STRUCTURAL STABILITY
RESEARCH COUNCIL

NEWSLETTER

April, 2021

Dear SSRC members and friends,

Greetings, and welcome to the latest incarnation of the SSRC newsletter!

As I look back through the archives, I see that our last formal Council newsletter included Chair's remarks from Ben Schafer wherein he proposed that the "C" in our name should stand for Community since we are much more than a Council. As I reflect on the unusual and challenging events of the past year, I agree wholeheartedly. Although our interactions have been virtual, I have appreciated the opportunies to connect with colleagues from around the world as we seek to translate cutting-edge stability research into pracetice. Even more, it was a year that emphasized our common humanity and the importance of friendships, which sustain us through difficult experiences.

In 2019, Andrés Sánchez spearheaded a fantastic SSRC International Liaison Newsletter, which rekindled our energy for publishing a regular update from the Council. This year, the effort has expanded into a full-blown SSRC Newsletter, and Andrés is co-editing this issue with Hannah Blum. We are still focusing primarily on research updates from around the world, and future issues will include other features like member spotlights. If you are interested in contributing to the newsletter with a research brief or other content, please send your ideas to ***ssrc@aisc.org***.

This is a season of SSRC leadership transition, and I am encouraged by the energy and enthusiasm that I see for advancing the mission of the Council, particularly from the Executive Committee and our Task Group leaders. In a couple weeks, I will officially become Past-Chair as I pass the proverbial baton to our new Chair, Dan Linzell, who will be joined by our new Vice-Chair, Craig Quadrato. We will be in good hands under their guidance, and I will stay connected through a couple major initiatives – one with significant history and the other brand new. In both cases, their success depends on vigorous involvement from SSRC members.

1. Ron Ziemian and I will be co-editing the 7 th Edition of the SSRC Guide to Stability Design Criteria for Metal Structures. Our Task Groups are working diligently on chapter revisions and new chapters, so if you are not yet involved but are interested in contributing your expertise to the Guide, please contact Ron (ziemian@bucknell.edu) and/or me (fhnstck@illinois.edu) and we will gladly find where you fit.

2. The Executive Committee and Task Group leaders are planning a multi-part event that will bring stability researchers together with practicing engineers to exchange ideas about industry needs and to initiate new funded research. We have been working closely with Devin Huber, Director ofResearch at AISC, and the plans are developing nicely for later this spring. Stay tuned for more details about the SSRC Innovations for Research-to-Industry Stability Engagement Summit (SSRC I-RISE Summit). This will be a virtual event, with invitations extended to all SSRC members.

Finally, I hope you will join the 2021 Annual Business Meeting and Task Group Meetings on April 9, 1:00-4:30pm CDT (request Zoom link from ssrc@aisc.org if you do not have it already), and then attend many sessions of the SSRC Annual Stability Conference, a track in NASCC: The Virtual Steel Conference, April 12-16 (www.nascc.aisc.org). These are important events for strengthening and growing our Council andCommunity, so I look forward to seeing you soon!

Larry Fahnestock
Chair, SSRC
Professor, CEE, University of Illinois at Urbana-Champaign

NEWS AND ANNOUNCEMENTS

STRUCTURAL STABILITY RESEARCH COUNCIL

2021 SSRC Annual Business Meeting and Task Group Meetings	April 9, 1 - 4:30 pm CDT
2021 SSRC Annual Stability Conference	April 12 – 16

2020 and 2021 SSRC Conference Award Presentations

Beedle Award	2020	Kim Rasmussen	Session S4: April 13th, 9-10 am CDT
	2021	Ronald D. Ziemian	TBD at 2022 SSRC Conference
MAJR Medal	2019	Cilmar Basaglia	Session S3: April 12th, 3-4 pm CDT
	2020	Kara Peterman	

2020 and 2021 SSRC Conference Award

Yoon Duk Kim Young Researcher Award	2020	André Martins
	2021	Hannah Blum
Vinnakota Award	2020	Nuno Peres
	2021	TBA

CONTENT

International Liaison Research Reports

STRUCTURAL STABILITY
RESEARCH COUNCIL

SSRC is one of the largest professional communities in the field of structural stability, with members and contributors from all around the world. To celebrate SSRC's international outreach, this issue focuses on highlighting research projects that are currently being conducted worldwide. Fifthteen reports with contributors from nine different countries summarize some of the most relevant research and recent developments in structural stability.

We would like to thank the researchers that contributed to this newsletter. If you are working on research or industry project that is in progress or that has been recently completed, we encourage you to submit a report to be included in the next issue of the SSRC Newsletter, with the following information:

- Project title
- Authors
- Sponsors (if applicable)
- Summary of the project (250 to 400 words)
- Figures and tables

The deadline to submit a research report for the Fall 2021 issue is August 31, 2021. Please, contact Andrés Sánchez at tasanchez@adstren.com for more information.

Buckling between soft walls: sequential stabilisation through contact

G.H.M. van der Heijden, Z.K. Wang, Department of Civil, Environmental and Geomatic Engineering,
University College London, London, UK

Summary:
Motivated by applications of soft contact problems such as guidewires used in medical and engineering applications, and the borescopic or soft robotic examination of pipe or tube systems, we consider a compressed rod (or sheet) deforming between two parallel elastic (Winkler) walls. Free elastica buckling modes other than the first are known to be (multiply) unstable. We find the soft constraining walls to have the effect of sequentially stabilising higher modes in multiple contact by a series of bifurcations in each of which the degree of instability (the index) is decreased by one. For instance, stabilisation of an *n*th mode (consisting of *n* half waves) requires *n*-1 pitchfork bifurcations. Further symmetry-breaking bifurcations in the stabilisation process generate solutions with different contact patterns that allow for a classification in terms of binary symbol sequences. In the hard-contact limit all these bifurcations collapse into highly-degenerate “contact bifurcations”.

For any given wall separation at most a finite number of modes can be stabilised and eventually, under large enough compression, the rod jumps into the inverted straight state. We chart the sequence of events, under index increasing compression, leading from the initial straight state in compression to the final straight state in tension, in effect the process of pushing a rod through a cavity.

We uncover various (nonlinear) symmetry-breaking phenomena that are expected to be universal and to occur widely in compressed elastic structures subject to lateral resistance other than hard or soft contact. These phenomena include multi-stage symmetry-breakings of higher-mode deformations. Example systems include rods or sheets under external force fields due to surface tension, electric or magnetic fields or deforming on an elastic foundation or in a surrounding soft matrix, for instance as models for polymers or biological structures.

This work also aims to be a showcase for a practical approach to stability analysis based on numerical bifurcation theory and without the intimidating mathematical technicalities often accompanying stability analysis in the literature. The method delivers the stability index and can be straightforwardly applied to other elastic stability problems.

India

CoSFSM: A Computational Tool for Stability Assessment of Cold-Formed Steel Built-Up Columns

Akshay Mangal Mahar, PhD Scholar, Indian Institute of Technology Madras, India
S. Arul Jayachandran, Professor, Indian Institute of Technology Madras, India

Summary:
This research work aims at stability assessment of cold-formed steel built-up sections formed by connecting single sections using screw fasteners (Figure 1). These types of cross-sections are gaining popularity as the strength and span limits of traditional cold-formed steel construction can be expanded. Self-tapping and self-drilling screws are used for the connection between the sections, which result in easy and rapid built-up fabrication.

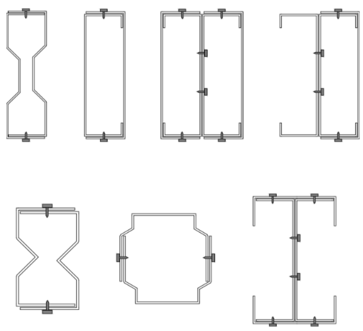


Fig. 1. *Different types of cold-formed steel built-up section profiles*

The stability assessment of built-up sections is a complex task as it will be dependent upon the stability behaviour of its individual section and the screw arrangement. The design of cold-formed steel section has been simplified by the Direct Strength Method (DSM), which is now a part of AISI S100-16 (2016) design standard. The design procedure of DSM requires elastic buckling stress solution of individual buckling modes. For built-up section, obtaining the buckling stress solution is a complex task, and this led to use of approximate buckling stress solutions for the design. Hence, the objective of this research work is to develop a computational tool, which can provide the exact elastic critical buckling stress solutions for different buckling modes, i.e., local buckling, distortional buckling, and global buckling. The formulations were developed based on the theory of classic compound strip method and merged into the spline finite strip method for the enhanced application. The screw fasteners were considered as three-dimensional beam elements (Figure 2), and their effect was integrated into spline finite strip formulations using specially developed transformation and rotation matrices.

