ISS

Institute of Steel Structures

Newsletter

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National Technical University of Athens
School of Civil Engineering

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Institute of Steel Structures - NTUA / January 2024

Designed & formatted by: **Aikaterini Michaltsou**

Front cover: **10th National Conference of Steel Structures**

Welcome to the new issue of ISS-NTUA Newsletter!

Dear students, colleagues, alumni and friends,

Already the first month of 2024 is over, and it is time for the new issue of our bi-annual Newsletter, providing a quick update of a selection of our teaching and research activities.

Prof. Vamvatsikos reports on the upcoming ERIES-RACKSLIDE project that will bring together 7 universities, one association of manufacturers and 5 supporting industrial partners to research rack pallet-sliding by means of tests, to be carried out at the 9DLAB facility of EUCENTRE, aiming at providing data for the next edition of EN16681.

For the Hellenic steel structures community the main event of 2023 was the 10th National Conference of Steel Structures, which took place in Athens on October 19 and 20. It was co-organized by the Steel Structures Research Society (SRSS) and the Technical Chamber of Greece, with a strong participation by ISS students, staff and faculty. Ms. Dasiou and Mr. Spiliopoulos present some of the highlights of the conference in the main article of this issue.

Experimental radial compression tests of hollow cylindrical specimens developed by filament winding that were carried out in our lab are briefly described by Prof. Gantes, Dr. Lignos, Mr. Katsatsidis and Mr. Papavieros.

Next, Mr. Karaferis, Dr. Melissianos and Prof. Vamvatsikos present simplified models to assess the seismic fragility of spherical pressure vessels.

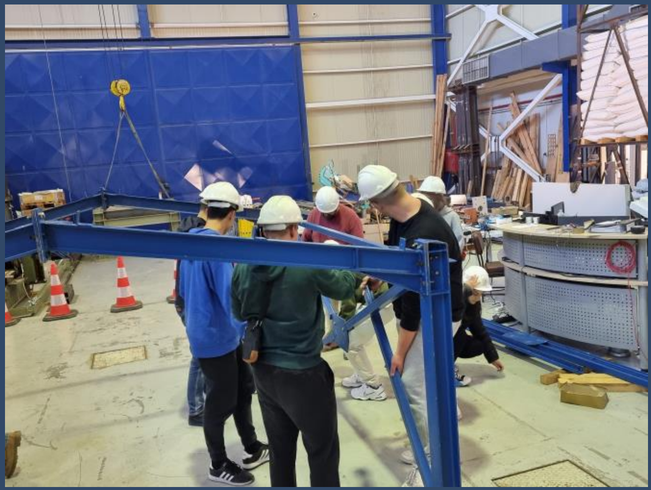
Last but not least, Ms. Antonodimitraki describes an experimental study to obtain the buckling resistance of angles for various support conditions, supervised by Prof. Vayas, carried out in the context of an ongoing research project called “New Steel” concerning the design of transmission lattice towers made of high strength steel.

We wish you all a productive and enjoyable year, and we hope to see you at one of our upcoming activities.

Charis Gantes

SCHOOL VISITS

On 20 November 2023 and on 13 December 2023 pupils from the high schools from Leros island and from Lygourio, respectively, visited the Institute of Steel Structures. They discussed with the faculty about civil engineering studies and profession and they also visited the laboratory area, where they assembled a scaled physical model of a simple steel building, thus getting hands-on structural engineering experience.



PUBLICATIONS

In 2023 the members of the Institute have published 17 papers in international journals. For a full list of publications please visit: http://labmetalstructures.civil.ntua.gr/cms/en/research/publications

LECTURES

The Institute of Steel Structures at NTUA in cooperation with the Hellenic Steel Structures Research Society continued the tradition of organizing lectures addressed to students and practicing engineers.

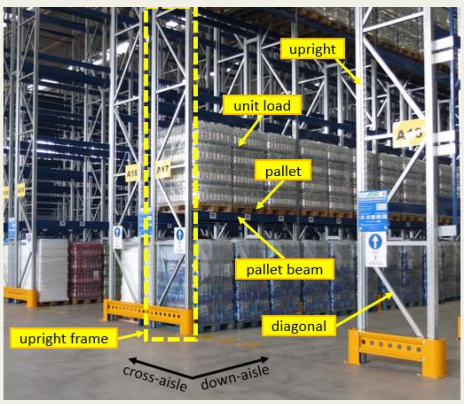
On 10 October 2023, Prof. Nicos Makris from the Southern Methodist University in the US gave a lecture entitled: “The inherent resilience of large cities to natural hazards: records, evidence and predictions”.

