the construction specifier

$7.00

solutions for the construction industry | august 2011

CONSTRUCT
hanley wood
55TH CSI ANNUAL CONVENTION
SHOW PREVIEW

Protecting with Tilt-up Concrete

also in this issue

Understanding Tapered Insulation

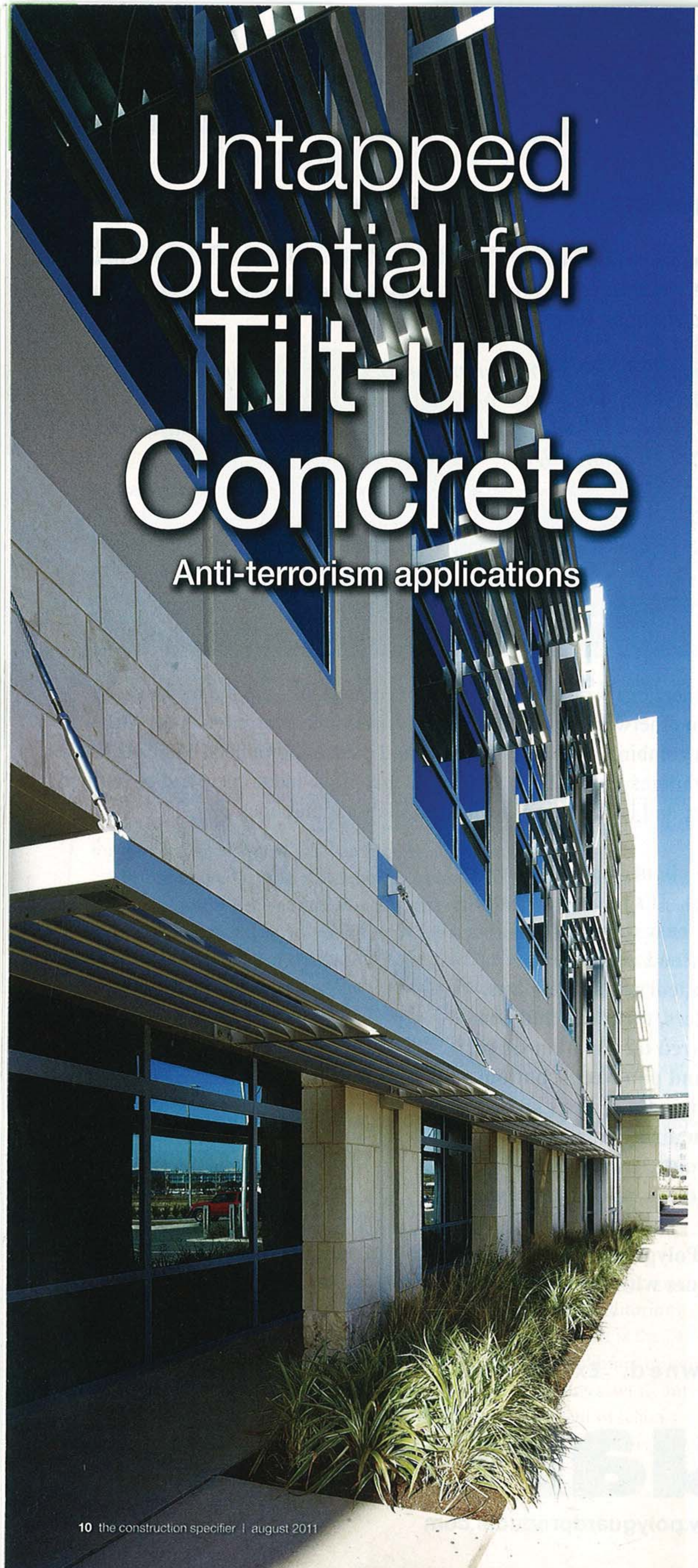
Pushing Envelopes with Metal Panels

Selecting Wood Flush Doors

The Official Magazine of the Construction Specifications Institute

Untapped Potential for Tilt-up Concrete

Anti-terrorism applications



by Jeffrey Brown, AIA, and Mark Gardner, PE

All images courtesy Powers Brown Architecture.
Photo © Dror Baldinger

AS A LOW-COST, LOW-TECHNOLOGY CONSTRUCTION METHOD, TILT-UP CONCRETE HAS BECOME ONE OF THE FASTEST GROWING SOLUTIONS FOR ADDRESSING LOWERED BUDGET CONSTRAINTS BROUGHT ABOUT BY THE RECESSION. IT HAS TYPICALLY BEEN CONSIDERED AN ACCEPTABLE BUILDING METHODOLOGY FOR EVERYDAY BUILDINGS AND BIG BOX RETAIL. RECENTLY, IT HAS GAINED A FOOTHOLD WITH ARCHITECTS AS AN INNOVATIVE WAY OF FORM-MAKING FOR OTHER PROJECTS.