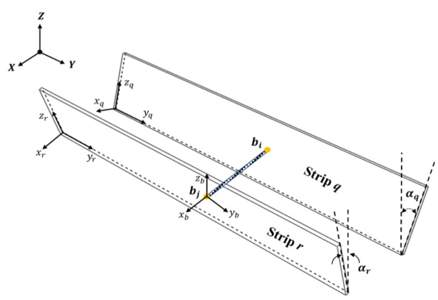


Fig. 2. *A compound profile of plate strips connected by a beam element*

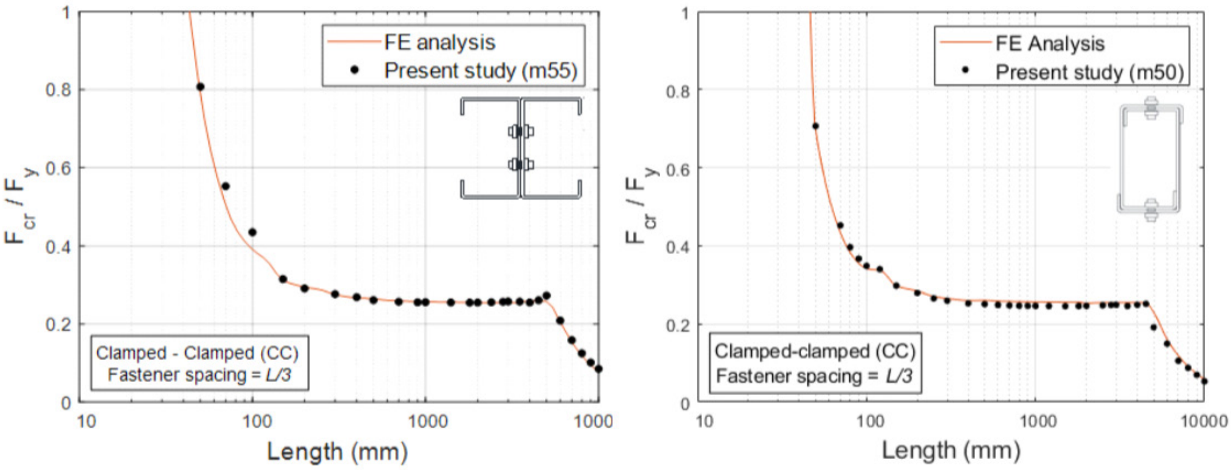


Fig. 3. *Validation of CoSFSM with results of finite element (FE) analysis for built-up I section and box*

The computational tool developed from these formulations; the compound spline finite strip method (CoSFSM) was validated with the results of finite element analysis (Figure 3). The CoSFSM can effectively solve the complex built-up section profiles, and obtain the elastic critical buckling stress solution for the design of these sections using DSM. This computational tool will help the designers for the accurate analysis and design of cold-formed steel built-up section columns.

India

Design of sheathed cold-formed steel structural members using sheathing stiffness and strength - Recommendations for the AISI S100

Sivaganesh Selvaraj, Indian Institute of Technology Hyderabad, India
Mahendrakumar Madhavan*, Indian Institute of Technology Hyderabad, India

Summary:

The sheathing board attached to the Cold-formed Steel (CFS) wall panels offers a bracing effect (stiffness and strength) through the fastener connections against the various instability failure modes of wall frame studs. The benefits of incorporating the bracing effect of sheathing in Cold-formed Steel (CFS) structural member design has been globally accepted. However, until this project, there was no design approach available in the existing design standards globally to design sheathing boards against the torsional buckling of the CFS structural members. The current design standards of AISI, Europe, and Ausses similar sheathing stiffnesses and recommends using stiff steel sheeting to brace the slender CFS structural members from failure.

The proposed design method is a simple one, has only two design steps: (i) determine the sheathing stiffness and strength demand per each sheathing fastener connection in the CFS wall frames; (ii) calculate the stiffness and strength of the sheathing fastener connection using the empirical equation developed. This design method is named as “Direct Stiffness-Strength Method Design for Sheathed Cold-formed Steel

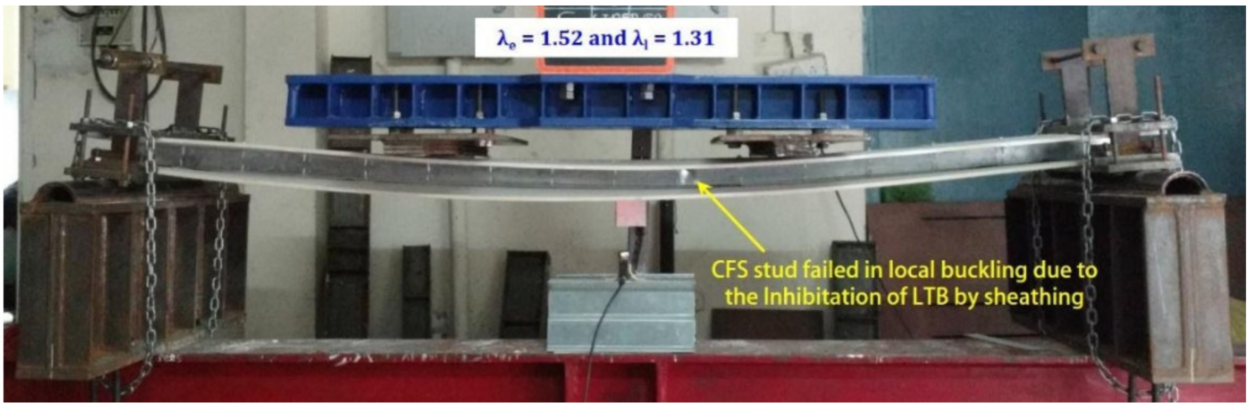


Fig. 1. *Realistic testing on sheathed CFS wall panels to check the suitability of the proposed Direct Stiffness-Strength Method Design*

Structural Members”. The proposed empirtric properties of the CFS stud and material properties of the sheathing boards. The design method's validity is verified for various CFS stud dimensions and various sheathing board materials, which are typically used by the industries. Currently, this design method is based on the nominal design strength of CFS wall frame studs. Thus, this design method can be adopted in the future revisions of AISI, Europe, and Australian/New Zealand design specifications. Full description of this design method is available in Selvaraj and Madhavan (2021). Zealand design specifications. Full description of this design method is available in Selvaraj and Madhavan (2021).

Colombia

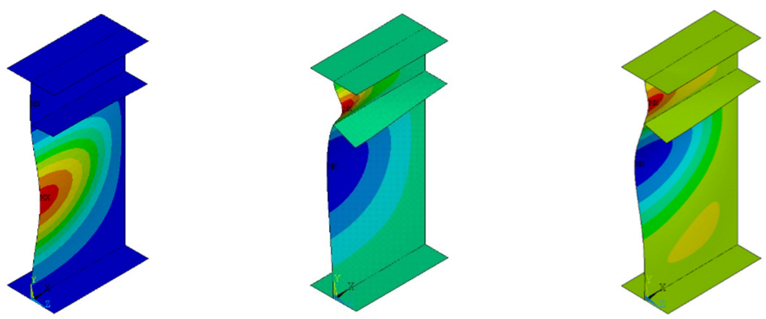
Effect of longitudinal stiffening on the ultimate resistance of plate girders subjected to patch loading

Nelson Loaiza, Universidad Nacional de Colombia, Medellín, Colombia
Carlos Graciano, Universidad Nacional de Colombia, Medellín, Colombia

Summary:

This works aimed at studying the effect of longitudinal stiffening on the ultimate resistance of plate girders subjected to patch loading. In the current Edition of the Eurocode 3: Design of steel structures - Part 1-5: Plated structural elements, EC3 Part 1-5, the ultimate resistance of girders subject to patch loading is calculated using a slenderness parameter (the ratio between the yield resistance and the critical buckling load). The latter rises with an increasing distance between the stiffener and the loaded flange. However, at ultimate load level experiments had shown that the resistance increases when the longitudinal stiffener is placed near the loaded flange.

To attain a similar behavior as the one described at ultimate load level, a hypothesis in which both vertical and out-of-plane-displacements are restrained at the stiffener location were implemented to model the elastic buckling behavior of webs subject to patch loading. From these results a new approach that corrects the calculation of the slenderness parameter and harmonize the behavior between critical load and ultimate load level was proposed. Figure 2 shows a comparison between critical buckling loads computed numerically and those calculated using various theoretical models taken from the literature. Only strong longitudinal stiffeners were considered in the analysis. In Figure 2, critical buckling loads computed considering a nodal line restricting both displacements at the stiffener location ($u_y = u_z = 0$) exhibit a similar trend as the one indicated for ultimate strength, i.e. an increa-



(a) buckling mode without restriction (b) buckling mode with $u_y = u_z = 0$ (c) failure mode at ultimate load level

Figure 1. *Buckling modes and failure mode for longitudinally stiffened plate girders (a/hw = 1.0, ss/hw = 0.2, b1/hw = 0.2, strong stiffener).*

sing Fcr for a decreasing distance of the stiffener b_1/h_w. This approach sustains consistency with the ultimate loads obtained experimentally, and with the calculation of the slenderness ratio proposed for theoretical predictions of patch loading resistances in the EC3 Part 1-5.

