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jpreston@STRUCTUREmag.org; Tel: 602-369-3037

EDITORIAL STAFF

Executive Editor Alfred Spada
aspada@ncsea.com

Publisher Christine M. Sloat, P.E.
csloat@STRUCTUREmag.org

Associate Publisher Nikki Alger
nalger@STRUCTUREmag.org

Creative Director Tara Smith
graphics@STRUCTUREmag.org

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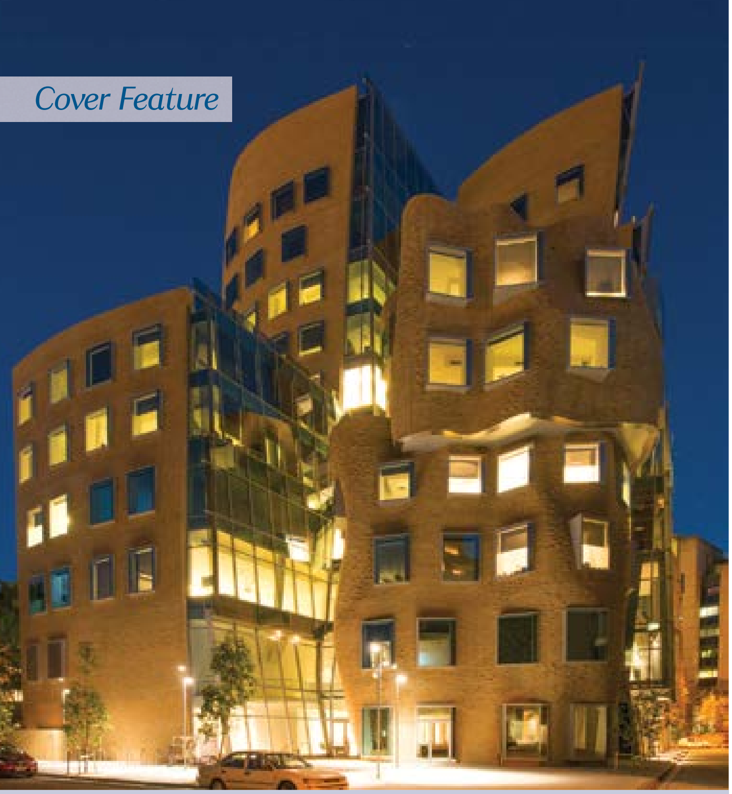
Cover Feature



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By Cathy Inglis and Jonathon Turley, S.E.

The use of brick challenges the norm with the design of the University of Technology Sydney's Dr. Chau Chak Wing Building. This building has been called everything from a treehouse, to a squashed brown paper bag, to a masterpiece.

22 A MASSIVE BEAM TO SPAN A NEW AUDITORIUM

By Casey Moore, E.I.T., and Thomas M. Corcoran, P.E., S.E.

The Central Kitsap High School and Middle School Replacement project's feature of the auditorium and the architect's desire to maintain the same material along the wall allowed CMU to be utilized to span across large openings.

Editor's Note

To continue to provide you, our readers, with the same wealth of information and articles during these extraordinary times, this issue of STRUCTURE includes Bonus Content only available in the digital magazine. Our Editorial Board is committed to delivering additional online articles, when available, until the situation improves.

If you have a success story as an SE working remotely that you would like to share, email your anecdote to **publisher@structuremag.org** for posting on the STRUCTURE website (all stories will be anonymous). A process or a product that improved your transition to working remotely may be the solution for someone else.

Stay safe and healthy.

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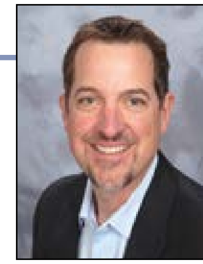
Channeling Tom Hanks

By Ed Quesenberry, S.E.



One of the last people I thought I would ever get professional advice from is Tom Hanks. Then it happened. It was during my daily lunchtime indulgence of surfing YouTube for a good comedy or anything unrelated to structural engineering. I stumbled upon a video of Tom Hanks' acceptance speech for the Golden Globe Cecil B. DeMille Award, which is for outstanding contributions to the world of entertainment. After the traditional, heartfelt expression of thanks to his family for their support, he summed up the key to his success by saying, **"…you're a dope if you don't steal from everybody you have ever worked with."** Hanks went on to name some of the people he had unapologetically stolen ideas from during his career, including names such as Streep, Eastwood, Scorsese, and DeNiro.

This kernel of wisdom resonated with me, and I immediately began assessing my career and, eventually, our entire profession through this lens. I will save you all from the reflections on my own past but would like to share a few on our profession.

When it comes to *stealing* technical knowledge, I do not believe Mr. Hanks would classify structural engineers as dopes. The history of structural engineering is steeped with the *pilfering* of ideas, *theft* of mathematical theories, and outright *looting* of scientific discoveries, all in the name of advancing the practice and enhancing public safety in the built environment. It all started with *stealing* concepts of structural stability and proportion from the Ancient Egyptians. It progressed through time with an *appropriation* of discoveries made by the likes of Archimedes, the Ancient Romans, DaVinci, Galileo, Hooke, and Newton. Our profession continued to refine its craft by taking ideas from Euler, Bernoulli, Bessemer, Freyssinet, and countless others, and formulating the foundation of structural analysis and design that we all still use to this day. Modern-day structural engineers have much more vast libraries of technical knowledge to *plunder* than our predecessors did, including the institutions of higher learning, national professional organizations such as SEI, NCSEA, CASE, and all of their respective state-level organizations. Perhaps the most enduring victim of our theft is our fellow Structural Engineer, for who among us would be where we are today without acquiring knowledge from our mentors and coworkers? It's an open-and-shut case; Structural Engineers are accomplished *thieves* of technical knowledge.

When it comes to banding together on a national scale to secure and solidify the future of our profession, it was not until recently that Structural Engineers created national associations to more easily share their thievery with other engineers across the country. CASE was formed in 1987, and NCSEA and SEI were formed in 1993 and 1996, respectively, all well after the AIA (1857) and ASCE (1852) were established by the professionals they represent. Until the last couple of years, these three national organizations have operated relatively independently from each other, with each advancing different aspects of the structural engineering profession. In 2019, the profession realized that there is something to the adage "there is strength in numbers." As a group, they formulated the *Joint Vision for the Future of Structural Engineering*, which is a roadmap for collaboration between each of the 3 national organizations that support our profession. It has taken us a while to get to this point, but thanks to our willingness and ability to *steal* from each other, we are working together in new, exciting ways to advance the practice of structural engineering.

This advancement is going to occur in areas beyond the technical realm and is going to require a sharp application of our knowledge of appropriation skills to be realized. We could learn a few things from our friends in the architecture industry about promoting the value of our profession, perhaps starting with studying the effectiveness of their use of social media, **www.youtube.com/user/AIANational**. We may want to steal some tactics from the sportswear and automotive industries (i.e., Nike and Tesla) about how to position ourselves as innovators in our industry. We could begin to fill the gaps in structural engineering education as the hi-tech industry has done for the computer science fields-of-study, through an investment of capital, materials, and human resources. As I write this, I see the need for our profession to learn from the world's reaction to the COVID-19 crisis as we both advocate for more resilience in the built environment and fortify our position in the disaster response community.

As you can see, there is plenty of heavy lifting to be done to achieve the *Joint Vision*. SEI, CASE, and NCSEA will need to rely on crafty thieving by all of you that read this article and by those that work with you to make it a reality. The time has come for you to channel your inner Tom Hanks and *steal* some great ideas for the good of the profession. Don't be a dope.▪

Ed Quesenberry is the Founding Principal of Equilibrium Engineers LLC and serves on the NCSEA Board of Directors. (edq@equilibriumllc.com)

Advancement in Masonry Today

By Peter Roberts

What is the future of masonry? Innovation in masonry is critical to meet the growing challenges facing our world. These advancements will create new markets, foster economic growth, and create new green technology. Over the next decade, masonry will evolve into several exciting new hybrid technologies and become a critical part of additive manufacturing. Traditional masonry will be expanded into new design and assembly models, using new materials and green technologies.

Current Trends: Robots

Building Information Modeling for Masonry (BIM-Masonry) is expected to shape the future of design. Buildings will be much more computer-designed, integrated with semi-automated and fully automated assembly methods. Robots are expected to play a significantly more substantial role in assembly in the coming years. Additive manufacturing (3-D printing) will be combining mortar deposition with robotic placement of block in an evolving field of masonry-based additive manufacturing.

The high efficiency of block manufacturing provides an affordable, engineered, finished Concrete Masonry Unit (CMU) with various textures, colors, finishes, and high strength, with tight dimensional control to be used as an element in additive manufacturing (unlike 3-D printing). CMUs are also made in a controlled factory environment, as opposed to on-site 3-D printing. The low cost of concrete block will allow it to win on price in the new realm of additive manufacturing.

3-D printing remains unattractive and unappealing when compared to masonry. Familiarity with masonry will help in the adoption of additive manufacturing innovation because it is based on what is known. This is expected to occur slowly at first, as transitions occur from manual to semi-automated and fully automated assembly. This transition will affect labor and must address the evolving role of labor (e.g., Bricklayers and Allied Craftworkers International Union, BAC).

Semi-Automated Mason (SAM) by Construction Robotics.

Insulated manufactured concrete block by NRG.

New Methods

Advances in automated additive assembly, 3-D printing, robotics, and digital design have created a new frontier in masonry innovation. A few companies are leading the way in this growing realm of advanced masonry technology.

- *Construction Robotics* provides the Semi-Automated Mason (SAM) and the mason's assistant MULE. The SAM unit uses additive assembly techniques of placing mortar while a robotic arm places block and/or brick in the wall.
- *Fastbrick Robotics* is a start-up out of Australia. Their Hadrian X masonry robot is capable of building all the vertical walls for a building in a fully automated method. The Fastbrick robotic system requires custom block and uses an adhesive rather than conventional mortar to bind the blocks together.
- *Built Robotics* is a company dedicated to providing robots for construction. While they do not currently provide a block or brick laying robot, by upgrading off-the-shelf heavy equipment with AI guidance systems, they enable machines to operate fully autonomously.

Exoskeletons

Masonry is strenuous manual labor, and the advances in the arena of exoskeletal technology are very promising. These external support systems will enable today's masons to keep working and attract young people into the future of the profession. There is a critical shortage of masons nationally, and many of the best are looking toward retirement. Several companies are addressing the challenges created by the demanding nature of masonry work through the research and development of various exoskeletal and other external support system technologies. *Levitate Technologies*, *Inc. Suit X* and *Ekso Bionics* are among the many companies providing various degrees of wearable external body support for workers.

Sustainability and Green House Gases

Masonry innovators have recently found ways for the industry to become much more carbon efficient. Here are three companies leading the way on this front.

- *bioMASON* is one of the exciting recent technology innovators in this area. This start-up has found a way to dramatically reduce the carbon footprint of Portland cement by using bacteria to grow calcium carbonate crystals to replace the carbon-intensive process of Portland cement manufacturing needed to produce standard concrete and concrete block.

- *Solidia Technologies* is a company developing a lower carbon footprint than Portland cement for concrete through its methods of cementing concrete together by using innovative chemical cements and curing approaches.
- *CarbonCure* seeks to reduce the carbon footprint by pumping liquid CO_2 into concrete and CMU through the mixing process.

New Applications

The versatility of masonry creates new design possibilities, including water storage, septic tanks, ships, boats, vessels, barges, bridges, seawalls, levees, flood protection infrastructure (culverts, etc.), and more. The use of CMU's to build roofs, including arches, domes, and flying buttresses, is another new application for manufactured concrete block (this includes work by the author). The use of fiber reinforced plastic (FRP) rebar creates rust proof reinforced masonry and concrete, which will become increasingly significant as sea levels are expected to rise. These new applications for masonry are expected to grow the industry significantly by creating entirely new markets.

New Materials

Ductile and elastomeric composite material create masonry appropriate for blast and ballistic applications, defense applications, hardened structures, seismic applications, and severe weather events. *ProtectiFlex* provides a proprietary technology combining recycled non-biodegradable material, composite fibers, and/or rebar in a cement matrix. This material offers protection against blast, ballistic, forced entry, impact, fire, and seismic loads, and can be used to mitigate risk against accidents, natural disasters, and direct attacks. This material design prevents bullet penetration, reduces spalling, and can absorb large amounts of energy without diminishing structural integrity. It has 20 times the strain capacity of traditional concrete before failure.

Masonry dome made with manufactured concrete block by Spherical Block LLC.

Autoclaved aerated concrete (AAC) is another newer material that holds promise due to its light weight and ease of cutting. *Aercon* provides AAC material in both blocks and panels. This material is lightweight, can be for both load-bearing and non-load bearing applications, has good acoustic performance, offers better thermal insulation than standard concrete, and includes many of the benefits of standard concrete such as fire safety, insect and pest resistance, and durability.

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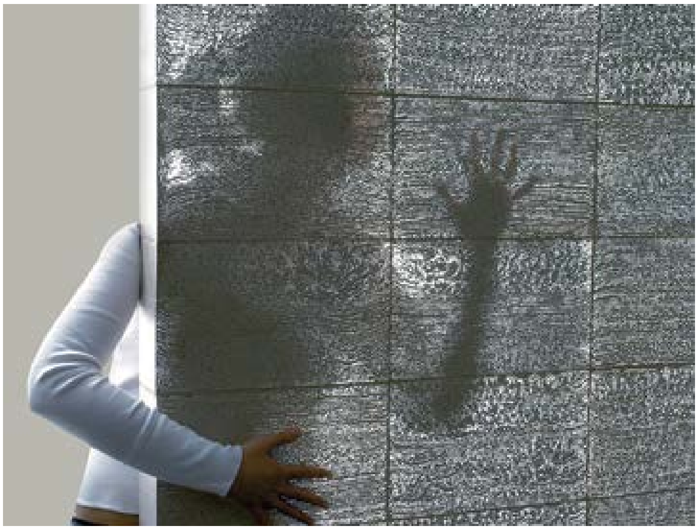

A concrete panel made with Litracon material.

Masonry arches and flying buttresses made with interlocking block by Spherical Block LLC.

Insulated concrete blocks are also relatively new to the marketplace and help to maximize the thermal mass benefits of concrete and masonry, creating more thermally efficient buildings. *NRG Block* makes thermally insulated CMU's which have a serpentine interlocking expanded foam thermal insert within the block. This design creates an insulated block with no direct thermal bridging from the inside of the building to the outside, resulting in a better thermally insulated building envelope. From both inside and outside, the wall looks like a conventional block wall.

Light-transmitting or translucent concrete and mortar are yet another new addition to the palette of masonry materials. Fiber optic cables are cast into concrete, allowing light to pass through dense opaque concrete and/or mortar, creating visually compelling architectural lighting effects. *Litracon* produces light-conducting concrete material for construction applications. The company uses both glass fiber optic elements, with a more randomized distribution of light-conducting elements cast in concrete, and a plastic light-conducting grid which creates regularly spaced light-conducting elements, appearing like LED pixels in a concrete grid. *Light Transmitting Mortar* is a start-up using technology similar to that found in light-conducting concrete, except that the light-conducting fibers are made of plastic. This creates a unique visual effect by allowing mortar joints to transmit light from outside to inside (or vice versa).

What was the Vision of the Future 30 Years Ago?

This question was posed by a Workshop on Masonry sponsored by the National Science Foundation (NSF) to a steering committee led by Clayford T. Grimm in 1988. Committee members included the National Concrete Masonry Association (NCMA), the Masonry Institute of America (MIA), and Clemson University. Here are the findings of the Grimm's steering Committee from 1988, "Why Are There So Few Innovations in Masonry?"

1) Tort Law
2) Bureaucratic Building Code Process
3) Unfunded Process of Writing Consensus Standards
4) Industry Fragmentation: "Economic pressures for fast construction time leave little time for the learning curve required by new ideas. The construction industry mindset supports the status quo."
5) Research Fragmentation
6) Educators teach what they know (few know masonry)
7) Designers are reluctant to use masonry structurally because of poor jobsite quality control
8) Academicians who dream up new names for old ideas and make a career out of it.
9) Designers who do not care about mason productivity.
10) Lack of financial incentive.

This question persists over 30 years later. The author has encountered the following responses from industry, trade groups, and end-users over the years: "it is a mature technology" and "there is no room for improvement after thousands of years of masonry practice." Much contemporary research looks back in time to understand some of humanity's achievements with masonry (for example, the work done by Jacques Heyman). Old ideas are often presented as "new," including, for example, Catalan arches, which originated in the 14th century around Valencia, Spain. Guastavino tile arches from the 19th century (Catalan arches) are also reexamined and often presented as new. This illustrates novelty versus innovation, as described by Loreto et al. in the 'adjacent possible' scheme.

What is the Vision for the Future Today?

Expect an increase in the automated assembly of buildings, gradually moving from worker's exoskeletons to semi-automated systems to fully automated robotic assembly of masonry. Expect the use of greener materials, new technologies, and methods to reduce carbon emissions. Expect new designs and forms from the CMU as designers continue to utilize its strength and value. Expect stronger, safer, more energy-efficient, affordable, beautiful masonry buildings.