As important a development as this is, perhaps tilt-up construction's most intriguing potential is in the leading-edge research in its use accommodating affordable access to a very high level of federal government-mandated criteria for blast and progressive collapse resistance.

The U.S. Department of Defense (DOD) and the military initiated a program to unify all technical criteria and standards pertaining to the planning, design, construction, and operation/maintenance of real property facilities. The Unified Facilities Criteria (UFC) program's overall objective is to streamline the military criteria system by eliminating duplication of information, increasing reliance on private-sector standards, and creating a more efficient development and publishing process. Both technical publications and guide specifications are part of the UFC program. Previously, each service branch had its own publishing system resulting in criteria being disseminated in different formats.[1] The current criteria does not specifically address tilt-up construction, requiring innovation and investigation by the design team.

This article explores the connection between the form-making potential of tilt-up construction and its untapped technical performance possibilities by way of a group research case study of the conversion of an existing design to meet the above criteria and the subsequent cost modeling to do so.

What is tilt-up construction?

Concrete is one of the oldest materials used in construction; it has persevered through numerous uses, advancements, and applications to near ubiquity in building anything anywhere around the globe. Yet for all its flexibility and innovative manifestations from cast-in-place, post-tensioning, and precasting, to its material advancement in foaming, autoclaved aeration, and fiber-reinforcing, few uses of concrete can be defined as a 'system,' with tilt-up construction being one of them.

Tilt-up involves using the building slab as a casting bed for the formation of load-bearing wall panels cast in place onsite and 'tilted,' typically via crane, into final position. There are variations and exceptions for this simple definition, but it suffices to support the claim of system and, by extension, consideration of tilt-up construction as a technology. As a construction technology, it has had an engineering and architectural pedigree going back to the end of the Industrial Revolution.

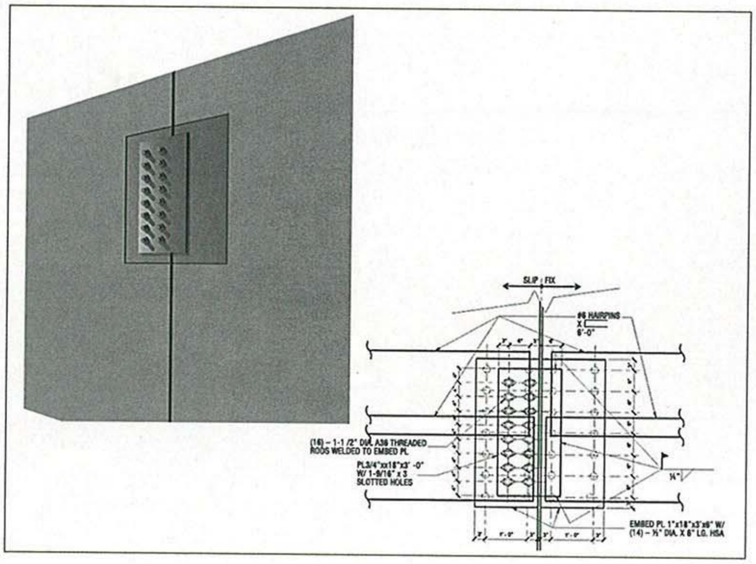
Invented in the last decade of the 19th century by army engineer Robert Aiken for military purposes, tilt-up was flirted with by Thomas Edison, Irving Gill, and Rudolph Schindler as a building technique, business venture, and innovative method of form-making. It went somewhat dormant until after World War II. Key innovations such as the traveling crane allowed tilt-up to become the low-cost method for constructing big box buildings that supported the massive suburban middle-class post-war growth. By the late 1970s and early 1980s, it had stalled in this category and retreated somewhat humiliatingly from avant-garde architectural and engineering consideration. That is, until recently.