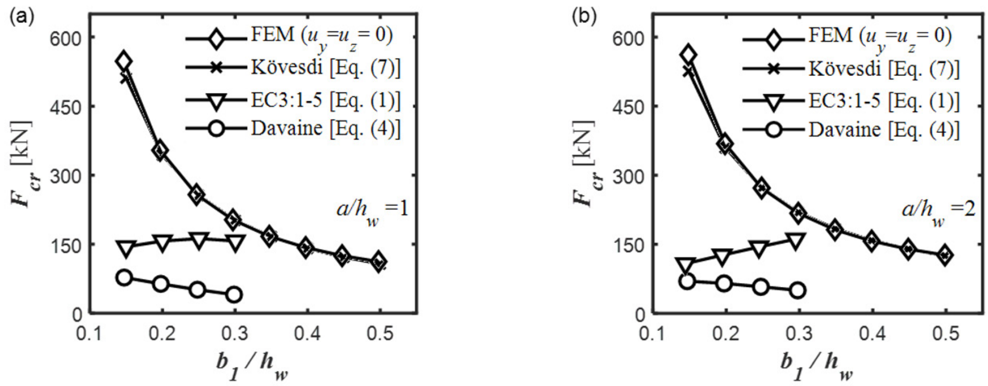


Figure 2. Critical load Fcr versus the relative position b1 /hw, for various loading lengths (a/hw=1.0).

International code provisions recommend to use a longitudinal stiffener welded at one-fifth of the girder height as the best position for flexural resistance (b_1 =$0.20h_w$), nevertheless for patch loading the optimum position to increase the resistance is lower (b_1 <$0.20h_w$). The ultimate resistance also increases when the slenderness of the directly loaded panel b_1/t_w decreases. Herein, two strategies were evaluated to investigate the impact of the ratio b_1/ t_w on the resistance: (1) changing the web thickness tw while the stiffener is fixed at b_1=$0.20h_w$, and (2) changing the position of the stiffener b1 for various web thicknesses. Figure 3 shows that the contribution of a stiffener placed at b_1=$0.20h_w$ is only significant for thinner webs.

Figure 3. shows a comparison between the ultimate resistance for stiffened and unstiffened girders (P_{UL}/P_{U0}) in terms of the slenderness ratio b_1/t_w. The dashed line represents the case of a stiffener placed at b_1/h_w= 0.20, while the continuous lines stand for fixed web thicknesses (t_w= 12, 16, 18, 20 and 24 mm) varying the stiffener position b1. In almost all cases where the web thickness t_w is fixed, the ratio P_{UL}/P_{U0} proportionally increases with decreasing slenderness ratio b_1/t_w. In contrast, the ratio P_{UL}/P_{U0} increases gradually with b_1/t_w when the longitudinal stiffener remained at b_1/h_w= 0.20. For short patch loading lengths (s_s/h_w ≤ 0.20), Figure 3a shows a reduction in the resistance for an increasing slenderness of the directly loaded panel b_1/t_w. Meanwhile, in Figure 3b a maximum is attained for a certain value of b1/tw, for s_s /h_w =0.40 the maximum is also achieved for t_w= 12 mm at b_1= 40 t_w (b_1/h_w= 0.13). For thicker webs (t_w ≥ 18 mm) the contribution of longitudinal stiffening on the resistance to patch loading is less pronounced.

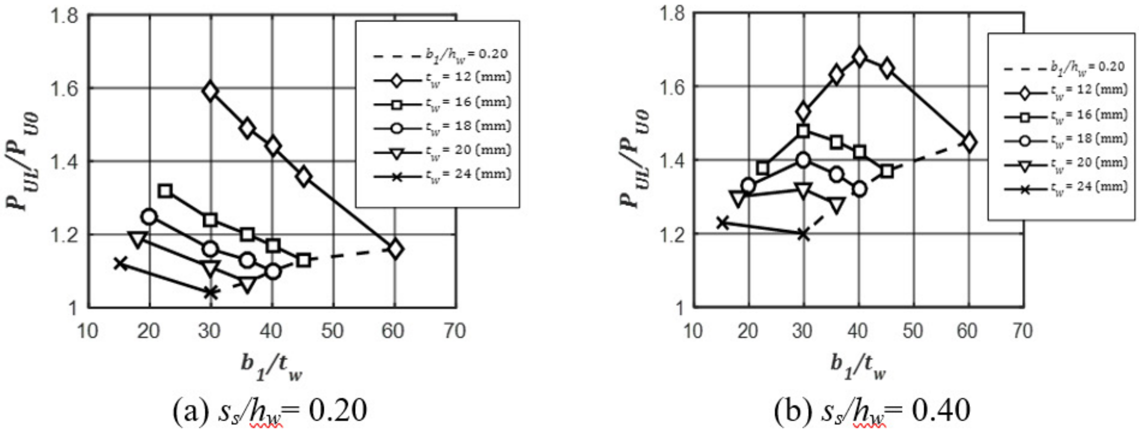


Figure 3. Comparison of ultimate strengths between longitudinally stiffened PUL and unstiffened PU0 girders in terms of b1/tw (a/hw = 1.00).

United States of America

Effects of Local Buckling on the Behavior of High Strength Steel Beams

Abdullah M. Alghossoon, Purdue University, USA
Amit H. Varma, Purdue University, USA

Summary:
The numerical model of the high-strength (600 Mpa to 900 Mpa) steel beam shown in Figure1 is an example of a series of models within a study matrix constructed using ABAQUS software to investigate the local buckling effect on the high-strength steel beam flexural behavior. These models were developed using the C3D20R element that assigned a stress-strain (SS) relationship extended beyond the necking point and simulating material deterioration. The main factors affecting the monotonic and cyclic behavior of steel beams were also included in detail, such as the residual stresses, initial imperfection, and flexible bracing points. The calibration of the damage initiation and damage evolution of the high-strength steel material uses the global stress-strain relationship from an experimental coupon test conducted in prior research alongside the correspon-ding numerical model of the coupon test.

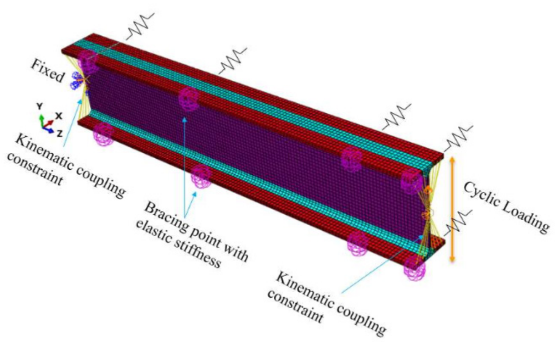


Fig. 1. 3D finite element model in ABAQUS

In addition to the calibrated 3D model, a fiber-based model has been developed to conduct a comprehensive parametric study, which would take forever using 3D finite element analysis and too much work to include their complex behavior.

OpenSees software was used to construct an idealization of the 3D models in ABAQUS. A series of effective stress-strain relations-hips were generated from the critical T-sha-pe section of the 3D finite element steel beam model, as shown in Figures 2 and 3.

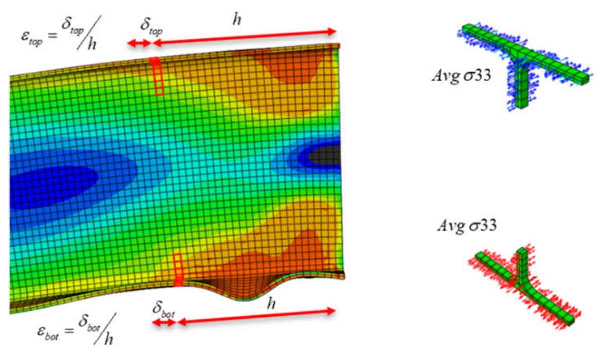


***Fig. 2.** Critical T-section for the effective stress-strain calculations*

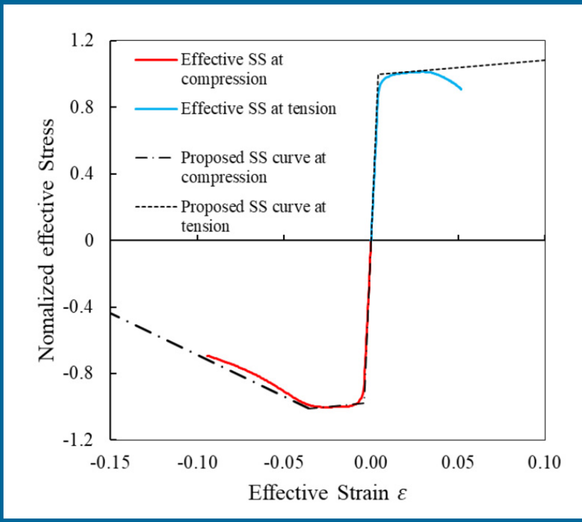


Fig. 3. Idealization of the effective stress-strain (SS) curve from the 3D model

A regression analysis was conducted on the generated effective stress-strain curves to develop a phenomenological effective stress-strain relationship which can be used in the fiber-based model and account for the complex deterioration of the steel beam (local buckling). The 3D finite element model in ABAQUS software and the suggested fiber-based model were verified using several experimental tests on high-strength steel beams and demonstrated a reasonable accuracy in simulating the high-strength steel beam's global behavior.

