STRUCTURAL STABILITY
RESEARCH COUNCIL

NEWSLETTER

Dear SSRC members and friends,

I hope you enjoy the 2022 edition of the SSRC Newsletter!!

I believe you will all agree that this year's edition of the Newsletter clearly shows the Council's dedication to being *the forum* where stability aspects of metal and composite metal-and-concrete structures and their components are presented, pertinent research problems proposed, cooperative research efforts initiated and supported, and impactful results widely distributed. I do not feel that emphasizing SSRC as *the forum* is too braggadocious… where else can you find information in a single newsletter highlighting collaborative research investigating effects of fire and earthquakes on frame and member stability, global and local stability performance of curved elements and bridges, buckling performance of cold-formed and other thin-walled sections, and buckling of slender, reinforced concrete columns? With work involving collaborative researchers from Asia, the Middle East, Europe, and the Americas? *Nowhere. Else.*

I would be remiss if I didn't thank those who contributed articles to year's edition – the research you are completing is truly amazing and impactful – and especially SSRC members Andrés Sánchez and Hannah Blum who worked tirelessly to gather this information and compile the newsletter. Without you it would not happen. Special thanks also go to Martin Downs who does an amazing job supporting all Council efforts on behalf of the American Institute of Steel Construction and our co-Chair, Craig Quadrato, who keeps me in line.

I would like to call your attention to our burgeoning collaboration with the Architectural Institute of Japan. Thanks (once again) to Andrés Sánchez for working with fellow Georgia Tech alum Masahiro Kurata from Kyoto University to develop what I know will be a longstanding collaboration (and… um… go Jackets!).

Please visit our recently updated website to access information on other SSRC activities and additional resources and expertise the Council can provide. We have many great, ongoing activities and are always interested in engaging with everyone in the metal and composite metal-and-concrete stability research and practice. Please make your colleagues aware of this newsletter and SSRC!

Finally – mark your calendars for the 2023 Annual Stability Conference, being held in conjunction with AISC's NASCC: The Steel Conference from April 11 to April 14 in Charlotte, North Carolina. Over 50 papers will be presented at ASC alone. Don't miss it!

Enjoy!

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CONTENT

Japan

AIJ’s Upcoming Publication on Stability Problems of Steel Structures

Overview and Ch. 1 Strength and Deformation Capacity of Buckling Braces

Reported by Dr. Yoshihiro Kimura (Tohoku Univ.), Dr. Ryota Matsui (Hokkaido Univ.) and Dr. Masahiro Kurata (Kyoto Univ.)

The subcommittee for the stability of steel structures (Chair: Dr. Yoshihiro Kimura, Tohoku Univ., Secretary: Dr. Iori Kanao, Kyoto Tech.), Architectural Institute of Japan (AIJ), consolidates the state-of-the-art stability problems concerning steel structures and publishes a book summarizing researches on these problems every decade. The new edition of the book is ready for publication this year. The book is available only in Japanese, but the contents may be interested in the members of the SSRC.

This report and the following two introduce the topics in the first half of the new edition upon the kind invitation from the SSRC’s International Liason Program. The covered topics are Ch. 1. Strength and Deformation Capacity of Buckling Braces, Ch. 2 Lateral Buckling of Continuous Braced H-sharped Beams with Restraint Ends, and Ch. 3 Column Strength and Deformation Capacity Limited by Local Buckling.

Ch. 1. Strength and Deformation Capacity of Buckling Braces

Chapter 1 contains topics on post-buckling behavior and deformation capacity of braces, braces with a large intentional eccentricity, and braces with an inherent eccentricity at connections. Among these topics, this report introduces a state-of-the-art analytical method for simulating the inelastic behavior of steel braces.

Fig. 1 illustrates a phenomenological brace model. The original model developed by Shibata and Wakabayashi (SW model) is well-known for its simplicity, where the force-deformation relation of the steel brace subjected to cyclic loading is expressed by only four stages. As the original model is not able to trace well a buckling-induced degradation for versatile steel braces, the newly introduced model modify repeadly the primary parameters of the SW model, such as compressive strength.

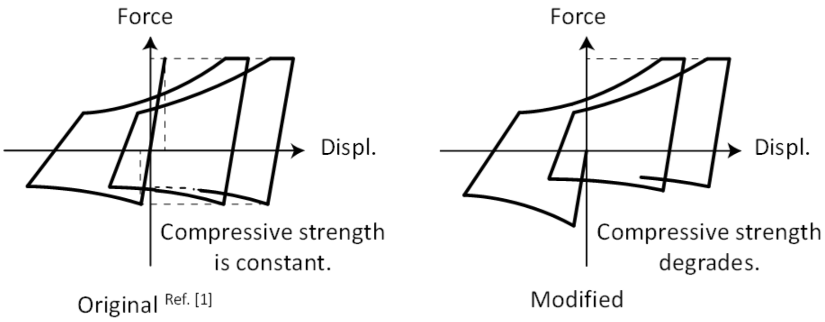


Fig. 1. *SW model.*

A method to estimate the deformation capacity of buckling braces is introduced. Fig. 2 shows a geometrical assumption of local-buckling induced strain concentration in an I-shaped section brace. The geometrical assumption of the failure mode enabled the quantitative evaluation of the average local strain in the plastic strain concentration zone. The proposed method determines the instant when the crack initiated in steel braces by relating the average local strain to the fatigue performance of steel alloy.

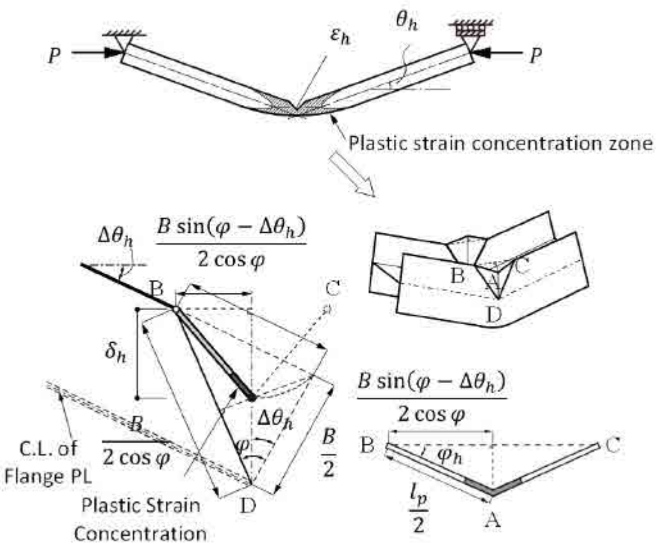


Fig. 2. *Geometry of local failure mode*

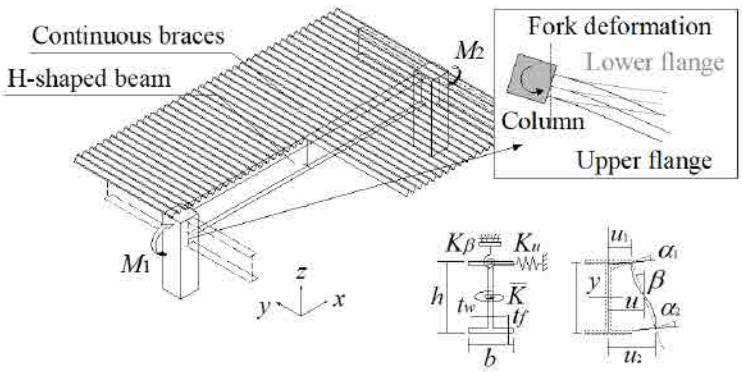
Ch. 2 Lateral Buckling of Continuous Braced H-sharped Beams with Restraint Ends

Reported by Dr. Atsushi Sato (Nagoya Tech.), Dr. Yoshihiro Kimura (Tohoku Univ.)

Chapter 2 of "Stability Problems of Steel Structures" reports the topics relating continuously-braced H-shaped beams subjected to uniform bending, with warping and fork restraints (Fig.1). The H-shaped beam in moment-resisting frames receives warping and fork restraints at the ends by the beam-column joint and the column torsional rigidities. The RC slabs and non-structural members, such as folded roof plates, firmly attached to the upper flanges of the beam effectively prevent lateral buckling.