Figure 1

Cost for progressive collapse and blast-resistant construction 9,128 m² (98,256 sf)

Description		Progressive Collapse/Blast	Conventional Construction	Premium
03 Concrete		$ 877,505	$696,775	$180,727
04 Masonry		$184,810	$184,810	
05 Metals		$ 2,117,634	$1,353,191	$764,443
06 Wood		$7,150	$7,150	
07 Thermal/Moisture		$330,663	$330,663	
08 Doors & Windows		$1,877,990	$1,006,775	$871,215
09 Finishes		$273,180	$273,180	
10 Specialties		$41,565	$41,565	
11 Equipment		$0	$0	
12 Furnishings		$0	$0	
14 Conveying		$150,000	$150,000	
15 Plumbing		$181,774	$181,774	
15 Fire Protection		$98,256	$98,256	
15 HVAC		$884,304	$884,304	
16 Electrical		$540,408	$540,408	
OH & P		$611,548	$480,578	$130,970
Totals		$8,176,787	$6,229,430	$1,947,355
	cost/sf	$83.22	$63.40	$19.82
	cost/m²	$895.78	$682.43	$213.34

Cost comparison for progressive collapse and blast-resistant construction.



Steel plates are provided on all tilt-up wall panel joints at each level of the building to transfer loads for progressive collapse resistance.

Well-established, high-design architects such as Stephen Holl, Rand Elliot, and Scogin Elam and Bray have engaged the technology to create significant works of architecture. The interconnection of downward economic pressure and accelerated construction schedules have elevated tilt-up to one of the fastest growing methods of building in the market. However, much of the mainstream architecture world still seems to be uninterested and unaware of its design and technological potential.

While typical office construction is intended to describe a steel or concrete frame with veneer cladding and perimeter columns, the authors use the term 'value office'[2] to describe use of tilt-up to build an investment-grade office building that competes with the definition of 'Class A' in the marketplace. The aesthetic flexibility of tilt-up, combined with its ability to improve on the characteristics of typical offices, ultimately establishes a niche for converting the typical office building to tilt-up technology in numerous markets.

Tilt-up improved on the conventional product, as it has no perimeter columns (making it more efficient to plan), it accepts any exterior cladding material, and offers column-free glazed corners. Most significantly and importantly, when combined with the above advantages, it averages \$75 to \$108/m^2 (\$7 to \$10/sf) less for the exact project built conventionally in most suburban markets at comparable floor plate and overall building sizes in a normal bidding market.[3]

A white paper produced by the authors' firms—Powers Brown Architecture and Hinman Consulting Engineers[4]—and based on a comparative case study of converting a typical conventionally constructed market office building to tilt-up technology to DOD medium-level blast resistance and progressive collapse resistance, illustrates both the method's aesthetic design flexibility and its technological potential.

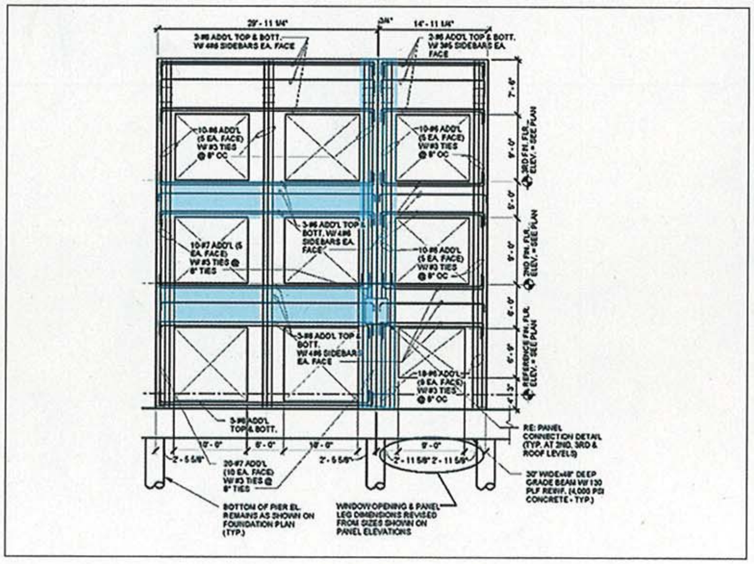
After building nearly 60,387 m^2 (650,000 sf) of 'value office' buildings in several southwest and western markets, tilt-up made a breakthrough for the authors' firms in the Washington D.C./Mid-Atlantic area nearly five years ago. With numerous buildings underway in the region, the inevitable question arose for that market with its third-party government contractors and government agency end-users: can building this way accommodate the Anti-terrorism Force Protection (ATFP) standards of the federal government? Will it maintain its savings advantage?