Prediction

Green masonry will become central to additive manufacturing. It is environmentally appropriate, economical, attractive, and builds on *what is known*. This prediction calls for a productive future for the masonry industry in which successful innovation will occur as creative ideas exist in a balance between the *familiar* and the *new*.▪

The online version of this article contains addition information about innovation and sources of innovation. Please visit **www.STRUCTUREmag.org**.

Peter Roberts, President, Spherical Block LLC, has been developing topological manufactured concrete blocks for roofing and complete building envelopes for over 30 years. (roberts.peter01@gmail.com)

New Digital Tool Simplifies Masonry Design

By Scott Conwell, FAIA, FCSI, LEED AP

Those familiar with masonry design understand its benefits for building construction: no other material provides the beauty, strength, durability, design versatility, and sustainable attributes as materials like brick, block, and stone. Unfortunately, however, younger designers or those new to masonry may be reluctant to consider it due to its perceived complexity, the overwhelming options of materials and subassemblies, and the lack of a recognized standard for organizing masonry systems, assemblies, and components. The International Masonry Institute (IMI) is addressing these obstacles by developing a systematic process for designing masonry walls: complimentary access, digital Wall Builder Tool to facilitate the process, and a crowdsourced Masonry Wall Systems Library (**imiweb.org/wbt**) that applies a logical taxonomy. This design approach quickly and systematically goes through a series of micro-decisions on a small number (eight or fewer) of subassemblies of the wall, resulting in a well-informed system design.

The Paradox of Choice

The Paradox of Choice is a premise put forth by author Barry Schwartz in his 2004 book of the same title that states, "the more choices we are presented with, the more difficult it is to make an informed decision." The argument posits that even if the options are of good quality and if the consumer or user desires many options to make an educated decision, too many choices will result in a state of paralysis and very likely lead to no decision at all. We encounter decision paralysis in a variety of everyday situations, from choosing a restaurant to dine at, a movie to watch, or what to do on a Friday evening. For design professionals making decisions about materials, structure, and components of a wall, navigating countless options can present the same difficulty.

Consider your experience dining at a Mexican restaurant, where you are presented an extensive menu offering a comprehensive selection of platters, small plates, specials, combos, and a la carte items. Deciding what to order with so many options often feels daunting. At a cafeteria-style restaurant, which limits its menu to five basic items, and prompts you to make a series of micro-decisions about the ingredients you want in your entrée, ordering dinner is much simpler.

Similarly, the Wall Builder Tool simplifies the process of designing a masonry wall system by guiding the user through a logical sequence of components that make up a wall.

Wall System
Assembly 1
Component 1
Component 2
Assembly 2
Component 1
Component 2

Components, Assemblies, and Systems

Because it comprises so many parts and pieces, a masonry wall system can be complex and even intimidating, but a little reverse engineering will make it easier to understand. The key is a three-tiered approach to every masonry wall system. From the granular to the general, there are components, sub-assemblies, and finally, the system itself. If masonry components, also known as masonry materials (for example, a brick, an air barrier, or a wall tie), are the building blocks of masonry sub-assemblies, then masonry sub-assemblies are the building blocks of a masonry wall system. Now that we've introduced the hierarchy, for the sake of simplicity, we will refer to a sub-assembly simply as an assembly.

Masonry Wall Assemblies

The key to simplifying masonry walls is the delineation of a manageable number of assemblies. The makeup of any masonry wall system using this approach, no matter how complex, comprises no more than eight subassemblies. A masonry wall may have fewer than eight, but never more than eight assemblies. Not considering the Interior Finish assembly, which is generally out of the engineer's scope, the primary seven assemblies are identified as follows, listed by location from the inside of the wall working toward the outside:

A. Structure
B. Sheathing*
C. Air/Moisture Barrier*
D. Insulation*
E. Drainage*
F. Attachment*
G. Cladding*
** indicates optional assembly*

Structure

Structure is the single assembly that every masonry wall requires. In this context, structure refers to the structure of the wall itself, not the framing system of the building, although they may be one in the same as in the case of loadbearing masonry. Examples of wall structure include concrete masonry (reinforced or unreinforced), steel studs, wood studs, or architectural precast concrete panels. In the case of a single wythe CMU wall with no exterior cladding and no interior finish, the Structure assembly would be the only assembly of the wall system; fields B through G would be blank.

Sheathing

If the wall's structure is loadbearing or light gauge steel or wood studs, it would likely require a sheathing over the studs. The sheathing imparts in-plane rigidity and provides a surface for an air/moisture barrier if desired. For adhered veneers, the sheathing also provides a surface to affix the adhered veneer cladding. Walls with a solid structure like CMU, structural clay masonry, precast, or cast-in-place concrete would likely not make use of the Sheathing assembly.

Air/Moisture Barrier

Although its form and location in the wall may vary, the typical location of an air/moisture barrier is directly over the structure or the sheathing. This assembly may take the form of a sheet or fluid-applied treatment. If the sheathing or the structure already meets requirements for resistance to air leakage outlined in the energy code or other applicable codes, a separate air/moisture barrier may not be required; therefore, this is an optional assembly.

Insulation

With the trend toward sustainable practices and lower energy costs, the thermal performance of walls is more important than ever. Therefore, many walls are designed with insulation that supplements masonry's natural thermal mass in the wall's ability to manage thermal changes. Insulation comes in varying types, thicknesses, and locations, and is an important assembly of most masonry walls.

Drainage

Drainage walls, cavity walls, or moisture managed walls are walls with some drainage mechanism to collect and divert moisture that infiltrates the exterior cladding and works its way into the wall. Examples of drainage mechanisms can be as simple as an air space behind the cladding, to more substantial accessories like drainage mats.

Attachment

Walls with a cladding assembly over the wall structure, whether the cladding is anchored or adhered, require a method to attach or affix the cladding to the backing. In the case of anchored veneer, the methods of attachment generally take the form of veneer anchors or wall ties; rainscreen systems typically have a more elaborate framing system that ties the cladding to the structural backing. Adhered veneers may utilize various forms of bonding mortar, either reinforced with lath or unreinforced.

Cladding

Unless the wall is a single wythe masonry wall, it will have a cladding assembly. The cladding, whether full-depth anchored masonry veneer or a thin adhered material, is the exterior skin of the wall. The variety of masonry cladding material, e.g., brick, stone, tile, terra cotta, architectural block, etc., provides the exterior element of beauty in a masonry wall.

Interior Finish

Interior finish is included in the eight subassemblies because it can be an important part of the wall's design even if not addressed by the engineer.

Design Decisions Sequence

Knowing each of the eight assemblies, the analogy of the build-your-own burrito experience provides a similar hierarchy and progression to the decision-making process. The first two decisions in the burrito line are the most important, and they are the ones that will inform the subsequent decisions: the type of protein and the type of wrap. In designing a wall system, the first decisions are how the wall supports itself and what it will look like. Subsequent options follow, like the insulation (or not), the drainage device (or lack thereof), and the interior finish.

Once the wall structure and cladding are selected, the Wall Builder Tool is intelligent when it comes to subsequent options. For example, if no cladding is selected, the program knows it to be a single wythe wall and will only offer the choice of "none" for the fields of sheathing, attachment, and drainage. If the structure is concrete masonry or any assembly other than wood studs, then corrugated wall ties will not be offered as an option. TMS 402, *Building Code Requirements for Masonry Structures*, does not allow those types of ties with those types of backings. If a thin material is selected as cladding, the only methods of attachment offered are the direct bond materials rather than mechanical anchors.

Deliverables

Once the user has completed the systematic process of selecting each of the subassemblies based on project requirements, he or she can download a PDF graphic of the wall system. This graphic shows each of the eight or fewer assemblies in a three-dimensional exploded view presented as in the field of the wall. A descriptive sheet title is automatically generated as well as a unique wall number, both appearing on the drawing sheet. Each time a wall is built online, the program pushes that same PDF file to IMI, who curates the user-generated Wall Systems Library.

The PDF graphic depicts only the field of the wall and not any special conditions like penetrations, terminations, or accommodations for movement or moisture. The Wall Builder Tool is intended to be a design aid in the conceptual or schematic stages of design. It does not generate complex construction details or a specification (IMI has other resources for those), but it does inform the details and the specifications since the generated walls provide a perfect starting point for the design development phase.

The PDF graphic can also serve as a communication tool among the design disciplines and even the client. It is also a useful teaching tool for engineering or architecture students or practicing professionals who are just becoming conversant with masonry design.

BIM Ready

Currently, the output is limited to the PDF graphic. However, BIM users can extrapolate the information into a file compatible with their BIM platform of choice. The next phase of the Wall Builder Tool may introduce Dynamo scripts able to generate Revit files of the wall designed, so it can immediately be brought into the BIM model.

Standardization

The Wall Builder Tool and the Wall Systems Library are the masonry industry's first step at developing a universally recognized taxonomy for masonry walls. The large number of combinations of materials in a masonry wall results in hundreds of thousands of unique walls, making it difficult to attempt any method of standardization until now. Because computer logic assigns a wall number based on the materials selected in each assembly and is adept at capturing and cataloging every wall designed using the Wall Builder Tool, the masonry industry is one step closer to achieving a standard classification system for masonry walls.■

Scott Conwell, with International Masonry Institute, educates design professionals, advances good masonry design, and advocates superior workmanship. Scott is a Fellow of the American Institute of Architects (AIA) and the Construction Specifications Institute (CSI). (sconwell@imiweb.org)

The Wilkes-Barre Tornado

Masonry Damage and Modeling

By Heather A. Sustersic, P.E., Michael Kinzel, Ph.D., and David Malyszek

On June 13, 2018, at approximately 10:00 PM, an EF-2 tornado passed over Wilkes-Barre, Pennsylvania, causing an estimated $18,000,000 in property damages and severely impacting commercial and retail buildings within its 600-foot-wide (183 meters) by 2.9-mile-long (4.7 kilometers) path (*Figure 1*). Losses to affected buildings ranged from complete or partial collapse to superficial damage to the fenestration.

Figure 1. Path of Wilkes-Barre tornado, including impacted buildings. Aerial photo from Google maps.

Current commentary provisions in ASCE 7-16, *Minimum Design Loads for Buildings and Other Structures*, for determining tornado wind pressures on buildings could have predicted some, but not all, of the damage observed in the aftermath of the Wilkes-Barre tornado. There are gaps in our understanding of how building irregularities and discontinuities affect design-tornado wind surface pressures, as the research to date has primarily focused on regularly shaped (rectangular) buildings with gable roof profiles. Much data exists for *straight-line wind* loads on buildings of variable geometry, but companion data for *tornado-induced* wind loads is lacking. Working across disciplines to leverage analysis tools used in aerospace and mechanical engineering, but not commonly used in structural engineering, may help to close the gaps and improve the way we design buildings with irregularities to withstand low-level tornadoes.

This article expands on material previously presented at the 13th North American Masonry Conference, where the authors summarized building damage observed in the wake of the Wilkes-Barre tornado (with particular attention to masonry) and introduced a cross-disciplinary modeling technique for predicting tornado wind loads on buildings.

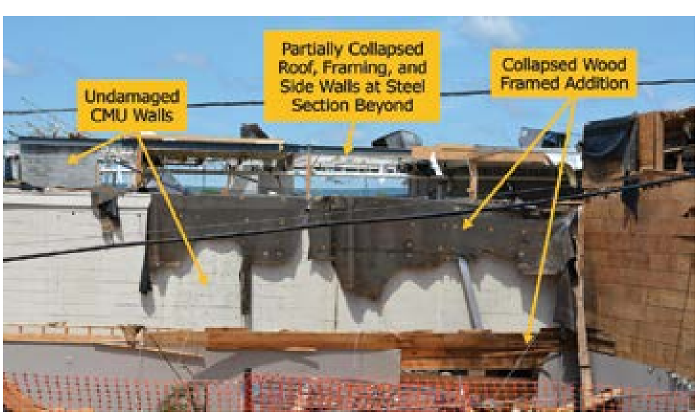

Figure 2. Building D (middle and background) and Building A (foreground) partial collapse of wood and steel framed elements in line with undamaged CMU walls.

Damage Observations

Interior access to most of the damaged buildings in Wilkes-Barre was not available. However, observations and photos taken by the author during an independent site visit on June 19, 2018, and aerial drone video footage available from local online media coverage after the event, were analyzed to arrive at the conclusions presented herein. Specifically, damage to seven buildings was observed. These are labeled A through F in *Figure 1*, and described below:

- Building A – wood-framed building addition to Building D, with shared masonry bearing walls
- Building B – single-story outdoor strip mall, open web steel joists, masonry bearing walls
- Building C – structural steel building, perimeter CMU apron, cold-formed steel studs walls
- Building D – structural steel building, open web steel joists
- Building E – structural steel building, open web steel joists, infill CMU exterior walls
- Building F – 'big box' building, open web steel joists, masonry bearing walls
- Building G – pre-engineered metal building

The observed wood-framed addition to Building D labeled Building A, and the pre-engineered metal building, Building G, experienced complete structural collapse. Cold-formed steel stud exterior infill walls at Building C collapsed. Building B and Building F experienced significant roof and fenestration damage. Building D experienced a partial collapse of the roof and sidewalls. Building E experienced separation of the leeward wall from the sidewalls and perimeter roof support.

Masonry Observations

Structural masonry walls performed very well during this tornado. In the absence of existing building drawings, the author considered the age, size, spans, and roof heights before concluding that the affected exterior CMU walls are most likely partially-grouted reinforced bearing and/or shear walls. The author observed no structural masonry wall collapses on any of the affected buildings. There were no wind-borne debris impact failures observed in masonry elements, and no base connectivity failures observed in structural masonry.

Figure 2 shows an undamaged CMU wall of Building D in the middle ground with the collapsed wood-framed addition (Building A) in the foreground, and significant roof, framing, and sidewall damage to the structural steel portion of Building D in the background. At Building C, the CMU apron beneath the cold-formed steel stud exterior walls remained unscathed while the cold-formed framing above was destroyed. Unreinforced, architectural masonry, such as the decorative oversized piers at a sporting goods store main entrance, experienced failures ranging from stepped cracks in the mortar joints to partial collapse.

Even though the tornado passed directly over Building B, destroying 75% of the roof and causing significant damage to the storefront and soffit, the rear CMU wall of the building was undamaged (*Figure 3, top and bottom right*). Unreinforced masonry column wraps at the front of Building B experienced shear failures, some of which twisted at their base and translated laterally 2 to 3 inches (*Figure 3, bottom left*) with mid-height torsional shear failures as well; others had more subtle shear stress failure limited to the mortar joints. Roof joist-to-masonry wall connections remained intact.

Figure 3. Building B overall damage; typical front column wrap shear failure in mortar joint (left); back wall of building undamaged (right). Aerial photo from 570 Drone footage.

Designing Buildings for Tornadoes

Most engineers do not design buildings to withstand tornado wind events without realizing that the wind speeds in lower level (EF-0 to EF-2) tornadoes are comparable to Category 1 to 3 hurricanes. When engineers do move beyond risk acceptance to design for tornadoes, a sacrificial building approach is often used, following FEMA and NIST recommendations for designated safe rooms and using ASCE 7-16 *Commentary*, Section C26.14, to determine design pressure coefficients. This is a conservative and safe approach to design but may be over-conservative for low-level tornadoes. ASCE 7-16 *Commentary* recommendations are primarily based on physical laboratory testing of simplified, scaled models, which could limit applicability for non-rectangular geometries.

New Cross-Disciplinary Modeling Approach

Computational Fluid Dynamics (CFD) is a well-established numerical approach for fluid dynamics used extensively within aerospace and mechanical engineering, as well as meteorological fields. CFD has

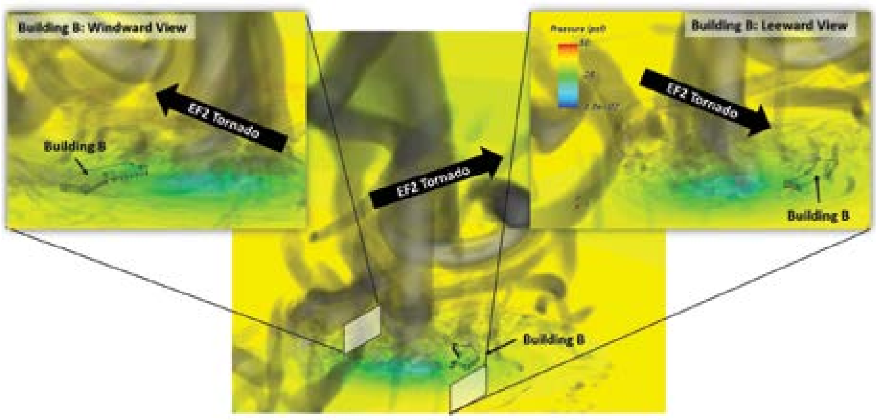

Figure 4. Building B subjected to simulated tornado (center); Blowup view of windward side (upper left); Blowup view of leeward side (upper right).