The design standard for steel structures (AIJ 2005) recommends modelling the boundary condition of beams as a simple support. The specifications do not consider non-structural members for lateral braces nor the columns that possess a high warping restraint against lateral buckling deformation of beams in steel moment-resisting frames.

Thus, the buckling strength of continuously braced H-shaped beams with restraint ends are evaluated theoretically, analytically, and experimentally. Primarily, cyclic loading tests on the steel frame subassembly failing by the beam lateral buckling demonstrated the contribution of continuous braces and warping restraint (Fig. 2). Then, the elastoplastic lateral buckling strength of those beams are estimated based on the buckling curves using a modified slenderness ratio computed by the theoretical investigation.



a) H-shaped Beam with Flexural Moment *(b) Buckling Deformation of Section*

Fig. 1. *H-Shaped Beam with Continuous Braces and Column*

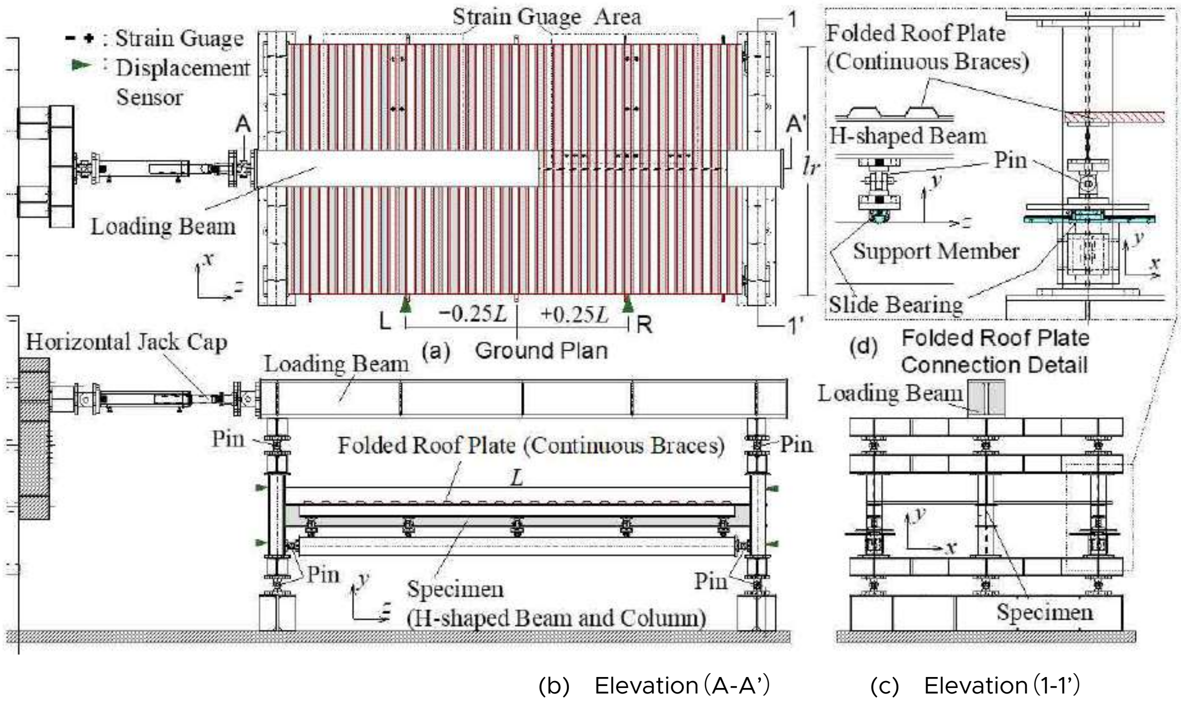


Fig. 2. *Specimen and Loading Instrument*

Ch. 3 Strength and Deformation Capacity of Columns associated with Local Buckling

Reported by Dr. Ryota Matsui (Hokkaido Univ.) and Dr. Yoshihiro Kimura (Tohoku Univ.)

Chapter 3 of "Stability Problems of Steel Structures" addresses the following topics: 1) local buckling-induced degradation of steel columns subjected to high axial force; and 2) the cyclic load tests of square structural hollow section columns subjected to both compression and simple curvature bending. The below is a brief summary of the first topic.

When columns sustain a high axial force (e.g., columns in a concentrically braced frame for fossil electrical power plants that supports an extremely heave boiler), the plastic zone near the column ends spreads to the axial direction during earthquake events. A newly developed displacement-based fiber model in Fig. 1, namely a physical fiber element, integrates the local buckling-induced degradation and predicts the force-displacement relation of the columns with high axial force. Fig. 2 shows the responses of an I-shaped section cantilevered column subjected to cyclic lateral force simulated by the continuum finite element (CFE) analysis and the physical fiber element, respectively. Since accuracy and expense are a trade-off, the physical fiber element reproduced the test response less accurately compared to the CFE analysis. Still, the error in the simulation may be tolerated in design practice with the advantage in the model simplicity.

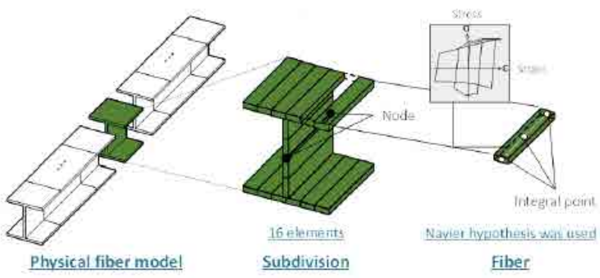


Fig. 1. *Physical fiber element*

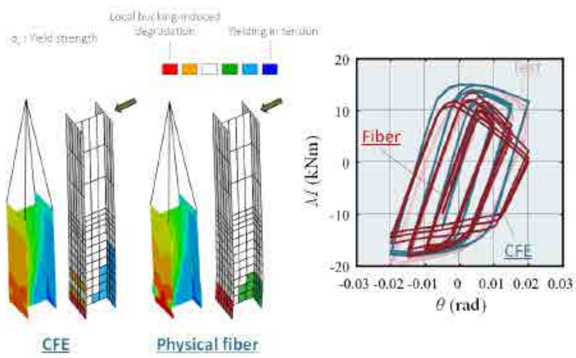


Fig. 2. *Validation*

Compression controlled design to avoid web buckling at supports of continuous steel-concrete composite bridges

Arul Jayachandran S., Professor, Indian Institute of Technology Madras, Chennai, India

Summary:

Ten numbers of all steel substructure and steel-concrete composite superstructure bridges are being built in the state of Kerala, in the southern part of India. The concept of simple for dead load and continuous for live load concept (SDCL) was adopted to satisfy the contractual obligation of continuous girders. This concept is well documented in the literature; Reza Farimani et al. 2014 is one. Figure.1 shows the schematic representation of the bridge at the location of piers in which the encircled location is the focus of this note which has a coincident maximum of negative bending moment and shear force. A reinforced concrete diaphragm is introduced at the supports, enabling a “negative moment resisting system ” that makes the girders continuous for the live load and loads due to the road finishes. The negative moment resistance is developed by the tension developed at the longitudinal reinforcement of the deck slab and the compression at the bottom flange of the steel plate girder. In calculating the tensile resistance, the strain hardening component of the rebar and any minor tension resisting system of the rebar at the top of the diaphragm is neglected. Hence in the Ultimate Limit State (ULS), the matching compression from the steel flanges may be more than what is calculated, making the flange compressive forces disperse into the web of the girders (Figure .2), making them vulnerable to buckling due to combined shear force and dispersed compressive force from the flanges. . The original concept could not be adopted in our case because of an apriori assumption that the girders on both sides of the diaphragm are collinear. However, we have girder line deviations around 10°. To include the girder line deviations and avoid web buckling at the bottom of the girders at support, a lip bearing plate is introduced with CG in line with the center of the bottom flange (Figure.3). The lip plates are separated by 300 mm so that the concrete enclosed between the two lip plates, as shown in Figure 4, will be under a state of confinement. The negative moment compressive resistance comes from the ultimate strength of M40 (Cube strength)

concrete sandwiched between the lip plates assuming an ultimate strain of 0.0035. In this case, the web of the steel plate girder transfers shear with very little direct compression coming from the bottom flange. Few shear studs are attached to the web throughout the depth. Hence, the shear component is shared by some shear studs relieving the axial force dispersion into the web. The webs are checked to be adequate in buckling when the diffuser arrangement (Figure 4) is used.