The complexity of the criteria required a committed team of consultants, including architecture, construction, structural engineering, and blast engineering. The investigating team determined that the best baseline case would be a comparative analysis of a recently constructed building with up-to-date structural connections and recent market-based cost indexing to 'convert,' if possible, to meet ATFP criteria.

With the permission of a client, the authors' firms chose a recently completed three-story office building they had designed as a site-adapt prototype—the most recent project using the scheme just completed in San Antonio, Texas. The building was familiar to all team members with the exception of the blast consultant. It had 3038-m^2 (32,705-sf) floor plates totaling 9128 m^2 (98,250 sf); structurally, it consisted of 9-m (30-ft) wide panels at the perimeter with the curtain wall at the center bay front corners, a composite steel and concrete floor deck system, and a steel joist and metal deck roof. The building was designed to meet Leadership in Energy and Environmental Design (LEED) Silver certification.

It bid at approximately \$62.40 by the team's contractor and went to contract for a similar cost. (This refers to the building core and shell only and does not include any fit out beyond core and lobby elements, nor site costs.) The task became conceiving, designing, and cost-modeling the modifications to convert it to DOD medium-level protection without altering the design in any way.

As previously mentioned, the DOD and military services initiated a program to unify all technical criteria and standards pertaining to planning, design, construction, and operation and maintenance of real property facilities. As part of this unification, UFC 4-010-01, *DOD Minimum Antiterrorism Standard for Buildings*, was developed.[5] First published in July 2002, and most recently updated in January 2007,



Spandrel panels at each level of the building are designed to span the full width of the typical 9-m (30-ft) wide tilt-up panel, supporting the gravity loads of one floor and one story of the tilt-up panel for progressive collapse resistance. Tilt-up panel legs are reinforced to support the load from adjacent panels for progressive collapse resistance.

Also pictured on page 10 and the cover, this three-story office building shows the potential (and economy) offered by tilt-up concrete construction when it comes to progressive collapse resistance.

Photo © Dror Baldinger

UFC 4-010-01 seeks effective ways to minimize likelihood of mass casualties from terrorist attacks against DOD personnel in the buildings where they work and live. By applying these design strategies, the facility becomes a less attractive target of opportunity for attack.

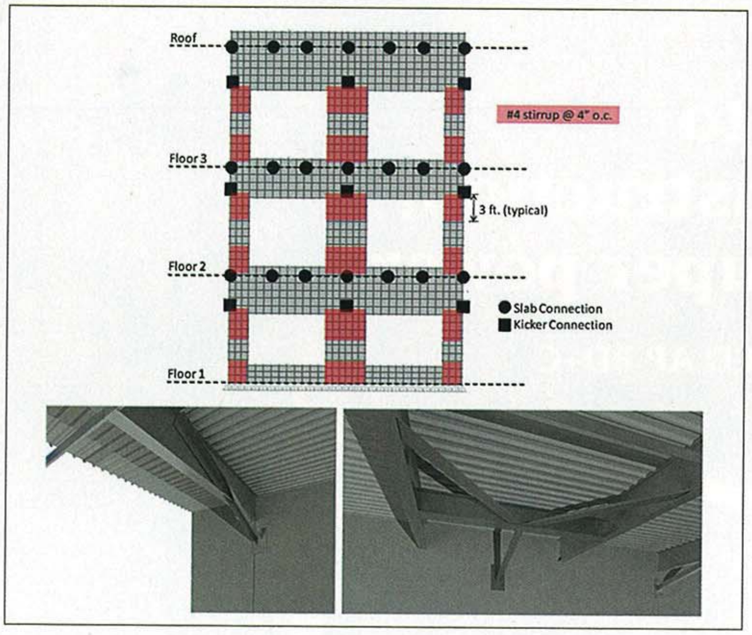
These standards assist designers in determining the proper level of protection for DOD buildings, whether owned or occupied by DOD personnel, where no specific threat has been developed. The intent of the standard is to provide a cost-effective design that includes employing proper site development, design, and construction. In the authors' case, the team had to assume a site that would provide for setbacks that comply with the criteria for blast and which were not included in the base case.