On 21 December 2023, Dr. Konstantinos Bakalis made a presentation on the “Behavior of steel structures subjected to dynamic loads”.

Rack pallet-sliding tests commencing on 2024

ERIES-RACKSLIDE brings together 7 universities, one association of manufacturers, and 5 supporting industrial partners with active interest in researching pallet sliding, to conduct innovative investigations that will form the state-of-art in content-structure-sliding interaction and inform the future of EN16681, the seismic rack-design standard. Racking systems form the backbone of modern logistics and goods supply chains, lying at the core of every physical product route from manufacturer to consumer. The vast majority stores palletized goods that stay put only by the force of gravity and friction. This is a potentially vulnerable situation that has been severely tested by recent earthquakes (Figure 2), resulting in disruptions of operation and some spectacular collapses. Presently, there are evident gaps in the slide-proof design of racking systems and even in their sliding assessment, both at the professional and the academic level.

To fill in such gaps, ERIES-RACKSLIDE will employ the 9DLAB facility of EUCENTRE (https://eries.eu/ta1-transnational-access-to-9dlab-shaking-table-and-mobilab/) to replicate the dynamic loading at the top and bottom of a specimen equivalent to two loading levels (i.e., stories) of a racking structure. The Institute of Steel Structures team is led by Prof. D. Vamvatsikos, assisted by Dr D. Tsarpalis, Dr. C. Lachanas, and soon-to-be-Dr A. Chatzidaki.



(a)

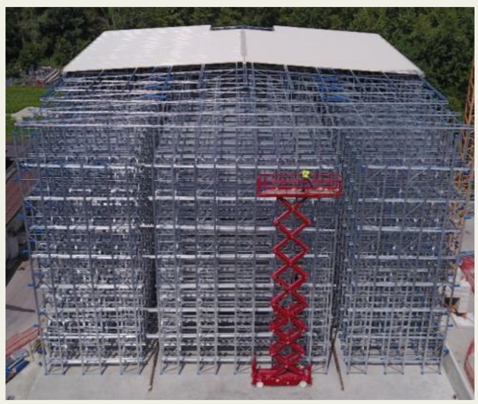

(b)

Fig. 1
(a) Structural components of an APR system and definition of cross- and down-aisle directions;
(b) Example of a multi-depth ARSW in the construction stage

In this effort, it is joined by ETH Zurich, the University of California, Berkeley, the University of Innsbruck, the Technical University of Cyprus, the University of Birmingham, and Aarhus University, as well as five racking manufacturers (SACMA, Mecalux, Metalsistem, Modulblock, Armes), and the Italian Association of Lifting-Handling-Racking (AISEM). Testing is expected to commence within 2024 and results will be due by early 2025. Stay tuned for updates as preparations heat up during the year!


(a)


(b)

Fig. 2 (a) Content sliding along the cross-aisle direction (Castiglioni et al., 2018) and (b) rack collapse due to pallet falling off (Clifton et al., 2011).

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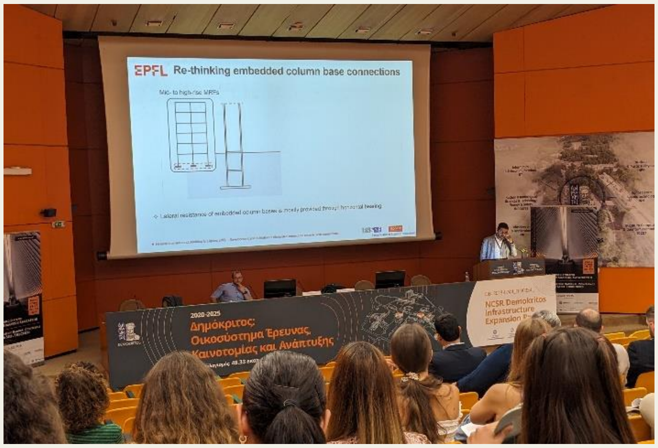
[2] Clifton, C., Bruneau, M., MacRae, G., Leon, R., Fussell, A. (2011). Steel structures damage from the Christchurch earthquake series of 2010 and 2011. Bulletin of the New Zealand Society for Earthquake Engineering, 44(4), 297–318. https://doi.org/10.5459/bnzsee.44.4.297-318