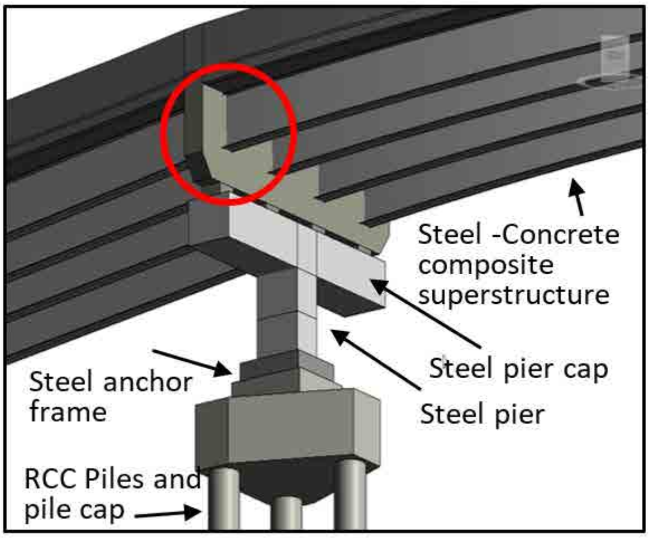


Fig. 1. *A schematic diagram of the all-steel substructure and steel-concrete composite superstructure bridge at the support location.*

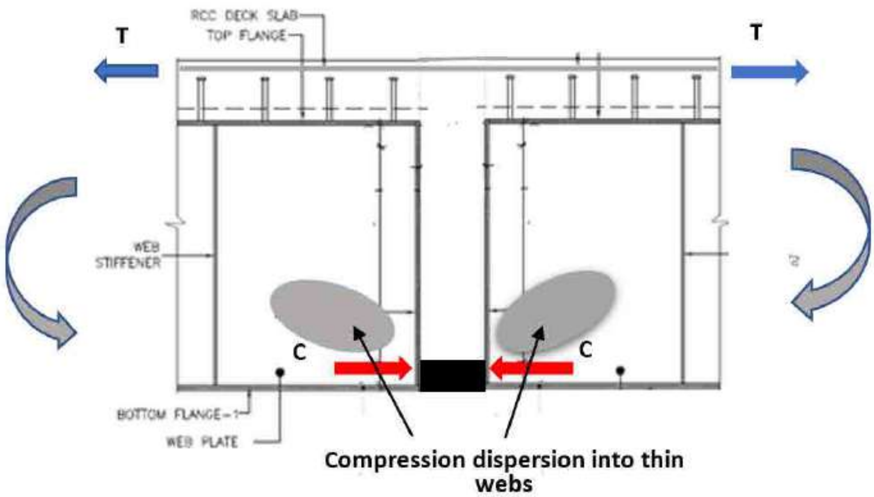


Fig. 2. *Negative moment compression resistance developed through bottom flange continuity.*

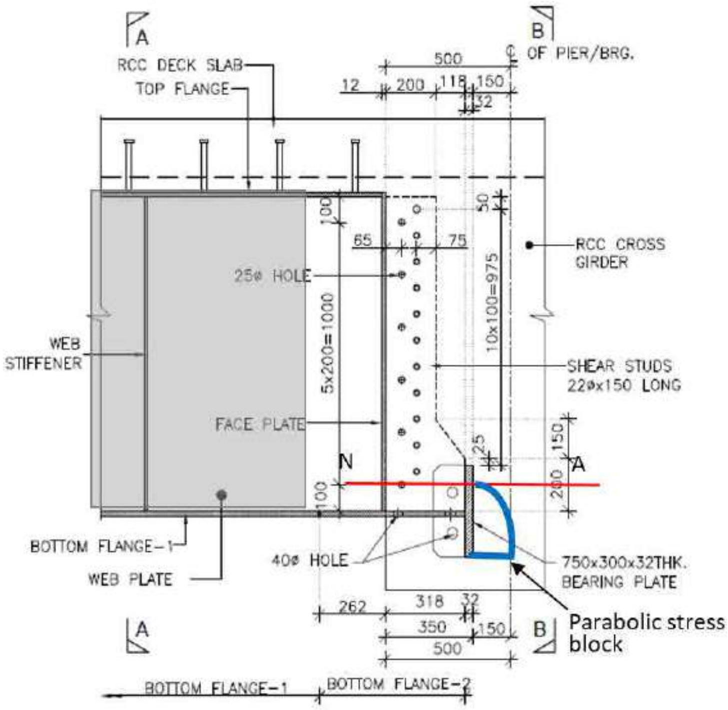


Fig. 3. *Utilizing the concrete compressive strength using a bearing plate*

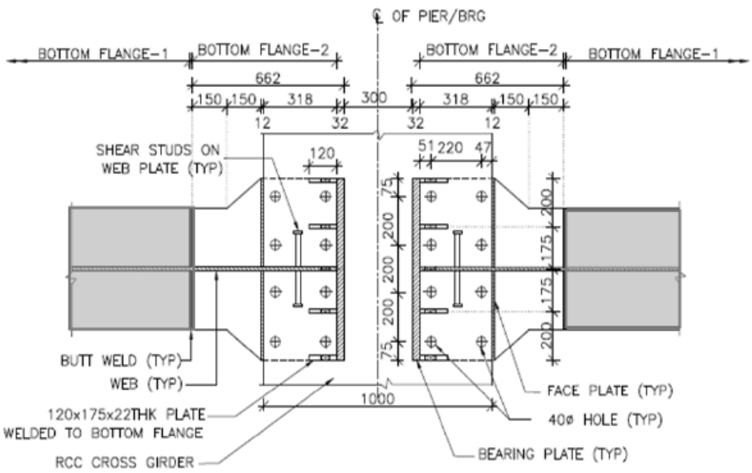


Fig. 4. *Compression diffuser arrangement which de-stresses the thin*

Curvature effect on fatigue performance of horizontally curved composite steel bridges

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Sponsor:
Alabama Department of Transportation

Summary:
Webs of curved steel bridges experience large deformations during fabrication, erection, and construction. These web distortions are intensified at the service stage due to non-colinear forces acting on the web and deflection amplification effects. The secondary bending stresses developed at the web panel connection to the surrounding elements, such as transverse stiffeners and flanges, decrease the fatigue performance of the bridge. Although the final configuration of the curved girder system is significantly affected by the construction phase, the majority of research has ignored the compounding effects on web stress intensities. Generally, initial web imperfections in terms of scaled buckling mode shapes are assumed for web geometry at the service state that do not represent real-life bridge conditions. This research aims at investigating the web behavior of horizontally curved steel bridges considering all accumulated effects from fabrication through service for the fatigue limit state.

The ongoing study includes field monitoring, measurements and finite element analyses of a three-span continuous composite steel bridge with a 444 ft radius of curvature. Web deformations will be scanned using high-resolution Lidar technology in three phases: a) fabrication, for curving and welding effects, b) construction, for non-composite deformations, and c) service, for the composite state under fatigue truck loading. Stresses will be measured through strain gauge installment for the same phases as the Lidar scanning of the bridge. The experimental data will be used to calibrate the FEM models for further parametric studies.

The construction of the bridge has not yet initiated, but simulation of the bridge using ABAQUS has defined the critical locations and stress magnitudes expected in the experimental phase. A multi-step superposition technique was developed to capture the continuous web deformation from the non-composite through the composite stages. Three critical web panels were investigated for high moment, high shear, and combined moment and shear conditions, as shown in the Figures 1 and 2. The

final results of the research will provide a better understanding of curved steel bridge web behavior and will help define fatigue limit state guidelines specific to curved girder web design.

