Structural Stability Research Council

NEWSLETTER

Volume 4, Issue 1 **October 20, 2014**

Message from SSRC Chair, Ben Schafer

Maybe we should change the C in SSRC? Our dear Council is much more than a deliberative body for structural stability research in steel. Our council is a Community. We are a group of individuals that understand the importance of structural engineering, that believes in the power of new knowledge to solve difficult problems, and that enjoys pictures of deformed structures far more than average folk. We are an international group bonded by our willingness to take on the charge of delving deeply into a difficult subject so that society may have safe and efficient buildings, bridges, and other structures. These stability-critical structures minimize material and smartly navigate the difficult nonlinear universe of behavior that emerges in slender solutions, i.e., in the world of structural stability. Perhaps our domain is not for everyone, but for our community, it is the thing.

Our community gathers together, at least once a year, to renew friendships and share our deep mutual interest in the fascinating field of the stability of structures. You should join us in Nashville this Spring at our Annual Stability Conference (March 24-27, 2015) once again held in conjunction with the American Institute of Steel Construction's North American Steel Construction Conference (NASCC). As is our tradition we will kick off the day before NASCC officially starts with research talks, task group meetings, our annual meeting, and our annual social gathering with "beverages" and appetizers. This day is followed by three days of excellent technical talks, interaction with the broader steel community at NASCC, and a chance to create new collaborations and learn all about the latest research in stability.

Like every community we have members who are special: members who have taken on the charge of our community and excelled at an extraordinary level. For these special few we honor them with the Beedle Award. This award is in recognition of the founder of our community and one of its most prestigious early leaders: Lynn Beedle. This year we are proud to honor Professor David Nethercot as the Beedle Award winner. He will be honored at the NASCC and present a special lecture, "Almost 50 Years Spent Seeking Stability" on Friday, March 27 at 10:15 am. I look forward to seeing you at his talk.

Our community has much to be proud of, particularly in its rich tradition of translating the complicated knowledge of structural stability into practice for the betterment of society. We are an open-minded group excited about our unique charge, but we are not a diverse group. We have the opportunity to grow and expand our community, and we should take it. As a small community it may seem that we have no influence on who chooses to take on the challenge of structural stability - but is that really so? Our passion is our calling card, and that can be spread to all. I ask that everyone in our community make an effort to expand their network: students, engineers, faculty – by our words and actions we can help new people find their place in our community. Invite people to our task groups, to our research sessions, encourage them to write papers, show them why structural stability interests you. Our community needs the diversity of ideas, new directions, and fresh energy that comes from enabling new voices. I look forward to continuing this conversation with our community and watching all of us grow and benefit from change.

See you in Nashville!

Ben Schafer, Ph.D., P.E.
Chair, SSRC
Professor and Chair,
Dept. of Civil Engineering
Johns Hopkins University
Baltimore, MD, USA

Inside this issue:

The Life of a Lehigh University Professor: Le-Wu Lu (1933 – 2014)

Le-Wu Lu served Lehigh University as a teacher, mentor, researcher and active scholar for over 43 years in the Department of Civil and Environmental Engineering. He started his career in 1954 by receiving a BS, Civil Engineering from the National Taiwan University. From there he traveled to the United States to pursue a graduate degree which he received from Iowa State University in 1956 specializing in Geotechnical Engineering. While at Iowa State he learned about the research being conducted at the new Fritz Laboratory, Lehigh University on the plastic design of steel structures by one of his structural engineering professors who suggested he attend that university for a PhD. He decided to switch his emphasis from geotechnical to structures and in 1957 came to Lehigh. In 1960 he received his PhD and joined the faculty as an Assistant Professor in 1961. By 1965 he was promoted to Associate Professor and became a Full Professor in 1969. Dr. Lu served the CEE department as its Chairman from 1994 to 1998 and was awarded the first Bruce G. Johnston Endowed Professor of Structural Engineering in 1999 which he held until his retirement in 2004.

Dr. Lu's teaching activities were extremely varied both at the undergraduate and graduate levels. They included the following courses: Structural Analysis 1, Probability and Statistics for Civil Engineers, Fundamentals of Structural Steel Design, Building Systems Design, Structural Dynamics, Research Methods, Structural Members and Frames, Advanced Mechanics of Materials, Methodology of Structural Design, Analysis and Design of Steel and Composite Structural Members, Analysis and Design of Ductile Steel Structural Systems, and Stability of Structural Systems.

Dr. Lu's areas of research were very broad, but concentrated on two types of structures: buildings and ships. He studied aspects of the behavior of building structures and components made of steel, reinforced concrete (both cast-in-place and precast) and composite steel and concrete and subjected to gravity, wind, and earthquake forces. A major part of the work on seismic behavior emphasized post-earthquake field studies and failure analysis of damaged or

collapsed steel buildings. The ship structure research was on double hull systems resisting forces due to severe wave motions. He was involved in development of an automated construction system for steel frames, utilizing a type of special steel casting connectors, referred to as the 'ATLSS Connector,' which he was a co-patent holder. He also worked on the use of fiber reinforced plastic composites for short span bridges and in strengthening reinforced concrete beams and columns. In nearly all the work, both analytical and experimental approaches were adopted and, in some cases, new testing techniques had to be developed. He has served as a consultant to design and construction industries on building projects in the U.S. and abroad.

During his 44 years of active teaching and research he supervised or co-supervised 24 PhD students that came to Lehigh from all around the world. Most of their research contributions can be summarized into five select areas, 1) Strength and Deformation of Steel Columns, Beam-Columns, and Structural Assemblages, 2) Ultimate Strength and Design of Steel Frames, 3) Steel Frames Subjected to Repeated Lateral Loads (i.e., simulating seismic effects), 4) Post-Earthquake Failure Studies of Steel Building Frames, and 5) Double Hull Ships Made of High-Performance Steel and Non-Magnetic Stainless Steel. As previously stated, Dr. Lu is best known for his extensive experimental and analytical studies on the seismic response of steel building structures, precast concrete structures, innovative structural systems, composite steel-concrete structures, structural connections, and the repair and retrofit of structures that were carried out both in Fritz Laboratory and later at Lehigh's ATLSS (Advanced Technologies for Large Structural Systems) Center. He and his students and colleagues not only enhanced Lehigh's global reputation in structural engineering, but his own work proved invaluable as architects and engineers around the world sought to advance the development of seismic-resistant buildings.

Among his many awards and honors were the following:

* The Leon S. Moisseiff Award for excellence in a paper published by the American Society of Civil Engineers recognizing his contributions to structural design, including applied mechanics as well as theoretical analysis, in 1967.
* A Senior Fulbright-Hays Lectureship as a member of an exchange program with the Moscow Civil Engineering Institute, in 1975.
* An honorary professorship from the Harbin Architecture and Civil Engineering Institute, China, in 1980.
* An honorary consultancy from the Central Research Institute for Building and Construction, China, in 1993.
* An honorary consultancy from the National Research Center for Industrial Building Diagnosis and Rehabilitation, China, in 1993.
* The Eleanor and Joseph F. Libsch

The Life of a Lehigh University Professor: Le-Wu Lu (1933 – 2014)

Award for distinction in research, Lehigh University, in 2001.

* A lifetime achievement award from the Asia-Pacific Network of Centers of Earthquake Engineering Research (ANCER), at the Third International Conference on Earthquake Engineering, Nanjing, China, in 2004.

