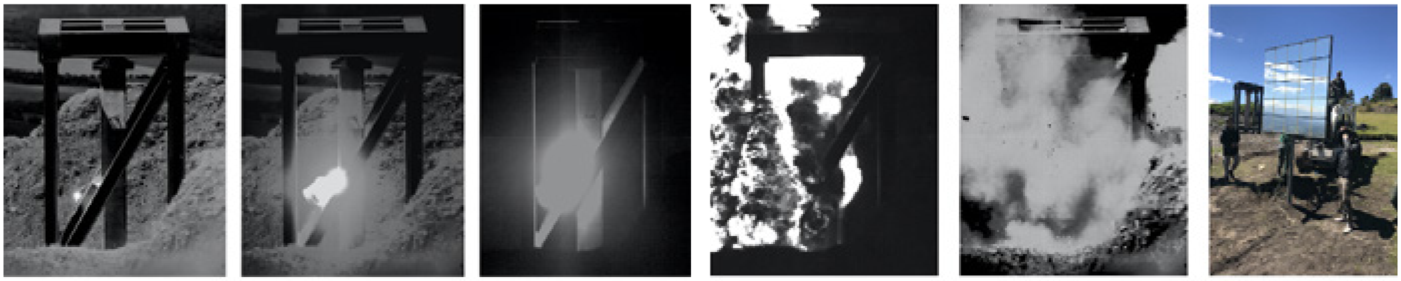
ASSESSING THE DAMAGE

Based on their experimental and numerical studies, the University of the Armed Forces ESPE researchers found that RC columns subjected to contact explosions are damaged via a simultaneous supersonic shock wave and fireball, which cause concrete fragmentation in the following order:

1. The concrete cover is fragmented.
2. The transverse bars suffer shear.
3. The longitudinal bars buckle.
4. The concrete is partially or fully fragmented.

The team also found that the subsequent collapse of the column involves many variables including the explosive mass — i.e., the quantity of pentolite in grams — as well as the axial load and compressive strength of the column.

Concrete columns that have sustained moderate and extreme damage, respectively.



(a) Initiation (b) Explosion (c) Detonation (d) Fire-ball (e) Concrete fragments (f) Mirrors

(g) Schlieren video

Results of the high-speed video taken using a Phantom v2512 recording at 75,000 fps at 512 x 512 resolution. Exposure time: 13.33 microseconds. Focal length: 32.41 millimeters.

"When detonations exceeded 500 grams of pentolite, the arrangement of the transverse reinforcement steel bars within the column had a significant impact on the final damage," Meija explains. "In these cases, the axial load also increased the blast strength of the column and improved the concrete core confinement. Put simply, axial load is an important parameter that must be considered when imploding buildings."

Meija and his team are currently publishing another study investigating cylindrical- and conical-shaped charge detonations. But this one is on a large scale: "For our next project," he says, "we'll be working with and imploding actual buildings — not just concrete specimens."

To learn more, please visit: ***www.phantomhighspeed.com****.*