steelwise

BLAST-RESISTANT CURTAIN WALLS

Innovative cold-formed façade panels make a blast-resistant structural steel frame even more economical.

BY ADY AVIRAM, P.E., PH.D., RONALD L. MAYES, PH.D., AND RONALD O. HAMBURGER, S.E.

EVER SINCE THE 1950s, steel stud construction has been extensively used in exterior building walls, as it provides an economical and architecturally flexible solution for exterior walls of steel-framed and other buildings.

However, traditional cold-formed steel construction does not provide significant blast resistance, which limits its use for projects where this sort of criteria is required. The U.S. defense community (including the Department of Defense, U.S. Army Research Laboratory, U.S. Army Engineer Research and Design Center, U.S. Air Force Research Laboratory at Tyndall Air Force Base and University of Missouri-Columbia), interested in taking advantage of the relatively low cost of steel stud construction, has devoted considerable research effort and funds over the past two decades to both characterize and improve steel stud wall blast resistance. While attempts to improve this resistance were narrowly successful, they relied on robust end connections to enable the studs to develop their full tensile capacity—which unfortunately rendered the system costly and impractical.

Recently, Simpson Gumpertz & Heger, Inc. (SGH) undertook a research and development program to develop a cost-effective, steel-based solution for blast-resistant curtain walls. Managed by SCRA Applied R&D and funded jointly by the U.S. Army Research Laboratory and the U.S. Air Force Research Laboratory (now the Air Force Civil Engineering Center) at Tyndall Air Force Base (AFB), Fla., the program resulted in development of the SEB wall (steel stud wall with enhanced blast resistance), a composite steel-sheathed stud wall system that provides superior blast resistance at a low cost. The wall has the ability to resist extremely large impulsive blast pressures in a stable and ductile manner without generating debris that could penetrate the habitable space and cause injuries. It relies on the flexural capacity of the studs, Sure-Board sheathing (or its equivalent) and simple connection details for wall anchorage.

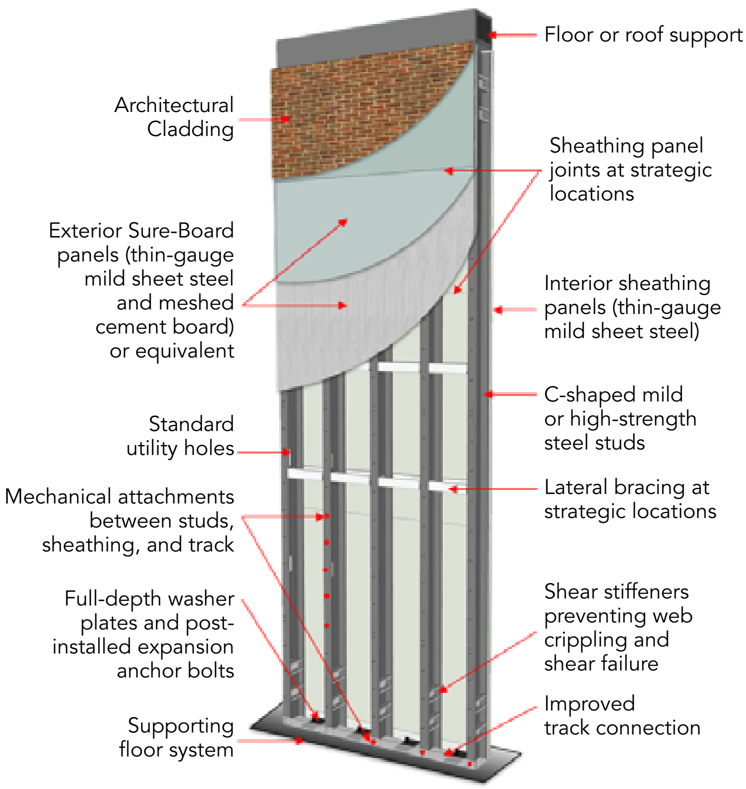
With a total construction cost of $27 per sq. ft (including materials and labor and excluding architectural finishes), it provides approximately 30% in cost savings in comparison to other high-performance blast-mitigating wall systems, including reinforced concrete, reinforced masonry and precast/prestressed wall panels. Although the added mass in these other systems helps mitigate blast effects, these systems may be more susceptible to brittle failure and impart significantly larger loads to the supporting structure. The high force demand can cause structural failures and possibly initiate progressive collapse. Conversely, the lighter SEB wall—designed to be ductile, redundant and have a predictable response—can in many cases provide a more economical solution.

We investigated the use of both mild and high-strength steels in the construction of SEB walls and found that both materials provide enhanced blast performance, while additional cost savings ranging anywhere from 15% to 70% can be obtained with high-strength steel.

Increasing Resistance

The blast-resistance of conventional cold-formed walls is limited by buckling effects and lateral torsional instabilities. Special detailing incorporated into the design of the SEB wall and

Ady Aviram, P.E., Ph.D., is a senior staff engineer, **Ronald L. Mayes**, Ph.D., is a senior consultant and **Ronald O. Hamburger**, S.E., is a senior principal and Western Regional Manager for Structural Engineering Operations, all with Simpson Gumpertz and Heger.



