The Fourth Little Pig Built His House with ICF

FPED (Force Protection Equipment Demonstration) is a tradeshow sponsored by the Joint Chiefs of Staff to demonstrate the latest technology to all branches of the military and other government agencies. A highlight of FPED is the blast testing. At this year's show, located at Quantico Marine Base outside Washington, D. C., six full-scale ICF specimens withstood a 50-pound TNT charge, the maximum quantity allowed during the FPED demonstrations.

With recent events in the world, bombings and terrorist threats have become very real concerns. Thus, life protection during a man-made disaster has become an important consideration of the design process of new and existing structures.

Although ICF buildings are renowned for their energy-conservation properties and their quiet interiors, another important benefit of ICF structures is their security and integrity during natural disasters such as hurricanes and tornados. However, there has been little evaluation of ICF under man-made disasters such as terrorist acts. This program was to demonstrate the blast-mitigation potential of ICF systems.

Fabricating the Assemblies

The ICF specimens were constructed off site about 45 days before the demonstrations. Each specimen consisted of three 8' by 8' walls arranged in a U-shape, a 6"-thick concrete slab and a 6"-thick concrete roof. The fourth, or back, side was left open to allow for inspection of the interior after the trial. All the concrete was reinforced with #4 bars at 16" o.c.e.w. and three specimens (C, D, and F) were further reinforced with VertiForce™ fibers. The only unusual reinforcement feature was the four lift point for transporting the specimens to the demonstration site. All six assemblies used a different brand of flat-wall ICF system. The concrete had a design strength of 4000 psi and was donated by several local ready-mix companies.

Although ICF walls are typical finished with stucco, brick, or wood siding, it was decided not put an exterior cladding on the specimens so that the wall was exposed to the full brunt of the explosive charge. This also simplified the assessment of damage after the blast.

Testing the Assemblies

Two ICF specimens were tested each day of the three-day show. A range of standoff distances were used to evaluate the damage at various levels of airblast. The farthest standoff distance was a relatively close 40' and the closest specimen was only 6' from the charge. Since the force of the airblast is proportional to the cubed root of the distance, the closest specimen faced an air blast pressure about 300 times the pressure encountered by the farthest specimen.

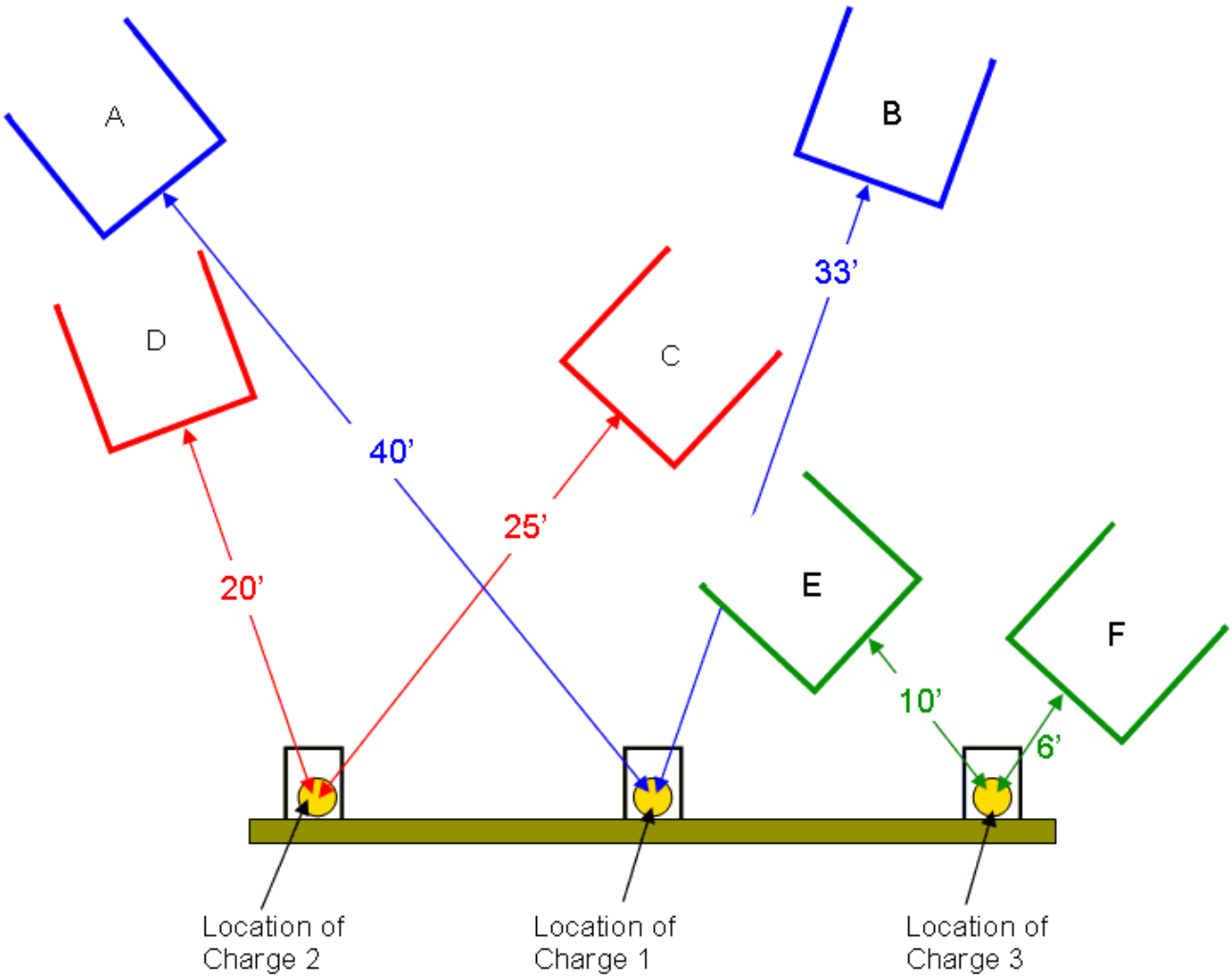

Figure 1 – Plan of the test. The standoff distance between the charge and the specimens ranged from 6' to 40'. Each day, two specimens were tested after which they were analyzed and then removed.