by Dimitrios Vamvatsikos

10th National Conference of Steel Structures

ATHENS, 19-20 OCTOBER 2023

On October 19 and 20, 2023, the 10th National Conference of Steel Structures was successfully organized by the Steel Structures Research Society (SRSS) and the Technical Chamber of Greece, in the facilities of the National Centre for Scientific Research "Demokritos" in Athens. The Steel Structures Research Society (SRSS), aiming to provide a forum for the exchange of knowledge, innovative research and remarkable construction projects between designers, contractors, researchers, suppliers and students who are interested and active in the field of steel structures, is organizing the National Conference of Steel Structures every 3 years in different cities of Greece. Due to the COVID pandemic, the 3-year period between consecutive conferences was not preserved, and the present conference took place 6 years after the previous one of 2017.



The organizing committee of the conference consisted of Ioannis Vayas, SRSS President, Andreas Spiliopoulos, SRSS Treasurer, Maria-Eleni Dasiou SRSS General Secretary, and Eirini Vourlakou, Architect.

The proceedings of the conference included 91 papers, which met the scientific criteria of novelty and academic excellence, and were subjected to double blind peer-review by the conference scientific committee. All manuscripts were distributed to the attendees in pdf format and are due to be uploaded soon on the SRSS' website (www.eeme.ntua.gr). The context of the presented papers, was within the scope of the following topics:

- Innovative research on steel and composite structures
- Strength, stability, fatigue, durability, serviceability
- Connections
- Seismic resistance and dynamic behavior of steel and composite structures.
- Innovative methods in the design, fabrication and erection of metal and composite structures.
- Remarkable steel construction projects (residential and office buildings, industrial buildings, bridges, masts and towers, tanks and silos, chimneys, thin-walled constructions, coverings of large openings, stadiums, gymnasiums, special projects).
- Steel behavior and resistance under fire.
- Sustainability of steel structures.
- Regulations and specifications
- Architectural applications of steel structures.

Following the tradition of the previous nine conferences, five distinguished speakers were invited to present their work in special sessions:

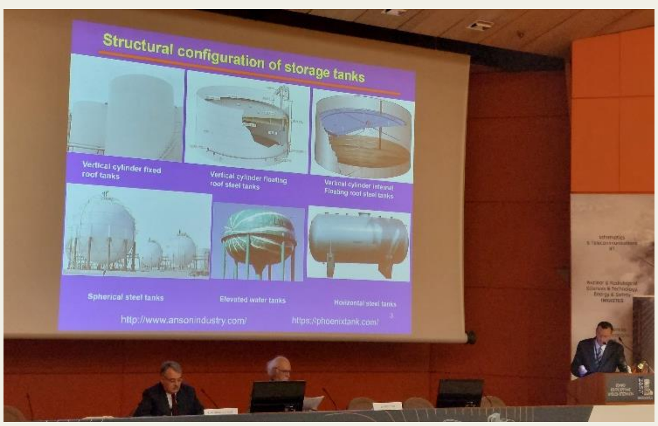
Manfred Grohmann, Professor and Chairman of the Supervisory Board at Bollinger + Grohmann

Thomas Lavigne, Architect at Lavigne et Chéron-Architectes

Francesco Morelli, Assistant Professor, Università di Pisa

Charis Gantes, Professor, NTUA

Pavlos Thanopoulos, Assistant Professor, NTUA



In the framework of the conference, a ceremony was held, where the three best theses in the field of steel and composite structures, conducted and presented in a Greek university within the timeframe of 2020-2022, were awarded. In total, 19 theses entered the competition and the evaluation committee consisted of members of the scientific community, who had not supervised any of the students participating in the competition. The competition and prizes were named after Professor Georgios Ioannidis, who passed away in 2022, in honor of his work and contribution to the steel structures community. The award winners were the following:

1st prize [1.000,00€]:
Nikolaos Michopoulos, «Numerical simulation of ring flange connections in wind turbine towers using hollow sections», Supervisor: C. Gantes

2nd prize [500,00€]:
Vasileios - Minoas Bampatsikos, «Structural design of a steel bridge with two consecutive diagonal arches and composite deck», Supervisor: P. Thanopoulos

3rd prize [500,00 €]:
Giorgos Pantazis, «Design of deployable shelters for emergency response», Supervisor: C. Gantes

Apart from the thesis awards, and within the scope of attracting and familiarizing young engineers with the steel structures community, the three best student term projects prepared in the framework of NTUA's Advanced Steel Structures course were selected and awarded. All award-winning students presented their work in a special session. The awarded students were Alexandros Avgerinos, Antonios Kotsias, Nikitas Tserlentakis, Andreas Giannoutsos, Epaminondas Koutsokeras, Gerasimos Stamatelatos, Bushra Rishmawi, Yasmin Beram, Danai Chamorousou-Lykourinou.

