NEW STEEL SYSTEMS ADD STRENGTH — AND BEAUTY

Advances in R&D are fostering new forms of structural and aesthetic steel.

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AESS steel columns at Lee Hall III, Clemson University, designed by Thomas Phifer and Partners with McMillan Pazdan Smith Architecture and Skidmore, Owings & Merrill.

LEARNING OBJECTIVES

After reading this article, you should be able to:

+ **EXPLAIN how novel steel structural systems can improve construction project delivery, building performance, and sustainability.**

+ **DESCRIBE the use of architecturally exposed structural steel and how new standards facilitate the design, delivery, and construction using these building systems.**

+ **DISCUSS the use of steel sheer walls and castellated and cellular steel structures.**

+ **LIST additional steel building techniques that simplify construction and design.**

Recent advances in steel structural systems, notably in architecturally exposed structural steel, steel plate shear walls, and castellated and cellular beams, have been the subject of development by structural engineers, steel specialty contractors, and industry groups.

Architecturally exposed structural steel (AESS) has been used in projects ranging from college buildings to airports. In these applications, architects toe the line between design and engineering by showcasing the form of a material generally recognized mainly for its function. “When left exposed, structural steel can express form, integrity, and beauty in buildings while simultaneously demonstrating function and strength,” according to *Modern Steel Construction.*

The benefit of AESS lies primarily in its expressiveness. Exterior bracing and diagrid systems have been shown to “reduce building materials, enhance structural performance, and decrease overall construction costs,” according to Kheir Al-Kodmany, of the University of Illinois at Chicago. They “visually communicate the inherent structural logic of the building while also serving as a medium for artistic effect,” he adds.

SMOOTHING STEEL DELIVERY

One major initiative over the last year has focused attention on Section 10 of the 2016 American Institute of Steel Construction Code of Standard Practice, which addresses AESS. Industrywide work led to significant revisions of the code, organized into multiple categories and different treatments required for each kind of exposed steel material. In general, since steel can be rolled or bent to tight specifications with widely available fabrication technologies, complicated designs can be easily accomplished with the material. Steel can also be test-fitted prior to shipping, helping ensure that on-site erection goes smoothly. Steel is considered among the most recycled building materials available, making AESS practical and sustainable as well as an aesthetic choice.

The code committee improved the ANSI document AISC 303-16 with a "defined approach to specifying AESS" in construction documents. Five categories (AESS 1, 2, 3, 4, and C) are given, corresponding to typically increasing cost and time for fabrication and erection. The approach follows on a successful 2009 update to the Canadian Code of Standard Practice. A growing pool of architects and structural engineers is endorsing the U.S. adoption by referencing the AESS categories in project submittals and CDs.

STEEL PLATE SHEAR WALLS OFFER BOTH CREATIVE AND STRUCTURAL ADVANCES FOR A VARIETY OF APPLICATIONS.

"The code defines the statement of custom and usage for fabricated structural steel," said Code Committee Chair Babette C. Freund, President, Universal Steel of North Carolina. "This is important to all—you don't have to reinvent the wheel every time you have a new project." AISC President Charles J. Carter, SE, PE, PhD, adds, "The most fundamental change is that, as of last year, the code is now an ANSI-approved consensus document."

These developments bode well for the art of building. The structural benefits of AESS have resulted in its employment in award-winning projects, including hundreds of buildings and even some wonders like The Linq Hotel's High Roller Hotel in Las Vegas, designed by The Hettema Group, Pasadena, Calif., with Klai Juba Architects, Las Vegas, and constructed by a team led by local contractor W. A. Richardson Builders. At 550 feet in height and built at a cost of approximately $300 million, The High Roller is "the largest observation wheel in the world," according to owner Caesars Entertainment. The exposed steel system has an impressive 50-year design life.

The twisting steel exoskeleton atop Samsung 837 in New York City shows the riveted girders in a rare example of AESS.

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The wheel's design gives passengers the feeling they are floating. This is accomplished with a single rim element and single cabin-support bearing. The wheel's steel structure is left completely exposed, allowing guests to notice design details as small as the steel connectors, according to Klai Juba.