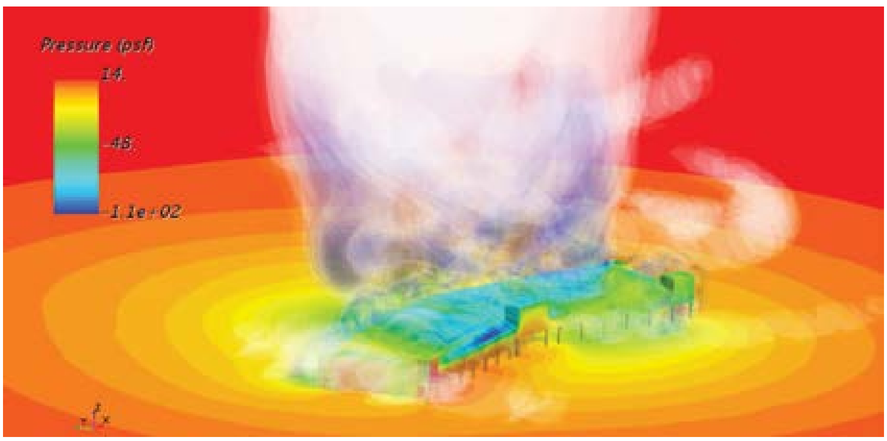

Figure 5. Surface pressure contour plot of Building B at the first contact of a simulated tornado.

thrived on the recent trend in the expansion of computing power. CFD uses numerical methods to approximately solve the notoriously difficult-to-solve Navier-Stokes equations, which reflect the governing equations of fluid dynamics: conservation of mass, energy, and momentum for each particle in a time-space computing domain. Such solutions provide highly detailed flow-field information and loading details associated with building shapes that can supplement structural design. One interdisciplinary approach would be through coupling CFD to computational structural dynamics solvers yielding a fully coupled fluid-structure interaction (FSI) solution. These CFD-based FSI methods describe an emerging engineering toolset that is finding applications in biological, marine, and aerospace engineering fields. They are even being utilized for atmospheric-scale engineering objects, such as wind turbines and solar panels. These engineering applications, considering FSI coupled to CFD as the approach, reduce assumptions and can pinpoint failure modes; hence, enabling design improvements over to full-scale models as well as enabling the reduction of engineering factors of safety. The overall goal of these CFD models is to expand understanding of full-scale tornadoes, without building physical models.

Preliminary Model and Observations

To demonstrate the feasibility of using CFD (in the context of the commercial tool Star-CCM+) in a structural engineering application, the authors modeled Building B, a 70-foot-wide by 300-foot-total-length building, with a 155-degree elbow approximately at mid-length and a mean roof height of 18 feet. A front extended soffit is supported by steel tube columns with masonry wraps spaced at 17 feet on-center maximum. Parapet heights vary from 2 feet to 9 feet on the sides and front of the building. The building was modeled as a solid, fixed mass with no openings or deformation capability. Structure deformation using FSI is outside the scope of this preliminary model; however, a deeper investigation is planned for the future. The building model is then considered in the context of a CFD model with an EF-2 tornado (tangential speeds ~120 miles per hour) approaching Building B at 40 miles per hour. Overall views from the model, including the main view and blowups of the windward/leeward views of the building, are shown in *Figure 4*. The grey features in the flow highlight the tornado. Here the tornado itself, its tentacles, and complicated wakes forming around the building can all be observed. All surfaces are colored by surface pressure, and lines on the main plot indicate the local velocity direction on surfaces. With the model, loading details (from both pressure and viscous shear forces) are evaluated on each square inch of the building, providing highly detailed loading information that can supplement design. An animation of this model is available at **https://bit.ly/34iF8Ln**. *Figure 5* illustrates the loading character on the building at first tornado contact. Note that the loads do not appear as pure constant pressure loading. Instead, the loading is complex and variable, with low pressures after each corner leading to a "bottle opener" effect applied to the roof, causing localized high pressures. This is consistent with the pattern of soffit, roof, and column wrap damage observed on the real building after the real tornado. Building designs that can consider these complex loadings during atmospheric events, such as tornadoes, are where CFD and FSI can enable next-generation, tornado-resistant designs.

New Tools for Designing for Tornadoes

Current guidance for engineers to determine design tornado wind pressures on buildings is based on tests of enclosed buildings with regular geometries that do not include provisions for extended soffits or other irregular building configurations. CFD is a powerful, established tool for non-building engineering disciplines that can model realistic, translating tornadoes interacting with modeled buildings, opening the aperture for predicting tornado wind loads on buildings with complex, irregular geometry.▪

*Heather Sustersic is a Project Engineer with Providence Engineering Corporation and former adjunct faculty member of the Architectural Engineering Department at Penn State University. She currently serves as a voting member of the TMS 402/602 Structural Members and Reinforcement and Connectors Subcommittees. (**heathers@proveng.com**)*

*Michael Kinzel is an Assistant Professor of Mechanical and Aerospace Engineering at the University of Central Florida. (**michael.kinzel@ucf.edu**)*

*David Malyszek is an undergraduate student in Aerospace Engineering at the University of Central Florida. (**dmalyszek1@Knights.ucf.edu**)*

A Structure as an Electric Battery?

Concrete Block Serves as Electrical Batteries and Sensors

By Peter Roberts

A new class of material has become the focus of much research in the field of cement science and concrete design. *Geopolymers* were initially named by French materials scientist Joseph Davidovits in 1979, who attributed this term to the amorphous to semi-crystalline tri-dimensional alumino-silicates that can be formed at low temperature and short time by alkali reaction with naturally occurring alumino-silicate solid materials – quite a mouthful but a precise representation of the chemistry involved.

Geopolymers create the potential for providing strong, robust, energy-efficient concrete buildings, where the concrete structure itself acts as an electrical battery to store energy and deliver power. These novel batteries can be charged by solar panels, wind turbines, or other renewable energy. The high thermal mass of the building's masonry shell provides passive operation capabilities because the masonry acts as a thermal sink. This heat sink can also be actively controlled with power delivered by the electrical storage capacity of these novel masonry batteries in the event of power loss from the grid. This arrangement provides better management of excess energy by feeding to the grid during peak demands, which has the double benefit of providing increased resiliency and improved energy efficiency.

This technology is featured in the use of novel potassium geopolymeric (KGP) cementitious material to make concrete block and configure this masonry as an energy storage receptacle and a self-sensing structural material. Geopolymers are being explored as a replacement for Ordinary Portland Cement (OPC), whose manufacture is a contributor to greenhouse gases. KGP's piezoresistive properties also allow it to detect stress within a structure for real-time diagnostics. KGP exhibits good ionic conductivity, which can be exploited for electrical storage and power. It has high strength, excellent high-temperature resistance, thermal stability, durability, and is easy to manufacture. This technology holds the potential to address both partial and complete power loss. Once fully developed and tuned, this concept could save up to 100% of a building's energy needs.

Because geopolymers use fly ash as part of their activation process, this novel material can help provide a valuable role for the vast waste repositories of fly ash created by burning coal to fuel electrical powerplants. If fully developed, tuned, and implemented, geopolymers could help turn the liability of fly ash deposits into a valued commodity in geopolymer production.

Electrical batteries currently serve as a component of some Distributed Energy Resource (DER) systems that are deployed to help provide a more robust energy distribution system. DER is a tactic used increasingly across the U.S. to provide increased resilience for buildings in the face of widespread electrical outages, which have become more frequent and prevalent in the wake of severe weather events. For example, the National Oceanic and Atmospheric Administration report "2017 U.S. billion-dollar weather and climate disasters: a historic year in context" listed 16 separate billion-dollar extreme weather event disasters in the U.S. resulting in power loss to significant portions of various communities. Currently, battery-based DER systems exist as a separate component from the building which they serve and occupy a significant footprint within the building. In other words, they are in the way of building occupants. The concrete block system places batteries within the structural wall of the building, out of the way of building occupants.

This innovation is expected to have a significant impact on efficiency and safety of buildings, on the efficiency and resiliency of the power grid, on reducing greenhouse gases produced by OPC, of finding a valuable use for fly ash waste, and in providing safe, secure, resilient homes and buildings. By creating affordable, easy-to-use concrete blocks as a distributed component of the evolving new smart power grid, customer acceptance is expected to be easy and adoption rapid for a large market segment.▪

*Peter Roberts, President, Spherical Block LLC, has been developing topological manufactured concrete block for roofing and complete building envelopes for over 30 years. (**roberts.peter01@gmail.com**)*


Figure 1. Curved masonry façade.

Masonry Madness

By Cathy Inglis and Jonathon Turley, S.E.

Brick is one of the simplest and the most versatile materials, one of the most ubiquitous, and often the least regarded. It is a fundamental staple among building materials, where the small scale and modularity yield enormous potential. Traditional masonry is typified by rectilinear building forms, repetitive laying patterns, and two-dimensional flatness. However, the humble brick is not limited to traditional, and its form can be fluid and sculptural.

The use of brick by renowned architect Frank Gehry challenges the norm with the design of the University of Technology Sydney's (UTS) Dr. Chau Chak Wing Building, School of Business.

This building has been called everything from a treehouse, to a squashed brown paper bag, to a masterpiece. Whatever description applied to it, the Frank Gehry-designed Dr Chau Chak Wing Building is now one of Australia's iconic buildings.

The defining characteristic of this building is its unique masonry façade, which contorts and twists in both vertical and horizontal directions for the full height of the 13-story structure (*Figure 1*). Each brick course snakes along a horizontal plane while vertical curvature is achieved by corbelling each progressive course outward or inward. Gehry chose brick for the exterior to reflect the colonial brick heritage of the surrounding area, curving it to achieve the unique desired form.

Brickwork, at a complexity never seen before, creates a façade that appears to have movement as the horizontal courses of bricks corbel to articulate the building's organic shape.

Although the construction methodology and arrangement of structural elements are like conventional brick façade walls, the wall inclinations and curvatures create structural engineering challenges that are not typically encountered in masonry façade construction.

This drove the development of a custom structural system that included custom brick units, ties, mortar, and construction methods – all designed specifically to cope with the distinctive engineering challenges of the project.

The Façade System

The overall façade system consists of several interconnected components.

The innermost element is a steel stud wall that spans between the concrete floors. Each stud is a curved, T-shaped profile that follows the curvature with the masonry skin in front of it. Since there is no repetition in the masonry façade, every stud wall panel is unique (*Figure 2*). The stud wall is clad with metal sheeting and a waterproof membrane.

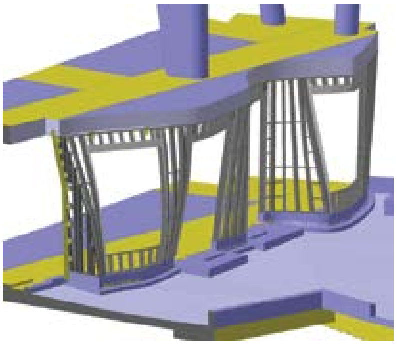
Figure 2. CAD model of curved steel stud wall.

Specially designed brick ties bridge a nominal 3-inch (75mm) cavity between the stud wall and the masonry skin. The ties brace the wall out-of-plane, transferring the horizontal load imparted by the masonry wall. The masonry skin itself is constructed from 5 unique brick units developed to achieve the architectural and structural requirements. These were laid meticulously on-site, brick-by-brick. The masonry skin is vertically supported at each level by stainless steel shelf plates which are bolted to the adjacent concrete floor structure. The concrete floor and shelf plate also curve in plan to match the façade geometry.

This arrangement resembles a traditional brick veneer system but functions very differently due to the distinctive geometry.

The Brick-Tie System

Traditional vertical masonry veneer systems resist lateral loads, such as wind and seismic, through a tie system transferring loads to the support system. The ties provide little or no contribution to gravity load resistance, which is transferred downward through the plane of masonry veneer.

This is not the case for the Dr. Chau Chak Wing Building. Each brick is offset from the brick below to create a wall that appears to lean in and out. The offset reaches as much as 1.7 inches (42mm), leaving only 2.7 inches (68mm) of mortar bed joint for the standard 4.3-inch-wide (110mm) brick. Inclinations of this magnitude create significant horizontal loads due to the masonry's weight, which must be carried by the brick ties. This, in combination with plan curvature, creates complex load patterns and concentrations. There is little guidance in the standards on how to deal with this type of loading. It fundamentally goes against the way that masonry is designed and conventionally constructed. When engineering the structural system, the authors had to remind themselves that traditional design and construction techniques could not be applied.

The ties become critical to the stability of the brick façade. They will take significant compression where the brickwork slopes in and tension where the brickwork slopes out (*Figure 3*).

The engineers initially explored the possibility of using a traditional metal tie system for the brick façade construction; however, off-the-shelf ties were found to be inadequate. They are typically embedded in mortar joints and, in this application, would not be satisfactory to resist the loads imposed by the brick eccentricities. It was clear that a more robust brick-and-tie system was required.

In searching for a solution, inspiration was taken from a traditional stone cladding support system in which every stone is supported individually using ties that lock into a groove in the stone edge. The question was: could there be a tie that engaged with the bricks in a similar way?

It is common for brick units to have a localized depression (also known as a *frog*) in the top of the brick to help with mortar bond. A modification of the frog created a continual channel where a tie could be placed. This would provide an internal surface to which the tie could engage and achieve a much higher load-carrying capacity as opposed to merely placing the tie in a horizontal mortar bed joint.

The tie would consist of a threaded rod with a square nut that sat in this channel. The brick tie system adopted is shown in *Figure 4*.

The use of a threaded tie allowed it to be adjusted in and out to suit the channel location, which varied significantly as the façade contorted in plan.

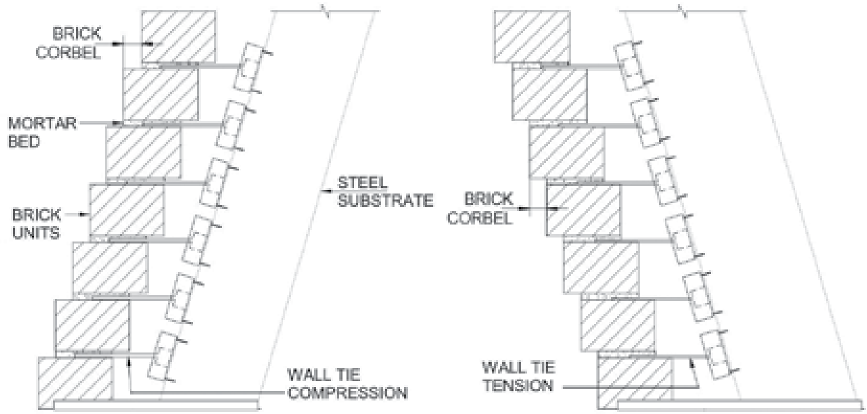

Figure 3. Brick ties in compression when the wall leans in (left) and ties in tension when the wall leans out (right).

This system was adopted for approximately 35% of the façade area. The remaining 65% consisted primarily of walls with fewer eccentricities. For these areas, a conventional style of masonry tie was adopted since the imposed forces did not require the high tolerance provided by the threaded type tie.

A critical aspect of the design was the vertical spacing of the ties. The goal was to eliminate tension in the mortar joints due to the self-weight of the wall and thus align with a fundamental design philosophy that masonry veneer is not intended to resist constant tensile forces, in line with the Australian and International Standards.

At maximum corbel, over one-third of the brick overhangs the brick below. If two bricks are laid on top of each other at this corbel without any mortar, it is unstable and will collapse under its own weight. The stability of the brickwork relies on mortar to resist tension. By locating a tie at every course in these areas, this localized instability is addressed and the tension in the mortar is eliminated. The spacing was increased to every 4th course where the corbel was less severe.

The wall tie is fixed to the stud backup with a special assembly that allows the tie to be adjusted during construction. The tie could be moved up and down and rotated relative to the sloping substrate. The tie could, therefore, be aligned to project horizontally into the brick mortar joints.

Temporary Stability

The question of localized stability under self-weight highlighted another challenge for the design team: the temporary stability of the wall during construction.

An off-the-shelf brick tie system was used for early mock panels but did not provide adequate temporary support of the bricks. They would not engage with the bricks until the mortar had hardened. In areas of significant corbel, it was found that only a few brick courses could be laid at a time before the wall began to collapse. The bricklayers were forced to wait until the mortar had begun to set before proceeding. This not only affected the efficiency of the bricklayers but also may have compromised the mortar bond. This highlighted the requirement for a temporary restraint to the brickwork.

Figure 4. The custom brick tie system.

To address this, an additional component was added to the system in the form of a small square nut to be used in areas of high corbel. This can be seen in *Figure 4* on the inside brick edge.

The final solution was a unique structural system developed in collaboration with AECOM Ltd, the façade structural engineer; ARUP, the structural engineers; Lendlease Ltd, the contractor; and Austral Bricks, the brick manufacturer.

The Brickwork

Gehry Partners specified an American manufactured brick with 22 custom shapes to create the unique brick façade. Many trials were undertaken to match the brick, at UTS's request, to manufacture an equivalent brick in Australia. Collaboration between the brick manufacturer and the project architects changed the brick to a standard Australian size (230 x 110 x 76mm), reducing the final number of custom brick shapes to five. Dry press brick manufacturing was selected as that method produces solid bricks and intricate shapes. The corbelled nature of the façade meant all brick surfaces needed "face" finish, as they would all be visible.

There were 380,000 bricks with the 5 custom shapes produced at Austral Bricks Bowral Dry Press Plant just south of Sydney. The custom bricks include the centered channel, the offset channel, the K brick, the L brick (*Figure 5*), and a solid brick without a channel.