USA

Japan

Frame-Spine System with Force-Limiting Connections for Low-Damage Seismic

Larry Fahnestock, University of Illinois at Urbana-Champaign, U.S.A.
Richard Sause, Lehigh University, U.S.A.
James Ricles, Lehigh University, U.S.A.
Barbara Simpson, Oregon State University, U.S.A.
Masahiro Kurata, Kyoto University, Japan
Taichiro Okazaki, Hokkaido University, Japan
Yohsuke Kawamata, National Research Institute for Earth Science and Disaster Resilience, Japan
Zhuoqi Tao, University of Illinois at Urbana-Champaign, U.S.A.
Jessica Duke, Lehigh University, U.S.A.
David Rivera, Oregon State University, U.S.A.
Bryam Astudillo, Oregon State University, U.S.A.
Yi Qie, Hokkaido University, Japan

Summary:

Although conventional ductile lateral systems provide reliable seismic stability, when subjected to a major earthquake, they experience significant inelastic structural response and may be susceptible to large drifts and accelerations that cause costly damage. A new structural system is being developed as a solution that protects buildings, their contents, and occupants during major earthquakes. This economical earthquake-resilient system is intended to be used in essential facilities, such as hospitals, where damage to the buildings and contents and occupant injuries must be prevented and where continuity of operation is imperative. The new system employs practical structural components to economically control building response and prevent damaging levels of displacement and acceleration. The primary components of the system are: (1) flexible steel moment frames, (2) stiff steel elastic spines and (3) force-limiting connections (FLC) that connect the frames to the spines. The moment frames serve as the economical primary element of the system to resist a significant proportion of the lateral load, dissipate energy through controlled nonlinear response and provide persistent positive lateral stiffness. The spines distribute response evenly over the height of the building and prevent story mechanisms, and the FLCs reduce higher-mode effects and provide supplemental energy dissipation.

The frame-spine-FLC system is currently being investigated collaboratively by an international team, and full-scale shake-table testing was conducted at the E-Defense facility in Miki, Japan in December 2020. The test building (Figure 1), which represented a

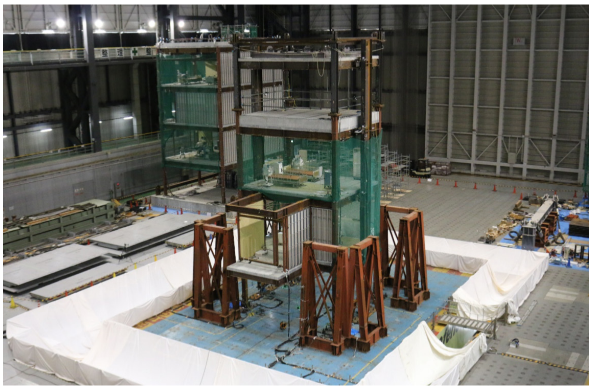


Fig. 1. Test Building on the Shake Table at E-Defense

hospital facility and included realistic nonstructural components and medical equipment, was subjected to six earthquake acceleration records, culminating with a 100% JMA Kobe record. A video of this final test is available at https://mediaspace.illinois.edu/media/t/1_0xqecj26. This research is supported by the National Science Foundation under awards CMMI 1928906, 1926365 and 1926326, with additional sponsorship and collaboration including: the American Institute of Steel Construction, the Disaster Prevention Research Institute at Kyoto University, Nippon Steel Engineering and the Tokyo Metropolitan Resilience Project.

United States of America

Hurricane Risk Analysis of Electrical Transmission Networks

Xinlong Du, Department of Civil and Env. Engineering, Northeastern University, Boston, MA, USA
Jerome F. Hajjar, Department of Civil and Env. Engineering, Northeastern University, Boston,

Sponsors:
National Science Foundation, Northeastern University

Summary:

Hurricanes are one of the main causes for blackouts and related infrastructure damage in the United States. Electrical transmission towers, which are key parts of the electrical transmission networks, are vulnerable to high wind speeds during storms (see Figure 1). The collapse of one transmission tower may lead to cascading failures of adjacent towers and a loss of functionality of the transmission line. This research first develops 3D geometrically and materially nonlinear beam-column element formulations that are suitable for analyzing members with asymmetric sections such as the steel angles used in transmission towers.The new displacement-based and mixed elements are implemented in the open source software OpenSees and validated against a set of experimental and numerical examples. This research then introduces a framework to develop collapse fragility curves that describe collapse probabilities of transmission towers after a hurricane. The intensity

Fig. 1. *Failure of transmission line lattice tower on the Neches River near Bridge City, Texas*

measure is the storm-maximum gust speed, and incremental dynamic analysis (IDA) is used to capture the collapse phenomenon. The collapse fragility curve is the cumulative distribution function (CDF) of the intensity-measure at the onset of collapse, which is assumed to follow a lognormal distribution. The record-to-record randomness of different hurricanes is considered by running IDA analyses for a suite of wind speed and direction time histories on transmission towers. The developed collapse fragility curves are

then incorporated into a regional transmission network failure analysis, using Massachusetts as a testbed. The HAZUS software is used to conduct hurricane wind field simulation, which is combined with the collapse fragility curves to determine the collapse probabilities of geographically distributed transmission towers. The failure probability of each transmission line (Figure 2) is then obtained by assuming a series system of multiple towers. These results thus produce a strategy for predicting the damage to the electrical power grid during hurricanes in urban coastal regions.

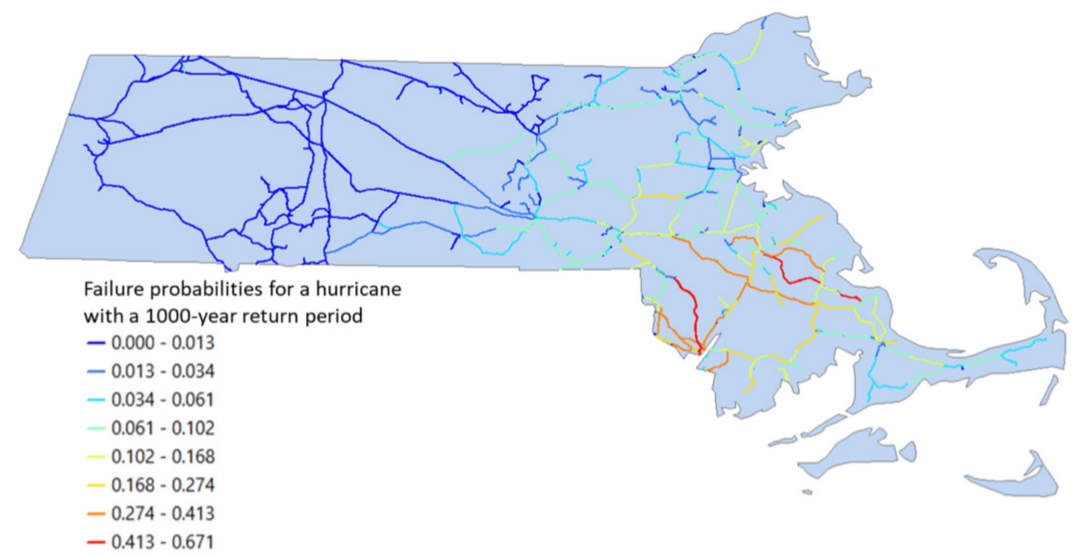


Fig. 2. *Predicted failure probabilities of transmission lines*

United States of America

Seismic Stability of Steel Buildings with Composite Steel Deck Diaphragms

Nicolas E. Briggs, Dept. of Civil and Env. Engineering, Northeastern Univ., Boston, MA, USA
Benjamin W. Schafer, Dept. of Civil and Systems Engrg., Johns Hopkins Univ., Baltimore, MD, USA
Matthew R. Eatherton, Department of Civil and Env. Engineering, Virginia Polytechnic Institute and State Univ., Blacksburg, VA, USA
W. Samuel Easterling, College of Engineering, Iowa State Univ., Ames, IA, USA

Sponsors:
National Science Foundation, American Institute of Steel Construction, American Iron and Steel Institute, Steel Deck Institute, Steel Joist Institute, Metal Building Manufacturers Association, and Cold-Formed Steel Research Consortium, Johns Hopkins University, Virginia Polytechnic Institute and State University, Northeastern University

Summary:
Experimental and computational work being conducted as part of a multi-institution project, the Steel Deck Innovation Initiative (SDII), is providing a comprehensive understanding of the seismic stability of steel buildings with composite steel deck diaphragms. Composite steel deck diaphragms are ubiquitous due to the speed of construction and efficient use of materials. However, there is limited data studying the strength and stability performance of buildings using this structural system during seismic events. In this research, a series of sixteen push-out tests, presented in Table 1, were conducted to study the strength and behavior of the composite concrete to steel connection through the use of headed steel stud connectors.