During the closing ceremony of the conference, an honorable award was given to three eminent colleagues, in recognition of their long-term and valuable contribution to SRSS and their work and contribution to the dissemination and development of steel structures in Greece: Ioannis Ermopoulos, Emeritus Professor at NTUA, Dr. Phaedon Solon Karydakis, Structural Engineering Consultant, and Antonios Karamanos, Structural Engineering Consultant.

Warm thanks are expressed to the sponsors of the conference:

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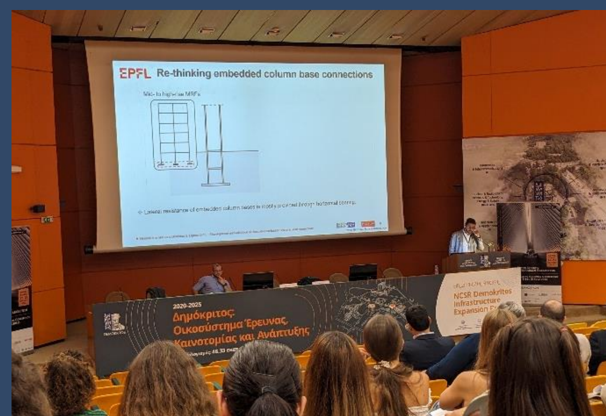
by Andreas Spiliopoulos
Maria-Eleni Dasiou



Experimental radial compression tests of hollow cylindrical specimens developed by filament winding

Experimental static radial compression tests of hollow cylindrical specimens developed by filament winding have been recently carried out at ISS NTUA. A total of five (5) specimens have been delivered by Delta MPIS. The specimens had an average outside diameter of 223mm, average thickness of 11.8mm and height of 151.1mm. The tests were carried out in a universal testing machine of type INSTRON 300LX, with a hydraulic actuator of 300 kN capacity. The main objective of the tests was to obtain the strength and radial stiffness of the specimens for this type of loading. For that purpose, the specimens were supported along the bottom generatrix on a stiff plate, while their top generatrix was pushed downwards by another stiff plate connected to the actuator (Fig. 1). Initial lateral stability of the specimens was ensured by placing double-sided tape along the bottom and top generatrices, while further lateral stability during the execution of the test was provided by friction.

The imposed vertical displacement and corresponding vertical load were reported by the testing machine and recorded in load – vertical displacement graphs. The obtained load-displacement curves for all specimens are illustrated in Fig. 2.