The K brick has an angled protrusion to create bends and shadowing appearing as though it has been offset from the standard coursing. The L brick is 5.5 inches (140mm) wide and installed at the shelf angles to reduce the size of the control joint from 2 inches to 1 inch (50 to 25mm) and improve the appearance, with the extra width giving sufficient bearing on the angle.

Figure 5. Left to right: centered rebate brick, K brick, offset rebate brick, and L brick.

Structural Analysis

Detailed finite element analysis was carried out to determine the force in the ties and stresses in the masonry under various load cases (*Figure 6*). The values determined from analysis were later compared to the capacities measured from laboratory testing.

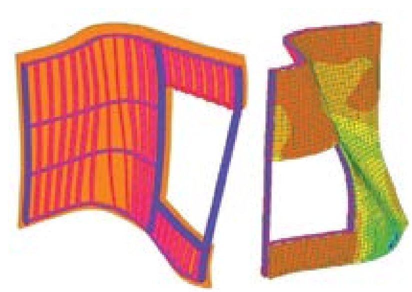

Figure 6. Finite element model of brickwork panel and associated steel substrate (left) and wall stress contour output (right).

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There was a particular focus on the most intricate brickwork panels to identify critical areas and complex behavior.

Laboratory Testing

Throughout the design phase of the system, a series of laboratory tests were carried out to determine the performance and properties of the various components. It was essential to demonstrate the structural adequacy of this completely new system. The brick tie pullout capacity and mortar bond properties were key to confirming the adequacy of the system.

Two full-size mock panels were constructed to evaluate constructability and calibrate the analysis models (*Figure 7*). Strain gauges were fixed to the brick ties, and the panel was tested to failure using horizontal and vertical hydraulic jacks.

Construction

The unique nature of the brickwork created many challenges on-site, with bricklaying production as low as 50 bricks per man per day in very complex areas.

Ensuring consistency of the mortar was crucial. Oven-dried sand was used to enable better control of the water content of the mix. The sand/cement mix was prepared in premixed bags to reduce the chance of error and inconsistency when mixing on-site.

Additives were also premixed in the water in an on-site reservoir to reduce variability between batches. This was trialed as part of mix design testing to ensure the process did not adversely affect the mortar properties. The brick packs were dipped in water for a specified time before laying to reduce the suction and ensure that all bricks had the same water absorption. This was in stark contrast to traditional brickwork construction where a wheelbarrow and a shovel are used to measure out the various mortar ingredients.

Brick cleaning posed another challenge onsite, as typical cleaning acids were not allowed on the project. The suggestion to use a commercial vinegar solution was offered up from a retired bricklayer that had used this method before the introduction of hydrochloric acid.

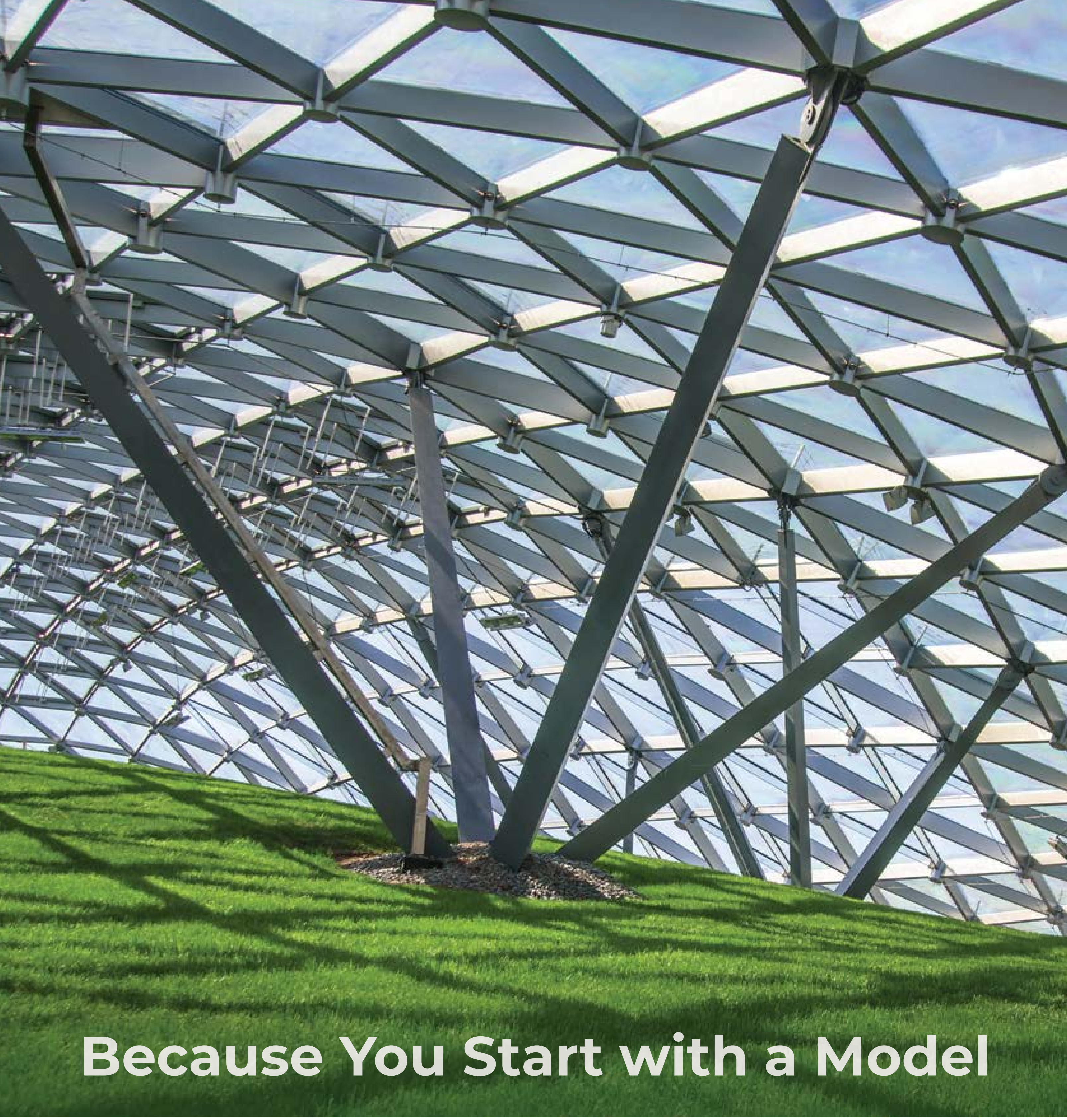
Figure 7. Full-size mockup panels before load testing.

Through the application of the latest design techniques, the design team pushed the boundaries of what can be achieved with masonry, one of the oldest building materials still in use. The problem was broken down and rebuilt from first principles. Unique and innovative engineering solutions allowed the reinvention of the masonry façade and the realization of Frank Gehry's vision.▪

The online version of this article contains additional graphics. Please visit **www.STRUCTUREmag.org**.

Cathy Inglis is General Manager Technical & Innovation, Brickworks. (cathy.inglis@brickworks.com.au)

Jonathon Turley is a Senior Structural Engineer at Aurecon. He led the structural design of the Dr Chau Chak Wing Building facade at AECOM. (jonathon.turley@aurecongroup.com)


Because You Start with a Model

A Massive Beam

TO SPAN A NEW AUDITORIUM

Central Kitsap High School and Middle School Auditorium

By Casey Moore, E.I.T., and Thomas M. Corcoran, P.E., S.E.

Aerial view of Central Kitsap High School and Middle School project during construction Courtesy of Skanska USA.

The new Central Kitsap High School and Middle School campus was celebrated with a grand opening ceremony in October 2019. Located west of Seattle in Silverdale, Washington, the campus houses the new three-story, 325,000-square-foot building that combines and modernizes the community's high school and middle school. The new structure sits at the center of the 52-acre site where the school will accommodate up to 2,100 students from grades 6 to 12 with two gymnasiums and an auditorium that both students and the community will use. The former middle and high school buildings were both located on the site and have been demolished to make room for the multiple playfields and parking lots.

Steel was the primary structural material utilized for the academic portion of the new facility, utilizing special moment frames for the lateral force-resisting system. Steel was also used for the gravity systems of the gymnasiums and auditorium but, in these spaces, special reinforced masonry shear walls were instead used for the lateral system. For all the masonry walls of the project, fully grouted 12-inch nominal concrete masonry units were specified.

The Auditorium

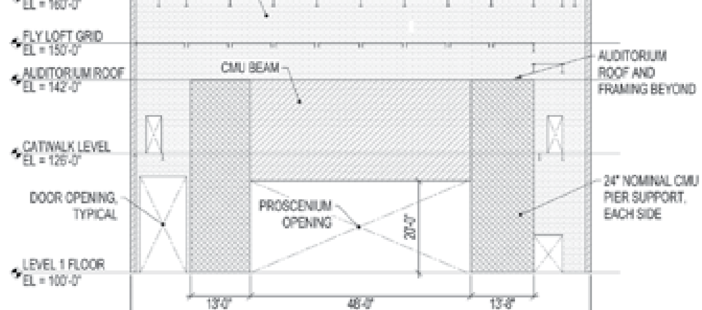
The 900-seat Auditorium is a central feature of the facility, centered between the high school and middle school wings of the campus. The audience faces a 48-foot-wide by 20-foot-high proscenium opening in a concrete masonry wall where musical and theatrical performances by students and community members will be given. There is an orchestra pit below the stage to provide space for live music with the shows at the school. Overhead catwalks and a 60-foot-high fly loft space provide for state-of-the-art lighting, sound, and prop equipment to be used.

CMU was the chosen building material to span across the proscenium opening and provide support for the roof structure above rather than other traditional materials such as steel or precast concrete lintels. For this design feature, it was decided that CMU would provide the best aesthetic to the exposed wall and would reduce cost by eliminating the need for multiple trades to work simultaneously in the same area. With the auditorium roof framing into the CMU wall at an elevation of 42 feet, the depth of the beam that spans across the opening was designed for the full height between the top of the proscenium to framing, a 22-foot beam depth. The 24-inch-thick (nominal) by 13-foot-long support piers to each side of the beam provided the gravity support for the beam as well as the primary shear walls of the structure.

Design Parameters

Various dead and live loads were applied to the beam from the multiple building levels being supported, the theater rigging equipment installed inside of the fly loft, and the catwalks hung to the roof structure. Along with the self-weight dead load of the beam, an additional self-weight of 22 feet of CMU wall supported immediately above the beam was directly applied without the reduction that arching action would provide. Worst case loading conditions of uniform snow load or snow drifting at the multiple roof levels supported by the beam were also considered. In total, the ultimate load applied to the beam using load combinations from ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures*, was calculated to be about 13.0 kips/ft.

With the beam parameters set at 22-feet-deep by 12-inch-thick (nominal) and 48 feet long, TMS 402, *Building Code Requirements for Masonry Structures*, was followed to determine the design approach to the beam. After calculating the effective length of the beam, an effective span-to-depth ratio, l_{eff}/d_v, of approximately 2.5 was determined. The code put



Labeled elevation of the CMU wall and beam.

the flexural design into the deep beam code section when fixed-end boundary conditions were applied, or to standard beam design when viewed as a simple span beam. Flexural reinforcement was designed for each case, but TMS 402, Section 5.2.2.3, required that the flexural reinforcement be detailed such that the reinforcement was distributed in the tension zones of the beam equal to half of the beam depth.

Although the required beam flexural reinforcement was determined, it was not the controlling factor for the longitudinal reinforcement; the out-of-plane load case would control. A vertical two-span condition from the top of the proscenium opening to the top of the fly loft roof, with mid support at the auditorium roof, was used to more accurately analyze the internal forces of the wall and beam. An equivalent spring reaction was placed at the top of the proscenium opening, with the stiffness of the spring calculated from the stiffness of the horizontal span of the bottom 11 feet of the beam between the support piers.

By using this method, the out-of-plane force against the wall at the critical location at the bottom of the beam was reduced from 60 psf to 50 psf. Fixed-end boundary conditions with the 48-foot span between supports were then used to design the reinforcement required for the out-of-plane flexure. With consideration of the in-plane strength, in-plane detailing, and out-of-plane strength requirements, the final design for the longitudinal reinforcing bars was U.S. #5 size at 8-inches on-center for the beam depth.

Shear design of the beam closely followed the procedure laid out in TMS 402, Section 9.3.4.1.2. The nominal shear capacity of the beam from the contributions of masonry shear strength and supplemental shear reinforcement was compared to the code maximum based on the beam's shear-span ratio, $M_u/(V_u d_v)$. U.S. #5 reinforcing bars at 8 inches on-center along the beam were also used for the shear reinforcement of the beam. The beam's shear design resulted in a demand-capacity ratio of approximately 0.50, with the code-maximum shear capacity values as the controlling capacity.

The TMS paper, *The Size Effect in Reinforced Masonry*, by S. Sarhat and E. Sherwood, was studied to determine how the size effect phenomena of a deep beam could affect the load-carrying capacity of the beam. As the effective beam depth increases, cracks along the tension face of the beam increase in width and spacing. This causes shear failure of the masonry at lower shear stresses due to reduced mechanical interlocking of the aggregate. It was discussed between engineering team members that, due to the amount of longitudinal reinforcement and shear reinforcement along the length of the beam, longitudinal cracks located in the tension face would be kept relatively small and would not impact the shear strength of the beam. Therefore, the size effect would be negligible.

Finished interior view of the auditorium and CMU wall.

Elevation of the CMS wall and beam during construction. Approximately 40 feet of 60 feet completed.

Construction Challenges

The primary challenge for the contractor in constructing this large beam was providing adequate support while the masons were laying the blocks. With the orchestra pit located directly below the proscenium, an engineer working with the mason subcontractor designed a two-level shoring system. Although the shoring was removed before the erection of the steel began, it was designed to hold the full self-weight of the beam, CMU wall above the beam, and steel roof framing. This gave the general contractor flexibility on the removal date once the wall's grout strengthened. Grout lifts of 5 feet 4 inches were used to minimize the number of lifts that were required to be poured.

Creative Beam Design

The Central Kitsap High School and Middle School Replacement project was an extensive campus overhaul that brought the two schools into a single facility and provided amenities that would be accessible to the community. The facility's feature of the auditorium and the architect's desire to maintain the same material along the wall allowed CMU to be utilized to span across large openings rather than other traditional building materials. The 48-foot-long CMU beam was a unique design challenge for the engineering team, demanding creative thinking and pushing the boundaries of beam design.▪

The online version of this article contains references. Please visit **www.STRUCTUREmag.org**.

Casey Moore is a Structural EIT at Integrus Architecture, P.S., an architectural and engineering firm with offices in Seattle and Spokane, WA. He performed the design and detailing for the masonry structure of the Central Kitsap school project.

Thomas M. Corcoran is a Structural Engineering Principal at Integrus Architecture, P.S., and is the Engineer of Record for the Central Kitsap school project. He is on several TMS subcommittees, serves on TMS 402/602, and serves as a Zone 1 Representative to the TMS Board of Directors.

Project Team

Owner: Central Kitsap School District, Silverdale, WA
Structural Engineers: Integrus Architecture, Seattle, WA
Architect: Integrus Architecture, Seattle, WA
General Contractor: Skanska USA, Seattle, WA
Mason: Keystone Masonry, Yelm, WA
Masonry Supplier: Mutual Materials, Bellevue, WA

Reinforced Masonry Shear Wall Systems

Seismic Design and Performance

By P. Benson Shing, Ph.D., Jianyu Cheng, and Andreas Koutras, Ph.D.

While they meet the safety requirement of building codes, special reinforced masonry wall systems designed according to current codes and practice may not perform in the manner consistent with the design expectation in the event of a major earthquake. This stems from the fact that seismic design provisions focus primarily on strength and reinforcement details, without sufficient consideration of the actual behavior of a wall system under severe seismic actions. To have a consistent level of safety and performance, a performance-based design approach may be followed to ensure that the structural system performs predictably. This article summarizes some recent research findings that may help this design process.

Shear walls are the main seismic force-resisting elements in a reinforced masonry building. Depending on the aspect ratio, reinforcement details, and loading and boundary conditions, masonry shear walls can exhibit one of several, or a combination of, failure mechanisms when subjected to in-plane lateral loading. Slender cantilever walls are expected to have relatively ductile flexural behavior, while walls with a low shear-span ratio ($M_u/(V_u d_v)$) tend to exhibit brittle shear behavior dominated by diagonal cracking. However, walls with very low shear-span ratios can develop base sliding in lieu of diagonal cracking. The masonry building code, TMS 402-16 (TMS 2016), has provisions for evaluating the strength of a reinforced masonry wall governed by each of these mechanisms, and reinforcing requirements intended to prevent brittle behavior.

For high seismic regions (Seismic Design Category D or above), reinforced masonry walls must comply with the *special wall* requirements. These require the shear capacity design to prohibit brittle shear behavior and impose an upper limit on the amount of vertical reinforcement to ensure adequate flexural ductility if special boundary element requirements are not met. However, despite the requirements mentioned above, a special wall designed according to current codes may not necessarily develop flexure-dominated behavior. The wall may have failure governed by diagonal shear cracking when subjected to severe seismic actions. Perforated walls and walls in low-rise masonry buildings often have low shear-span ratios such that their flexural resistance is much higher than the shear strength. Such design is permitted by the code as long as the shear strength of the wall component is at least 2.5 times the shear demand, V_u. Hence, with the R factor equal to 5 and an expected overstrength factor of 2.5, the shear strength of a special load-bearing reinforced masonry shear wall so designed can be lower than the shear demand of the Maximum Considered Earthquake (MCE), which is 1.5 times the intensity of the design earthquake. In that situation, diagonal shear failure is likely to occur.