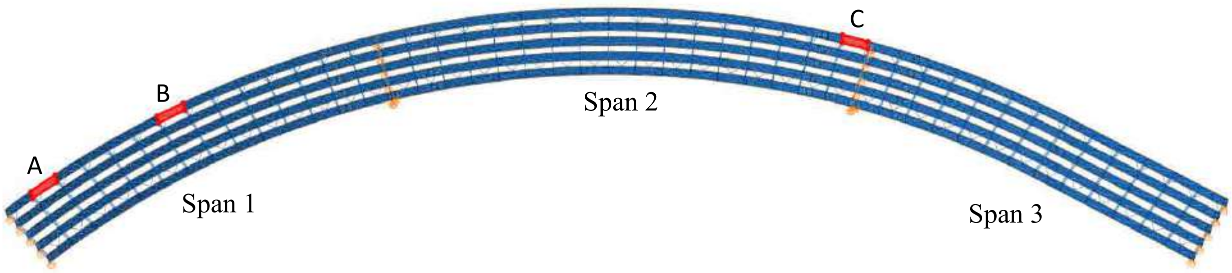
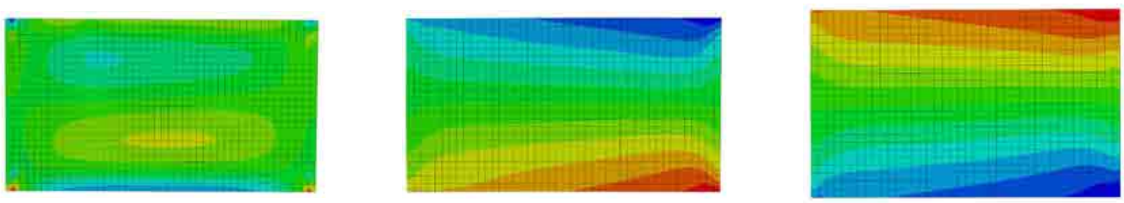


Fig. 1. *Global assembly and critical web panels under consideration: A) shear; B) bend; C) combined bend and shear.*



A) Bend panel B) Shear panel C) Bend and shear panel

Fig. 2. *Distribution of principal stresses in critical web panels.*

Effect of Moment Gradient on Local Buckling of Thin-Walled Beams

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Summary:
Thin-walled flexural members can either be designed by the effective width method or the direct strength method. However, when the flexural member is subject to a moment gradient along its span due to the effect of different loadings, the effective width of compression elements is only applicable at the maximum moments. This means that using the effective section for the whole span is too conservative, as local buckling will only occur at the sections near the maximum moment.

The main purpose of this research is to explain and investigate the effect of moment gradient on local buckling of a thin-walled lipped channel beam by using ABAQUS to illustrate the behavior of the compression part of the section and the shape of the failure modes of the cross sections under changeable load values, different load conditions, and different cross sections of lipped channels. To determine the effect of moment gradient on the effective section, a nonlinear ABAQUS model was made to see how close the deflections of the model were to the theoretical deflections calculated on the assumption that the whole span was the effective section. After this the nonlinear ABAQUS results were compared with the theoretical calculations using the effective width method to develop correction factors for different moment gradients.

Cold Formed C Section With Lips Dimensions and properties													
Dimensions (mm)					Area	Wight	X - X		Y - Y			e
h	b	d	t	r	(cm2)	(Kg/m')	Sx (cm3)	rx (cm)	Iy (cm4)	Sy (cm3)	ry (cm)	(cm)
100	50	20	2	6	4.33	3.4	13.18	3.9	15.36	4.85	1.88	1.84
160	70	30	3	6	9.95	7.81	48.09	6.22	70.8	15.7	2.67	2.49
160	80	34	3	6	10.79	8.47	53.4	6.29	103.1	20.68	3.09	3.01
180	80	25	3.6	6	12.91	11.14	71.36	7.05	109.2 9	20.3	2.91	2.62
185	60	25	1.5	6	5	3.93	27.22	7.09	25.6	6.12	2.26	1.82
185	60	26. 4	2	6	6.69	5.25	36.02	7.06	34.09	8.22	2.26	1.85
215	60	25	1.5	6	5.46	4.29	33.55	8.13	26.88	6.21	2.22	1.67

Table. 1. *Cross-sectional dimensions and properties*

Two different cases of cantilever beams were used to perform this study, a cantilever beam with a point load at its free end and a cantilever beam with a distributed load along its span. Table 1 shows the sections that were used in the analysis. Figure 1 shows the theoretical and finite element deflection curves for the cantilever with a point load at its free end.

The results of this research proved that the moment gradient clearly affects the main properties of the cold formed sections which directly affects the deflection and buckling mode. The finite element deflections are smaller than the theoretical deflections calculated assuming a full effective section along the beam's span. According to the previous results and analysis, it is recommended to use the nonlinear analysis to determine the actual properties for the cold-formed sections instead of the theoretical analysis or identify an error factor to increase the percentage of accuracy for the deflection for each load condition. This study is still to be supported using experimental results.

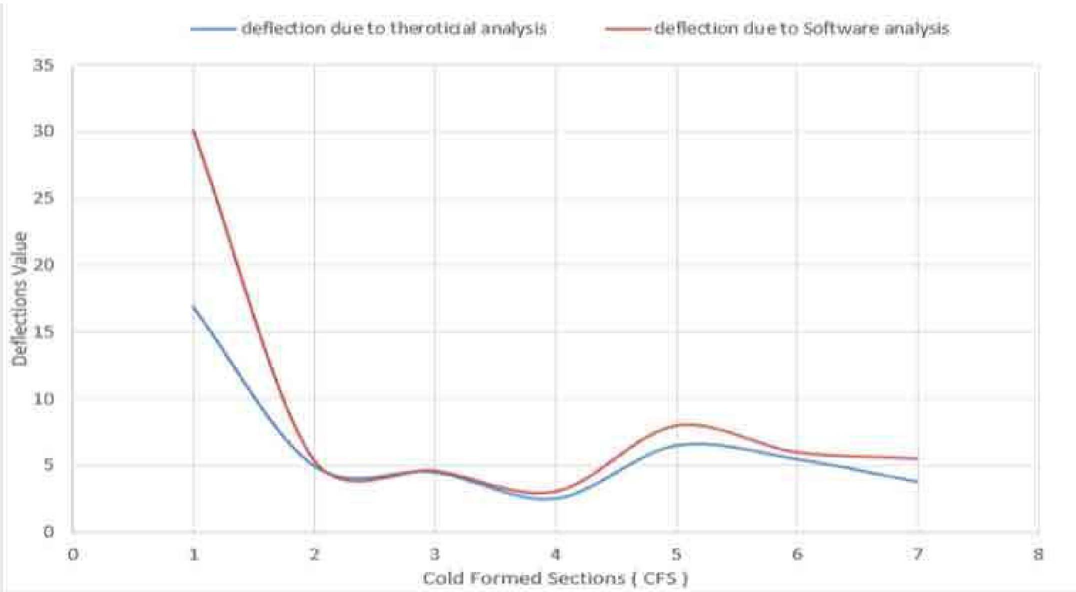

Figure. 1. *Deflection curves for cantilever with point load*

Portugal

Fire design of stainless steel members

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Paulo Vila Real, RISCO, DECivil, Universidade de Aveiro, Aveiro, Portugal
Dinar Camotim, CERIS, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
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Sponsor:
Portuguese Operational Program "Competitividade e Internacionalização (FEDER/FNR component) and "Fundação Portuguesa para a Ciência e a Tecnologia" (FCT – Portugal) (State Budget component)

Summary:
Despite its high initial cost, stainless steel has important advantages when compared to conventional carbon steel, such as superior corrosion resistance, aesthetic appearance, ease of maintenance, durability and better behavior at elevated temperatures. The lower erosion of its mechanical properties and the higher ductility, at elevated temperatures; lead to structures with higher fire resistance, which can be decisive in several applications. Following the increasing interest in stainless steel structures, design standards are being developed (such as ANSI/AISC 370-21 and EN1993-1-2), aiming to provide more accurate and specific fire design rules for this type of steel structures. However, further research is still needed to acquire a more in-depth understanding of their behavior. Hence, this project aims at contributing towards increasing the knowledge about the behavior of stainless steel members under fire situation.