Test Number	Steel Section	Steel Deck	Concrete Weight	Edge or Center Specimen	Studs	Stud Location	Loading Protocol
P1	W10x39	Perpendicular	Lightweight	Center	One @ 12" O.C.	All strong	Monotonic
P2	W10x39	Perpendicular	Lightweight	Center	One @ 12" O.C.	All weak	Monotonic
P3	W10x39	Perpendicular	Lightweight	Center	One @ 12" O.C.	All weak	Cyclic
P4	W10x39	Perpendicular	Lightweight	Center	One @ 12" O.C.	50-50	Monotonic
P5	W10x39	Perpendicular	Lightweight	Center	One @ 12" O.C.	50-50	Cyclic
P6	W10x39	Perpendicular	Lightweight	Center	Two @ 12" O.C.	All strong	Monotonic
P7	W10x39	Perpendicular	Lightweight	Center	Two @ 12" O.C.	All weak	Monotonic
P8	W10x39	Perpendicular	Lightweight	Center	Two @ 12" O.C.	All weak	Cyclic
P9	W10x39	Perpendicular	Lightweight	Center	Two @ 12" O.C.	50-50	Monotonic
P10	W10x39	Perpendicular	Lightweight	Center	Two @ 12" O.C.	50-50	Cyclic
P11	W10x39	Parallel	Lightweight	Center	One @ 12" O.C.	Alternate sides	Monotonic
P12	W10x39	Parallel	Lightweight	Center	One @ 12" O.C.	Alternate sides	Cyclic
P13	W10x39	Parallel	Normal	Center	One @ 12" O.C.	Alternate sides	Monotonic
P14	W10x39	Parallel	Normal	Center	One @ 12" O.C.	Alternate sides	Cyclic
P15	W10x39	Parallel	Lightweight	Edge	One @ 12" O.C.	Alternate sides	Monotonic
P16	W10x39	Parallel	Lightweight	Edge	One @ 12" O.C.	Alternate sides	Cyclic

Table. 1. *Push-out test matrix*

Key parameters included deck oriented perpendicular or parallel to the steel girder, stud spacing and position within the rib, concrete material density, and concrete deck reinforcement. The specimens were tested in a new and innovative rig, presented in Figure 1, that allowed for the use of larger specimens and for cyclic testing of seven of the specimens.

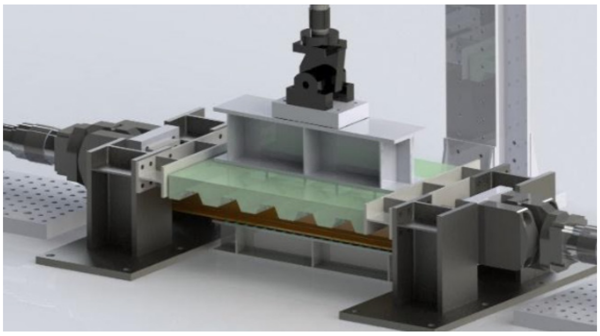


Fig. 1. *Push-out test setup*

These tests demonstrated that load transfer along the composite interface was shared equally by the shear studs at least until the ultimate strength was achieved. In addition, these tests demonstrated that the 0.75 reduction factor for shear studs under cyclic loading is reasonable and conservative. Figure 2 presents three force versus slip plots which demonstrate the relative strength of a cyclic specimen to it's two monotonic counter parts. The cyclic specimen is identical to one of the specimens when loaded in one direction and identical to the other specimen when loaded in the opposite direction and thus the results are presented accordingly. Simultaneously a composite modeling framework capable of simulating cyclic fracture through the use of high fidelity, user-defined, steel and concrete material models is under development to predict failure and collapse in composite structures.

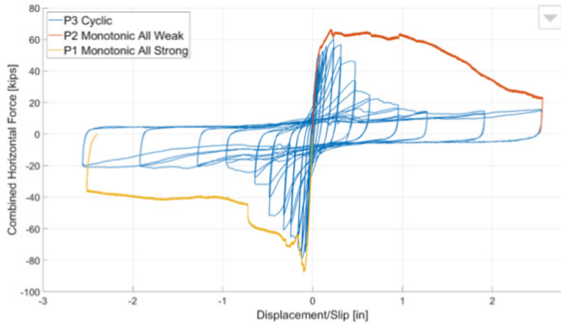


Fig. 2. *Representative cyclic and monotonic experimental pushout test results*

A full-scale composite steel deck diaphragm test is also being constructed in the STReSS Laboratory at Northeastern University. This test will be the first of its kind; a rendering is presented in Figure 1. The specimen has been designed to represent typical construction practice in high seismic zones of the United States. Through this work, the behavior exhibited will inform modeling frameworks applied to full building behavior to study seismic stability as part of this project.

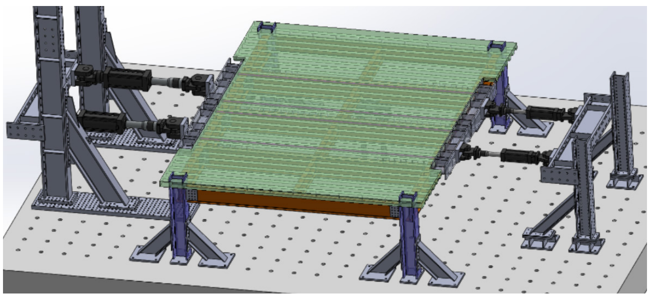


Fig. 3. *Diaphragm test specimen and rig*

United Kingdom

Shock sensitivity in the localised buckling of a beam on a nonlinear foundation:
The case of a trenched subsea pipeline

G.H.M. van der Heijden, Z.K. Wang, Department of Civil, Environmental and Geomatic Engineering,
University College London, London, UK

Summary:
We study jump instability phenomena due to external disturbances to an axially loaded beam resting on a nonlinear foundation that provides both lateral and axial resistance. The lateral resistance is of destiffening-restiffening type known to lead to complex localisation phenomena governed by a Maxwell critical load that marks a phase transition to a periodic buckling pattern. For the benefit of having a concrete and realistic example we consider the case of a partially embedded trenched subsea pipeline under thermal loading but our results hold qualitatively for a wide class of problems with non-monotonic lateral resistance.

Lateral foundation forces considered in the literature are often somewhat artificial, especially if they are treated as purely elastic. The pipeline problem offers a natural case for a realistic non-monotonic lateral resistance. Embedment of the pipeline, due to its own weight, produces a softening behaviour after breakout, while the trench walls give rise to restiffening behaviour at larger deflections. On the downside, due to the frictional nature of the resistance the proposed foundation characteristic is only valid in situations in which the displacements grow monotonically. We show that, nevertheless, valuable results can be obtained, by focusing on stability of the trivial state under finite perturbations (shocks). So, unlike the usual practice of reading load-displacement bifurcation diagrams, with or without imperfections included, as quasi-static processes that might encounter *linear instability* under *infinitesimal* perturbations, we are here interested in *nonlinear instability* phenomena with the pipeline being forced, by external *finite* disturbances, out of a linearly stable state and into another stable state. In particular, we are interested in the energy barrier, represented by an intermediate unstable 'mountain pass' state, to be overcome for such a transition from the straight pre-buckled state to a localised state, and its dependence on the axial resistance.

In the absence of axial resistance the pipeline is effectively under a dead compressive load and experiences shock-sensitivity for loads immediately past the Maxwell load, i.e., extreme sensitivity to perturbations as

may for instance be caused by irregular fluid flow inside the pipe or landslides. Nonzero axial resistance leads to a coupling of axial and lateral deformation under thermal loading. We define a Maxwell temperature beyond loading. We define a 'Maxwell temperature' beyond which the straight pipeline may snap into a localised buckling mode. Under increasing axial resistance this Maxwell temperature is pushed to higher (safer) values. Shock sensitivity gradually diminishes and becomes less chaotic: jumps become more predictable. We compute minimum energy barriers for escape from pre-buckled to post-buckled states, which, depending on the magnitude of the axial resistance, may be induced by either symmetric, or anti-symmetric or non-symmetric perturbations.

[Journal of the Mechanics and Physics of Solids **143**, 104044 (2020)]

Croatia

Stability Analysis of Shear-Deformable Composite Beam-Type Structures

Goran Turkalj, Faculty of Engineering, UNIVERSITY OF RIJEKA, Rijeka, Croatia
Damjan Banić, Faculty of Engineering, UNIVERSITY OF RIJEKA, Rijeka, Croatia
Domagoj Lanc, Faculty of Engineering, UNIVERSITY OF RIJEKA, Rijeka, Croatia

Sponsors:
This research is funded by the Croatian Science Foundation (project No. 6876) and the University of Rijeka (uniri-tehnic-18-107 & uniri-tehnic-18-139).