Another factor that makes reinforced masonry walls prone to developing shear-dominated behavior is the coupling effect of the horizontal diaphragms in a building. The coupling moments exerted by the horizontal diaphragms could significantly reduce the effective shear-span ratio of a wall. This effect is often under-estimated or neglected in masonry wall design primarily due to the lack of a reliable analytical method to capture the behavior of the diaphragms or the diaphragm-to-wall connections. As a result, the actual shear-span ratio of a wall could be significantly lower than what has been assumed in design. One justification for this design approach is that the absence of the coupling moments results in a lower lateral resistance of the walls, and ignoring these effects would, therefore, produce a more conservative design. However, this is true only if the resulting overstrength introduced by the diaphragm coupling is high enough to compensate for the reduction in wall ductility should the wall become shear dominated.

Despite the issues mentioned above, special reinforced masonry shear wall systems mostly meet the safety expectation of the codes according to recent studies (Stavridis et al. 2016; FEMA 2020). This can be attributed to the overstrength in a typical masonry building or the presence of other gravity load-carrying elements in the structural system, which can enhance the displacement capacity of the system by providing an alternative load path.

Masonry buildings often have significantly more structural walls than what is needed to resist seismic actions because of their dual function as architectural elements, such as exterior building envelopes and interior partitions. This is especially true for low-rise masonry buildings. The unintended coupling action of the horizontal diaphragms is another source of overstrength. This, however, depends on the out-of-plane bending stiffness of the diaphragms and the strength of the diaphragm-to-wall connectors. The study by Stavridis el al. (2016) has shown that a wall system with horizontal diaphragms constructed of precast hollow-core planks with cast-in-place concrete topping could have an overstrength factor of 4. The high shear strength of the walls was mainly attributed to the horizontal reinforcement required to satisfy the prescriptive requirement of the code for special walls.

Furthermore, studies have shown that a reinforced masonry building with shear-dominated walls can develop a displacement capacity substantially higher than what has been observed in quasi-static tests conducted on planar wall segments. This can be attributed to the presence of wall flanges or gravity frames, which can carry the additional gravity load after the webs of the walls have suffered severe shear failure, as discussed later in this article.

Performance Assessments

ASCE/SEI 41-17, *Seismic Evaluation and Retrofit of Existing Buildings,* the standard for assessing the seismic performance of existing buildings, considers multiple performance levels, and permits nonlinear analysis procedures. However, it has the same drawback as the design codes for new buildings by focusing on the performance of structural components rather than that of the system. In the standard, reinforced masonry walls are classified as either flexure controlled or shear controlled. For nonlinear static or dynamic analyses, it specifies modeling parameters to define the in-plane lateral force versus displacement backbone curves that represent the behavior of reinforced masonry wall components. The shape of the backbone curve and the maximum deformations permitted for a wall component depend on the expected failure mechanism, and for the flexure-controlled mechanism, on-the-wall aspect ratio, applied axial compression, and the total amount of reinforcement. Even though these curves are intended for assessing the performance of existing buildings, they may be adopted for the displacement-based design of new buildings or for evaluating the performance of a code-based design. Nevertheless, the nonlinear modeling parameters in the standard have not been updated for many years. Recent studies have shown that these parameters tend to substantially under-estimate the displacement capacity of a wall component or a wall system.

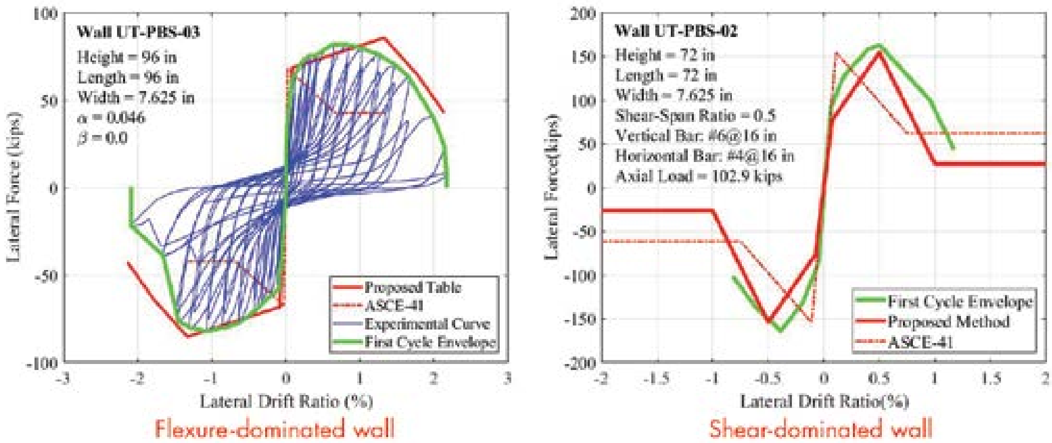


Figure 1. Comparison of nonlinear backbone curves constructed with ASCE 41 and new parameters proposed by Cheng and Shing (2018) to experimental data.

Based on quasi-static wall test data, Cheng and Shing (2018) have proposed a set of new modeling recommendations and parameters for reinforced masonry walls. The study has shown that wall cracking should be taken into consideration to estimate the elastic lateral stiffness of a wall. The value given by the theoretical formula recommended in ASCE/SEI 41-17 based on an uncracked section can significantly overestimate the stiffness observed in a wall test. *Figure 1* compares the backbone curves constructed with the modeling parameters specified in ASCE/SEI 41-17, as well as those proposed in the study mentioned above, to the experimental data for a flexure-dominated planar wall and a shear-dominated one.

While the proposed backbone curves provide a good correlation with the wall test data, a recent study discussed below has shown that they would still under-estimate the displacement capacity of a wall system by a considerable amount. Furthermore, it should be noted that, for the design of new reinforced masonry walls, the use of the stiffness formula proposed by Cheng and Shing (2018) could result in a substantial story-drift value that may not be practical with the stringent drift limits of ASCE/SEI 7-16, M*inimum Design Loads for Buildings and Other Structures*.

Seismic Performance

To investigate the displacement capacity of shear-dominated reinforced masonry wall systems and the influence of wall flanges and planar walls perpendicular to the direction of shaking (out-of-plane walls) on the seismic performance of a wall system, shake-table tests were conducted on two full-scale, single-story, fully grouted, reinforced masonry wall specimens to the verge of collapse. Each specimen had two T-walls as the seismic force-resisting elements and a stiff concrete roof diaphragm. The second specimen had six additional planar walls perpendicular to the direction of shaking. The design conformed to the special wall requirements of TMS 402-16. Each specimen was subjected to a sequence of earthquake ground motions with gradually increasing intensities. Specimen 2 on the shake table is shown in *Figure 2a*.

Figure 2b shows the base shear versus roof drift ratio curves obtained from the tests. The roof drift ratio is the roof displacement divided by the wall height of 235 mm (8 feet). The behavior of the T-walls was initially dominated by flexure; shear deformation became significant when the roof drift ratio reached 1%. Failure was eventually dominated by shear, as shown in *Figure 3* (*page 26*). The maximum roof drift

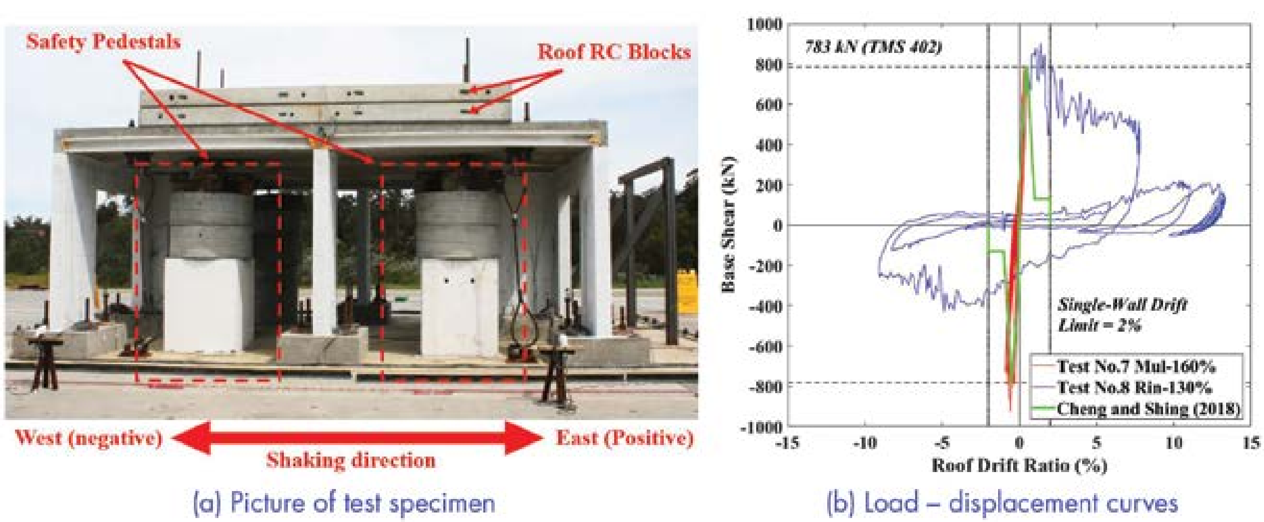


Figure 2. Reinforced masonry wall system (Specimen 2) tested on the outdoor shake table at the University of California, San Diego.

Figure 3. Damage in the T-walls of Specimen 2 at different roof drift levels.

ratio reached was 13.4%. The structure did not collapse. At the end of the tests, the webs of the T-walls had lost a significant amount of masonry due to spalling, and the residual roof drift was close to the maximum reached in the tests. At that stage, the roof weight was essentially carried by the wall flanges as well as the out-of-plane walls.

Figure 2b also shows the backbone curve constructed with the parameters recommended by Cheng and Shing (2018). In that calculation, it was assumed that the lateral resistance was provided by the T-walls only, and the shear strength of the T-walls was calculated with the formula given in TMS 402-16. The shear-span ratio ($M_u/(V_u d_v)$) of the T-walls was taken to be 0.86, assuming fixed-fixed end conditions because of the stiff roof diaphragm. It was assumed that the axial force in the T-walls was due to the gravity load only, with the axial force introduced by the horizontal load ignored. This is a reasonable assumption because the increase of the axial force in one wall due to the coupling effect of the roof diagonal is offset by a decrease in the other wall. It can be seen that the TMS formula provides a good estimate. Most importantly, it can be observed that the specimen exhibited a much higher displacement capacity and a gentler post-peak load degradation than the proposed backbone curve. Similar observations were obtained for Specimen 1.

The higher displacement capacity and gentler load degradation exhibited by the shake-table test specimens can be attributed to a couple of factors. One is the loading protocol. In quasi-static tests, wall segments were typically subjected to a large number of high-amplitude displacement cycles, which could be beyond what could have been experienced in an earthquake. The second is the presence of wall flanges and/or out-of-plane walls, which would carry the vertical load after the webs had been severely damaged in the tests. In quasi-static tests of planar wall segments, this alternative load path did not exist. However, it should be pointed out that the displacement capacity depends on the P-Δ effect of the gravity load as well as the residual lateral resistance of the walls.

Furthermore, it should be noted that the shake-table tests reported here had only uni-axial ground motions. In an earthquake, a building is subjected to forces in multiple axes. In that case, walls in different directions could suffer damage, and the displacement capacity of the structure would depend on the degree of damage in each direction. The damage would also depend on the presence or absence of gravity columns that could carry additional gravity load after the vertical load-carrying capacity of the walls has been depleted. Further shake-table tests are needed to investigate the effect of bi-axial horizontal ground motions. However, a recent numerical study using refined finite element models (Koutras 2019; FEMA 2020) has shown that reinforced masonry archetype buildings with shear-dominated walls and steel gravity frames could develop story drift ratios exceeding 10 to 15% without collapsing when subjected to bi-axial motions.

Figure 3 shows the damage states of the T-walls in Specimen 2 when the roof drift level reached 2%, 5%, and 10%, respectively. The damage was relatively moderate and appeared to be easily repairable at a 2% roof drift. At 5% roof drift, the webs of the T-walls had widely opened diagonal cracks but without significant masonry spalling. At 10% roof drift, severe damage was incurred in the webs.

Recommendations for Design

A reinforced masonry wall system designed according to current code provisions could exhibit shear-dominated behavior in a significant seismic event. The displacement capacity and post-peak behavior of such a wall system depend on several factors, such as the presence or absence of wall flanges or gravity frames, the P-Δ effect of the gravity load, and the severity of wall damage induced in each of the two horizontal directions. If the flanges of the walls or walls in one direction have not been severely damaged or gravity frames are present in the building system, they can carry the additional gravity load when the webs of the walls have suffered severe diagonal shear failure. Such systems can sustain a much larger drift level than what has been observed from planar wall segment tests. However, damage to the walls can be severe when the story drift approaches 5% or more. To ensure safety and limit damage, it is essential to determine the potential failure mechanism and the associate drift capacity. The possibility of shear-dominated wall behavior can be checked by either elastic analysis or limit analysis with the consideration of the coupling moments of the horizontal diaphragms. If shear-dominated behavior is likely, sufficient shear reinforcement should be provided in the walls to control the opening of diagonal cracks and provide sufficient overstrength to limit the story drift to desired levels for both the design earthquake and the MCE. The sufficiency of the residual wall strength to counteract the P-Δ effect should also be considered. The Limit Design Method in Appendix C of TMS 402-16 may also be used to design and reinforce special walls whose strengths are limited by shear. However, the deformation limits imposed by this method are very low compared to the test data discussed above.▪

The online version of this article contains references.
Please visit **www.STRUCTUREmag.org**.

P. Benson Shing is a Professor of Structural Engineering at UC San Diego. (pshing@ucsd.edu)

Jianyu Cheng is a doctoral candidate and graduate student researcher in the Department of Structural Engineering at UC San Diego. (j7cheng@eng.ucsd.edu)

Andreas Koutras is a Postdoctoral Researcher in the Department of Structural Engineering at UC San Diego. (akoutras@eng.ucsd.edu)

The Shape of Things to Come

The Use of Shape to Drive Innovation

By Mark Weber, AIA, Jim Kirk, P.E., S.E., and Jillian Weber, Ph.D.

The construction industry often thinks of structures as limited by the materials available to build them. Those materials – concrete, steel, wood, and so on – have different characteristics and strengths. Building components and, importantly, their shapes tend to develop based on the natural strengths and weaknesses of each of these materials. However, to be genuinely innovative and expand the bounds of design abilities, we need to think more explicitly about the ways that *shape* itself has utility and function.

For instance, because of its shape, a ball rolls. For that ball to roll, its form is initially more important than the materials from which it is made. Only once it is understood that we want the ball to perform in a particular way can we then find materials that will allow us to enable that function practically. In the same way, an airfoil's shape makes flight possible. The material a plane is made from matters very little if the form does not first facilitate lift.

In today's construction industry, materials are usually the drivers of what a shape becomes. It is possible to shift that paradigm, using shape as the primary catalyst for utility. Can we look to already-existent materials within the masonry world and reshape them to keep them relevant? BlockUp, a new dry-stack building system that has given much thought to the form of masonry units, does just that and provides a blueprint for the masonry industry as it considers how shape can transform a building.

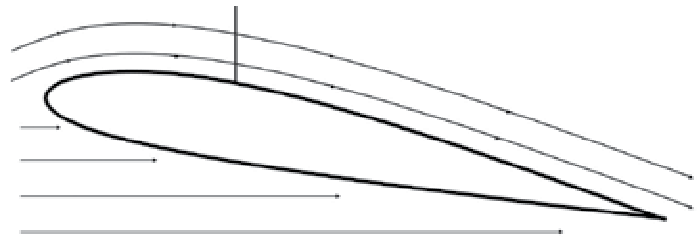
BlockUp promotes lapping installation, easy placement of reinforcing bar, and intuitive construction.

Shouldered and aligned cores give confidence for grouting and reinforcement.

The Current State

Nowhere are the benefits of focusing first on shape greater than within the masonry industry. The traditional Concrete Masonry Unit (CMU) has a familiar form and is a reliable building system, one with many strong characteristics. In a 2015 survey conducted by the National Concrete Masonry Association (NCMA) about market perceptions, over 500 key industry decision-makers ranked "concrete masonry as the best material among all trends." They noted CMU's strengths in durability, performance, and resiliency. Yet, that same group of decision-makers acknowledged that masonry's market share is at a plateau, if not slightly decreasing. Why would masonry lose ground or stagnate despite its recognized strengths? In two words, cost and convenience.

CMU consistently scored near the bottom amongst building materials in the speed of construction and initial costs. Because initial installation costs of CMU can be higher than other materials and the speed of construction is perceived to be slower, builders tend towards cheaper, faster materials. These materials, however, are typically less durable and can lead to higher maintenance costs. The question, then, is how to overcome the short-term objections to concrete block construction so that its long-term benefits can continue to be harnessed. The answer lies in shape. The masonry industry needs to look to the shape of innovative, dry-stack construction systems that use a form to shorten installation and lower labor costs, while also improving upon the traditional strengths of concrete block.