Simplified fire design rules, provided by codes of practice, are of the utmost importance to designers who often have no access to advanced calculation methods. Eurocode 3 states that these stainless steel members must be checked using the same design formulae developed for carbon steel, an approach that has been shown to be inaccurate (mainly excessively safe, but sometimes also unsafe). The two materials have different constitutive laws, which influences the member load bearing capacity.

Studies on isolated members (columns, beams and beam-columns) with non-slender and slender cross-sections (I, hollow and cold-formed open sections) were performed. The fact that such members are susceptible to various instability phenomena, combined with the non-linear material behavior at high temperatures, implies that the determination of their ultimate strengths require carefully performed and complex test campaigns and non-linear numerical

simulations. Experimental and numerical results concerning stainless steel structural elements under fire conditions were obtained to assess the merits and, if necessary, improve the existing design rules.

The experimental results, obtained from tests on austenitic stainless steel members, were used to validate the numerical models validation. According to the most recent draft of the (currently under development) second generation of Eurocode 3, a constitutive law based on a two-phase Ramberg-Osgood formulation was applied to simulate the stainless steel mechanical behavior at elevated temperatures. Extensive numerical parametric studies were carried out, involving austenitic, ferritic and duplex stainless steel members and using different software (for model verification purposes), such as ANSYS, ABAQUS and the program SAFIR, developed specifically to perform fire analyses. In addition, the member critical buckling loadings and associated instability modes were determined by means of GBT (Generalized Beam Theory) linear stability analyses.

The results obtained are being used to develop design proposals aimed at improving the quality (accuracy, safety and reliability) of the Eurocode 3 (EN1993-1-2) rules, including simplified ones, for the fire design of stainless steel members.

Figure. 1. *(a) Fire bending test of stainless steel RHS members and (b) corresponding numerical simulations [1]*

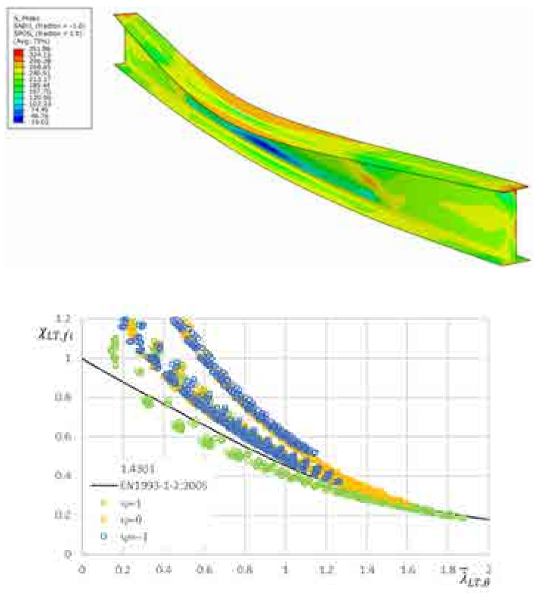

Figure. 2. *(a) Deformed configuration and von Mises stress contours at an equilibrium state of an IPE 360 duplex 1.4462 beam [2] and design curve against lateral-torsional failures [3]*

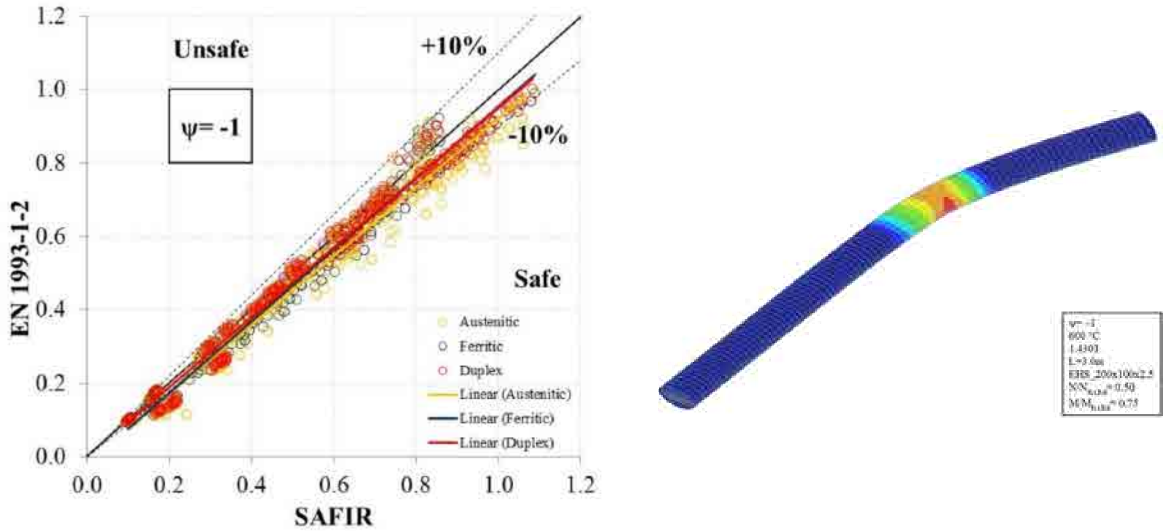

Figure. 3. *(a) Accuracy of the EN 1993-1-2 design rules in predicting the numerical ultimate strengths of elliptical hollow section beam-columns [4]*

Reference:

[1] Alves, M.; Mesquita, L.; Piloto, P.; Lopes, N.; Arrais, F.; Vila Real, P.; Cruz, J. “Bending resistance of stainless steel beams at elevated temperatures”, Proceedings of 12th National Congress on Experimental Mechanics (CNME2020), Monte Real, Leiria, 2021. (Portuguese)

[2] Martins, A.; Camotim, D.; Gonçalves, R.; Lopes, N.; Vila Real, P. “Transversally Loaded Stainless Steel Beams under Fire: Local/Global Behaviour, Strength and Design”, Journal of Constructional Steel Research, Elsevier, ISSN 0143-974X, volume 189, 107080, 2022.

[3] Lopes, N.; Couto, C.; Vila Real, P. Camotim, D.; Gonçalves, R. “Influence of the loading type on the fire design of stainless steel beams against lateral-torsional failures”, Proceedings of the XIII National Congress of Steel and Composite Construction (XIII CMM), ISBN 978-989-99251-9-9, pp. 473-482, 2021. (Portuguese)

[4] Arrais, F.; Lopes, N.; Vila Real, P. "Fire resistance of stainless steel slender elliptical hollow section beam-columns", Journal of Structural Fire Engineering, Emerald Group Publishing Ltd, ISSN: 2040-2317, 2021. DOI (10.1108/JSFE-06-2021-0035).

Predicting the resistance of stainless-steel and aluminum plate girders subjected to concentrated loading using artificial intelligence algorithms

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Summary:

Artificial intelligence (AI) and machine learning (ML) algorithms have been widely used for regression or classification purposes. For instance, an artificial neural networks (ANN) approach mimics the connections in human brains and uses the available data to learn and predict the outputs. Neuro-fuzzy systems, on the other hand, combine the features of fuzzy logic and neural networks to solve problems such as regression and classification. Support vector machines (SVM) is another ML approach that is employed for similar purposes. As in other areas of civil and structural engineering, AI has also been employed to study the resistance of carbon steel girders subjected to patch loading. IN contrast to many other AI techniques (e.g., artificial neural networks, support vector machines) which are considered black box, symbolic regression (SR) reveals easy-to-use explicit models with modifiable coefficients without requiring a specific model structure as a starting point. This project aimed at investigating the resistance of austenitic stainless-steel girders and aluminum beams subject to concentrated loading using symbolic regression.

Symbolic Regression (SR) is a ML algorithm that works searching a space of mathematical expressions to find the best fitting model. SR is also considered as an improved version of genetic programming. As opposed to traditional regression methods fitting the parameters to a predetermined equation, SR searches both for equations and parameters simultaneously. SR creates new models by recombining previously found equations and their sub-expressions on a random basis.