Summary:
In this research, a shear-deformable beam model for stability analysis of beam-type structures made of composite materials is being developed. The incremental equilibrium equations for a straight beam element are derived within the framework of updated Lagrangian formulation and the displacement field of cross-sections, which accounts for the restrained warping and the large rotations effects. Timoshenko's theory for non-uniform bending and modified Vlasov's theory for non-uniform torsion are applied to include the shear deformation effects. An improved shear-deformable beam formulation is introduced by taking into account the bending-bending and bending-warping torsion coupling shear deformations effects occurring for the asymme-

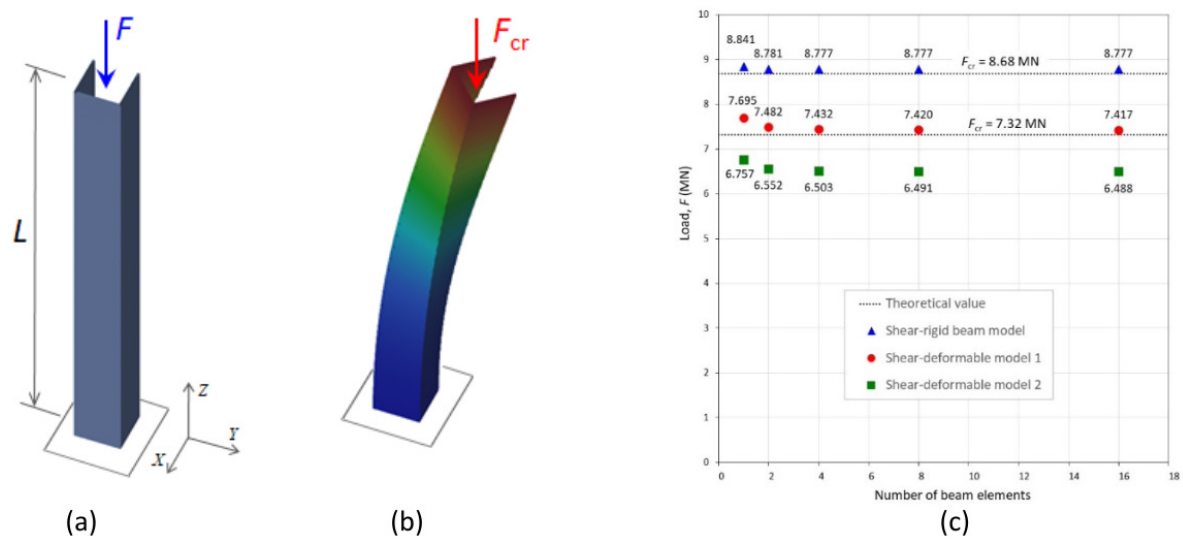


Fig. 1. *Cantilever mono-symmetric column: (a) geometry; (b) buckling mode; (c) buckling loads*

tric cross-section where the principal bending and principal shear axes do not coincide. To account for the semi-rigid connection behavior, the hybrid finite element is introduced. The obtained results indicate that the proposed model can be classified as shear locking-free one. Figure 1a shows a cantilever column under an axial force *F*. The column is made of the laminated mono-sym nel section with: 60 × 60 × 3 cm (*b* × *h* × *t*), with he length *L* = 300 cm. The material properties of CFRP with unidirectional reinforcements are: E_1 = 144 GPa, E_2 = 9.65 GPa and G_{12} = 4.14 GPa. The web and the flanges are considered to be four layered laminates with stacking sequences [0,90,90,0].

The flexural-torsional buckling mode, shown in Figure 1b, is considered by using five different meshes with one, two, four, eight and sixteen beam elements. The results obtained by the eigenvalue approach are shown in Figure 1c and compared with the theoretical values (Cortínez & Piovan, *J. Sound. Vibr.*, 2002, 258: 701-723), and those obtained by using the *shear-rigid* beam model. Figure 2 shows a FRP portal frame with fixed bases and semi-rigid beam-to-column connections subjected to two equal vertical forces. The length *L* = 274 cm and the height *H* = 183 cm. All members are made of the wide-flange H-profile 20.32 cm × 20.32 cm × 0.95 cm (*b* × *h* × *t*). The material properties of FRP with unidirectional reinforcements are: E_1 = E_2 = $11.83 \cdot 10^5$ N/cm^2 and G_{12} = $4.17 \cdot 10^5$ N/cm^2. The lateral instability mode is analyzed for six tyφes of beam-to-column connections such as type: i, ii, iii, iv, rigid and hinged. Mosallam-'s piecewise linear expressions of *M*( ) reported by Mosallam (*Design Guide for FRP*

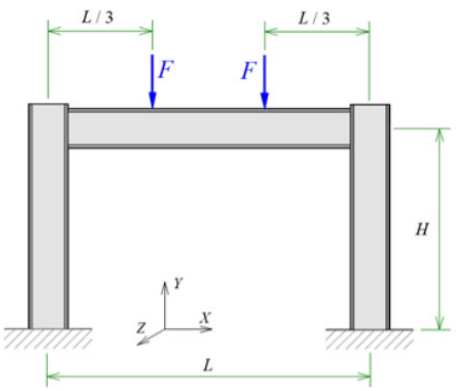
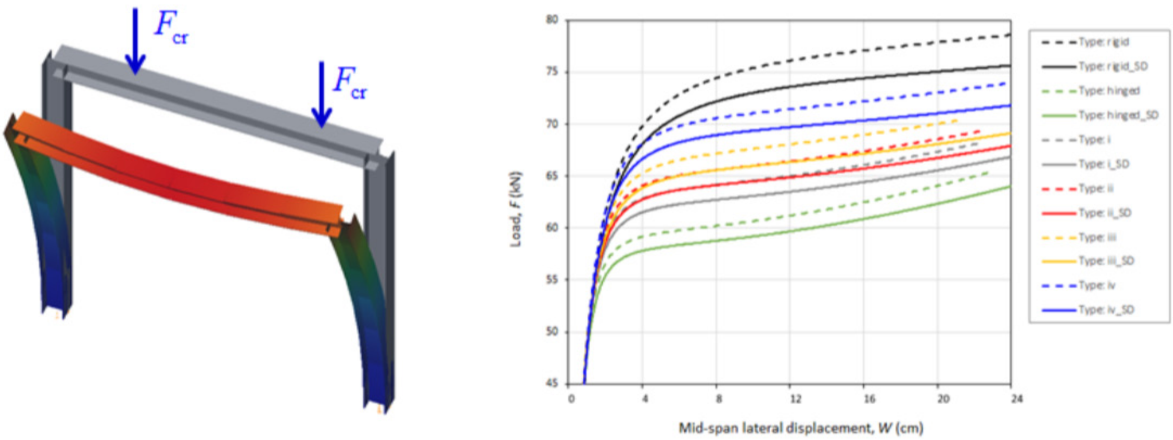


Fig. 2. *Local buckling of steel bridge pier, Kobe Earthquake, January 1995.*

Connection type	$M_x = f(\varphi_{x\,cd})$ (kNcm)	
I	$M_x = 79\,007\,\varphi_{x\,cd}$	$0 < M_x < 136$
	$M_x = 89 + 27\,289\,\varphi_{x\,cd}$	$136 \le M_x < 362$
	$M_x = 239 + 12\,241\varphi_{x\,cd}$	$362 \le M_x < 587$
	$M_x = 478 + 3\,766\,\varphi_{x\,cd}$	$587 \le M_x < 621$
Ii	$M_x = 79\,007\,\varphi_{x\,cd}$	$0 < M_x < 136$
	$M_x = 89 + 27\,289\,\varphi_{x\,cd}$	$136 \le M_x < 362$
	$M_x = 239 + 12\,241\varphi_{x\,cd}$	$362 \le M_x < 813$
	$M_x = 560 + 5135\varphi_{x\,cd}$	$813 \le M_x < 864$
Iii	$M_x = 102\,709\,\varphi_{x\,cd}$	$0 < M_x < 226$
	$M_x = 181 + 22\,596\,\varphi_{x\,cd}$	$226 \le M_x < 904$
	$M_x = 679 + 6\,974\,\varphi_{x\,cd}$	$904 \le M_x < 1295$
Iv	$M_x = 294\,219\,\varphi_{x\,cd}$	$0 < M_x < 294$
	$M_x = 213 + 81\,281\varphi_{x\,cd}$	$294 \le M_x < 1840$

Tabla. 1. *Local buckling of steel bridge pier, Kobe Earthquake, January 1995.*

Composite Connections. ASCE Manuals and Reports on Engineering Practice No.102, ASCE, 2011) are adopted to represent the nonlinear connection behavior with the instantaneous tangent connection stiffness the values of which are listed in Table 1. The frame is idealized by four elements per column and six elements for the beam. A small perturbation force of 0.01F acting in the positive Z-direction is applied at the mid-span of beam to perform the nonlinear stability analysis. The results obtained for both the shear-rigid and shear-deformable (SD) cases are shown and compared in Figure 3b.



(a) (b)

Fig. 3. *LFRP portal frame: (a) lateral buckling mode; (b) load-lateral deflection curves*

Spain

Structural Analysis of Stainless Steel Frames

Esther Real, Rolando Chacón, Itsaso Arrayago, Enrique Mirambell

Department of Civil and Environmental Engineering.
Universitat Politècnica de Catalunya, UPC Barcelona-Tech

Sponsors:
Mineco, Spain under the research agreement BIA2016-75678-R, AEI/FEDER, UE

Summary:
The use of stainless steel in structures has increased in recent years due to its unique combination of mechanical properties, durability and aesthetics. This research project encompasses experimental and numerical analysis of stainless steel frames for the sake of contributing to the understanding, design and management of such types of structures. Four full- scale laboratory tests on stainless steel frames as well as tests on elements and coupons have been performed at the Structural Technology Laboratory in Barcelona. Furthermore, numerical analyses of stainless steel frames subjected to static, seismic and fire loads have also been developed.

More over, a set of BIM-enabled layers of instrumentation which IoT, Lidar technologies and Virtual and Augmented Realities tests together with other sensor- and image-based measurements. Contributions to the design of structurally efficient sustainable buildings following EN1993-1-4 as well as ANSI/AISC 360-16 have already been proposed.