Dr. Lu was still an active researcher well into his retirement. He served as one of six principal investigators for Lehigh's Chinese Bridge Project, a project that has been supported by the Henry Luce Foundation. He helped to teach two courses on modern Chinese fiction, and aided in the effort being undertaken by the Lehigh Library Materials Center to organize a donation of more than 2000 Chinese books.

Dr. Lu was a member of the original joint Committee on Tall Buildings which later became the Council on Tall Buildings and Urban Habitat, served as CTBUH's Secretary (1969-1972), and was on the organizing committee that brought the First International Conference on Tall Buildings to Lehigh in 1972 where the event drew nearly 800 attendees. Subsequently, he held the following positions at CTBUH: International Conference Committee Chairman (1973-1975), Monograph Working Group Secretary Volume SB Tall Steel Buildings (1978-1980) and was involved in the editing of the five Monographs that were published on the Design and Planning of Tall Buildings, Advisory Group Member (1982-1984), and Research Coordinator (1988-1992).

Over his career he was actively involved in numerous professional societies: American Society of Civil Engineers Administrative Committee on Tall Buildings (Chairman, 1978-1982), ASCE Committee on Seismic Effects (1968-1969), ASCE Committee on Plastic Design, Structural Division (Chairman 1969-1973), ASCE Committee on Composite Construction (1982-1985); Earthquake Engineering Research Institute; International Association for Structural Safety and Reliability; Structural Stability Research Council Task Group on Stability under Seismic Loading; CTBUH Group Secretary for Criteria and Loading, and Structural Design of Tall Steel Buildings; ECCS Committee 13 on Seismic-Resistant Design of Steel Structures (ECCS-European Convention for Constructional Steelwork); and Applied Technology Council, Board Member (1987-1990).

Le-Wu Lu is survived by his wife of more than 50 years, Dorothy Lu, his daughter, Julia, son, Paul, and one grandchild.

On a personal note, Dr. Lu was a real mentor to me, always positive and insightful. My first recollection of him was during my first graduate days at Lehigh. He taught CE453, Structural Members and Frames, in Fall 1978 – a very challenging course which, among other things, made sure we understood the behavior of structural members, stability issues,

and most importantly how to think. I returned to Lehigh in Fall 1991 to start my PhD studies and got reacquainted with Dr. Lu while a Graduate Research Assistant working on the U.S. Navy's Fleet of the Future program, 1992-1994, and then on my dissertation research 1994-1997.

As CEE Department Chairman, Dr. Lu seemed to always keep an eye on my progress towards graduation whether it was from an informal discussion after class, meeting for lunch in the Faculty Staff Dining Room, or when witnessing one of my many experiments in Fritz Laboratory or ATLSS. He appointed me a Visiting Instructor Summer 1997 and Adjunct Assistant Professor Fall 1997 which, as it turns out, was just what my CV needed to secure a number of interviews for a Faculty Position and subsequently my appointment as an Assistant Professor at the University of Florida. I will always be indebted to him for the opportunities that he gave me.

Dr. Lu, you will be greatly missed.

- Perry S. Green, MS 1979, PhD 2001, Lehigh University

PROFESSOR LU PRODUCED MORE THAN 250 JOURNAL ARTICLES AND CONFERENCE PAPERS PUBLISHED BY ACI, AISC, AISI, ASCE, TRH, SSRC, JSCE, RILEM, IABSE, WRC, EXPERIMENTAL MECHANICS, JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH, AUTOMATION IN CONSTRUCTION, JOURNAL OF WIND ENGINEERING, INDUSTRIAL AERODYNAMICS, JOURNAL OF INTELLIGENT MATERIAL SYSTEMS AND STRUCTURES, SPECTRA, AND ENGINEERING STRUCTURES. HE ALSO HAD A NUMBER OF CO-AUTHORED AND CO-EDITED BOOKS, PROCEEDINGS, MONOGRAPHS AND MANUALS.

News/Announcements

2015 Beedle Award Winner: Professor David A. Nethercot

Prior to his retirement in the autumn of 2011, David Nethercot was, for 12 years, the Head of the Department of Civil and Environmental Engineering at Imperial College London; he is now an Emeritus Professor.

He was previously on the staff at Cardiff, Sheffield and Nottingham universities. He was awarded a DSc degree in 1993 and elected to the Royal Academy of Engineering in that same year. He is a Past President of the Institution of Structural Engineers and a former Council Member of the Royal Academy of Engineering. In 2006 he was awarded an OBE for services to Structural Engineering; the 2008 Charles Massonet Prize from the ECCS and in 2009 the IStructE Gold Medal. In 2010 he was elected as a Foreign Fellow of the Academy of Technical Sciences and Engineering of Australia. For more than 40 years he has been active in research, teaching and advisory work in the area of steel structures. He has published over 400 papers, including 10 prize winning papers. For 25 years he was a member of the BSI committee responsible for the UK Steel Building Code as well as for UK input into the Structural Eurocodes, including serving as chairman for a decade. He now chairs the BSI committee with oversight of all structural design codes. In addition to his academic career he has advised on several complex and high profile projects, including Wembley Stadium roof and the Gerrards Cross tunnel collapse.

PROFESSOR NETHERCOT WILL BE MAKING HIS BEEDLE PRESENTATION, "ALMOST 50 YEARS SPENT SEEKING STABILITY" ON FRIDAY, MARCH 27, 2015 AT 10:15 AM

Beedle Award Details

The award has been established in honor of the late Lynn S. Beedle, an international authority on stability and the development of code criteria for steel and composite structures. He was a leader and outstanding contributor to the work of the Structural Stability Research Council for a period of more than 50 years, establishing the council as the preeminent organization worldwide in the area of structural stability.

Through Lynn Beedle's dedicated work and leadership in the national and international arenas, the structural engineering profession has seen advanced concepts developed into practical engineering tools. He consistently and successfully endeavored to advance collaboration between researchers, engineers and code writers worldwide.

THE BEEDLE AWARD WAS ESTABLISHED TO HONOR THE LATE LYNN S. BEEDLE, A LEADER AND OUSTANDING CONTRIBUTER TO SSRC

Recipients of the Lynn S. Beedle Award must meet the following criteria:

- Longtime member of SSRC.
- A worldwide leading stability researcher or designer of structures with significant stability issues.
- A leader in fostering cooperation between professionals worldwide.
- Significant contributions to national and international design code development.

The SSRC Executive Committee serves as the award committee. The award may be presented as frequently as annually. An individual can only receive the award once. The award is presented at the SSRC Annual Stability Conference. It consists of a framed certificate, signed by the SSRC Chair and Vice Chair.

News/Announcements

2014 Vinnakota Award

The Vinnakota Award is given for the best student authored paper presented at an SSRC Annual Stability Conference. The paper shall be based on the thesis research of an M.S. or Ph.D. student.

The award consists of a certificate, which is presented to the student and his/her advising professor, as well as a cash honorarium presented to the student.

The Vinnakota Award was established in 1997 by Ramulu S. Vinnakota, longtime member of the SSRC, in honor of his parents who believed in the importance of education and research.