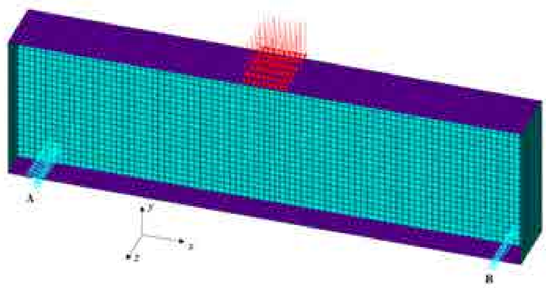


Fig. 1. *A numerical model for a plate girder subject to concentrated loading.*

Several resistance models are available in the literature for stainless steel and aluminum beams subject to patch loading. These models indicate that the resistance can be expressed in terms of the yield strength of the web, the thickness of the web, and various geometric ratios as follows

$$F_R = f\left(f_{yw},\ t_w^2, \frac{t_f}{t_w}, \frac{a}{h_w}, \frac{s_s}{h_w}, \frac{b_f}{t_f}\right) \tag{1}$$

Employing two extensive numerical databases obtained previously in for austenitic stainless-steel girders [1], and for extruded aluminum beams [2] subjected to patch loading, the algorithm automatically divides these data into two sets (training set and testing set) on a random basis, and uses the training set to develop expressions. Then, the testing set is employed to evaluate the resulting models via the fitness function. For stainless steel girders, among other functions developed by SR [3], Eq. (2) was selected for further analysis as it yielded to the best correlation and has the least complexity

(2)

$$F_R = 0.0252\, f_{yw}\, t_w^2 \left(\frac{t_f}{t_w}\right)^{0.415} \left(\frac{h_w}{a}\right)^{0.211} \left(\frac{s_s}{h_w}\right)^{0.220} \left(\frac{b_f}{t_f}\right)^{0.224}$$

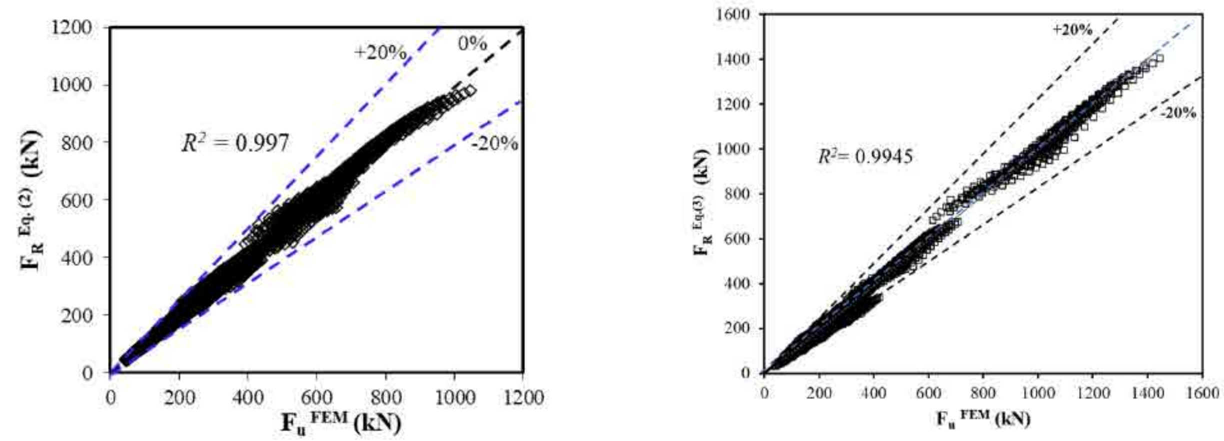
In a similar manner and using the numerical database elaborated in [2], the patch loading resistance of aluminum beams [4] can be calculated with

(3)

$$F_R = 0.0181\, f_{yw} t_w^2 \left(\frac{t_f}{t_w}\right)^{0.442} \left(\frac{h_w}{a}\right)^{0.174} \left(\frac{s_s}{h_w}\right)^{0.183} \left(\frac{b_f}{t_f}\right)^{0.193}$$

Figure 2 shows the relationship between computed and predicted resistances using Eqs. (2) and (3), high coefficients of correlation were attained as 0.997, and 0.995, respectively. It is worth noting that these relationships were obtained using numerical databases [1,2] due to a limited number of experimental results available in the literature. Therefore, additional tests are required to fully validate the models.

Finally, the results showed that ML approaches provide a feasible alternative for the explicit solution of complex problems in civil engineering applications.



(a) Stainless steel (b) Aluminum beams

Fig. 2. Comparison between computed and predicted resistances.

Reference:

[1] Graciano C, Loaiza N, Casanova E, Resistance of slender austenitic stainless steel I-girders subjected to patch loading. Structures 2019;20:924-934. (https://doi.org/10.1016/j.istruc.2019.07.008)

[2] Graciano C, Loaiza N, Casanova E, Numerical study and design of extruded aluminum beams subjected to concentrated loads. Thin-Walled Struct. 2020;155:106917. (https://doi.org/10.1016/j.tws.2020.106917)

[3] Graciano C, Kurtoglu AE, Casanova E, Machine learning approach for predicting the patch load resistance of slender austenitic stainless steel girders. Structures 2021;30:198-205. https://doi.org/10.1016/j.istruc.2021.01.012)

[4] Graciano C, Kurtoglu AE, Casanova E, Prediction of patch loading resistance of extruded aluminum girders using artificial intelligence algorithms. To be submitted to Structures 2022.

United States of America

Second Order Effects on the Design of Slender Reinforced Concrete Bridge Columns

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Mark Denavit, University of Tennessee, Knoxville, USA

Sponsor:
California Department of Transportation (Caltrans)

Summary:
The AASHTO approximate method for the design of slender reinforced concrete (RC) bridge columns was adopted from building design codes. Accordingly, the AASHTO method applies to a certain range of parameters and configurations based on floor framing stiffness, building story heights, material properties, and reinforcing ratios. While some analogies carry over to bridge columns, the superstructure stiffness and unbraced column lengths can be quite different for bridge systems compared to buildings. As a result, engineers typically make very conservative assumptions on the strength of slender RC bridge columns. Although engineers can obtain more efficient designs using refined analysis, this approach is rarely used in practice due to computational effort and model uncertainty. This project, funded by the California Department of Transportation (Caltrans) through the Pacific Earthquake Engineering Research (PEER) center, will evaluate the AASHTO approximate moment magnification method using advanced second-order inelastic analyses. Parametric studies will be conducted on single column models and common Caltrans bridge types. The impact of major parameters, e.g., slenderness, out of plumbness, and superstructure stiffness on structural behavior according to both the approximate method and advanced analysis will be quantified and refinements to the approximate method will be developed where these methods differ substantially.

Through the development of design recommendations, this project will help engineers design more efficient slender RC columns in bridge structures when compared to approximate methods in AASHTO. Design recommendations will be based on inelastic second-order finite element analyses performed using the OpenSees software framework. A new approach for modeling the time-dependent effects of creep and shrinkage in slender RC columns will be developed and validated against published experimental data. Effective stiffness and effective length factors will be assessed along with design limitations and guidance for second order analysis of RC bridge columns. To increase confidence in and applicability of analysis results, modeling recommendations based on OpenSees analyses will be further validated using CSiBridge.

Photo courtesy of Caltrans.