The shape of an airfoil facilitates lift.

An Innovative System

It is imperative to understand dry-stack masonry to understand how innovative shape within a masonry system can shift the paradigm. CMU dry-stack masonry systems, those laid without mortar, are still relatively new and are often touted for their efficiency and cost-effectiveness. However, many mortarless systems simply adapt a traditional block to a dry-stack scenario. One alternative discussed in the following paragraphs is a system that features a tight tolerance unit and new shapes to compliment installation and utility. By placing precision into the masonry unit, faster installation is possible with less labor skills. This gives the mason a tool to win back work on the entire wall assembly, rather than remaining relegated to portions of the veneer. The conversation to follow will consider how this alternative form, which uses the BlockUp construction system as its model, can help dry-stack become a viable and accepted building method.

The creation of modified block shapes for dry-stack systems can produce inventive solutions to the problems outlined in the NCMA survey. There are four features of the system mentioned above that set its shape apart from traditional CMU and lead to increased utility: lapping profiles, recessed webs, shouldered cells, and vertically aligned webs. With all this modification, though, the block still maintains a familiar format. These shape features make more efficient masonry systems while enhancing the traditional benefits of concrete masonry. New block forms within this model answer two guiding questions: how do we take valuable materials and keep them relevant, and how do we rethink the relationship between form and function in building materials?

Shape Facilitates Function

Just as traditional CMU features a stretcher block, the dry-stack system outlined here also uses a stretcher as its workhorse, though with some distinct differences in the unit's shape and speed of assembly. The form-related features of this system, such as uniquely shaped webs and profiles, are found within that stretcher, producing a multi-functional unit with expanded utility. Thus, the stretcher block, because of its shape, provides masons the ability to create a building in less time and with added flexibility.

Within this system, much thought has been given to how CMU's shape affects the laying of a base course; the result is a quick and more precise process for masons. Creating a distinctive, long-length leveling component addresses the need to level the first course of a structure accurately and quickly. Three stretchers are bonded together to form a single four-foot-long unit. Threaded, mechanical levelers are then placed in the bottom block recess at opposite ends. This bottom recess is a shape design that receives the levelers and then permits masons to swiftly and efficiently level the entire base course with the turn of a screwdriver.

After a level and plumb base course is established and grouted, rapid assembly of a structure can begin. Lapping profiles on both the bed and head joints of the stretcher make quick construction possible. Stretcher units have a raised profile on the inner half of the face shell head that is received by the overlap from the block above. The overlapping contours self-align the blocks as they are stacked. Installers can simply lay a block on the course below and slide it into place. The shape of the stretcher unit allows for reduced stress on the mason and much faster installation. With a decrease in the time of construction, the cost of a true masonry wall system is significantly improved due primarily to utility derived from shape.

Lapping unit profiles not only serve to speed installation but also to improve weathering performance by pushing water away from the interior of the block. The stretcher's lapping joints resist the intrusion of water and direct it to the exterior, similar to traditional lapped shingles. Mortar is porous, and it is generally accepted that water will penetrate a traditional mortared wall. When that happens, myriad steps are then taken to direct water back to the outside of the unit. In this system, these reactive measures are rendered unnecessary.

Masons can then turn their focus to structural reinforcement, as water penetration is a lesser concern. Stretcher units contain recessed webs, a component of the block's shape that broadens the modes by which structures can be strengthened. Unless the traditional unit is manufactured as a bond beam, the CMU web is flush with the top of the face shells and needs to be cut out to lay reinforcing bar. In this system logic, the web is recessed to a depth that forms usable horizontal chase ways. Reinforcing bars can be placed in these indentations, creating bond beams at any course of a structure. For instance, the stretcher can be used to form lintels, eliminating the need for special lintel blocks and steel angles. This shape provides flexibility to reinforce a building in many ways, as required by code or structural design.

While important, horizontal chase ways formed from recessed webs are not the only opportunity for reinforcement within this system design. When set in a running bond pattern, the stretcher units result in vertically aligned webs. These webs align from top to bottom, which is often not the case with traditional CMU. They create continuous vertically stacked cores, enabling masons to install and grout reinforcing bars for entire wall heights easily. Within this particular dry-stack blueprint, grout can be placed confidently in any of the cells because there is a clear path of travel. These vertically aligned webs also create a space for a shimming device to be inserted. A curving, inclined-plane shim can be placed in the recess between the aligned webs and rotated to move the height of the block above into alignment. This adjustment, which is made within the flow of installation, assures that the blocks are flush and level; this trues the block, preventing inaccuracies in later courses.

The ability to plan and control where grout is placed during installation is significant. Shouldered cells accept a grout stop, which in turn closes a vertical void and partitions the block horizontally to limit the grout flow. Reinforcing bars can be placed horizontally in the recessed webs with grout confined to only that course. Now greater flexibility exists. If a mason is assembling an interior wall and does not want the extra weight, cells can be left without grout.

Finally, consideration of shape will help to address a common objection to concrete masonry – lack of ductility. In a time when hurricanes and earthquakes seem ever more frequent, using shape to adjust for strong forces has the potential to save money and lives. An innovative metallic shear insert can provide added ductility to an inherently brittle structural system. This insert can be placed at horizontal joints throughout the structure. Upon initial joint failure, the inserts act as a network of ductile connections between many smaller structural pieces. They hold the masonry structure together while distributing energy throughout the wall. The inserts resist shear forces that flow at each horizontal course above the shear friction threshold. Combined with vertical reinforcement, the shear inserts create a resilient structural matrix. The aggregation of strength and elasticity that the insert

The placement of shear inserts add to the system's ductility.

lends to a masonry system may prove especially valuable to designers when seismic and high wind areas demand special attention.

The Path Forward

The BlockUp system is a model for the shape features outlined here; these new block forms produce innumerable benefits for masons and the industry alike, which stem from the shape of both individual units and the ways that they work together as a whole. Within this model, a block's shape is not different solely for the sake of standing apart from traditional CMU; it is purposeful. Form builds upon and amplifies the positive characteristics of the materials from which units are made. Innovations in CMU's shape should spur a conversation about how to derive utility through form and reinvigorate the masonry industry, keeping concrete units relevant.

Currently, masonry design codes refer to and provide values for systems that use mortar. However, The Masonry Society (TMS) is drafting guidelines for dry-stack masonry. This publication will provide guidance for the strength values that building communities can apply to engineer reinforcing in walls. It will normalize the values used for dry-stack masonry. Significantly, this illustrates that dry-stack is becoming a more relevant part of the industry. Dry-stack systems offer real value – flexibility and speed of construction – and should be a robust part of the building industry, now and in the future.▪

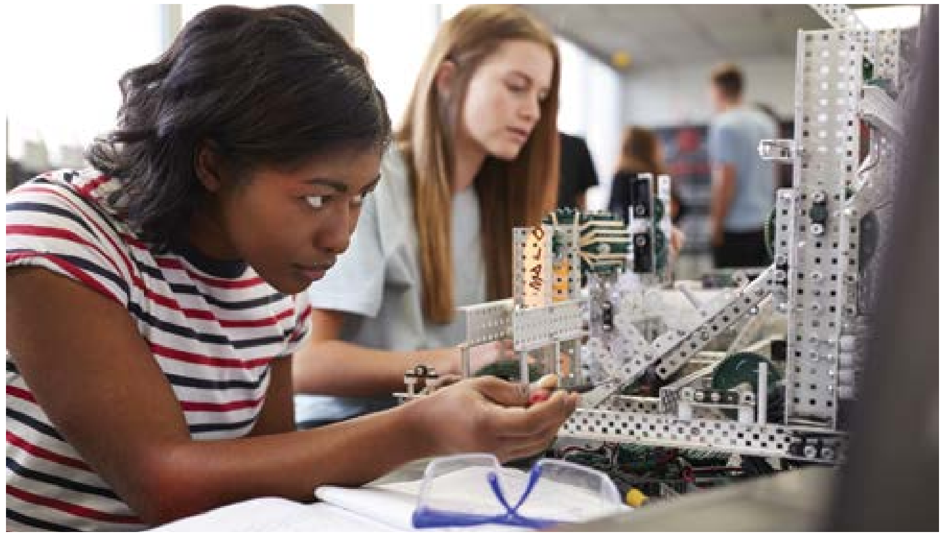
*Mark Weber is with Max Block Development and is the original developer of the BlockUp dry-stack masonry system. (**mark@block-up.com**)*

Jim Kirk has been a Professional Structural Engineer in Indiana for over thirty years.

Jillian Weber has a Ph.D. in Literature.

Inviting and Keeping Women in Engineering

By Jennifer Anderson



There is much talk about how to engage more women to join the engineering field. From elementary schools to universities, career advisors, teachers, and special interest groups are encouraging girls and women to consider and stay in engineering. Why do we want to add more women to the ranks of engineering? Their unique perspective is key to the success of the industry.

While both men and women can learn and apply science the same way, men and women bring different mindsets and aspects to a project team. For the sake of providing your clients with a versatile skillset and well-rounded perspective, it is important to have both men *and* women as equal contributors to a project team. Despite the best efforts of our educational institutions, the fact is there are still fewer women than men in the engineering fields. So, it is more important than ever to encourage women into engineering positions. Their diverse talents make a difference to the team, department, and firm. Below are some ideas on how to invite more women into the engineering field as well as help keep more women in engineering.

Inviting Women into the Engineering Profession

1) **Start with girls**. Early introduction of girls to engineering is the best way to get them to realize that they can have a career in engineering. Many women are not exposed to engineering career options until they are in high school and are, therefore, at a disadvantage to their male counterparts. For many girls, much of the information they receive early on is about traditionally female-focused careers, e.g., nursing and teaching. Studies show that girls also feel less confident around math. Ganley and Lubienski's article on gender differences in math, published in *Teaching Children Mathematics* (**https://bit.ly/39Qo1RY**), highlights that girls are performing the same as boys on math tests. Still, the girls have a hard time relating to careers associated with strong math and science knowledge. So, if you have a young girl in your life, talk to her about engineering and engage her with age-appropriate activities to show her that she can do science, math, and technology-related activities.
2) **Continue the conversation with girls.** Encouraging adolescents and teens to stay interested in engineering requires more than one conversation. This concept needs to be understood and endorsed by teachers, school advisors, family members, adult friends of parents, community groups, and more. Again, keep engaging the girls in your life. Be that uncle who gives her presents that are engineering related. Take her to meet your friends at work and show her what an engineer does. Many girls see other women doing jobs that are not engineering related, so it is harder for them to relate.

Keeping Women in Engineering

1) **Be real about mothers' needs.** Women need time off for maternity leave (ideally, the dad's need time off for paternity leave too) because it leads to healthier babies, less post-partum issues, and more satisfied women in the workplace. Regardless of the family dynamic, often one parent will stay home to help raise children through their pre-school years. During that time, some women feel like they are losing ground with their careers because they choose to spend time with their littles. If you are in management, seek ways to keep those SAHM (stay at home moms) engaged with your firm by having real conversations before going on maternity leave.
2) **Support programs**. Whether starting an initiative at your local schools or supporting another existing program, look for ways for your firm to support programs that aim to attract women (and marginalized groups) into engineering. You can support with monetary donations, employee volunteering, by encouraging adjunct teaching, or use of your facilities for learning and ongoing education.

In both inviting and keeping women in engineering, current female and male engineers have a responsibility to continue to speak up and share ideas with their managers, their alma-maters, their current firm, and with professional organizations, all of whom are seeking more diversity in engineering roles. Make it a priority to communicate and help to bring about the necessary changes for firms to be profitable and provide excellent workplaces for everyone.

In the end, workplaces will continue to change and evolve. Look at how your firm is engaging with the community at large because even though you cannot hire that 7-year-old girl today, you can in about 15 years. If you are an individual contributor, a manager, or the owner of a firm, seek opportunities to invite and keep more women in engineering. The profession, your firm, your clients, and the community need the effort and will benefit from it.▪

Born into a family of engineers but focusing on the people side of engineering, Jen Anderson has over 21 years of helping leaders build stronger careers for themselves and their teams. (www.CareerCoachJen.com)

OSEA Participates in E-Week 2020: Bridge Breaking Competition

During E-Week, the Oklahoma Structural Engineers Association's Young Members Group had the opportunity to volunteer during the Bridge Breaking Contest at the Science Museum of Oklahoma. Students competed in three different categories: structural efficiency, load capacity, and aesthetics. The YMG judged the load testing and aesthetics, but also had the opportunity, after bridge failure, to speak to students on the failure mechanism of the design and explain how the bridge could be improved. Additionally, volunteers were able to walk around and speak about what structural engineers do and why the profession is important to the public. OSEA was able to participate in this great opportunity to educate young people and to encourage them to learn more about the profession, thanks in part to the 2019 NCSEA grant they received.

Have you Considered a Diamond Review of your Education Offerings?

NCSEA has recently enhanced its Diamond Review Program, which was created to evaluate the quality of in-person and online continuing education courses, seminars, and conferences geared toward structural engineers. After the education content is evaluated and Diamond Review Approved, structural engineer attendees are eligible to receive PDHs in all 50 U.S. states. Diamond Review approval is one of the key values behind NCSEA's high-quality, expert-led webinar program, which has only grown in success since adopting the process. The Diamond Review Program can be beneficial to the following groups:

- **SUPPLIERS** to the structural engineering profession so they can provide their structural engineer customers technical education!
- **SEAs** (and other associations) that have annual conferences, monthly meetings, and webinars to deliver structural engineers a tangible value for their membership in your SEA!

To submit education to be Diamond Reviewed, visit **www.ncsea.com**. When submitting a course, you will need to have the following information available:

- A detailed outline of the program content,
- The presentation materials,
- The qualifications of the speaker(s), and
- The number of hours of continuing education credit to be awarded upon completion of the course.

Visit **www.ncsea.com** to learn more about this benefit to you and your members.

2020 NCSEA Awards Open for Submissions

NCSEA's **Excellence in Structural Engineering Awards** annually highlight some of the best examples of structural engineering ingenuity throughout the world. Projects are judged on innovative design, engineering achievement, and creativity. The awards are presented to multiple winners with an outstanding winner chosen for each of the following categories:

- New Buildings < $30 Million
- New Buildings $30 Million to $80 Million
- New Buildings $80 Million to $200 Million
- New Buildings Over $200 Million
- New Bridges or Transportation Structures
- Forensic/Renovation/Retrofit/Rehabilitation Structures < $20 Million
- Forensic/Renovation/Retrofit/Rehabilitation Structures > $20 Million
- Other Structures

Entries are due on July 14, 2020. *Structural engineers and structural engineering firms are encouraged to enter.* More information about the awards and the submission process can be found on **www.ncsea.com**.

NCSEA's **Special Awards** are presented to members who have provided outstanding service and commitment to the association and to the structural engineering field. Special Awards are granted to worthy recipients in four different categories:

- **NCSEA Service Award,** presented to an individual who has worked for the betterment of NCSEA to a degree that is beyond the norm of volunteerism.
- **Robert Cornforth Award,** presented to an individual for exceptional dedication and service to an SEA and the profession.
- **Susan M. Frey NCSEA Educator Award,** presented to an individual who has a genuine interest in, and extraordinary talent for, effective instruction for practicing structural engineers.
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Advancing the Profession

A Message from the SEI President

I hope you and yours are well and successfully navigating the challenges of the COVID-19 pandemic.

As we continue to experience remote work and social distancing, it is inspiring to watch and engage with our communities as we pull together to meet current challenges. Most of us have shifted from in-person staff and client meetings to virtual business meetings, video chats, and even virtual social events. I have witnessed the collaboration of university professors sharing ideas on digital course delivery, leaders of competing engineering companies helping each other deal with impacts on their businesses, and engineering firms making creative use of technology to service critical infrastructure projects while keeping their employees safe.

Please maintain your incredible resilience and continue to apply your leadership in creative, innovative ways in your practice and community. Thanks for all you do for the SEI community. And first and foremost, stay safe and healthy.

Glenn R. Bell, P.E., S.E., C.Eng, F.SEI, F.ASCE, SEI President

Don't Miss Resources

- View the free April 7 Structures 2020 Virtual Event with presentations on Generations@Work, Confidential Reporting on Structural Safety CROSS-US, and Performance-Based Design at **https://bit.ly/39XLuk8**
- Ask Me Anything with SEI and Industry Leaders: Access at **https://collaborate.asce.org/integratedstructures/home**
- #SEILive chats on SEI Instagram
- Confidential Reporting on Structural Safety – CROSS-US first newsletter and reports available at **www.cross-us.org**.
- Structures Congress 2020 Proceedings are available for free access at **ascelibrary.org** through October 2.
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SEI Standards Supplements and Errata including ASCE 7. See **www.asce.org/SEI-Errata**.
If you would like to submit errata, contact Jon Esslinger at **jesslinger@asce.org**.