2014 Vinnakota Award Recipient
Merih Kucukler
Imperial College London, UK
"Stiffness Reduction Method for the Design of Steel Columns and Beam-Columns"
Supervisor: Professor Leroy Gardner

Honorable Mentions

Zhichao Lai
Purdue University
"Analysis and Design of Noncompact and Slender Concrete-Filled Steel Tube (CFT) Beam-Columns"

André D. Martins
University of Lisbon
"On the Relevance of Local-Distortional Interaction Effects in the Behavior and Design of Cold-Formed Steel Columns"

Reidar Bjorhovde Named Distinguished Member of the American Society of Civil Engineers

DR. BJORHOVDE HAS BEEN A MEMBER OF SSRC SINCE 1973; DISTINGUISHED MEMBER 1998 TO PRESENT, MEMBER OF THE SSRC EXECUTIVE COMMITTEE 1987-2008, SSRC VICE CHAIR 1995-98, SSRC CHAIR 1998-2002, IMMEDIATE PAST CHAIR 2002-05

Reidar Bjorhovde, Dr.-Ing., Ph.D., P.E., P.Eng., F.SEI, Dist.M.ASCE was recently named a Distinguished Member of the American Society of Civil Engineers (ASCE). The society's highest accolade, to date only 649 of ASCE's worldwide members have been elected to receive this honor since the society's founding in 1852.

Bjorhovde will be recognized for his seminal research on the stability and reliability of steel columns, for reliability and design of bolted connections, for reliability and performance of composite frames and heavy steel members, for classifying bolted and welded connections, and for his significant contributions in preparing national and international steel design codes. He will receive the award at the ASCE Global Engineering Conference in Panama City, Panama, Oct. 7-11, 2014.

Bjorhovde is currently the president of The Bjorhovde Group, which he founded in 1998. He consults on construction projects, engineering projects, design codes and research around the world, with a focus on steel materials.

Before his work in consulting, Bjorhovde was a professor for many years at the University of Arizona and the University of Alberta in Canada, and he was professor and chair of the Department of Civil Engineering at the University of Pittsburgh.

He is currently the editor of the Journal of Constructional Steel Research of Elsevier Science and the research editor of the American Institute of Steel Construction Engineering Journal.

Bjorhovde holds doctoral degrees from the Norwegian Institute of Technology and Lehigh University.

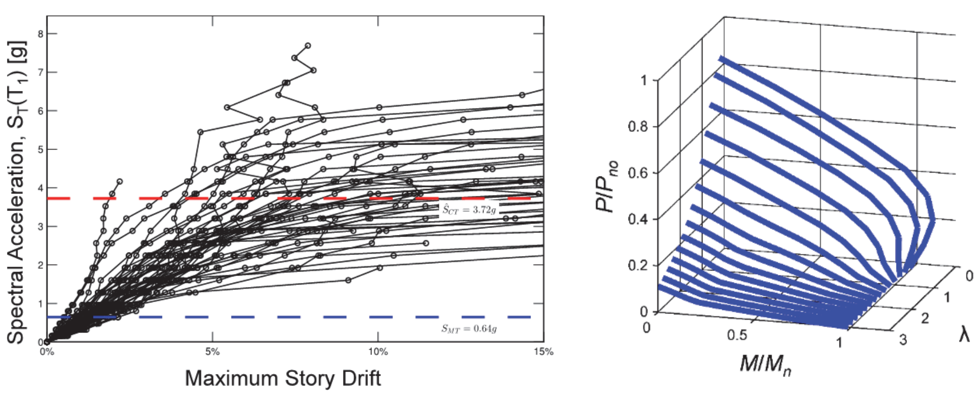
Ongoing Stability Research

System Behavior Factors for Composite and Mixed Structural Systems

Roberto T. Leon, Virginia Polytechnic Institute and State University
Jerome F. Hajjar, Northeastern University
Tiziano Perea, Universidad Autónoma Metropolitana
Mark D. Denavit, Stanley D. Lindsey and Associates, Ltd.

Sponsored by National Science Foundation and the American Institute of Steel Construction

This research aims to fill key gaps in the design provisions for frame systems that include steel-concrete composite columns. The experimental portion of the project, in which 18 full-scale slender concrete filled steel tube beam-columns were tested under a variety of load cases, is complete. The experimental data has been valuable in the assessment of behavior as well as to validate second-order inelastic analysis models capable of performing broad parametric studies. Among the studies performed with the models was an assessment of the seismic performance factors for special composite moment and braced frames. Following the FEMA P-695 procedure, numerous static pushover and dynamic response history (Figure 1a) analyses were performed. The results provide quantitative evidence in support of the current factors used in design. Also, current stability design provisions for composite frame systems have been evaluated. The results indicate that while the current design provisions are safe and accurate for the majority of common cases, there exist cases where the current provisions result in unconservative error. One case of unconservative error is slender columns subjected to combined axial load and bending moment, where the error can be traced to the change in shape of the interaction diagram with slenderness (Figure 1b). Practical modifications to the current AISC design provisions, specifically changes in the direct analysis stiffness reductions and the effective flexural rigidity for the determination of the compressive strength have been proposed. Further design recommendations are in development including modifications to the ACI design provisions and effective flexural rigidity for drift determination.



(a) (b)

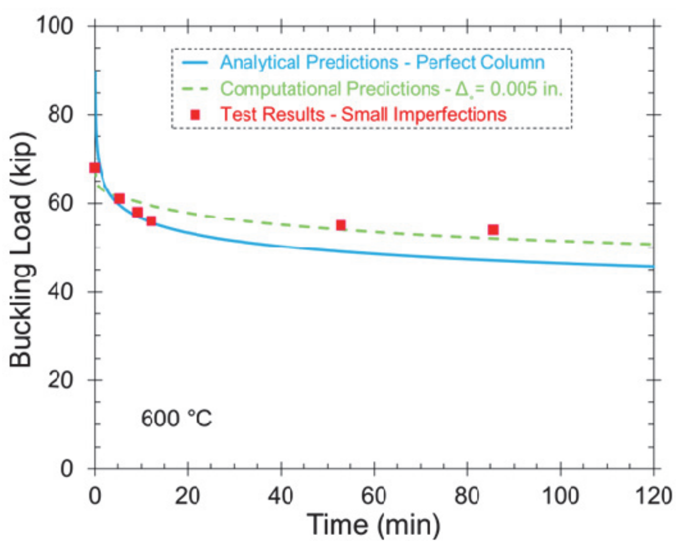
Figure 1. a) Incremental dynamic analysis results for a composite moment frame; b) Axial compression – bending moment – slenderness interaction diagram for a composite beam-column

Time-Dependent Buckling of Steel Columns Exposed to Fire

Mohammed A. Morovat, Michael D. Engelhardt, Todd A. Helwig and Eric M. Taleff
The University of Texas at Austin, Austin, TX

Sponsored by National Science Foundation

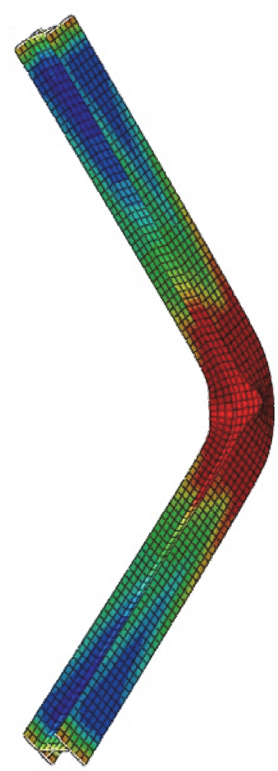
A column specimen following a buckling test at 600 °C



Creep buckling curves at 600 °C – predictions from different methods (W4×13, 51 in. long)

The ability of steel columns to carry their design loads is greatly affected by time- and temperature-dependent mechanical properties of steel at high temperatures due to fire. It is well known that structural steel loses its strength and stiffness with temperature, especially at temperatures above 400 °C. Further, the reductions in strength of steel are also dependent on the duration of exposure to elevated temperatures. The time-dependent response or creep of steel plays a particularly important role in predicting the collapse load of steel columns subjected to fire temperatures.