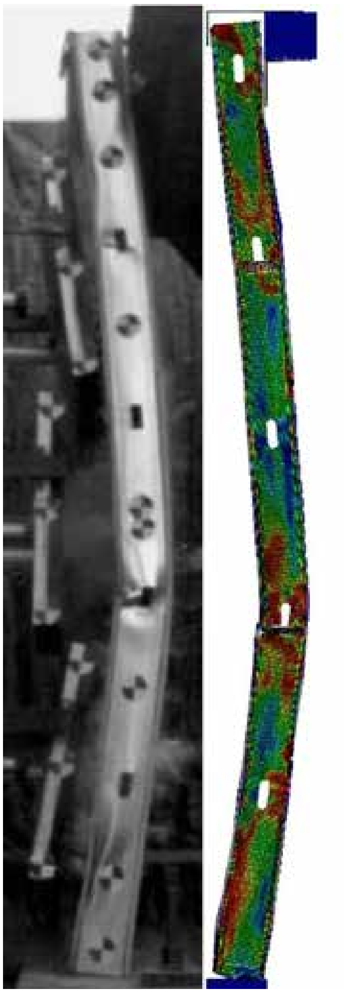


Figure 1. Components of the SEB wall.

Figure 2. Stud wall finite element model (by SGH) used for response predictions of blast simulation tests at the University of California, San Diego.

the use of the Sure-Board panels mitigates these problems. These special details (see Figure 1) include composite Sure-Board sheathing on both interior and exterior wall faces, effective lateral bracing solutions at strategic locations coinciding with stud utility holes, shear stiffeners at stud ends, improved track connections and continuous attachment between the different wall components using closely spaced mechanical fasteners or stich welds. The connection of SEB walls to the supporting frame uses relatively simple details including full-depth washer plates and post-installation expansion anchor bolts. The resulting SEB wall designs prevent stud instabilities and premature failure modes and exhibit ductile flexural response, which is predicted with a high level of accuracy using both finite element models (see Figure 2) and simple single-degree-of-freedom formulations.

We successfully validated the SEB wall concept using field tests employing explosive levels equivalent to large vehicle bombs, approximately four times larger than those previously resisted by conventional stud walls. Our experimental program included numerous full-scale tests that helped identify and resolve system instabilities, premature failures and deficient connection details encountered in other experimental programs. Initial testing consisted of blast simulation tests using high-speed impact actuators at the Englekirk Facilities at the University of California at San Diego (UCSD) under the direction of Dr. Gilbert Hegemier. We conducted seven full-scale stud wall specimen tests under single and multiple actuator impulsive impacts. This program focused on development of connection details and finite element model calibration.

The experimental program's second phase consisted of five live explosive tests of full-scale stud walls at Tyndall AFB. These field tests simulated vehicle bombs and validated the system for secondary support of unreinforced masonry and standalone construction. The field tests also identified sheathing limit states under direct pressures and additional detailing measures required to ensure wall stability.

Finally, we performed several quasi-static load tree tests at Tyndall AFB to validate the stud wall analytical resistance functions under uniform loads. In this test setup, a total of 16 point lateral loads were applied to a stud wall segment using steel cylinders.

In all of these full-scale tests we achieved survivable levels of interior pressures and protection against flying debris under stable and predictable wall flexural resistance. The resulting system provides an economical and practical solution resisting large, never-before-achieved blast resistance without the need to fully develop tension membrane resistance.

In Use

System application of the SEB wall includes use as a backing for unreinforced or lightly reinforced masonry cladding, as well as stand-alone construction under direct blast pressures. Government, military, commercial and industrial facilities can all be protected from external air-blast explosions using single- or multiple-story SEB wall panels. The system can also be effective for the construction of interior walls subjected to limited pressure build-up. The SEB wall can be installed on-site or prefabricated and transported, which allows its use for expeditionary military applications as well as domestic bases. The practical and easy installation procedure, as well as the potential removal of the blast walls, is feasible, allowing the potential for modular construction and reuse; the system allows general contractors and their curtain wall fabricators the flexibility of attaching the wall components either by welding or mechanical fasteners such as self-drilling, self-tapping screws.

Since the SEB wall has only been validated to date for non-load-bearing applications, our ongoing research and development efforts include extensive analytical and experimental studies for the characterization and development of load-bearing stud wall capabilities. This effort is sponsored by the Air Force Civil Engineering Center at Tyndall AFB, where both quasi-static and full-scale field tests will be carried out. A joint venture called HWH Protective Structures has recently completed a series of validation tests of blast-resistant modules (BRMs) constructed using the SEB wall concept. SGH has designed these modules to resist high blast levels for military expeditionary applications and petrochemical facilities under terrorist, insurgency or vapor cloud explosion threats.

This façade system can be used with steel framing designed as described in AISC Design Guide No. 26 *Design of Blast Resistant Structures* (see p. 46 for more on this guide) to provide buildings with increased blast and progressive collapse resistance. MSC

This work was sponsored by the U.S. Army Research Laboratory under Cooperative Agreement DAAD19-03-2-0036 and managed by the Advanced Technology Institute dba SCRA Applied R&D. Additional funding and technical support were provided by the U.S. Air Force Research Laboratory at Tyndall Air Force Base, Fla., for execution of field and quasi-static tests. Any opinions, findings and conclusions expressed in this material are those of the authors and do not necessarily reflect those of the funding agencies.