United States of America

Shear-Acting Structural Fuses Optimized to Resist Buckling

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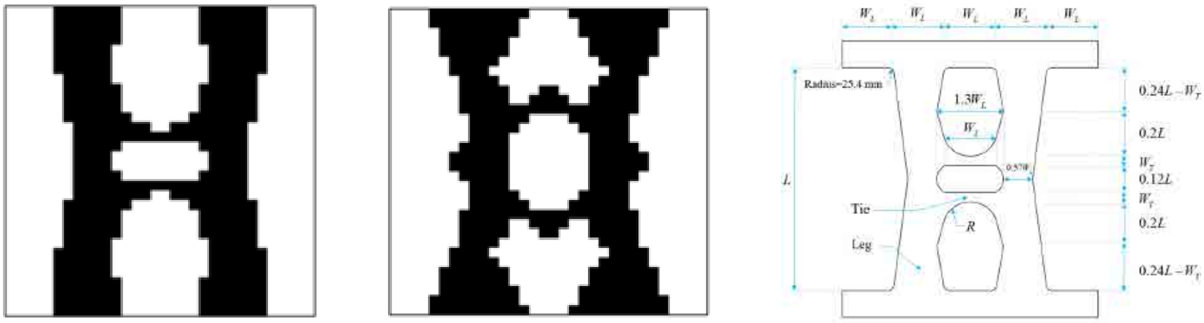
Summary:

Previous studies on shear-acting structural fuse shapes have focused on increasing ductility, energy dissipation, and stiffness, while neglecting the effects of buckling which can lead to reduced energy dissipation, loss of shear strength, and fracture at sharp creases. A recent study recognized that resisting shear buckling while promoting yielding is a way to improve the behavior of shear-acting structural fuses and used topology optimization to create buckling resistant shapes. The investigation of two of the resulting buckling resisting structural shapes, as illustrated in Figure 1a and 1b, was conducted. First, to make the optimized structural fuse shape practical for design, the shape was post-processed into a collection of defined curves with all dimensions being a function of five unique design parameters as shown in Figure 1c. Then plastic mechanism analysis was used to derive a generalized equation for the shear strength of the parameterized configuration, as presented in Figure 2. Figure 3 shows a picture of the experimental test setup used to investigate the cyclic load-deformation behavior for these optimized structural fuse shapes. Nonlinear finite element models were then validated against the experiments and used to conduct a computational parametric study to evaluate the effect of the design variables on aspects of structural fuse behavior such as strength, stiffness, maximum out-of-plane displacement, maximum equivalent plastic strain.

The experimentally obtained hysteretic behavior presented in Figure 4 shows that the structural fuse shape that was optimized to provide the most buckling resistance (Figure 4b), experienced fracture at a shear angle of 4.8%, while an optimized topology with slightly less buckling resistance (Figure 4a) could reach 10.7% shear angle without fracture or buckling. Based on the results of the experiments, FEM validation and parametric study, design guidance is provided for the more ductile of the two topologies (Figure 4a) including an approach for reproducing the shape based on a set of five parameters, an equation to predict shear strength of the structural fuse, and recommendations for selecting appropriate values of the parameters based on the results of the computational parametric study.



a) Optimized Topology 1 b) Optimized Topology 2 c) Parameterized Shape for Design

Fig.1. *Optimized Structural Fuse Shapes following Hurricane Rita (photo credit: NIST)*

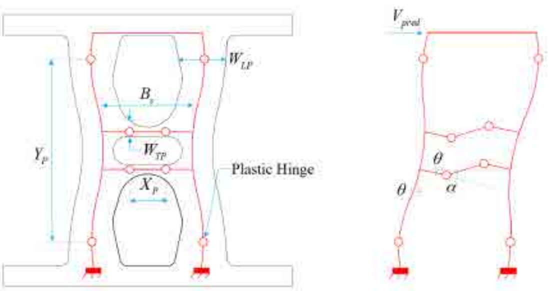


Fig.2. *Plastic Analysis*

Fig.3. *Test Setup*

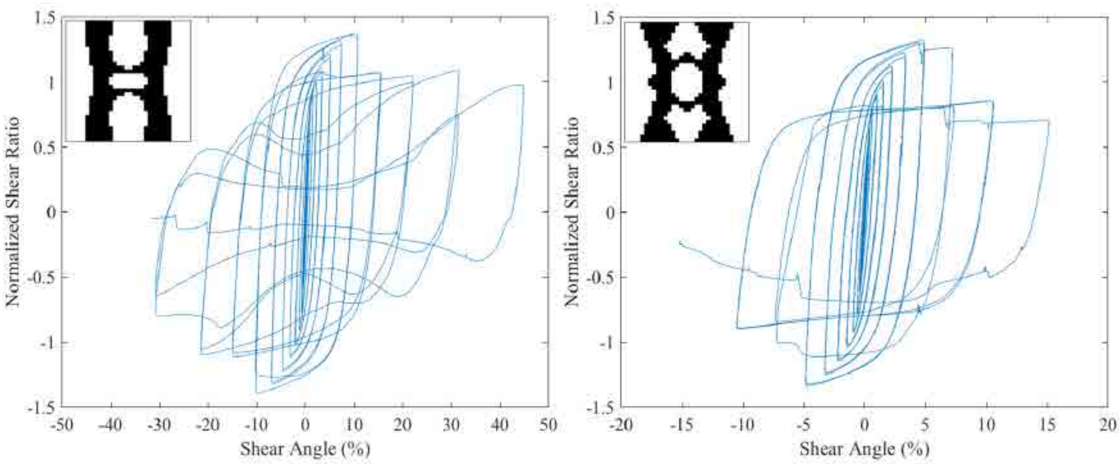


Fig.4. *Resulting Hysteretic Behavior*

Iran

USA

Stability Performance Assessment of Steel Thin-Walled Open-Top Tanks Subjected to Local Support Settlement

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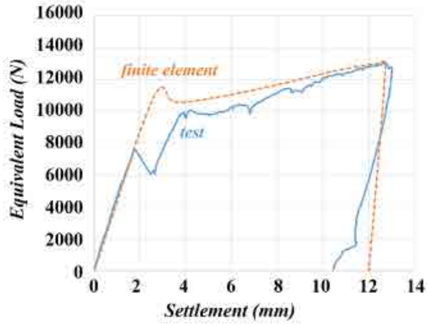
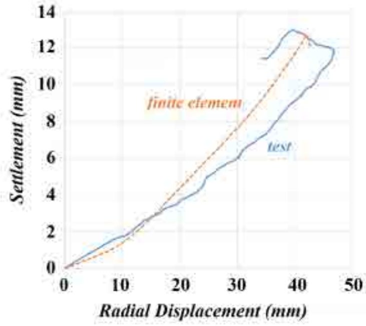
Summary:

Cylindrical welded steel storage tanks are typical thin-walled structures which are generally located in coastal areas. The major concern in the design of these thin-walled structures is buckling under settlement. Considering prior research works as well as effectiveness of different settlement types, systematic studies are still required to investigate and enhance the stability performance of steel thin-walled open-top tanks subjected to local support settlement. In this research program, the buckling stability performances of numerous cylindrical open-top tank specimens as well as models with various height-to-radius, radius-to-thickness, and settlement span ratios are investigated through laboratory tests as well as numerical parametric studies. The effects of addition of a top stiffening ring on the buckling behavior of cylindrical steel tanks are studied as well. Figure 1 shows typical unstiffened and stiffened tanks without and with the top stiffening ring, respectively. As an example, the experimental and numerical results for the equivalent load versus settlement as well as settlement versus radial displacement responses are illustrated in Figure 2; moreover, shown in Figure 3 are the experimental and numerical deformations of the unstiffened and stiffened tanks. The results and findings of this comprehensive research endeavor demonstrate that the choice of the height-to-radius, radius-to-thickness, and settlement span ratios as well as addition of the top stiffening ring can be quite effective on the stiffness and strength performances, deformations, and stress distribution as well as intensity of vertical cylindrical welded steel tanks subjected to local support edge settlement. The current experimental and numerical studies intend to deliver qualitative and quantitative insight into the proper design and detailing of such thin-walled structures through effectiveness assessment of the aforementioned key parameters.



(a) Equivalent load vs. settlement

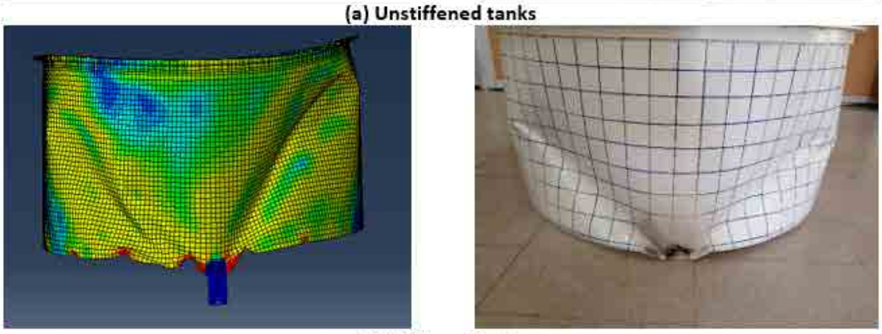


(b) Settlement vs. radial displacement

Fig.1. *Steel thin-walled open-top tanks*

Fig.2. *Test results and finite element predictions*

(a) Unstiffened tanks



(b) Stiffened tanks

Fig.3. *Experimental and numerical deformations*

Mexico

Ultimate strength curves of stiffened panels

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Summary:
Ship and offshore structures are fabricated through continuous panels reinforced by stiffeners and supporting members. The plate panels between stiffeners and frames are the most fundamental structural components and are subjected to lateral actions due to direct action of water and cargo pressure, as well as in-plane actions caused by structural responses at the system level (Figure 1).