AESS was also used in the twisting steel design for Samsung 837, at 837 Washington Street, New York. The seven-story "digital playground" of glass and steel features a modern exoskeleton of riveted beams and girders. It was built on top of a building constructed in the 1920s, creating a historical mashup of two architectural statements.

Another noteworthy new case, Lee Hall III at Clemson University, presents treelike structures in an elegant, minimal pavilion for an expansion of the school's College of Architecture, Arts, and Humanities. The architects from Skidmore Owings & Merrill and a blue-ribbon project team used AESS to support the building and roof plane with slender Y-shaped columns. Close-up inspection reveals exceptionally careful craftsmanship by the steel fabricator, allowing the finished members to appear smooth and visually consistent to campus visitors.

SHEAR EXCITEMENT IN SHEAR WALLS

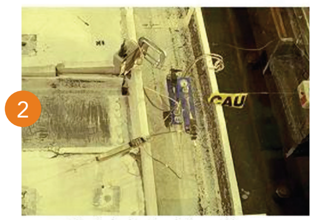
Steel plate shear walls (SPSW) offer both creative and structural advances for a variety of applications. The basic approach is to weld steel plates to columns and beams, creating a stiffened structure that is relatively slender compared to alternative reinforced concrete walls; this can yield greater rentable area in the buildings. Prefabricated steel plates are common production items in the manufacturing world, making SPSWs easy to source. Plates can be easily bolted into place, too; in this way, columns can be connected with plates to stitch a reinforcing building structure to resist large loads as part of the column erection sequence.

The AISC has partnered with Charles Pankow Foundation to initiate a new study aimed at advancing steel-plate composite shear walls filled with concrete. (See BDCnetwork.com/PankowR&D for more about the Charles Pankow Foundation's work.) The goal of the research—conducted by civil engineering professor Amit H. Varma, PhD, and his team at Purdue University—is nothing less than to create a new way to optimize the designs and speed the construction schedules for high-rise buildings.

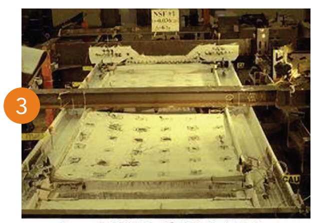
Concrete-filled composite plate shear walls, known as CF-CPSWs, are becoming more familiar to project teams that use jump-formed reinforced concrete

SPECIMEN ONE-INNOVATIVE COMPOSITE SHEAR WALL

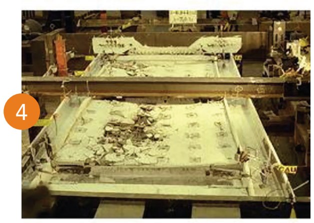
Steel Plate at $5\delta_y$ (Drift of 3.0%)



Ductile Behavior of Connection



Concrete Wall at $6\delta_y$ (Drift of 3.6%)



At $7.3\ \delta_y$ (Drift of 4.4%)

COURTESY HONGSONG HU, TSINGHUA UNIVERSITY

as shear walls in high-rise building core systems. "More permissive concrete industry tolerances can be a challenge for these cores, and the speed at which the jump-forming can progress generally slows the project down," says AISC's Carter, a structural engineer. The steel-concrete composite plate approach, the research partners expect, "will eliminate these drawbacks and still provide a system with excellent stiffness and damping." Proponents of concrete core systems counter that their designs enjoy wide acceptance and availability.

CF-CPSW core wall structures are gaining momentum because they take advantage of steel prefabrication in the shop, which improves construction precision, quality, and speed. CF-CPSW systems also use stay-in-place formwork in the field, which can cut construction time required at the project site, says Purdue's Varma. His team's $600,000 research project is receiving technical support from structural engineer Ron Klemencic, PE, SE, Hon. AIA, Chairman/CEO, Magnusson Klemencic Associates, Jim Malley of Degenkolb Engineers, and seismic structures expert Ronald Hamburger, SE, Simpson Gumpertz & Heger. Steel fabricator Supreme Group LP, Vancouver, is donating to the effort.