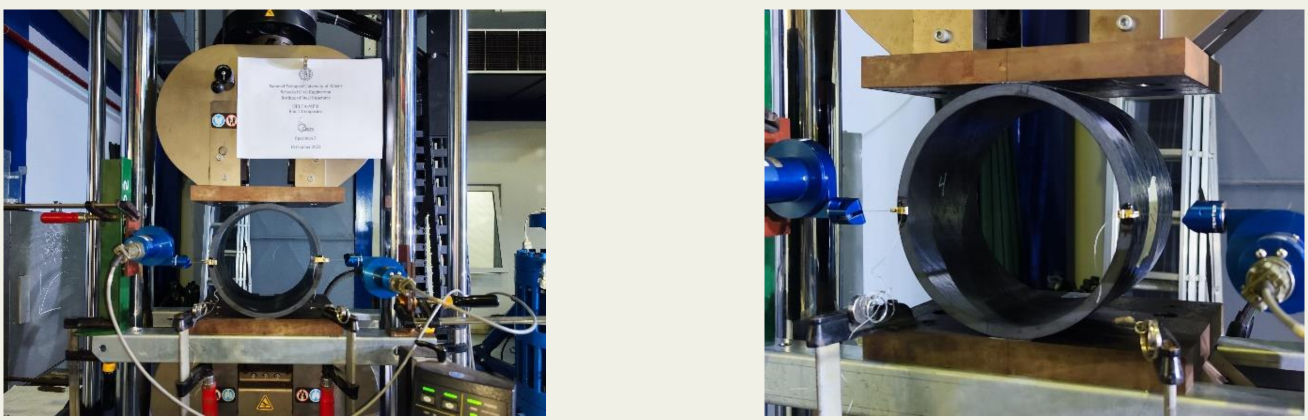


Fig. 1 Typical specimen on testing machine

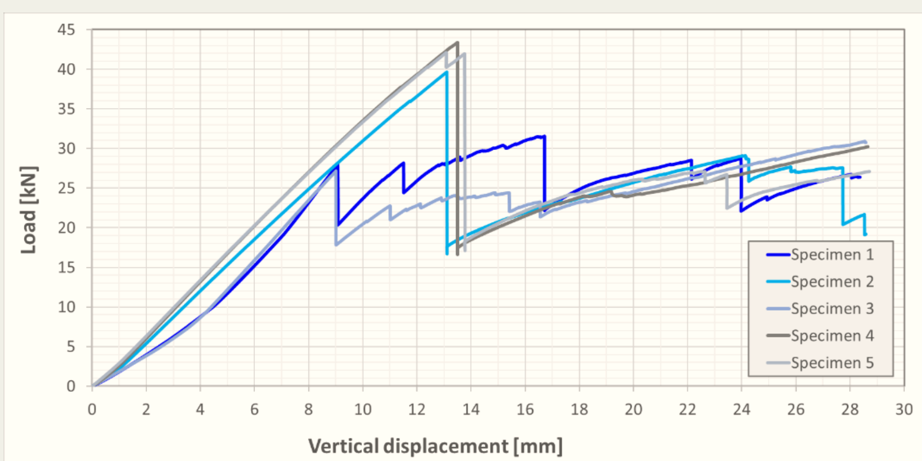


Fig. 2 Load- vertical displacement curves of all specimens

All specimens behaved nearly linearly up to failure (Fig. 2), exhibited significant deformation capacity (Fig. 3) and failed by delamination (Fig. 4). After removal from the testing machine, the specimens recovered their original cylindrical shape to a large extent (Fig. 5).

Fig. 3 Deformation of typical specimen

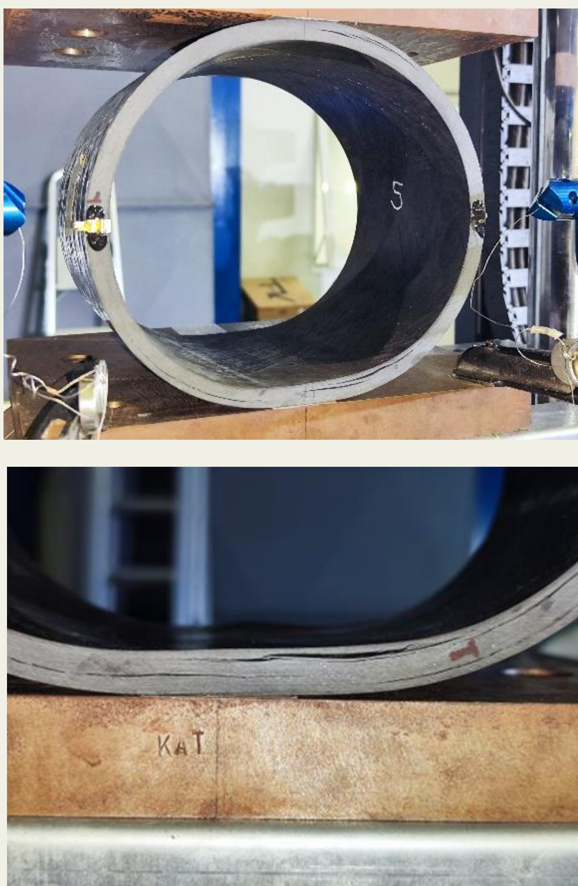


Fig. 4 Failure modes of typical specimens

Reasonably good repeatability was observed for three of the specimens, while the two other specimens failed at substantially smaller load, possibly due to imperfections in their manufacturing. For the three specimens that seem to be more representative, the load and vertical shortening at first delamination were in the order of 40kN, and the corresponding vertical displacement was approximately equal to 13mm, yielding an approximate radial stiffness of 3kN/mm. The corresponding horizontal expansion of the middle diameter was approximately equal to 9.5mm, giving a ratio of vertical shortening to horizontal expansion of approximately 1.37.