Along with the main goal of developing a fundamental understanding of the phenomenon of creep buckling, this project has shown that time-dependent effects are significant in response of steel columns in fire. Now that the buckling tests on W4×13 columns have ended, the methodology developed to account for the effect of material creep on the buckling of steel columns in fire can be further verified. An example of such verifications is shown where analytical and computational creep buckling predictions are compared against test results for W4×13 columns with KL/r of 51 at 600 °C. Analytical solutions are based on the concept of time-dependent tangent modulus. Computational creep buckling analyses are performed in Abaqus®. A material creep model developed in this study for ASTM A992 steel is utilized in analytical and computational buckling analyses. Considering all the uncertainties in material creep models and buckling prediction methods, reasonably well agreements can be seen.



Creep buckling simulation of a W4×13 column tested at 600 °C

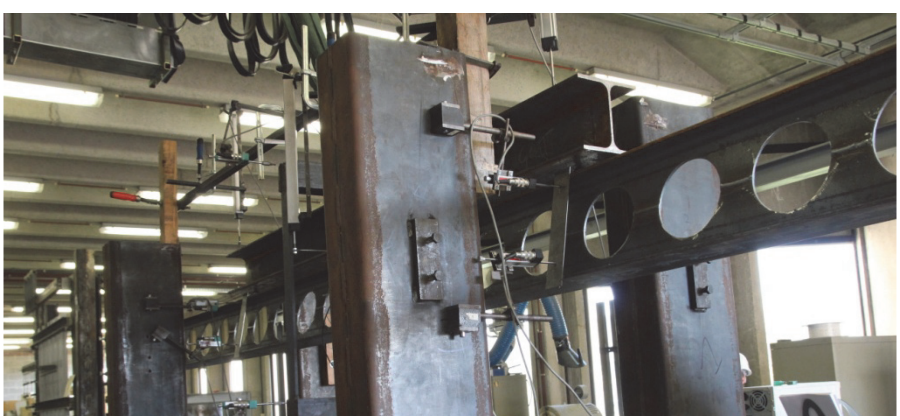
Global Buckling of Castellated and Cellular Steel Beams and Columns

Delphine Sonck
Ghent University
Belgium

Cellular and castellated members are usually made by performing thermal cutting and welding operations on hot-rolled I-section members. The global buckling behavior of these members will be qualitatively similar to that of I-section members. However, it is expected that the buckling resistance will be influenced by the different geometry and the modification of the residual stress pattern during the production of the cellular and castellated members. Current design guidelines for the global buckling of these members are conflicting or lacking altogether and do not take into account the effect of the modified residual stresses, which could possibly be very unsafe. Therefore, the lateral-torsional buckling and weak-axis flexural buckling behavior of castellated and cellular members were investigated in a recent PhD investigation at Ghent University.

A series of residual stress measurements demonstrated the increase of the compressive residual stresses in the flanges during the production of these members, which is detrimental for the global buckling resistance. This was taken into account in the proposed modified residual stress pattern. The numerical model in which this residual stress pattern was introduced, was validated using the results of a series of lateral-torsional buckling experiments. Based on the results of the numerical parametric study of the global buckling behavior, a first design rule proposal was made. This proposal is similar to the currently used European guidelines for I-section members without openings, but with a different calculation of the cross-sectional properties and a modified buckling curve selection. The PhD dissertation can be downloaded from http://hdl.handle.net/1854/LU-4256332.

Production of a castellated member



Lateral-torsional buckling experiment on a cellular beam

System Behavior Factors for Composite and Mixed Structural Systems

Aritra Chatterjee and Cristopher D. Moen
Virginia Polytechnic Institute and State University (Virginia Tech)
Blacksburg, VA

Yibing Xiang and Sanjay Arwade
University of Massachusetts, Amherst
Amherst, MA

Benjamin W. Schafer
Johns Hopkins University
Baltimore, MD

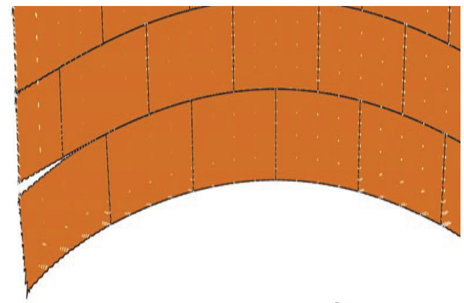


Figure 1: Finite Element Simulation of Diaphragm Response under in-plane lateral loads

Structural design continues to be a component based process, typically checking beam, column and connection capacities against design demands. However, end-user safety in the event of natural hazards hinges on system performance. The challenges in casting structural design as a 'system-based' process stems from a fundamental lack of understanding how component level properties, namely component ductility and uncertainty, propagate to system behavior -- redundancy, overstrength and system ductility.

This National Science Foundation sponsored Grant Opportunities for Academic Liaison with Industry (GOALI) project, coordinated through the Cold-Formed Steel Research Consortium, www.cfsrc.org, seeks to meet this challenge for typical building structural systems: roof, walls, and floors. Buildings framed from cold-formed steel are targeted for initial application. The industry partner, the American Iron and Steel Institute (AISI), is working directly with the academic research team to insure the research has maximum impact on the practical design of cold-formed steel building sub-systems.

So far the focus has been on wood-sheathed cold-formed steel floor subsystems under in-plane lateral loads (wind or seismic). High-fidelity finite element models have been developed in ABAQUS and shown to replicate real behavior previously seen in monotonic experiments. Surrogate models were generated to study system response in a computationally efficient manner, and dedicated experiments were used to determine component response and uncertainty. These were coupled together to generate system-level strength distributions at first yield and ultimate limit states, and it was shown that component load-deformation behavior has a great impact on system over-strength and ductility. The ongoing parallel efforts are focused on generalizing these methods, and building a full-scale experimental setup at Virginia Tech for testing floor diaphragm sub-systems in order to validate the computational models.

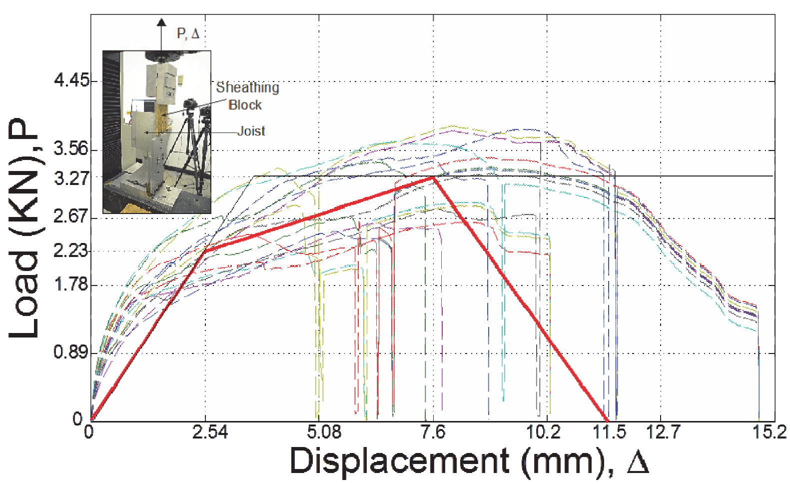


Figure 2: Component level force deformation relationships and approximate models

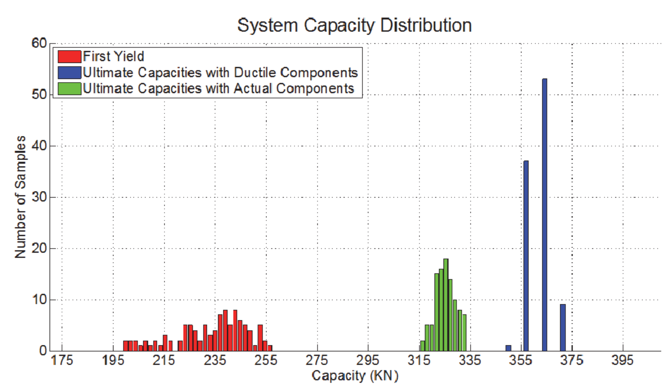


Figure 3: System Capacity Distributions at 2 limit states

Building a Better Understanding of Build-Up Cold-Formed Steel Member Buckling Behavior and Capacity