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Tool 2-4: *Project Risk Management Plan*
Tool 3-1: *A Risk Management Program Planning Structure*
Tool 3-4: *Project Work Plan Templates*
Tool 5-6: *Lesson Learned*

CASE Contracts Currently Available

CASE #1 – *An Agreement for the Provision of Limited Professional Services*

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CASE Updated Tools Available

CASE 5-1: *A Guide to the Practice of Structural Engineering*

This tool is intended to teach structural engineers the business of being a consulting structural engineer and things they may not have learned in college. While the target audience for this tool is the young engineer with 0-3 years of experience, it also serves as a useful reminder for engineers of any age or experience. The Guide also contains a test to measure how much was learned and retained. Other sections deal with getting and starting projects, schematic design, design development, construction documents, third party review, contractor selection/project pricing/delivery methods, construction administration, project accounting and billing, and professional ethics.

Primary updates to 5-1 included changes in technology that the engineer uses today and keeping the document current with best business practices.

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- Continual staff education including both leadership and technical skill development
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The most recent revisions to the Standard have restructured the format of its wind design procedures and added step-by-step checklists for each procedure to help clarify how to use its provisions. The Standard is continually updating and editing its procedures based on the latest research, data, and studies.

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Celebrate the Structural Engineering Community

By Chad S. Mitchell, P.E., S.E.

For the longest time, I avoided following other structural engineering firms on LinkedIn or liking their posts. As the President of the Structural Engineers Association of Colorado, I have seen the positive impact of what engineers can do when they come together. But for some reason, I was still hesitant to celebrate the achievements of my peers publicly. Why? Mostly to avoid a perception by my supervisors and coworkers that I was thinking about leaving my current firm. Sitting at my desk a couple of months ago, on my first day back at work after attending the National Council for Structural Engineers Associations (NCSEA) Summit, I quietly proclaimed, "This stops today!!" No longer will I refrain from following or liking other firms for fear of how it might look. The week I spent in Anaheim, CA, at the Summit was magical and not just because I met Micky and Minnie. Witnessing the community of structural engineers at a national level was truly transformational.

We should see each other for what we are: a community, not just competitors. Building a community driven by mutual respect allows us to commend each other's achievements and applauds a profession that brings excellent value and expertise to the public. By celebrating each other more, we will pave the path for the public to celebrate us as well.

The concept of mutual respect is best demonstrated after competitive sporting events. It is common for athletes to meet at midfield and embrace each other, even to exchange jerseys after competing at the highest levels. One of my favorite parts of watching the final round of PGA tournaments on a Sunday afternoon is to see the other professional golfers waiting just off the green on the final hole to congratulate the winner. Professional athletes compete at the highest levels on the field, but they also celebrate each other after the competition is complete. They respect the hard work it takes to compete. They enjoy the challenge of competition, and the challenge makes them better.

As engineers, we can also thrive on the challenge. We should challenge each other to increase the quality of our product. With higher quality comes higher value. There will always be a competitive side within our community. Whether it is new techniques or high-quality service, we continually compete to win projects. We should use that competition to make the structural engineering profession better, not just to win projects. Let's enjoy the challenge.

Demonstrating mutual respect not only drives us to improve our profession, but it also improves the perception of our profession in the public eye. Few members of the public truly understand what we do. If you are like me, when you first started your career, your family and friends thought you were an architect. Even now, it is difficult to explain to the average person what it is we do and how our profession protects life safety. We are only in the news when a building or bridge collapses. Greater positive exposure will pave our way to greater respect and perception in the public eye.

"The more positive exposure we receive, the more the public will understand the value that we provide."

One of the issues preventing us from receiving greater public exposure is that we, as engineers, lean towards being introverts. I know it is not always true, but it is close. I always say the best way to tell if a person is an engineer is if they are looking at their shoes when they are talking to you. If they are a structural engineer, they will be looking up at the structure above. Introverts do not typically draw praise to themselves. They try and avoid attention. This is why we are not celebrated for the real value we provide the public in our profession. What we do is equally as amazing as what the architects do. The public just does not know it yet. We need to ensure that the public sees us as a skilled profession, not as a commodity.

Since it can be difficult to praise ourselves, we need to celebrate each other more. The more positive exposure we receive, the more the public will understand the value that we provide. When we work *together*, we have more visibility. Celebrate each other!!

When asking a preschooler what they want to be when they grow up, their response should not be firefighter or doctor, but a structural engineer. Well, we might not knock off those lofty professions as top preschooler's career goals, but we may inspire a high school senior to choose civil engineering as their college major.

Retention studies repeatedly find that, more than money or working conditions, people who stay with their jobs are motivated by feeling like a part of something larger than themselves. By connecting to others within the community, we are not just elevating our practice; we are re-energizing ourselves and encouraging the bright young people who were drawn to our profession to stay in our profession.

How do we foster collaboration, encourage mutual respect, and drive visibility? Connect on LinkedIn with peers, not just clients. When a competitor posts a success story, like or comment, or better yet, reach out a congratulatory hand. If you do not have the bandwidth or expertise to handle a project, refer the client to a competitor you respect. Join one of your local structural engineering organizations; in addition to CEUs, you can grow a network of peers, mentors, and, dare I say, friends that all share a common goal and inspire you to contribute outside of deadlines. Volunteer at a local school to help kids get excited about the bones of the structure – let them see just how cool our jobs really are.

How will you explain to your employer why you are connected with your competitors on LinkedIn and giving them kudos? Bring information back to your employer with fresh ideas, code updates, resources, etc., and they will soon see the value of being plugged into our professional community.

Will everyone operate in good faith? Probably not. But I have the impression that, in general, our profession is filled with good, ethical people. Reach out – you just may be surprised.

Challenge makes us better. Mutual respect and collaboration drive innovation. Increased visibility for our profession benefits all of us. Make that LinkedIn connection; join that professional committee; volunteer at your local school. You will be more fulfilled and, maybe someday, structural engineers will give firefighters and doctors a run for their money in the pre-K crowd.■

*Chad S. Mitchell is an Associate at S.A. Miro, Inc. in Denver, Colorado, and President of the Structural Engineers Association of Colorado (SEAC). (**cmitchell@samiro.com**)*


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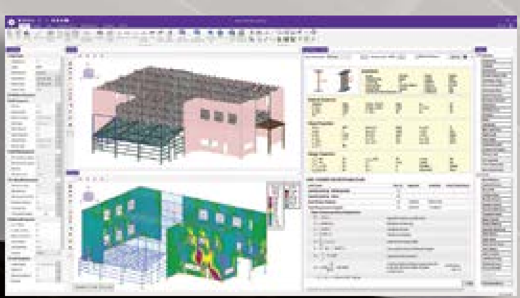

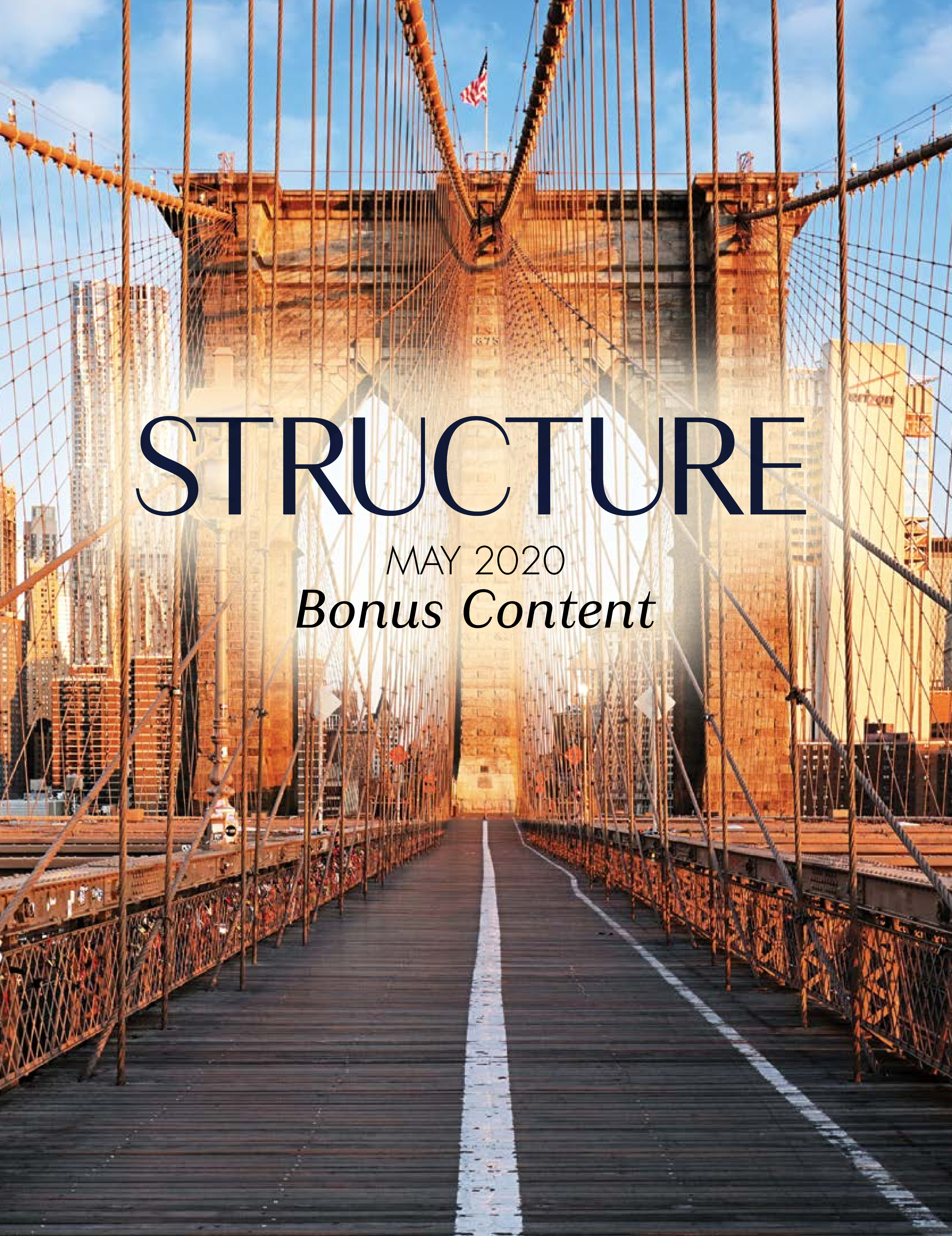

STRUCTURE

MAY 2020

Bonus Content

Small Unmanned Aerial Systems

Assistance for Building Façade Assessment

By Peter M. Babaian, P.E., S.E., and Sean D. Gordon

Building owners need to routinely assess the condition of their building façades for many reasons, including compliance with façade inspection ordinances, to check for deterioration, to monitor known deterioration, and to plan for maintenance and capital repairs. Traditional methods for façade inspection include ground-based visual observations and hands-on inspection using various means of access, which both have limitations. Access to building façades for hands-on inspection can range from straightforward to very complex. The more complexity involved in accessing the façade, the higher the costs, and the less likely that building owners will routinely assess the conditions of their building façades, potentially allowing deterioration to occur unchecked.

Figure 1. Masonry Bell Tower.

Visual ground-based assessment may be a suitable technique for low-rise buildings that do not feature significant articulation in the façade. Taller buildings result in a greater angle of incidence for ground-based viewing or require the viewer to be further away from the building, requiring visual aids such as binoculars. Distance and limited viewing angles can make the detection of potential issues difficult. Low-rise buildings featuring significant articulation also may not be suitable for visual review. The articulation can hide significant deterioration that cannot be seen due to the angle of incidence, distance, or the need to be above the item in question.

Hands-on inspection is the "gold standard" for detecting deterioration and potential hazards. Temporary access for inspection, such as aerial lifts, suspended staging, or industrial rope access, is required. However, access methods have practical constraints and can be costly. Aerial lifts are an efficient and low-cost way to access building façades, but require open, supportive, and level ground around the building, and are limited in height. Suspended staging is generally not limited by height or ground access, but can be costly to set up, requires tie-back anchors safety lines, and cannot cover a wide area very quickly. Industrial rope access is also not generally limited by height or ground space. Still, it requires more staff to cover the same amount of area and more tieback anchor availability for safety lines.

Small Unmanned Aerial Systems (sUAS or Drone) technology offers a new means of efficiently documenting building façade conditions with less time and cost, but with limitations that are specific to the technology itself. Drone technology can be a suitable way to complement visual building façade condition assessments or as a tool for planning hands-on inspections by identifying areas of concern. Equipment, such as an infrared camera, can be added to the drone to obtain additional information during the façade survey.

FAA Regulation

All commercial drone operations are regulated by the Federal Aviation Administration (FAA) and require a certified operator to perform the work. Before September 2016, operators performing commercial work required a Section 333 exemption, which mandated possession of a pilot's license. After September 2016, the FAA enacted Part 107. The necessary Part 107 certification is acquired by fee and examination. Upon completion, the certificate holder is authorized to perform work in Class G airspace, uncontrolled airspace outside the controlled airspace of airports, and below controlled airspace where commercial aircraft travel. Currently, the FAA requires recertification every 24 months.

Operation Process

A Small Unmanned Aerial System (sUAS) operation can generally be broken down into four stages: establish the scope of survey, operation planning, on-site operation, and postprocessing/data deliverable. There are several items and steps to consider within these stages. The following is not a complete list. Operators may find some aspects to be more critical than others.

Establish Scope of Drone Survey

For a successful drone survey, the survey team and drone operator should understand the project, the survey goals, obstacles that may affect the survey, and expected deliverables. Asking the right questions can help the project team optimize the survey.

The most crucial consideration when proposing a drone operation is the airspace restrictions, if any, at the project site. The FAA provides an ArcGIS UAS Map that, when entering an address, will provide the most current airspace restrictions, including maximum allowable altitude above ground level. If the project is within proximity to an airport, some additional authorization may be required.

Operation Planning

Operation planning begins once the goals of the façade assessment are established. During this stage, verify the scope and the agreed-upon final product. Once an operation date is finalized, there are a few essential factors to consider. It is possible the height restriction at the project site has changed, so make sure to revisit the airspace restrictions and be sure you still have the proper authorizations in place. Verify that there are no temporary flight restrictions (TFR) in place in the proposed area of observation. TFRs will be put in place during large public events or VIP movements. TFRs are generally considered no-fly zones and will require additional FAA approval. Some municipalities may have their own ordinance, which may require you to submit information about your operation. Be sure to confirm these restrictions by checking online or calling local law enforcement.

Figure 2. Drone image of the top of Bell Tower.

Figure 3. Drone head-on close-up image of deteriorated masonry.

Several airports participate in LAANC (Low Altitude Authorization and Notification Capability), which allows for instant authorization assuming the flight will remain at or below the published altitude limit in the FAA's ArcGIS UAS Map. If operation at a higher altitude than the published limit is required, you will need to submit a request through one of the LAANC providers, identifying the location of your operation and why you are requesting to fly higher than the posted maximum. Depending on the region, you should get a response back between two and seven days. If you need to operate in an airspace that does not participate in LAANC, you will be required to submit an airspace authorization through the FAA's Drone Zone portal. The response time for these will vary, so it is important to submit this as soon as you know you need it to get approval before your operation date.

The weather forecast for the upcoming operation is an important consideration. While a bright sunny day is nice and can be acceptable, data collection may be affected by excessive brightness. High winds, rain, or other precipitation will require rescheduling. An overcast day can be best for photography, but keep in mind that heavy clouds can affect the GPS signal.

It is best to make an initial site visit to identify obstructions and drone takeoff and landing locations. If this is not feasible, best practice is to use available aerial imagery software to mark proposed takeoff and landing areas, understanding these could change at the site. Be sure to consider areas that restrict operation around pedestrians and moving vehicles due to safety concerns. At the same time, be sure to mark potential obstructions to operation.

It is vital to have a checklist to ensure that you have everything you need for a safe and successful operation.

On-site Operation

The site visit date has arrived, and Mother Nature has provided appropriate weather. As an sUAS operator, the priority is always safety. The first task when arriving on-site should be to walk around and verify potential takeoff/landing locations. Take note of any obstructions, such as trees, overhead wires, high traffic areas, construction equipment, and anything that may not have been obvious from the initial in-office planning. Be aware of nearby tall buildings and other objects that could cause issues with GPS connectivity. Follow the preflight checklist to minimize issues. Before takeoff, be sure visual observer(s) and all team members are clear on their tasks.

Once airborne, keep the goals of the project in mind. If capturing images manually as opposed to an automated flight path, consider focusing on areas that may otherwise be inaccessible to the project team either due to visibility or safety. Always be aware of the surroundings, and do not get distracted. Remain confident in your abilities to control situations. During takeoff and landing, always communicate with the team members so that they can help verify the area is clear of any pedestrians or other obstructions. Remember, safety is the priority.

After the first flight, review the images with the project team to verify you are getting the desired results. Make sure to back up all data.

Postprocessing/Deliverables

Once back in the office, the final step is to generate the agreed-upon deliverable. Data backup and organization are critical. A detailed folder structure by building, elevation, or whatever other attribute is helpful. Consider keeping multiple copies of the unedited data. In its simplest form, the deliverable might consist of formatted and organized images. More detailed deliverables are also possible, including annotated photos, videos, imaging sequencing, or other data processing (e.g., if additional equipment, such as infrared cameras, is used). Understand the deliverable options and educate the client regarding options for report presentation. Use this information to focus and optimize the report for its intended purpose.