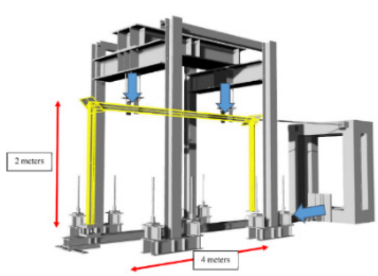


Fig. 1. *Laboratory set-up*

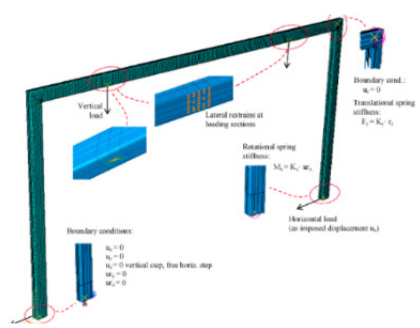


Fig. 2. *Laboratory set-up*

Stainless steel frames with full immersion in circular economies and with particular abilities of instrumentation and data management provide designers and users more controllable, sustainable and safer structures in the age of information and digital economies.

Fig. 3. Detail of beam-to-column

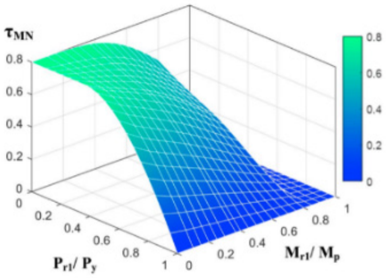


Fig. 4. Stiffness reduction with GNA

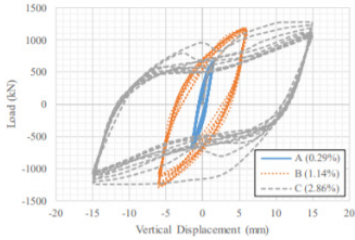


Fig. 5. Seismic loads

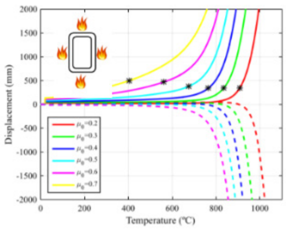


Fig. 6. Fire loads

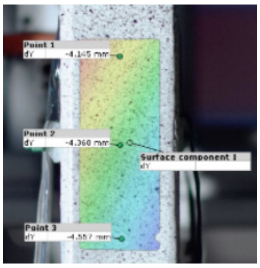


Fig. 7. Digital Image Correlation

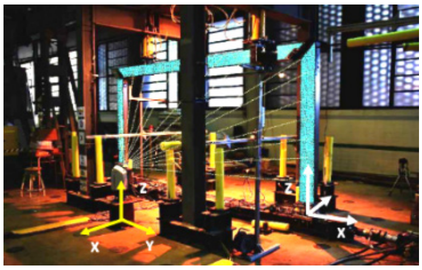


Fig. 8. LIDAR and imperfections

Fig. 9. Augmented Reality

United States of America

Structural Stability and Ductility Evaluation of Thin-Walled Steel Tubular Columns Modelling Bridge Piers

Iraj H.P. Mamaghani, Department of Civil Engineering, University of North Dakota, Grand Forks, ND
Iraj.mamaghani@und.edu

Summary:

Thin-walled steel tubular columns with circular, rectangular, or square cross sections are widely used as cantilever piers in bridges due to their excellent structural and constructional advantages in urban earthquake-prone regions. These columns are commonly constructed as a cantilever bridge pier due to high strength-to-weight ratio, aesthetic exposed appearance, and their potential for concrete infilling. The most important parameters considered in the practical design and ductility evaluation of thin-walled steel hollow rectangular sections are the width-to-thickness ratio of the flange plate R_f for rectangular sections, the radius-to-thickness ratio of the circular section R_t, and the slenderness ratio of the column λ. While R_f and R_t influence local buckling of the section, λ controls the global stability [1-8]. Local buckling (Figure 1), flexural buckling, or the interaction between local and flexural buckling is usually the main reason for the reduction of the strength and ductility in these members, which eventually leads to their failure [9].

Fig. 1. *Local buckling of steel bridge pier, Kobe Earthquake, January 1995.*

This research investigates the behavior of thin-walled steel tubular columns with conventional columns (CCs) of uniform circular and square sections and newly proposed graded-thickness columns (GCs) of circular and square sections under combined constant axial and cyclic lateral loading. Both unidirectional and bi-directional lateral loading are considered. The analysis is carried out using a finite-element model (FEM), adopted in commercial computer program ABAQUS, that considers both material and geometric nonlinearities. First, the accuracy of the employed FEM is substantiated using the experimental data available in the literature. Then, the GC column with a size and volume of material equivalent to the CC counterpart column is introduced. The proposed GC columns is proved to have significant improvements in strength, ductility, and post-buckling behavior compared with its counterpart CC columns. As part of the investigation, an intensive parametric study is conducted to investigate the effect of main design parameters including: width-to-thickness ratio parameter (R_f), radius-to-thickness ratio parameter (R_t), column slenderness ratio parameter (λ), magnitude of axial load (P/P_y), loading path and number of loading cycles (N), on the overall hysteretic behavior of CC and GC columns under both unidirectional and bidirectional cyclic lateral loading in the presence of constant axial force. Subsequently, design formulae have been derived to predict the ultimate strength and ductility capacities of the CC and GC columns considering interaction of local and overall buckling. To enhance the seismic behavior of the columns, the effects of longitudinal stiffeners, diaphragms, and double skin with partially infill concrete (composite) cross sections are being investigated. Moreover, the behavior of CC and GC columns under impact force caused by vehicle accident is under investigation [10].

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Iran

USA

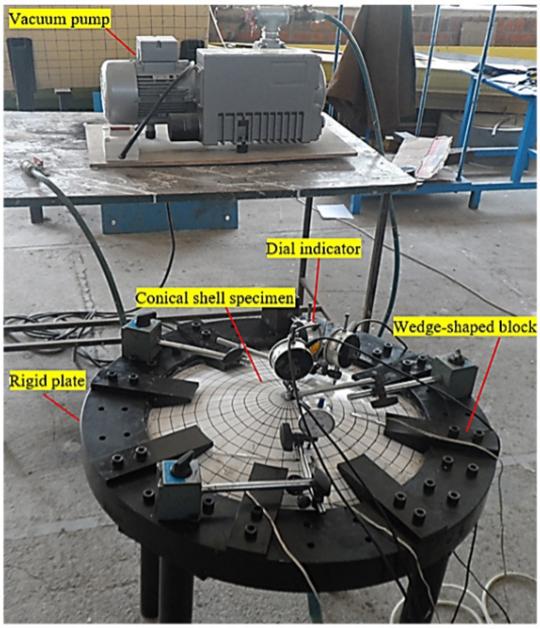
Structural Stability of Shell Structures Subjected to Uniform External Pressure

Pouya Taraghi, CE Dept., Urmia University, Iran
Tadeh Zirakian, CECM Dept., California State University, Northridge, USA

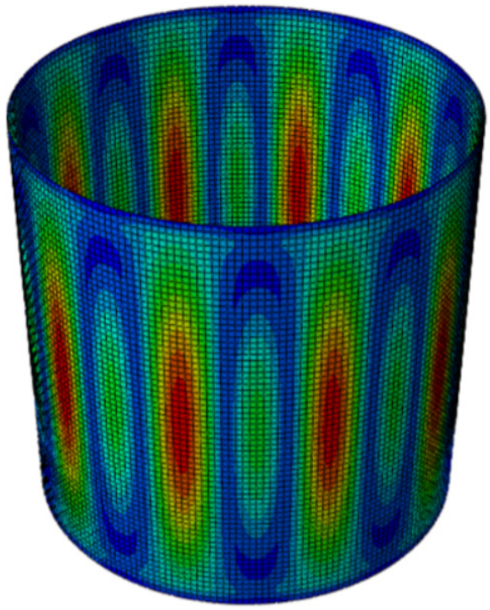
Summary:
Shell structures are known as vital practical structures in different engineering fields and industries. These structures possess a great structural performance due to their particular geometry. Thin-walled shells can be served as pressurized tanks and silos (see Figure 1) which are susceptible to lose their stability and structural strength due to the buckling phenomenon resulting from applied external
pressure during the discharge of internal contents.