David C. Fratamico
Johns Hopkins University
Baltimore, MD

Built-up cold-formed steel members are integral parts of shear walls and are frequently included in frames as king and corner studs. Current predictions for buckling capacity in AISI S100-12 Section D1.2 employ the modified flexural slenderness ratio, which reduces the buckling capacity of columns in part due to a loss of shear rigidity in the overall member's interconnections (fasteners). There exist provisions for calculating fastener spacing and layout, whether screws or welds are used to connect two sections together. However, a detailed understanding of the effective section rigidities of these composite, thin-walled members does not yet exist.

Interestingly, connecting two standard CFS channel sections together does offer a boost in flexural capacity. Elastic flexural buckling loads of back-to-back channel sections frequently used in design, for example, are theoretically more than twice the buckling load of the individual channel sections. A recent approach to understanding the behavior of built-up columns at Johns Hopkins University employs the concept of composite action, in which this boost in flexural capacity can begin to be quantified.

A parametric study using elastic buckling analysis was conducted on a representative population of built-up structural columns in ABAQUS (using discrete fasteners) and Finite Strip Method-based software CUFSM (using smeared constraint interconnections). Member cross-sections, fastener spacing, and fastener grouping at the column ends were varied. Prevailing buckling modes are shown in Figure 1. Buckling loads from the study are compared to code-based equation predictions and show considerable composite action (illustrated by the signature curve in Figure 2), which can increase a column's flexural buckling load by up to 85% from its non-composite lower bound, for trials in both CUFSM and ABAQUS. Future work includes more accurate modeling of fastener stiffness and experimental studies.

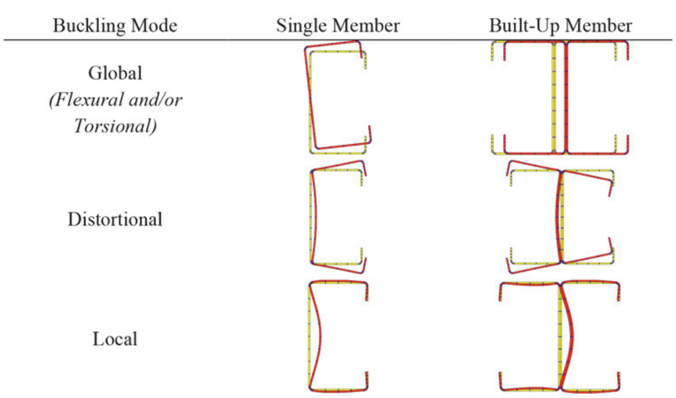


Figure 1. Prevailing elastic buckling modes of built-up CFS columns from CUFSM analyses

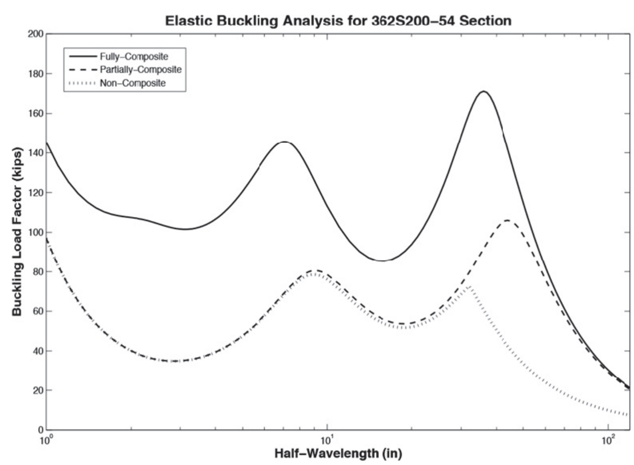


Figure 2. Composite action boosts buckling capacity of a back-to-back 2X362S200-54 section

Buckling Mode Identification for a Cold-Formed Steel Column Experiment with 3d Image-Based Reconstruction

Abraham Lama-Salomon , Fannie Tao , Junle Cai and Cristopher D. Moen
Virginia Polytechnic Institute and State University (Virginia Tech)
Blacksburg, VA

Recently developed thin-walled modal decomposition algorithms are merged with 3d-image based reconstruction (Figure 1) to document and quantify buckling deformation throughout a cold-formed steel column experiment. The buckling deformation is recorded with strategically located high-definition video cameras. The video footage is decomposed into individual frames, and a gradient-based optimization algorithm, available in low cost commercial software packages, is applied that finds the 3d image coordinates and camera position by maximizing the number of matching (overlapping) features from frame to frame. Once the 3d coordinate system and camera locations are established, a dense point cloud is generated resulting in the 3d column representation throughout the experiment. The 3d point cloud is analyzed with a buckling mode identification tool that employs cross-sectional deformation modes from generalized beam theory. Local, distortional, and global buckling participation are documented, including contributions just prior to column failure which can be useful for the development of future strength prediction design approaches, especially where buckling modes mix near an ultimate limit state.

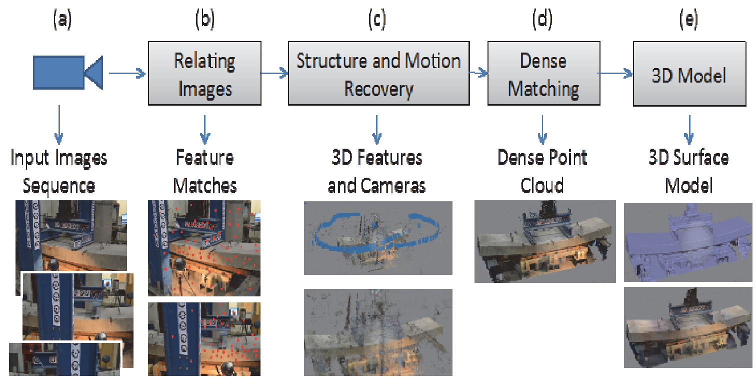


Fig. 1. 3d image-based reconstruction applied to a one-way bridge deck slab test at Virginia Tech

Stiffness and Strength Requirements of Shear Diaphragms Used for Stability Bracing of Steel I-Sections

O. Ozgur Egilmez
Izmir University of Economics
Izmir, Turkey

Mustafa Vardaroglu and Andac Akbaba
Izmir Institute of Technology
Izmir, Turkey

Lateral torsional buckling is a failure mode that often controls the design of steel I-beams during construction. During this critical stage, the buckling capacity of the beams can be increased by reducing the laterally unbraced length by providing bracing at either discrete locations or continuously along the length of the beam. Light gage metal decking, which is often used in the building and bridge constructions as concrete deck formwork, acts like a shear diaphragm and can provide continuous lateral bracing to the top flange of non-composite beams and girders by restraining the warping deformations along the beam/girder span. Past studies that investigated the stiffness and strength behavior of shear diaphragms used to brace steel beams mainly focused on the strength of the end connections (sheet to beam connections along the length of the beam). However, the strength of a diaphragm is generally controlled by either the shear strength of the end connections or shear strength at interior connections between panels. Therefore, strength requirements for shear diaphragm bracing should address both end and sidelap fasteners. This study investigates the stiffness and strength behavior of shear diaphragms used to brace stocky and slender beams/girders by taking into account both end and sidelap fastener connections. A simple finite element analytical model is utilized in the study that enables the end and sidelap fasteners to be separately modeled. The parameters that are investigated include diaphragm stiffness, thickness, and width, number of side-lap fasteners, web slenderness ratio, and section depth. The results indicate that web slenderness ratio is not as much effective as section depth on fastener forces. The findings of the study will be used to develop strength and stiffness requirements for shear diaphragms used to brace steel beams.