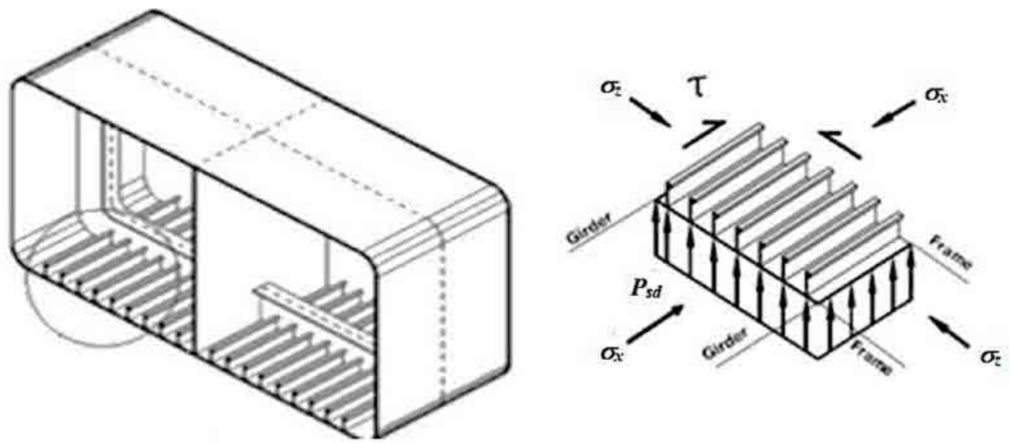

Fig. 1. *Biaxial stresses and hydrostatic pressure (adapted from DNV-RP-0S-C102)*

The main objective of this research is to develop a methodology for the optimization of critical stiffened panels for semi-submersible production systems considering the dimensions of panels, the dimensions of the stiffeners, and the loads (i.e., biaxial stresses and lateral pressure). Angle, plate, and T stiffeners are evaluated in the stiffened panels as shown in Figure 2. The ultimate capacity of the stiffened steel panels is calculated from finite element analysis and the interaction equations of the recommended practice RP-C201 (DNV, 2002). The critical panel in semi-submersible production systems is located at the lower midspan of the pontoon since the maximum internal stresses are reached here due to the waves and permanent loads in calm water condition, and so the panels are subjected to the effects of biaxial stresses and lateral pressure.

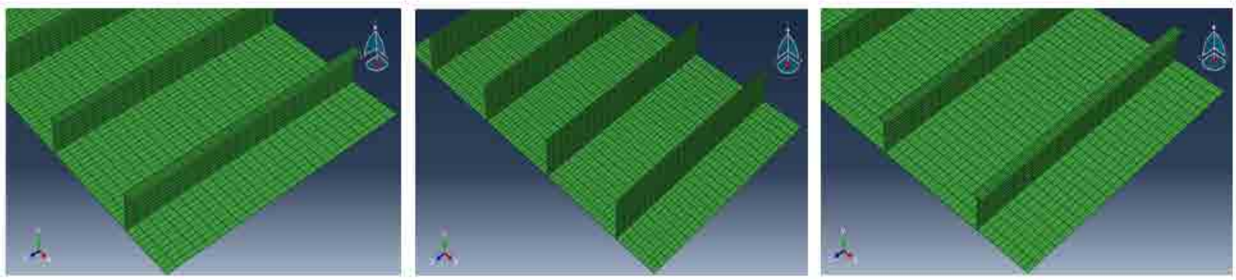

Fig. 2. *Stiffened panel models with angle, plate, and T stiffeners*

With the aim to validate the proposed methodology, finite element analyses are performed to the optimal panels using the software Abaqus. In these analyzes, quadrilateral elements with four nodes and reduced integration are used, which minimizes the execution time to one third compared to that of full integration elements. These elements are efficient for complex nonlinear analyzes involving contact, plasticity, and large deformations. The model and meshing are generated through a MATLAB script, which automatically generates the geometry of the panel with the stiffeners including the initial imperfections of the panel, the supports at the edges of the panel, the different loads steps, and the meshing within the plate. The structural steel plate is assumed elastic perfectly plastic using the true stress-strain values, with a yield stress of 355 MPa and modulus of elasticity of 210 GPa. The boundary conditions on the edges are assumed as simply supported.

The analyzes of these panels are performed by applying the following load cases: (1) The initial out-of-straightness imperfection, which is directly considered in the panel geometry and the mesh; the initial imperfection considers the deformation of the first buckling mode of the plate and a maximum displacement that corresponds to the maximum out-of-straightness tolerance (i.e., one thousandth of the panel length) in accordance with the local Code of Standard Practice. (2) The hydrostatic pressure that is applied to the panels due to the permanent loads in the calm water condition. (3) Finally, an axial load in compression is applied in displacement control simultaneously in both axial directions of the panel, controlling the displacements proportionally with different longitudinal-to-transversal ratios. The ultimate strength of a steel panel with angle-type stiffeners calculated with the interaction equations of the recommended practice DNV-RP-C201 and obtained from finite element analysis with different longitudinal-to-transversal ratios is shown in Figure 3. This figure shows excellent agreement between both results, and similar results are obtained for plate-type and T-type stiffeners.

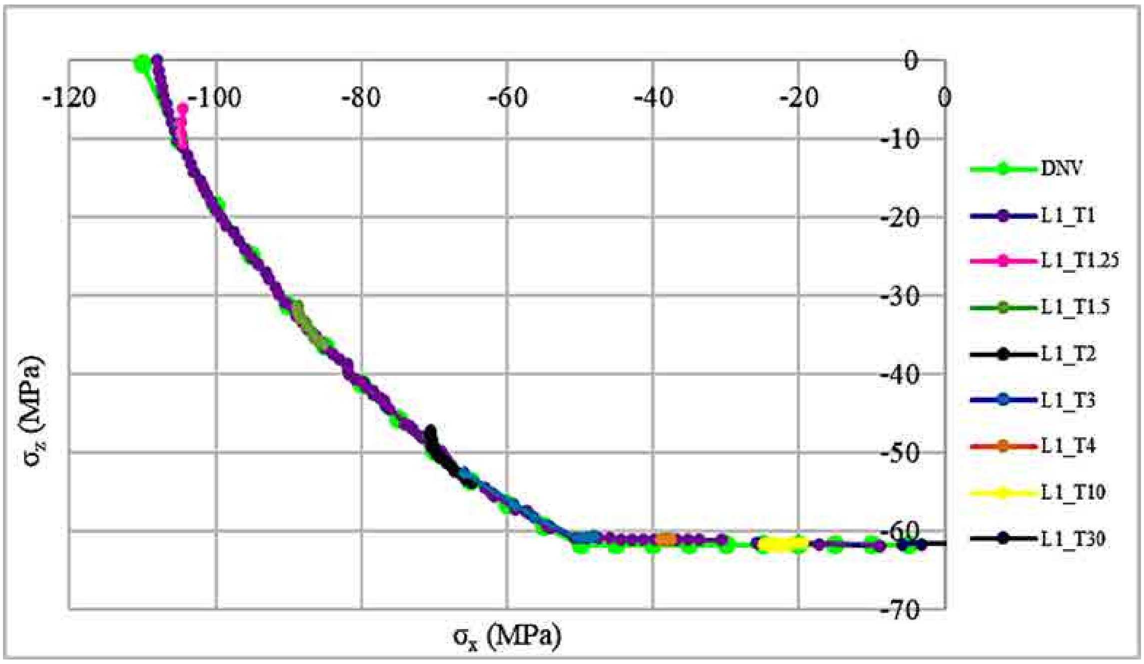

Fig. 3. *Ultimate strength of a stiffened panel with angle-type stiffeners obtained from finite element analysis and with the DNV interaction equations*

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