Case Studies

Masonry Bell Tower

The masonry bell tower on a college campus exhibited signs of deterioration of the spires at the top of the tower (*Figure 1*). The masonry bell tower has a church adjacent to its west elevation for approximately 50% of the tower height. A one-story building connects to the bell tower on the east elevation. The south elevation is located within a limited access courtyard. The north elevation was unencumbered by other structures but had a sloped ground, making access via mobile lift impractical. Previously, the college accessed the bell tower exterior utilizing a crane basket, which cost $5,000 per day, plus mobilization.

Interior access allowed for visual observations of the northeast and southeast corner spires from small roofs behind the spires. However, the northwest and southwest spires did not have access. Also, the entire bell tower above the spire level was inaccessible. Ground access for a binocular survey was generally uninhibited but, due to the angle of incidence, it was not possible to see the tops of the step-backs up the tower and the masonry spires on the west elevation.

The college considered multiple options for temporary access, including crane basket, industrial rope access, drone access, and supported scaffolding. They quickly ruled out the crane basket and supported scaffolding due to the cost. They also ruled out industrial rope access due to costs and safety concerns. Therefore, the façade assessment was

Figure 4. Preprogrammed flight path for façade mapping.

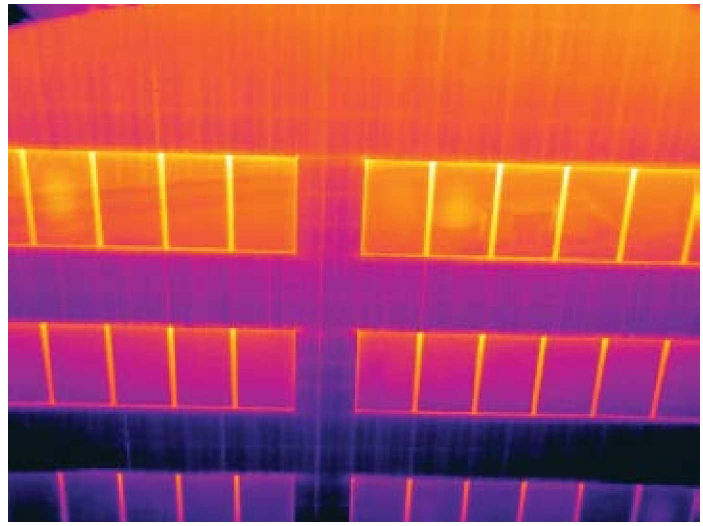

Figure 5. Infrared image of façade.

completed from the ground and utilized a drone to focus on areas not visible from the ground.

For this project, the weather was less than cooperative, with a clear day forecast several days out, turning into a day with constant precipitation. As a result, it took two days to capture the information rather than a single day. This is something to consider when planning a project; consider building in an extra day for contingency in requesting authorization (e.g., local air traffic control, local officials, building users, etc.). Once airborne, the drone captured video and still images of areas not visible from the ground, and allowed for close-up, head-on photos in other areas (*Figures 2* and *3*). The drone has some limitations. It cannot remove small falling hazards, such as loose mortar, cannot remove samples, and cannot sound masonry to detect delaminations. The drone typically cannot fly closer than 10 feet to the building due to the potential for a wind gust to carry it into the building.

Overall, using a drone allowed a more cost-effective and time-efficient façade assessment that quickly identified potential hazards for the college to evaluate and determine how best to address.

Supplemental Access

The authors recently completed condition assessments on three buildings on a university campus using aerial lifts and ground-based observations. A drone supplemented the survey for multiple reasons. First, the time available with the aerial lift was limited, and there was a need to focus on areas of significant distress. The drone was useful in determining whether areas of significant distress existed that were not visible from the ground. Second, despite having an aerial lift and roof access, some areas of the building façades were still inaccessible due to low roofs being in the way or an inability to get the aerial lift close enough to the building. The drone provided up-close views of these façades. Third, using a drone allowed for whole-building infrared scans to determine whether air leakage or heat loss was potentially occurring through the walls, windows, or roofs. And finally, the facility group wanted to employ new technology to evaluate its potential application to the remaining buildings on campus.

The drone captured video and still images of the building façades and roofs. The drone was preprogrammed to photo map each building first (*Figure 4*) and then free-flew to look at areas inaccessible from the aerial lift and capture specific close-up, head-on images. The infrared scanning occurred after sunset and provided an overview of the overall thermal and air leakage performance of the buildings (*Figure 5*).

Working on this campus was challenging and required significant coordination with the class schedule and the university safety office. Knowing the class schedule is very helpful to maximize the time of the drone in the air, as well as knowing when it needs to be on the ground during periods of substantial pedestrian activity. Also, notification of building and grounds occupants is especially important, as the drone flew outside the windows of professors' offices, classrooms, administrative offices, and performance spaces.

The drone information helped supplement the visual assessment and other evaluation work. More importantly, it allowed a visual review of areas completely inaccessible using other methods. The university can now decide how soon to access these areas to address issues discovered by the drone observations.

Summary

Drones can be an incredibly useful and efficient tool with the potential to save both time and money. They provide a means of access to obtain visual information rapidly and potentially more detailed, when other means of access are too restrictive or costly. Also, drones provide another cost-effective perspective to view the building façade even when façade access is possible. Like any new technology, education and understanding of limitations are imperative to implement it effectively. Proper planning is necessary to obtain an effective drone survey that adds to the understanding of the building façade. As a drone operator in the AEC industry, it is essential to remember that the primary goal is to enhance engineering work by safely generating useful data that provides value. Being an integral member of the survey team is crucial to providing that value.▪

Peter M. Babaian is the Building Technology Division Head of SGH's Chicago, Illinois office. (**pmbabaian@sgh.com**)

Sean D. Gordon introduced and manages SGH's drone program from the Waltham, Massachusetts office, and is an FAA-licensed drone pilot. (**sdgordon@sgh.com**)

Industry Perspective on Masonry Education

By Heather A. Sustersic, P.E.

The author's "Masonry Education Survey," administered in October 2018, sought to answer two overarching questions: 1) are industry practitioners satisfied with the masonry design knowledge that graduating structural engineers bring with them into the workforce, and 2) what aspects of masonry design are most important for graduating structural engineers to master. This survey elicited passionate responses from engineers, architects, contractors, suppliers, instructors, and industry representatives involved in the design, specifying, installation, and/or manufacturing of masonry systems for buildings. This article expands on material previously presented at the 13th North American Masonry Conference, with additional survey results gathered through September 2019.

Industry Survey & Respondent Demographics

A total of 237 individuals voluntarily took a nine-question online survey in response to an open invitation circulated by the Masonry Society, the Pennsylvania Concrete Masonry Association, the Mid-Atlantic Masonry Association, the Northwest Concrete Masonry Association, the International Masonry Institute, and word-of-mouth. 185 respondents completed all required questions, and 31 completed the ninth optional comment question. Participant attrition increased quadratically up to 8% at question six, topping out at 21.9% for question seven – an improvement over preliminary survey responses wherein a reduced percentage completed the survey.

More than half of the respondents were engineers, a quarter were suppliers/manufacturers, and the remaining were a mix of architects, professors/instructors, contractors, and industry representatives (*Figure 1*). Sixty-eight percent of the respondents had more than 16 years of experience, with 8.3% having more than 45 years of experience (*Figure 2*). Respondents worked on projects across the continental United States, distributed as shown in *Figure 3*.

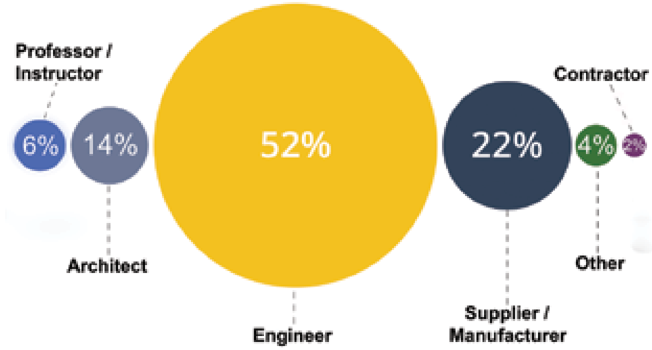

Figure 1. Survey respondent professional role in the industry.

Satisfaction Ratings

Participants rated their level of satisfaction with new engineers' level of masonry knowledge upon entering the workforce. Forty-six percent of respondents indicated that they are dissatisfied, 6% were very dissatisfied, 36% were neither satisfied nor dissatisfied, and 11% were satisfied. Only 1% indicated that they were very satisfied. *Figure 4* depicts overall satisfaction ratings for the entire group of respondents, while *Figure 5* breaks out the satisfaction ratings by discipline. Generally, engineers and suppliers/manufacturers were "dissatisfied" while professors/instructors were "satisfied." Contractor opinion was bimodal but weighted more heavily towards "dissatisfied." Architects' opinions were more balanced, centered on "neither satisfied nor dissatisfied."

When asked whether topics beyond basic member design should be included in masonry engineering courses, 93% said "yes." Most comments on this question were positive, encouraging the inclusion of topics such as constructability, economy, understanding masonry as a system, arching action, control joints, fire safety, detailing, and durability. However, many remarked on the complete absence of masonry courses in engineering curricula, or the lack of technical depth provided in existing masonry courses. Several respondents cautioned against reducing class time spent on steel and concrete design in favor of including more masonry, but still supported that masonry should be taught to engineering students.

Topic Rankings and Results

Respondents weighed in on which topics should be included in the ideal masonry course, ranking five general topic areas on an importance scale from 1 (most important) to 5 (least important). *Figure 6* displays these results in descending order of ranked importance from left to right. There is insufficient

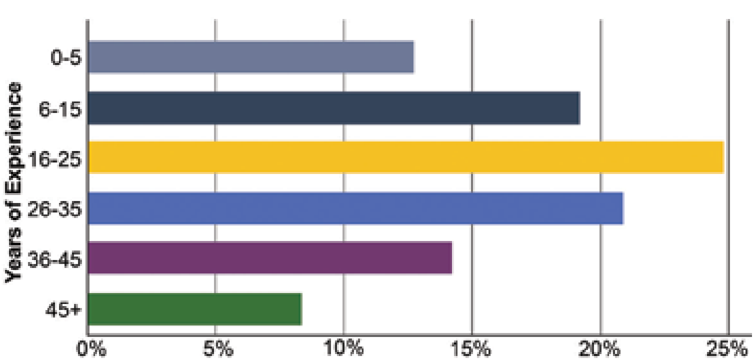

Figure 2. Respondent professional experience distribution.

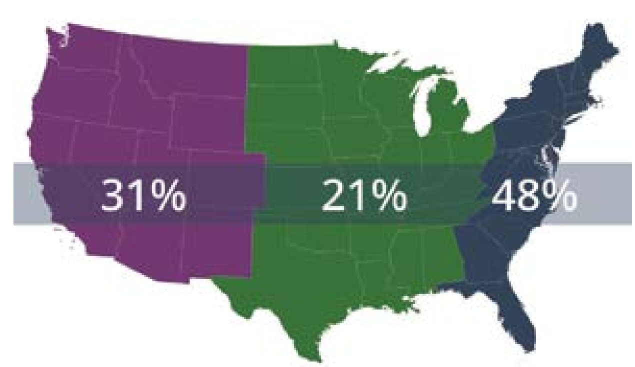

Figure 3. Graphic location of respondents' projects.

space within this article to address the many generous comments received from survey respondents. Below is the author's 'highlight summary' that encapsulates the most common comments and respondent suggestions, in condensed form:

System Behavior

Understanding masonry as a system of modular elements is most important, relating to how masonry is similar to but also different from other materials. Topics such as arching action, thermal expansion, historical masonry behavior (e.g., flying buttresses), the effect of control joints on wall behavior and lateral stiffness, veneer, wall systems, and how masonry can work together with architecture – not against it – should be included. Teaching engineered masonry also reinforces the fundamental engineering mechanics skills that students need, without emphasis on prescriptive code compliance.

Constructability

"Passionate" is the best way to describe respondent comments regarding constructability. Engineers, especially new engineers, need to understand how masonry systems are constructed to avoid costly schedule delays, increased labor costs, and increased material waste. The industry strongly recommends hands-on field experience before designing, specifying, or detailing masonry systems. This would result in reduced field cutting of blocks, improved cell space for grout consolidation at rebar laps, more constructible attachments, and reduced installation difficulty.

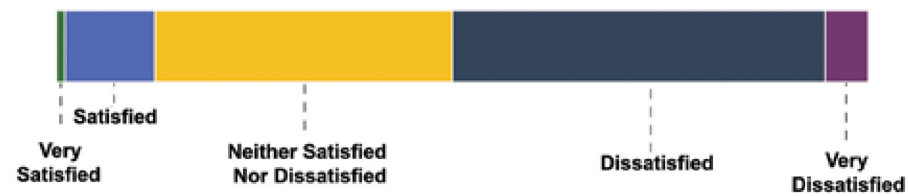

Figure 4. Overall rating of satisfaction with the level of masonry knowledge in graduating engineers.

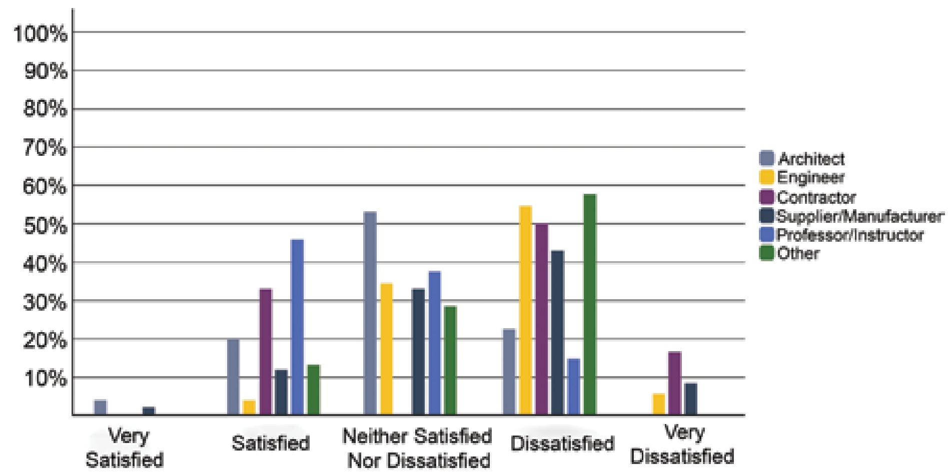

Figure 5. Satisfaction ratings by discipline.

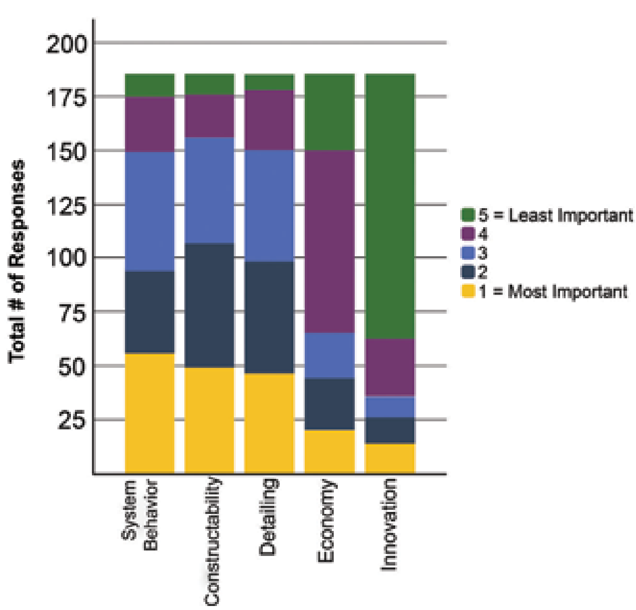

Figure 6. Top rankings in order of importance.

Detailing and Economy

Economy follows good detailing that leads to constructible masonry solutions. Understanding the modularity of masonry and why it is selected as an economical material is vital. Physical limitations for placing reinforcement, crack control with appropriately detailed joints, familiarity with cast-in and post-installed anchors, and the effect of air spaces in cavity walls on anchorage to masonry is also essential. While engineers typically do not specify waterproofing, flashing, weeps, etc., an understanding of these issues is essential to good detailing.

Innovation

Engineers need to stay abreast of new technologies and developments related to masonry; however, this was ranked less important than the other categories. Several respondents cited the use of the ASTM C-90 minimum *f´m* of 2,000 psi, instead of the previous 1,500 psi, as an example of missed innovation opportunity. While limited class time should be spent on innovative technologies, graduating engineers may be expected to be more familiar with newer technologies. They should be prepared to critically review and introduce innovative concepts to their more experienced colleagues.

Industry Wishes

This survey revealed that the masonry industry would like to see graduating engineers who: 1) have successfully completed a course in masonry – with an emphasis on system behavior, constructability, and detailing of masonry structures, 2) have had hands-on experience with masonry installations, and 3) strategically leverage masonry for economy and simplicity on projects. Instructors are encouraged to attend a Masonry Educators Workshop (MEW) and contact The Masonry Society (TMS) for support as they develop masonry content for their courses.▪

Heather Sustersic is a Project Engineer with Providence Engineering Corporation and former adjunct faculty member of the Architectural Engineering Department at Penn State University. She currently serves as a voting member of the TMS 402/602 Structural Members and Reinforcement and Connectors Subcommittees. (heathers@proveng.com)