The 50-pound charge of TNT was placed on a concrete bolster directly against a blast wall. Thus, the force of the airblast was amplified from the rebound off of the blast wall. The force experienced by the two closest specimens was further amplified due to the confined area created by the specimens and the blast wall. (*See Figure 1.*) Therefore, the closest specimens faced an incredible quantity of destructive force. Since the explosion decimated the concrete bolster, the location of the charge had to be moved every day. (*See Figure 2.*)

The detonation itself was awe inspiring. A large fire ball encompassed the area around the specimens. (*See Figure 3.*) Since the viewing area was several hundred yards form the detonation, more than a second was required for the airblast and sound to reach the observers. Even at that far distance, the force of the airblast was considerable.

Figure 2 – Since the TNT charge decimated the concrete bolster on which it was sitting, the TNT charge was placed on a different bolster each day. This photograph was taken after the second day. The bolster to be used on the third day can be seen in the foreground. (The charge will be placed where the blue folder in the photograph is located.) The remnants of the bolsters used on the first and second day can be seen along the center and right side of the wall. The rebar in the bolsters is #7. Damage to the blast wall itself can also be observed behind the sites of the first and second charges.

Figure 3 – The fireball created by the TNT charge. The two 8' ICF specimens can be seen at the base of the fireball.

Evaluation of the Specimens

After each test, the specimens were thoroughly evaluated. After the EPS (Extruded Polystyrene or foam) was assessed, portions of the EPS were manually removed so that the underlying concrete could be evaluated. None of the specimens experienced catastrophic failure; in fact all the assemblies were readily lifted by the crane after the demonstration. The only damage to specimens A and B (the farthest two specimens) was the EPS peeling away at the corners. Specimens C and D displayed minor distress to the foam, but no damage to the concrete was observed. It was only after the standoff distance was reduced to a mere 10' were cracks observed in the concrete. None of the cracks exceeded 2 mm across. Chunks of concrete were dislodged from Specimen E, the specimen at the 10' standoff distance. (*See Table 1.*)

Table 1 – Damage Evaluation

Sample	Standoff Distance	VertiForce Fibers?	Evaluation
A	40'	No	EPS removed from the corners. Concrete was not exposed. No signs of cracking in the concrete.
B	33'	No	EPS removed from the corners. Concrete was not exposed. No signs of cracking in the concrete.
C	25'	Yes	EPS removed from the corners and compressed. Concrete was exposed only at corners. No signs of cracking in the concrete.
D	20'	Yes	EPS removed from the corners and compressed. Concrete was exposed only at corners. No signs of cracking in the concrete.
E	10'	No	EPS damaged. Concrete exposed in several sections and several large chunks (up to ~20 pounds) of concrete were dislodged. Cracking in the concrete of the walls, slab on ground and elevated slab. All cracks were less than 2 mm in width.
F	6'	Yes	EPS severely damaged and singed. Concrete exposed in several sections. Cracking in the concrete of the wall, but not in either the elevated slab or the slab on ground. All cracks were less than 2 mm in width.

The EPS on the interior of the specimens was never damaged and no significant deflections were observed in any specimen.

Pieces of shrapnel were imbedded into the exterior EPS but there were no indications that the shrapnel penetrated to the underlying concrete.

The EPS cover is a major reason for the superior blast mitigation of the ICF system. Evidence of the EPS compressing could be seen in all specimens. As the specimens came closer to the charge and the blast force increased, the compression of the EPS became more pronounced. This compression dampened the force of the airblast and absorbed a considerable portion of the blast energy.

Figure 4 – Specimens C (left) and D (right). Signs of compression of the EPS can be seen in the wall facing the blast of Specimen D. (Note how the ribs are only seen on the side facing the blast.) Embedded shrapnel can be seen on the bottom of Specimen D. Also, although exposed, no damage was seen to the edge of the upper slab.

Conclusion

This demonstration at FPED IV confirms the effectiveness of ICF specimens for blast mitigation. The specimens at the larger standoff distance only suffered superficial damage while the specimens closest to the charge maintained their structural integrity.

The EPS cover is a major reason for the superior blast mitigation of ICF walls. Evidence of the compressing could be seen in all specimens, dampened the force of the airblast and absorbed a considerable portion of the blast energy.

Since all explosions are complex phenomenon with many factors influencing the damage to a structure, a competent design professional must consider all factors when designing a structure to withstand threats and assaults.

Figure 5 – Specimens D (left) and E (right). Specimen E had the closest standoff distance to the charge. The EPS was severely damaged, but the concrete maintained its structural integrity.

Figure 6 – Evaluation of Specimen E after the EPS was manually removed to expose the underlying

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