Fig. 1. Pressurized storage tanks

Therefore, there is an essential need for engineers and designers to consider the instability issues in shell structures under external pressure and provide some preventive measures to protect such structures against buckling collapse. In this study, systematic experimental, numerical, and theoretical investigations have been made to evaluate the buckling stability behavior of steel conical, cylin drical, and tank shells under uniform external pressure in order to provide practical recommendations and effective strategies to improve the stability performance of such structures. Figure 2 shows a typical test setup, instrumentation of a specimen, and finite element
simulation of a cylindrical shell model as representatives of the different employed investigationmethods. In the experimental program, specimens were constructed in accordance with the available standards and code recommendations and were tested for real observations and behavior assessments. Numerical simulation was employed using ABAQUS commercial finite element package to model and
analyze the stability performance of shells in further detail. Linear eigenvalue buckling analyses as well as detailed nonlinear stability analyses using the Static, Riks method were performed to determine the critical buckling region(s), buckling capacity, dominant (circumferential and/or meridional) stresses, and buckling modes of shells. Based on the results and findings of this study, a practical strengthening strategy was proposed. The results showed that the



(a) Test setup and instrumentation of a typical specimen



(b) Typical finite element model and buckling of a cylindrical shell

Fig.2. *Views of the test setup and numerical model in this research section*

critical regions of the conical and cylindrical shells under external pressure are located at the bottom (near the edge) and middle areas of such structures, respectively. Circumferential stress was found to be the dominant stress in the critical region which results in the development of the circumferential buckling mode. Also, it was shown that circumferential CFRP-strengthening of the critical region is an effective strategy in preventing or delaying the occurrence of buckling instability. Fiber angle, CFRP stripe thickness, and slenderness ratio of shells were found to be the most effective parameters in reinforcement of such thin-walled structures. This comprehensive research endeavor is still in progress and the stability performance of tanks is currently under investigation.

India

Towards use of Direct Strength Method for Cold-formed Steel Built-up Structural Members

Sivaganesh Selvaraj, Indian Institute of Technology Hyderabad, India
Mahendrakumar Madhavan*, Indian Institute of Technology Hyderabad, India

Summary:
The structural behavior of cold-formed steel (CFS) built-up beams that are gaining interest in the construction industry is investigated in this study. As per the current American Iron and Steel Institute (AISI) CFS structural members specifications (direct strength method), there are no explicit guidelines or procedures for the types of built-up sections being evaluated in this research. The present study, therefore, examines the suitability of using the current AISI design specifications for the design of CFS built-up beams and columns with various cross-sections. The CFS built-up beams and columns investigated in this study are assembled using two identical sections, and interconnected face-to-face orback-to-back by discrete spot welding or fastener. The test parameters studied include the length of the member, spacing between the interconnection and cross-section dimensions. Based on the failure modes observed in experiments and numerical studies, new limitations for the interconnection spacing of the built-up beams and columns is suggested. The design strength prediction for the tested built-up beams is calculated using current AISI design procedure for the purpose of verification and to extend the current design procedure for the built-up members. The comparison between test results and design

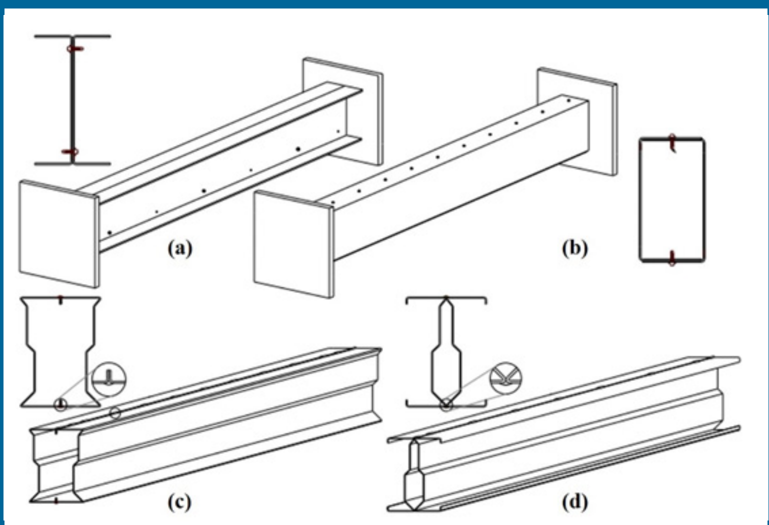


Fig. 1. Cold-formed Steel Built-up Structural Members being investigated: (A) Back-to-back connected CFS columns; (B) Face-to-face connected CFS columns; (C) Face-to-face connected CFS beams; (D) Back-to-back connected CFS beams

predictions indicates that the design results are unconservative and unreliable due to the incorrect failure mode prediction.

Hence, modified design procedures and design equations were suggested for the CFS built-up members after carrying out a comprehensive investigation on failure modes. It was also shown that the newly suggested procedures and equations are reliable for the design of CFS built-up structural members. More information about the experiments and design results can be found at Selvaraj and Madhavan (2019, 2021a and 2021b).

Reference:

Selvaraj, S. and Madhavan, M., (2019). Structural design of cold-formed steel face-to-face connected built-up beams using direct strength method. Journal of Constructional Steel Research, 160, pp.613-628.

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USA

Serbia

Web crippling strength of steel plate girders

Sasa Kovacevic, Washington State University, Pullman, USA
Nenad Markovic, Belgrade, Serbia

Summary:
Extensive experimental testing was recently carried out to study the influence of bearing length on the web crippling strength and behavior of I-shaped steel plate girders. The most dominant load case is present during the incremental launching of multi-span steel and composite bridges over temporary or permanent supports. This research included 28 tests in total and considered longitudinally unstiffened and stiffened steel plate girders reinforced by a single flat longitudinal stiffener.

Fig. 1. *Experimental setup*

The steel plate girders were assembled at the University of Belgrade (Serbia), and experimental testing was performed at the University of Montenegro. The experimental setup is given in Fig. 1. Various bearing lengths in combination with two different web panel aspect ratios were varied in this study, while all other geometric parameters were kept unaltered. Initial geometric imperfections of each steel plate girder were recorded before testing started. During the testing process, the following data were measured: (i) web panel out-of-plane deflection (Fig. 2a), (ii) deflection of the loaded and unloaded flange, and (iii) strains in the web panel and loaded flange (Fig. 2b).

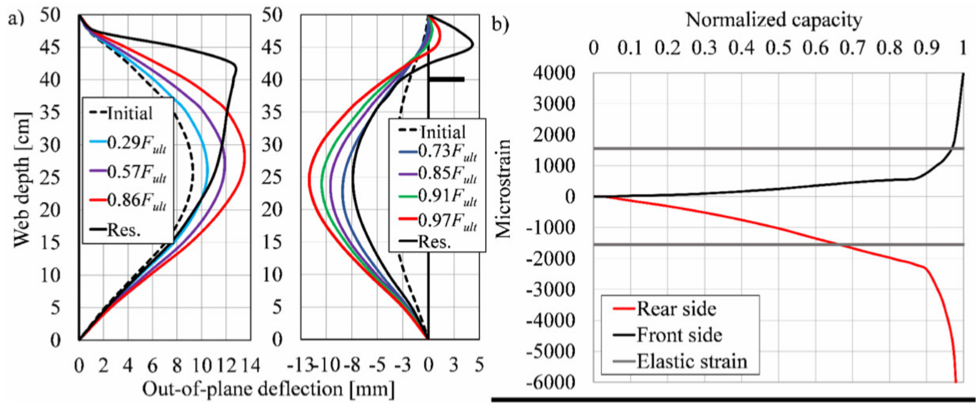

Fig. 3. *(a) Vertical web profiles for different ultimate load (F ult) levels and residual deformation (Res.) for unstiffened and stiffened steel plate girders. (b) Vertical strain in the web panel on both sides for longitudinally stiffened steel plate girders. section following Hurricane Rita (photo credit:*

Once the web crippling strength was reached (which manifested through rapidly increasing web panel and loaded flange deformation in the vicinity of the point of loading without an increase in load, Fig. 3), the girders were unloaded, and residual deformations were measured.

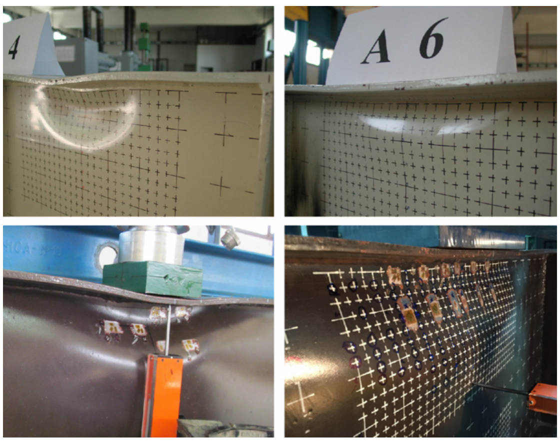

Fig. 3. *Failure modes*

Several key findings were identified from this research:

1. The web crippling strength of longitudinally unstiffened and stiffened steel plate girders increased with increasing bearing length.

2. An appreciable increase in web crippling strength was achieved using longitudinal stiffening.

3. For very small bearing lengths, longitudinal stiffening had a small influence on the web crippling strength.

4. The longitudinal stiffener changed the buckling pattern (failure mode) and either restricted the web deformation between the loaded flange and stiffener (for smaller bearing lengths) or reduced the web deformation at the stiffener position (for longer bearing lengths).

5. Increasing the web panel aspect ratio decreased the web crippling strength of longitudinally unstiffened and stiffened steel plate girders.

The current project is still in progress and succeeding work will include numerical modeling.

Address:
Structural Stability Research Council
c/o AISC 130 E. Randolph Street,
Suite 2000 Chicago, IL 60601-6204

Phone:
312-670-7015

Email:
ssrc@aisc.org