The track record for steel plate shear walls has been solid. SPSW's benefits include reductions in wall thickness and building height while still offering strength values comparable to concrete but with decreased density, according to Peter Timler, VP of Engineering, Supreme Group. SPSWs are also ductile and so can be constructed quickly. Recent SPSW testing covers many types of building projects and has shown considerable success. Their use in the construction of nuclear power plants attests to their tight tolerances, reliable erection record, and good performance in load resistance.

WITH THEIR LONG BEAM SPANS, CELLULAR AND CASTELLATED BEAMS CAN PRODUCE SAVINGS IN BEAM DEPTH AND SHEAR CONNECTORS.

These benefits have rung true for many project teams in recent years. SPSWs were used in the 5.5 million-sf L.A. Live entertainment complex in downtown Los Angeles, designed by RTKL Associates and constructed by Clark Construction and others for the Anschutz Entertainment Group. Miami University's Psychology Building and Animal Care Facility, in Oxford, Ohio, designed by NBBJ and structural engineer SMBH, Columbus, Ohio, also used SPSWs.

Thanks in great part to the use of SPSW, the overall weight of the L.A. Live structures was reduced by 30%. For the Miami University facility, the resistance needed for lateral loading is provided by steel plates that are narrower than spacing of the facility's steel columns, improving the openness and accessibility of the facility. The alternative—typical diagonal bracing—would have decreased the usability of several laboratory zones. The success of SPSWs in the Miami University project led directly to their use in another project, Ohio State University's Main Library.

Steel plate shear walls have also seen many advances in design and behavior in recent years, thanks to research linking top academic groups and industry leaders. The latest studies have helped improve the cyclic loading response of steel plates, as well as engineers' understanding of plate strain and other behaviors under real-world loading.

SPSW column design has also seen improvement, including some with plastic hinges above the base, resulting in significant reductions in column weight. Other studies of coupled SPSWs are improving design methods, the detailing of steel coupling beams, and steel moment frames. Many of these have applications to better seismic design approaches and post-earthquake repair strategies.

CASTELLATED/CELLULAR STEEL BEAMS

Castellated and cellular steel beams are yet another promising direction in the development of structural steel systems. The quickly growing body of knowledge surrounding the application of these beams makes them a possible new choice for designers and builders. Castellated and cellular beams offer unique benefits over traditional beams, making them advantageous for projects ranging from parking garages to workplaces, according to David Dinehart, PhD, Professor, Department of Civil and Environmental Engineering, Villanova University, and co-author of a new guide on the topic.

Castellated and cellular steel beams have openings within sections. This effect is created by cutting along the length of the section in a wave form and welding the two pieces together to form a deeper section with openings. Castellated beams employ hexagonal openings; cellular beams have circular or oval openings. "Longer spans and the ability to run utilities through the web openings are just two advantages," says Dinehart.

Since services no longer have to be supported beneath the beams and the need for this space is eliminated, overall building height can be greatly reduced, too. With their longer spans, cellular and castellated beams can produce savings in beam depth and the number of shear connectors required.

Cellular beams differ from castellated beams in that the spacing of the cells can be changed between limits. This ultimately eliminates excessive infill use and allows for greater flexibility. Even within the same cellular beam, several depths and diameters of the cell are possible without change in the fabrication. Cellular beams also use ring stiffeners, allowing more zones to be available for service.

The AISC's new design guide, *AISC Design Guide 31: Castellated and Cellular Beam Design,* offers technical information necessary for employing castellated and cellular beams. The guide, written by Dinehart, provides a review of the current state of practice of the design of castellated and cellular beams, making note of differences in failure mode with traditional beams. It also includes detailed models of both composite and noncomposite beams.

Of these beams, Sameer Fares, PE, SE, an R&D structural engineer at New Millennium Building Systems and co-author of the AISC guide, says that "the web openings in these beams introduce new limit states and unique design considerations."

Castellated and cellular beams are making a splash in innovative projects nationwide. The Lowes Company Headquarters Parking Deck, Mooresville, N. C., saved $300,000 in initial costs over precast concrete, according to the project team, due to the use of castellated beams, some over 60 feet long. The beams also added to the visual appeal of the parking complex, as noted by the American Galvanizers Association: "It is not often that a parking structure is viewed as an attractive piece of a building complex, but, in this case, the aesthetic value of castellated beams elevates this Lowes structure to an integral element of its appealing surroundings."