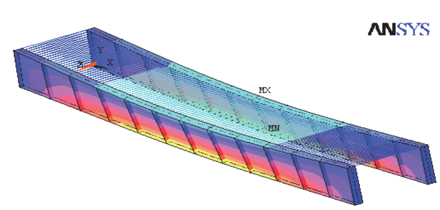


Figure 1. Twin girder braced by shear diaphragm displaced in z-direction.

Shear Wall Behavior in Cold-Formed Steel Structures

Guanbo Bian and Benjamin W. Schafer
Johns Hopkins University
Baltimore, MD

Stephen G. Buonopane
Bucknell University
Lewisburg, PA

In the design of cold-formed steel buildings, shear walls are typically used to provide lateral resistance for seismic or wind load. The wood sheathing, such as oriented strand board, is screw-fastened to the cold-formed studs and tracks to develop shear stiffness as well as strength in the wall system.

The composite shear wall response is dominated by the local behavior at each steel-fastener-sheathing connection. Researchers from Johns Hopkins University and Bucknell University currently conduct research addressing this topic. They extend the development of a mechanics-based approach to predict lateral response of wood sheathed cold-formed steel (CFS) framed shear walls.

An OpenSees model is developed that uses standard beam-column elements for the framing members and a rigid diaphragm for the sheathing. The stud-to-sheathing connections are represented as zero-length springs utilizing a Pinching04 material response developed based on isolated fastener tests. The OpenSees model is validated against previously conducted, monotonic and cyclic full-scale shear wall tests, and shown to have good general agreement. In addition, the developed force distribution of the fasteners in the studs of a typical shear wall is explored. Work remains to further calibrate the OpenSees model, but the developed results demonstrate that the shear wall response relies on connection deformations and this is the critical nonlinearity. This observation makes the possibility of determining lateral response for gravity walls and wood-sheathed floor diaphragms a distinct possibility- and this capability is critical to better understanding the seismic system-level response of cold-formed steel framed buildings.

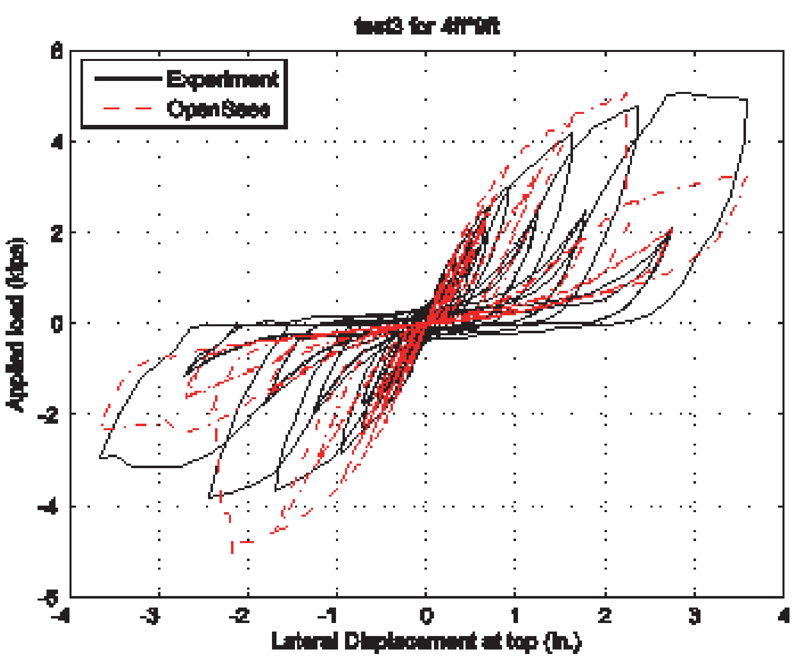


Figure 1. Cyclic performance of shear wall

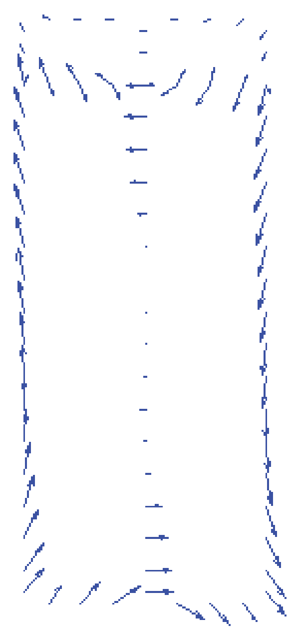


Figure 2. Force distribution for all fasteners

Structural Collapse Modeling of Steel Structures Design

Jerome F. Hajjar, Northeastern University
Junho Song, Seoul National University
Vitaliy Saykin, Wentworth Institute of Technology
Derya Deniz, University of Illinois at Urbana-Champaign
Tam Nguyen, KTP Consultants Pte Ltd.

Sponsored by National Science Foundation

The prediction of collapse of structures has gained growing attention in recent years to enable the structural engineering community to predict possible extreme loads that precipitate collapse. To predict collapse of steel structures, finite element deletions strategies have been used successfully in the past to account for fracture in steel members. Prior work has often used a constant critical strain approach (CS), which deletes an element when it achieves a specific level of strain (e.g., 0.2, which is used in this work), typically without modeling of material softening. This approach requires frequent recalibration depending on the configuration of the structural components and systems. This research proposes a more robust and general-purpose approach to collapse modeling of steel structures through the use of a Void Growth Model (VGM) to simulate the initiation of softening and the Hillerborg model for modeling the subsequent material softening, followed by an element deletion strategy that is developed in this work. In addition, a second approach is investigated that adds a Bao-Wierzbicki model to the VGM strategy (VGM-BW) in order to better account for lower and negative triaxiality regions in determining softening. The parameters of the VGM strategy were calibrated to a comprehensive set of experimental test results of circumferentially notched tensile (CNT) coupon specimens, while the Bao-Wierzbicki parameters in VGM-BW strategy were determined analytically. These strategies were then validated without recalibration through comparison with a comprehensive range of experimental test results of material characterization specimens and full-scale structural steel connection tests (Figures 1 and 2), moment resisting frame experiments (Figure 3), and multi-story braced frame experiments. The VGM strategy provided most accurate prediction, while VGM-BW has better potential if it is calibrated to experimental results directly in the low and negative triaxiality range (Figures 1 and 2). In general, the constant strain strategy did not compare well to experiments (Figures 1 and 2). The VGM and VGM-BW approaches thus enable high-fidelity parametric simulation capabilities of interest to researchers, practitioners, and code developers who address collapse of structures.

REFERENCES

- Rentschler, G. P., Chen, W.-F., and Driscoll, G. C. (1978). Tests of Beam-to-Column Web Moment Connections, Report #405.9, Fritz Engineering Laboratory, Bethlehem, PA.
- Sadek, F., Main, J. A., Lew, H. S., Robert, S. D., Chiarito, V. P., and El-Tawil, S. (2010). An Experimental and Computational Study of Steel Moment Connections under a Column Removal Scenario, NIST Technical Note 1669, National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg, Maryland.
- Saykin, V. V. (2014). "A Validated Approach for Modeling Collapse of Steel Structures," Ph.D. Dissertation, Civil and Environmental Engineering, Northeastern University, Boston, Massachusetts.
- Schutz, F. W., Schilling, C. G. J., and Beedle, L. S. (1953). The Collapse Strength of a Welded Single Bay Frame, Report #205D.5, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania.