While the minimum standards are designed to establish a level of protection against terrorist attacks where no current known threat of terrorist activity exists, certain entities within the federal government perceive a higher threat environment for their facilities. In this case, the level of protection provided by the minimum standards establishes the foundation for a rapid application of additional protective measures. For the purpose of the authors' study, the building was evaluated for a medium level of protection against the DOD standard threats and standoffs to a controlled perimeter.

The medium level of protection requires the structure to sustain minor damage during the design threat. This is further defined as the building damage being economically repairable. Space in and around the damaged area can be used and will be fully functional after cleanup and repairs. The glazing will fracture and remain in the frame, and results in a minimal hazard consisting of glass dust and slivers. Doors will stay in frames, but will not be reusable. Finally, personnel in damaged areas potentially suffer minor to moderate injuries, but fatalities are unlikely. Personnel outside damaged areas will potentially experience superficial injuries.

These criteria are evaluated by determining the air-blast loading applied to the building by the design basis threat at the appropriate standoff. Once the air-blast loading is determined, each building element is analyzed, usually through single degree-of-freedom (SDOF) analysis. The DOD provides SDOF structural response limits for antiterrorism design in the 2006 TR 06-08, *Single Degree of Freedom Structural Response Limits for Anti-terrorism Design*.[6] This technical report provides the response limits dependent upon the components category (*i.e.* primary, secondary, and non-structural) and material construction (*i.e.* concrete, masonry, and steel).

In association with UFC 4-010-01, all buildings with three or more stories that meet the required occupancy category must achieve the progressive collapse criteria as defined in the 2010 UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse*.[7] The definition of progressive collapse is "the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it."



Kickers are installed between the floor/roof systems to the bottom of the spandrel panel to provide lateral restraint for progressive collapse resistance.

The standard further states buildings should be designed "to sustain local damage with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage."

Using tilt-up construction to meet the blast criteria was a seamless transition. Similar to precast construction, the air-blast load is transferred from the façade back to the building floor diaphragm. With the standard horizontal connections inherent in tilt-up, the medium protection level was achieved with slight modifications to the floor connections and additional vertical reinforcement within the wall.

The team faced two major challenges in incorporating the design criteria. First was the analysis approach of the tilt-up for the air-blast loading. Analyzing the tilt-up for blast using SDOF methods proved difficult to accurately capture the redistribution of the forces from the window system, through the wall, and into the floor slab. The reason for this was the tilt-up tends to act as a two-way distribution system, which is challenging to capture in a simplified approach. To more accurately capture the forces, the wall was modeled as a series of shell elements and analyzed using the time history of the air-blast loading. While the computational effort was longer than that of typical façade construction, the approach more accurately modeled the tilt-up panels.

The second major challenge was designing the building for progressive collapse requirements. For the structure, the alternate path method was studied. Typically, this involves analysis of a framed building with one of the exterior columns missing.

For tilt-up construction, the load-bearing portion of the wall to be removed had to equal twice the height between lateral supports. This is approximately equal to twice the floor-to-floor height. For the purpose of the authors' study, two unique cases were analyzed. The first was removal of the entire panel (a 9-m [30-ft] width). The second case removed two adjacent wall piers, so the span was about 12 m (40 ft) between vertical supports.

Compared to typical framed construction where the building loads are redistributed to the adjacent exterior building columns, capturing the load redistribution in tilt-up construction was more challenging. First, a 3-D model of the building was constructed to properly distribute the loads from the floor systems. To solve this problem, a series of connection plates was added at each floor. These plates transfer the load from the wall panels above the removed section to the adjacent panels' vertical elements. In addition to the connections, the adjacent panel piers had to be analyzed to ensure their moment capacity could withstand the transferred loads. These two major challenges impart the design forces in opposite directions on the tilt-up piers, so the unique analysis is required.