HYBRID STRUCTURES IN THE FRAME

Another area of study has been hybrid structures, including wood-panel structural floor systems combined with a steel frame. Under development by Skidmore, Owings & Merrill with the AISC, the concept shows promise in fire-related testing. The approach uses cross-laminated timber (CLT), which effectively spans distances of up to 30 feet. Such a structural element has appeal for multifamily construction due to its acoustical and damping properties. The typical design carries CLT panels nested between asymmetric steel beams; the loads are carried by steel columns. A concrete topping applied above prepares the subfloor.

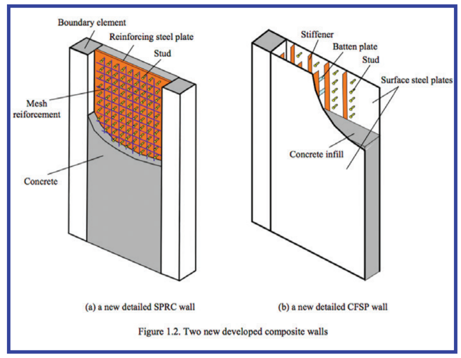
AISC's Carter says the technique could make steel more attractive in multistory projects, especially for its span advantages, while also reducing the floor system's weight. It also has benefits for seismic applications. The approach offers an option for those who typically use reinforced-concrete flat plate systems, which have been dominant in the residential marketplace and in some hotel designs.

In search of lower floor-to-floor heights, a number of new systems present steel alternatives to flat-plate concrete. Some employ low-profile beams that are known to speed construction and help create open interiors with great flexibility for room layouts. Using steel T-sections to span the floors, the systems allow for the floor planks to also be used as the ceiling. This is beneficial because the underside of planks tends to be the smoother side. In some cases, the project teams clean and glaze the bottom (ceiling) side of the plank, while alternative designs employ a furring channel and gypsum board finish. According to Dan Fisher, Jr., with system maker Girder-Slab Technologies, about 200 buildings, mostly along the eastern seaboard, have successfully employed these and similar approaches.

Some thin-floor systems help reduce the site area required for equipment and material laydown, especially formwork, according to the AISC. They also protect the steel from fire risk, so spray-applied products or encapsulation detailing may not be necessary. Like flat-plate or thin-slab structures, this growing class of structures relies on the tight tolerances and efficiencies of prefabricated elements, which can bring a building to market faster than ever before—if proper planning and lead times are observed.

"In-wall beams" is another successful approach for thin-floor technology. These beams are aligned such that they fall along partition lines or soffits, through which the beams run. The approach uses conventional steel framing or with a steel deck or long-span type of deck. The resulting floor assemblies may be as slender as 10 inches or less, and in some smaller spaces may be as thin as five inches or less.

AESS, STEEL PLATE SHEAR WALLS, and castellated and cellular beams are all proven technologies that can be considered for a wide variety of building types. These advances point to a future in which steel structural systems will be regarded as much for their beauty as for their structural functionality. +



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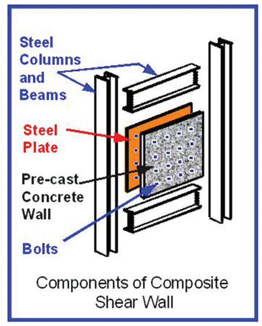

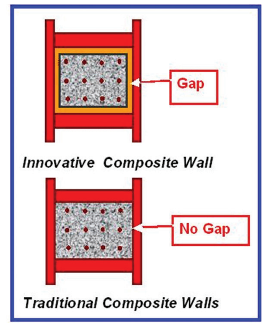

[Top] Steel-plate shear walls perform well in seismic-resistant construction assemblies. Novel composites of steel and concrete are under consideration. [Bottom] Composite shear walls provide options for buildings in high seismic zones. Many are made with steel plates connected to reinforced concrete walls. Courtesy Abolhassan Astaneh-Asl, UC Berkeley

+EDITOR'S NOTE

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