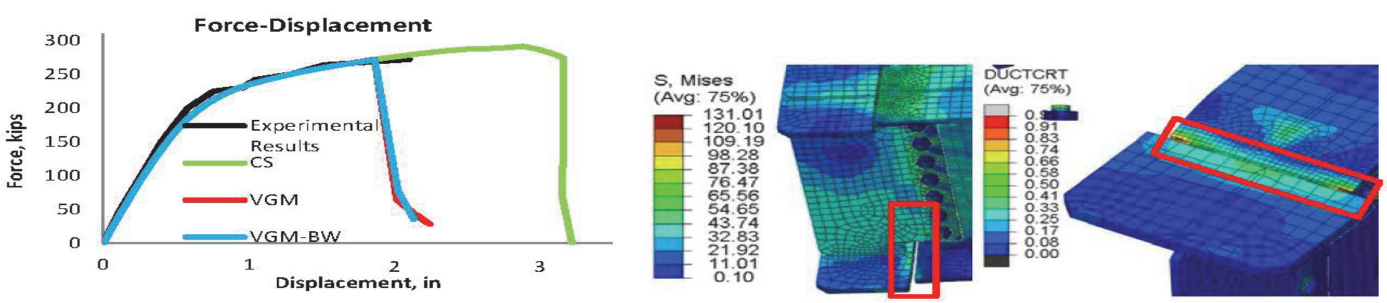


Figure 1: Force-displacement plot of validation versus experimental results (left) and simulation results of a welded flange-bolted web (WUF-B) moment resisting connection specimen with contours representing von Mises stress (ksi) (Rentschler et al. 1978): VGM / VGM-BW typical (middle), and CS (right), which shows fracture that was not reported in the experiment (Saykin et al. 2014).

Structural Collapse Modeling of Steel Structures Design, Continued

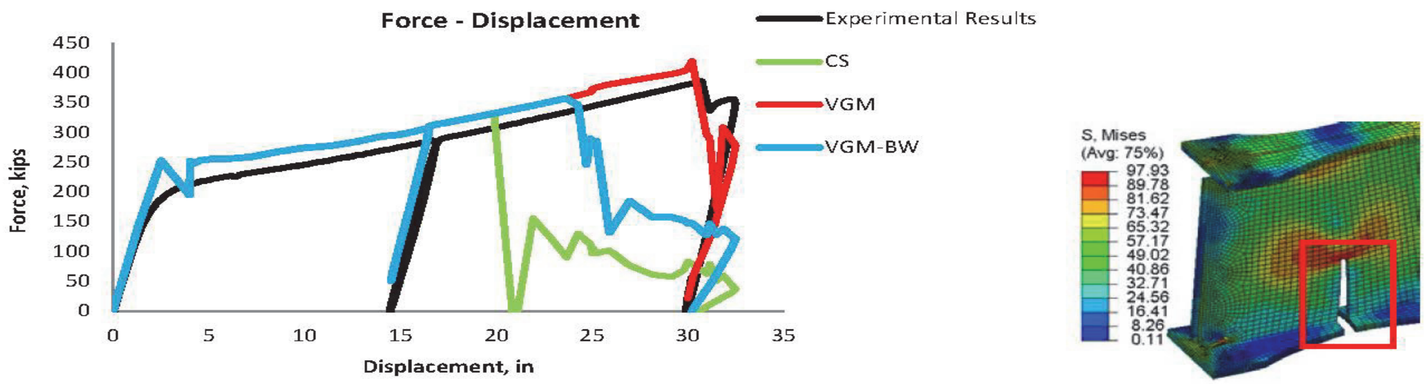


Figure 2: Force versus displacement validation results for RBS connection (Sadek et al. 2010) (left) and simulation results with contours representing von Mises stress (ksi) (right).

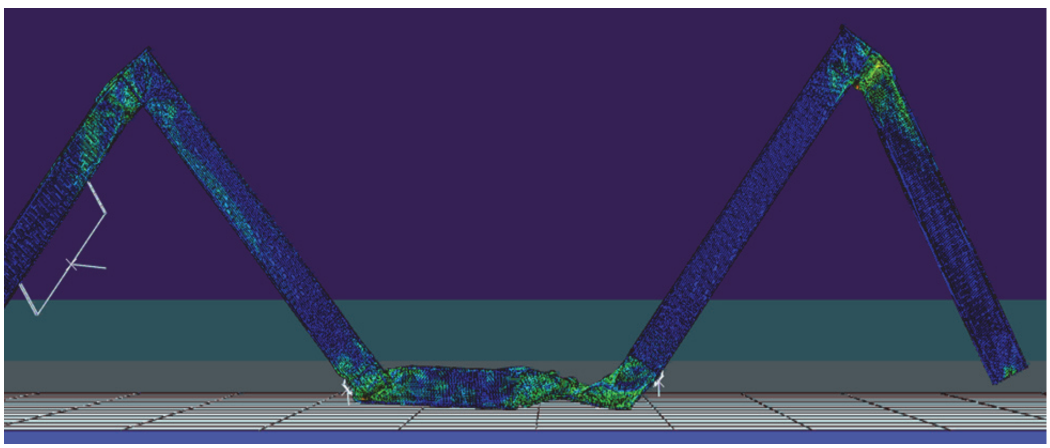
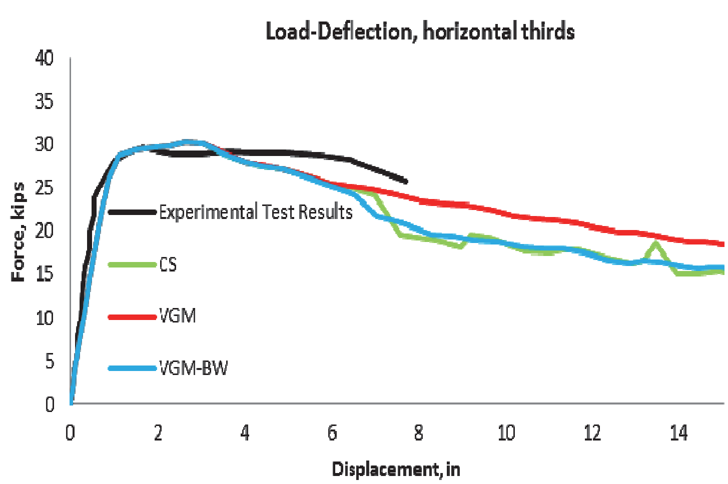


Figure 3: Validation results for portal frame (Schutz et al. 1953) showing vertical load versus horizontal deflection (top) and simulation results showing collapse (Saykin 2014).



Modeling Cyclic Axial Response of Cold-Formed Steel Members Including Local Buckling

David A. Padilla-Llano, Cristopher D. Moen and Matthew R. Eatherton
Virginia Polytechnic Institute and State University (Virginia Tech)
Blacksburg, VA

A modeling approach for simulating steel axial cyclic response including local buckling deformations is in development. Two methods are proposed – (1) a nonlinear *spring model* with concentrated nonlinear *axial load-displacement* (*P*-δ) behavior, and (2) a *nonlinear beam-column* with distributed nonlinear section *axial load-strain* (*P*-ε) behavior (Fig. 1). The models are implemented in OpenSees using *Pinching4* as the underlying material model with parameters derived as a function of the dissipated energy, member slenderness, and buckling half-wavelength. Parameter relationships have been shown by recent lipped C-section cold-formed steel cyclic experiments and finite element simulations [1-4]. The presented models would provide means to explore limit states associated to thin-walled member behavior and its application to light steel framed building systems (e.g., shear wall in Fig. 1a).