Fig. 5 Typical specimen after testing

by Charis Gantes, Xenofon Lignos,
Stylianos Katsatsidis, Spyridon Papavieros

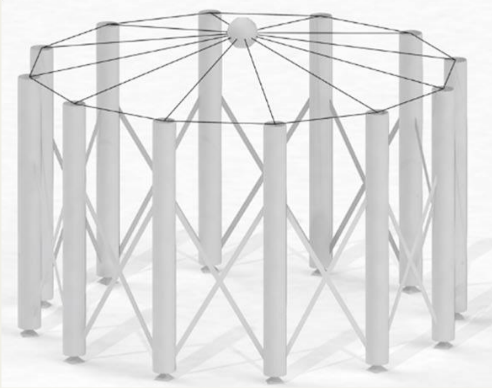
Simplified models and seismic fragility of spherical pressure vessels

Spherical pressure vessels (Fig. 1) are typical structures found in oil refineries and tank farms for the storage of gaseous fuels, such as propane and butane. The structure consists of a steel sphere that is circumferentially supported by braced or unbraced steel columns. The geometry of the vessel is denoted by the diameter and the average shell thickness of the sphere, the height to the equator of the sphere, as well as the cross-section and the total height of the columns. The latter usually have circular hollow sections.

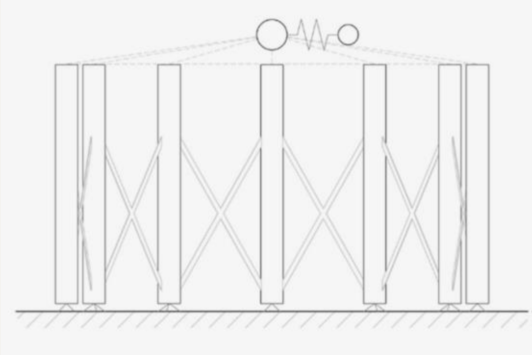
Spherical pressure vessels can be numerically modeled using either rigorous 3D finite element models or simplified ones. In the former case, the sphere and the supporting system (columns and potential bracing) are meshed with shell finite elements and the stored fuel is modeled with appropriate 3D elements in order to simulate the response of the liquified gas during the earthquake excitation, as well as its interaction with the steel shell. This approach yields reliable results when the interest is on issues like shell buckling and column-sphere connection. However, it comes with very high complexity and increased computation time. Contrarily, a simplified (reduced-order) model is the appropriate choice for seismic risk assessment studies, where numerous nonlinear dynamic analyses are required to assess the structure's mechanical behavior to multiple levels of seismic intensity.

Fig. 1 Schematic illustration of typical spherical pressure vessels

A reduced-order model that accounts for the salient characteristics of the structure and its most important failures modes is developed (Fig. 2).



(a) Model 3D view; impulsive mass located at the center of the vessel and connected to the supporting system



(b) Introduction of convective mass being connected to the impulsive one via translational springs

Fig. 2 Proposed reduced-order numerical model of a typical spherical pressure vessel with X-braced legs

The main characteristics of the model are the following:

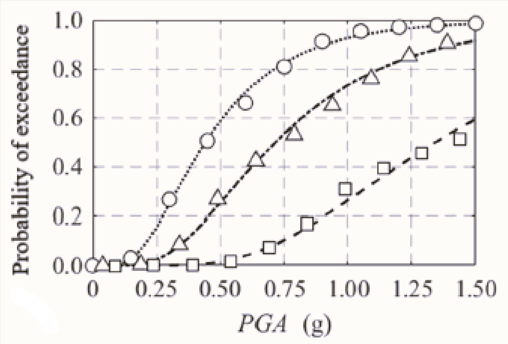
- The fluid mass is reduced to its impulsive and convective components; the stored material is represented by two point masses.
- The flexibility of the spherical shell and its internal pressure are neglected, as the latter is actually beneficial against any potential local buckling occurrence.
- The flexibility of the supporting system is the main contributor to the entire structure's flexibility.
- The sphere-column connection is assumed to be appropriately designed and details, thus not expected

to fail prior to the supporting system.

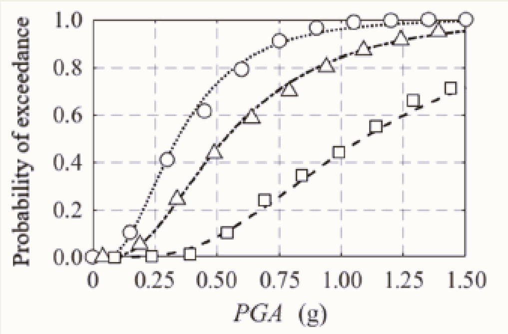
- The impulsive mass is located at the center of the vessel and is connected to the supporting system via rigid links.
- The convective mass is connected to the impulsive one via translational zero-length springs.