In general, while the plates were new to the structural connection system, all enhancements from thickened panel legs, kickers at the panel joints, and the embed connections were simply enhancements to the existing elements. The panel reinforcing required upsizing the vertical and horizontal rebar by about 50 percent over base conditions. The roof was converted to composite construction from joists and the foundation required, again in line with the enhancements, the addition interstitial piers at panel mid spans.

Once the conversion elements were engineered and quantified over the course of several months, they were packaged and bid to subcontractors for a conversion price. As shown in Figure 1 (page 11), the premium was approximately $213/m^2 ($19.82/sf), very much in line with the cost to convert a conventional structure, thus preserving the savings delta over a similarly designed Class A structure. An additional exercise was run converting several of the design features such as cantilever and extensive curtain wall at the corners to more conservative configurations. The result was an adjusted cost for a purpose-designed tilt-up structure of $161/m^2 ($15/sf) premium.

Conclusion

The team came to several conclusions. They found it was feasible to use the tilt-up load-bearing capacity technology to achieve high levels of force protection, As a construction technology, tilt-up concrete has had an engineering pedigree dating back to the end of the Industrial Revolution. Now, its most intriguing potential may be found in research for blast resistance.

without adding columns or excessive steel. It is cost-effective to use tilt-up as the advantage in monetary savings generated in 'value office' is preserved and there is no premium above that to convert to progressive collapse/blast resistance. Each project is standalone; four stories are possible, but cannot be extrapolated from this investigation. For blast resistance alone (under three stories), the authors believe it is possible to compete on a building cost basis with non-blast conventional construction as \$6.04/m^2 (\$65/sf) is a proven number for blast and less than typical conventional construction. The same may also be true for progressive collapse and blast resistance.

Ultimately, through additional engineering analysis, some creative thinking, and upgraded connection design, tilt-up construction can meet the current DOD requirements for air-blast to a medium level of protection and progressive collapse analysis using the alternate path method. It may also be the best low-cost high-design alternative for doing so. **CS**

Notes

[1] See the National Institute of Building Sciences (NIBS) *Whole Building Design Guide*'s Construction Criteria Base (CCB) at www.wbdg.org/ccb/browse_cat.php?0=29&c=4.

[2] 'Value office' is a term coined by Powers Brown Architecture for the conversion of a conventionally constructed market office building to tilt-up technology.

[3] There were some buildings in the market, but they were not commonplace. Further, they were typically relegated to secondary status in outlying low-land-cost developments.

[4] Additional team members included Haynes Whaley Associates (structural engineering) and Kevin Rogge of Harvey Cleary Builders (estimators).

[5] See UFC 4-010-01, *DOD Minimum Antiterrorism Standard for Buildings*, (January 22, 2008).

[6] See TR 06-08, *Single Degree of Freedom Structural Response Limits for Antiterrorism Design* (October 20, 2006).

[7] See UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse* (January 27, 2010).

ADDITIONAL **INFORMATION**

Authors

Jeffrey Brown, AIA, is principal at Powers Brown Architecture, which he co-founded. He has more than 20 years of experience in architecture, and serves on the board of directors for the Tilt-up Concrete Association (TCA) and the Gulf Coast chapter of the U.S. Green Building Council (USGBC). Brown can be contacted via e-mail at brown@powersbrown.com. Mark Gardner, PE, is a managing engineer at Hinman Consulting Engineers. He has 11 years of engineering experience focusing on protective design. Gardner is in a member of the American Society of Civil Engineers (ASCE), Society of American Military Engineers (SAME), and Structural Engineering Institute (SEI). He can be reached at mgardner@hce.com.

Abstract

Tilt-up concrete construction has become a growing solution in lowering budget constraints brought about by the recession. It has been considered an acceptable building methodology for everyday buildings and big box retail, and recently it has gained a foothold with architects as an innovative way of form-making. An intriguing research potential is located at the leading edge of its use in accommodating affordable access to federal government-mandated criteria for blast and progressive collapse resistance. This article explores the connection between the form-making potential of tilt-up construction and its untapped technical performance potential by way of a group research case study.

MasterFormat No.

03 47 13–Tilt-up Concrete

UniFormat No.

B2010–Exterior Walls

Key Words

Division 03

Anti-terrorism Force Protection

Department of Defense

Progressive blast

Tilt-up concrete

Unified Facilities Criteria program