The proposed methodology is established for thin-walled cold-formed steel members, however the *Pinching4* parameters are posed generally as a function of member slenderness and could be extended to hot-rolled steel members and cross-sections with future validation.

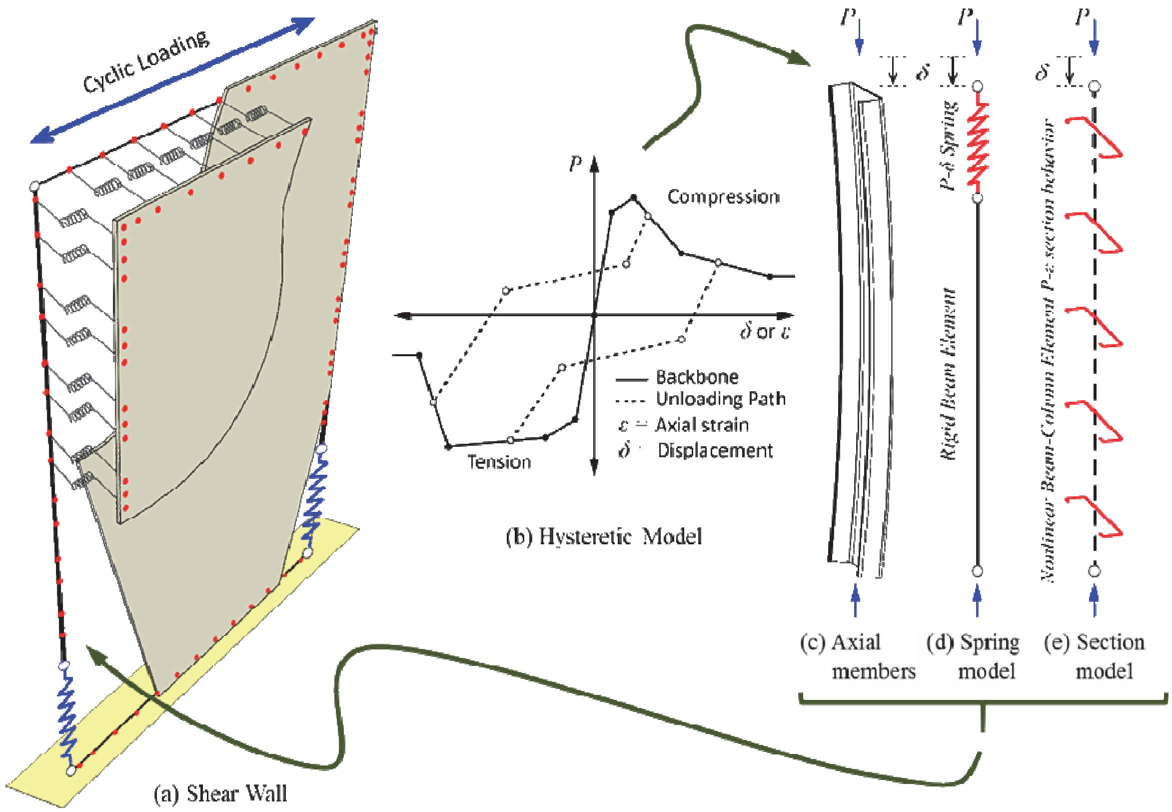


Fig. 1. (a) Cold-formed steel building subjected to earthquake in two directions where framing members experience cyclic axial and flexural deformations, and (b) axial and (c) flexural nonlinear behavior models.

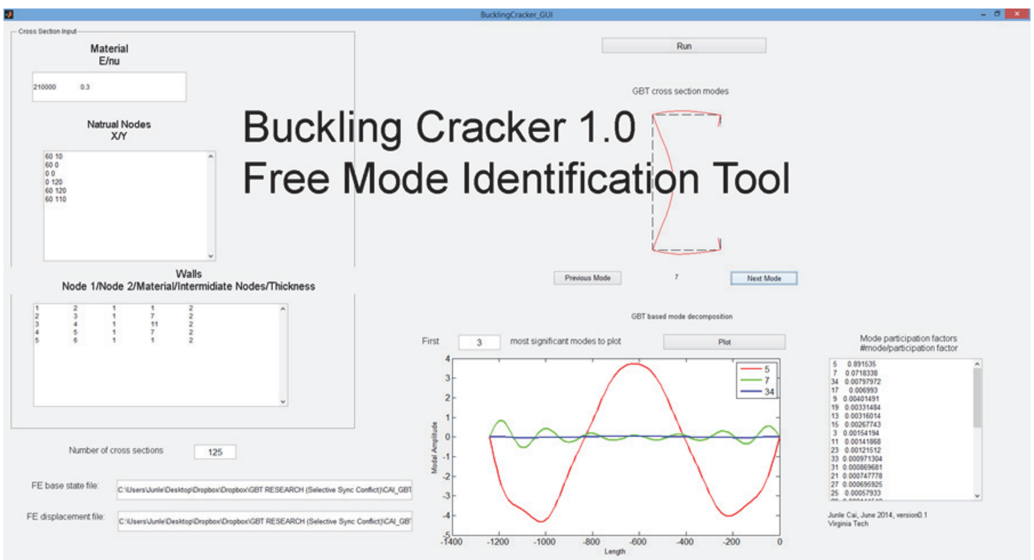
A New Free Tool to Identify Buckling Mode for Thin-Walled Structures Now Available

Junle Cai
Virginia Polytechnic Institute and State University (Virginia Tech)
Blacksburg, VA

A new and free buckling mode identification tool (Buckling Cracker 1.0) is now available online at: http://www.moen.cee.vt.edu/category/tools/.

Developed by Junle Cai from Dr. Moen's research group at Virginia Tech, this tool is dedicated to free researchers from subjective and tedious process of determining mode participation visually. Hopefully, this is helpful for strength prediction and design code development of thin-walled structures.

Based on genuine generalized beam theory (GBT), the software uses a novel algorithm to extracts modal amplitudes and modal participation factors quantitatively from 3d displacements field gained by either FEA or experiment for thin-walled members with an open cross-section. Taking advantage of GBT kinematics, the software is applicable to different boundary and loading conditions.



2015 SSRC ANNUAL STABILITY CONFERENCE

Tuesday, March 24 (SSRC Annual Meeting) through Friday, March 27, 2015
Nashville, Tennessee

Over 50 outstanding abstracts were submitted for consideration for the Annual Stability Conference that is part of the North American Steel Construction Conference. Due to time limitations, not all of the abstracts could be accepted for the final program; however the conference planning committee wants to encourage SSRC membership to continue to submit abstracts for the upcoming technical programs.

In addition, there are numerous outstanding opportunities to interact with other SSRC members in the technical program. In keeping with the format of the recent programs, the task group meetings will be held on Tuesday along with the SSRC Business Meeting and two technical sessions. We strongly encourage all of our members to attend the Tuesday sessions. In addition, please encourage your students that are attending the SSRC/NASCC conference to attend the Tuesday sessions so that they can become familiar with the SSRC Task Groups.

TO VIEW THE ADVANCE PROGRAM CLICK HERE