The dynamic response of the spherical vessel is evaluated using the horizontal displacement that is calculated at the center of the spherical vessel at the location of the impulsive mass. Three progressive and distinct damage states (DSs) are introduced to assess the vessel's structural integrity. DS1 is attained on the first yielding of any brace in tension. Progression to DS2 is signaled by the yielding of more than 50% of the braces in tension, indicating non-negligible damages. Finally, DS3 occurs when any of the braces fails in tension, leading to potentially catastrophic failure. Appropriate limit state thresholds are defined in terms of the horizontal displacement at the center of the vessel, following nonlinear static analysis.

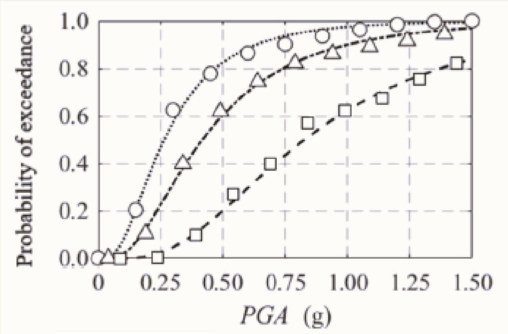
A typical spherical pressure vessel is examined as a case study. The diameter of the sphere is 20.22m, the average shell thickness is 42mm, and the height of the equator of the sphere is 13.63m. The support system consists of 12 columns of CHS1100x30 (lower part) and CHS1100x25 (upper part) cross-sections and are X-braced (braces are 250x35mm plates). The steel confronts to grade SA 572 Gr. 50. The proposed reduced-order model of the structure is analyzed via Incremental Dynamic Analysis using a set of 30 (non-pulse-like, non-long duration) hazard-consistent natural ground motion records from the NGA-West2 database. The peak ground acceleration (PGA) is adopted as the intensity measure, which ensures the flow of the seismological information from the seismic hazard analysis to the structural analysis. The seismic fragility curves of the vessel are depicted in Fig. 3, where the empirical fragility curves from the analysis are presented with single markers and the lognormal fittings are shown with continuous lines. At this point, it should be pointed that pressure vessels are filled to different levels that may vary within a single day. The fill ratio (FR) determines the structural behavior as it defines the mass of the structure. Therefore, considering always the worst-case scenario of a fully filled vessel, i.e., FR = 0.95, in a seismic risk assessment study may not yield realistic results in terms of risk estimates. To this end, it is useful to examine the fragility of the vessel at different fill ratios and perform appropriate probabilistic calculations in order to take into account the variability of FR. The fragilities of the vessel for three indicative fill ratios, i.e. FR = 0.55 (half-filled), FR = 0.75 (almost filled), and FR = 0.95 (fully filled), are shown in Fig. 3. It is observed that for lower FRs the probability of exceedance of any DS is lower given the same PGA level, compared to vessels with higher FRs. This evidence highlights that accounting for the variability of FR is required within a risk assessment study and it cannot be replaced by the ultra-conservative case of a fully filled vessel (FR = 0.95).



(a) Fragility curves for FR = 0.55



(b) Fragility curves for FR = 0.75



(c) Fragility curves for FR = 0.95

Fig. 3 Pressure vessel fragility curves for various fill ratios (FR)

by Nikolaos D. Karaferis, Vasileios E. Melissianos, and Dimitrios Vamvatsikos

Buckling resistance of angles for various support conditions: An experimental study

Despite their simple geometry, angles are quite peculiar structural members exhibiting more complex structural behaviour compared to members with other common cross-sections. Angles have a wide application in lattice towers as well as in various types of structures where mostly used as bracing members. The fact that angle bracings are usually connected to the rest of the structure by bolting or welding only one of their legs results in eccentric and oblique support conditions rendering their design even more complicated.

In Europe, the design of angle bracing members is traditionally executed according to the effective slenderness method, which is covered by two relevant normative standards, i.e. the prEN 1993-3 and the EN 50341-1. However, this method (a) can lead for some cases to inaccurate results, both overconservative and unsafe [1] and (b) it is not validated for high strength steel (HSS) members. Recently, a new design approach, based on interaction formulae, has been developed in the framework of the ANGELHY RFCS project and included as Annex F in the new version of EN 1993-3. Although promising and validated for HSS, this method cannot be directly applied for the design of angle bracings since there is no guidance on how to evaluate the required critical buckling load and the developing bending moments, both greatly affected by the support conditions. In the framework of a joint PhD thesis between the National Technical University of Athens and the University of Liege, the behaviour of angle members, including the influence of the support conditions, is being studied extensively.

In this context, ISS contributes to an ongoing research project called “New Steel” concerning the design of transmission lattice towers made of high strength (S460) steel. The aims of the project include the development of design rules for angle bracings and its outcomes will have direct application on the design of a 240 m high power transmission tower planned to be erected soon in Belgium. Partners of the project are the University of Liege, the ELIA Transmission Belgium and the ArcelorMittal Luxemburg whose teams are leaded by Prof. J.F Demonceau, Mr. J. Maesschalck and Mr. M.O. Anwaar, respectively. ISS participates with Prof. I. Vayas and the doctoral candidate Ms. S. Antonodimitraki.

In the framework of the “New Steel” project, buckling tests on angle members made of both compact and slender cross-sections, with various slenderness, and bolted only on one leg at their extremities with one or two bolts were conducted at the “Laboratoire de Mécanique des Matériaux et Structures” of the University of Liège in Spring 2023. The buckling tests were complemented with coupon tests for material characterisation, and measurements of the residual stresses and of the initial geometric imperfections. These additional measurements provided all the necessary data for the proper validation of the numerical models and subsequently of the analytical design formulae to be developed.

The residual stresses of the examined profiles were evaluated according to the sectioning method. An indicative distribution pattern of the measured residual stresses is illustrated in Fig. 1.

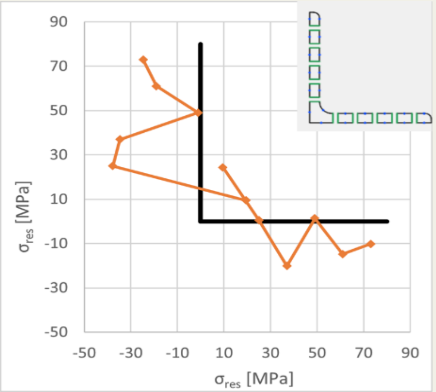


Fig. 1 Measured residual stresses of a S460 L80.8 profile

The initial geometric imperfections were measured with an in-house laser system as presented in Fig. 2(a). The measurements were appropriately post-processed in order to obtain the distribution of each type of relevant imperfections for comparison with the normative acceptable limits and for inclusion in the numerical models. The geometric imperfections along the length of one of the specimens as derived from the post-processing are presented in Fig. 2(b).

(a)

(b)

Fig. 2 (a) Laser system for geometric imperfections measurement, (b) Distributions of various types of measured imperfections

The response of the specimens throughout the buckling tests was monitored with several displacement transducers and inclinometers. The former were located at key positions along the specimens, while the latter at their extremities measuring the rotations of both the specimens and their supporting gusset plates. Moreover, the strain and displacement fields in the region of the lower joint of the specimens were recorded with a 3D Digital Image Correlation system. For the interpretation of the measurements, a software was developed in MATLAB platform to process the raw measurements and derive tables, diagrams and graphs from the processed data (Fig. 3).

From the analysis of the measurements, it was found that most of the specimens exhibited a flexural torsional (FT) buckling failure mode (Fig. 4a). Only the shortest specimens with slender cross-sections failed due to an interaction of global FT and local buckling of the bolted leg in the region of the end joints (Fig 4b).

More information about the experimental campaign can be found in the corresponding technical report [2].

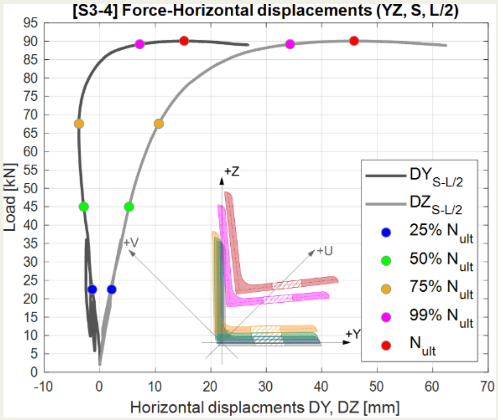


Fig. 3 Load-Horizontal displacement curves and deformed shape of the middle cross-section at various loading levels

(a)

(b)

Fig. 4 Characteristic failure modes of a long (a) and a short (b) specimen with slender cross-section and 1-bolt end joints

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by Sofia Antonodimitraki

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