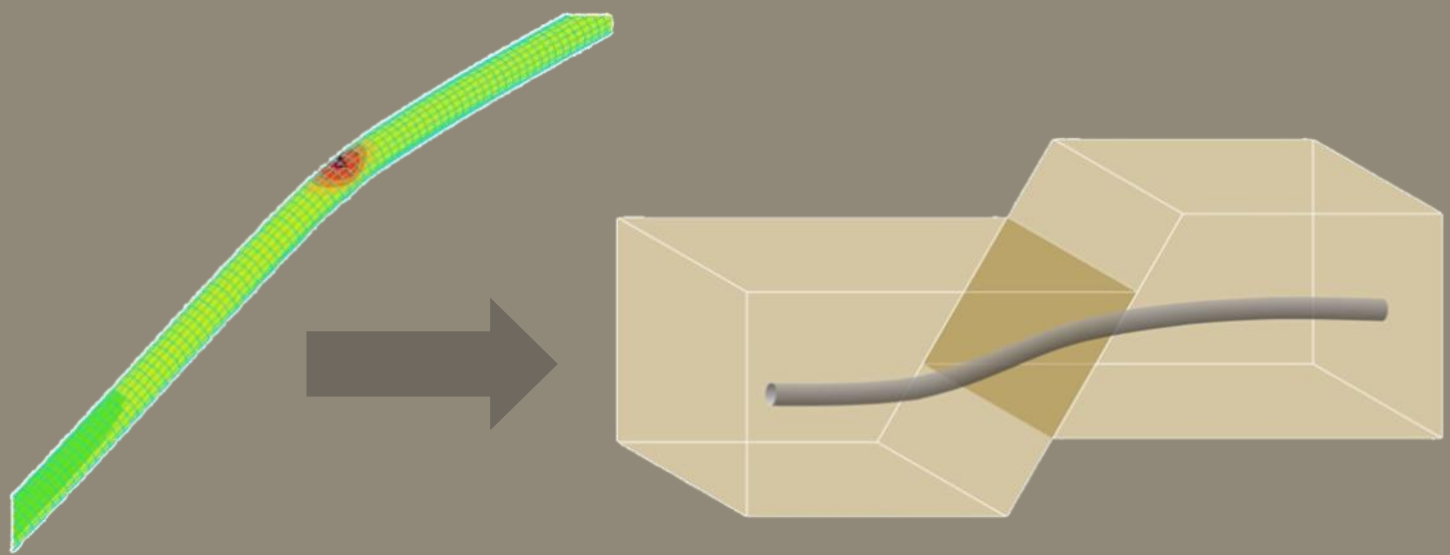
ISS

Institute of Steel Structures

Newsletter

July 2024



National Technical University of Athens
School of Civil Engineering

Table of contents

Institute of Steel Structures - NTUA / July 2024

Designed & formatted by: **Aikaterini Michaltsou**

Front cover: **Onshore buried steel fuel pipelines at fault crossings**

Welcome to the summer 2024 issue of ISS-NTUA Newsletter!

Dear students, colleagues, alumni and friends,

As the academic year comes to an end, it is a time to reflect on our recent accomplishments and plan ahead.

In the present issue of our bi-annual Newsletter, we are very proud of two recent distinctions by our younger colleagues. Dr. Vasileios Melissianos is the recipient of the prestigious 2024 ASCE State-of-the-Art of Civil Engineering Award for his work on critical analysis and design aspects of onshore buried steel pipelines at fault crossings. Sofia Antonodimitraki won the Best Paper Award at the Nordic Steel Construction Conference 2024 for her research on the effect of joints on the buckling resistance of angle members. Summaries of both winning papers are included in the present issue.

Other young members of our community are also represented in this issue. Last February Akrivi Chatzidaki successfully defended her PhD thesis on “Risk and resilience assessment of highways under multiple natural hazards” supervised by Prof. Vamvatsikos, of which a summary is included here. Dr. Stefanos Gkatzogiannis highlights his numerical and experimental investigation of the dynamic behaviour of reconfigurable buildings, carried out as part of his Marie Skłodowska-Curie Grant at the University of Cyprus. Last-year undergraduate students Alexandros Avgerinos, Antonis Kotsias, Nikitas Tserlentakis, Eleftherios Chatzellis and Ilias Chatzidimitriou briefly present the preliminary structural design of an aircraft maintenance hangar, which they carried out as their project for the “Integrated structural design” course, demonstrating significant maturity for their age.

Last May a strong ISS delegation participated in a workshop between steel structures groups from most Greek universities, which was organized in the city of Xanthi, highlighting educational, research and technological activities in the field and demonstrating the significant progress in steel structures achieved in the country in recent years. The contents of the meeting are summarized in a short article.

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

Charis Gantes

ASCE AWARD

Dr. Vasileios Melissianos, Senior Researcher at NTUA and member of ISS has been selected to receive the prestigious 2024 ASCE State-of-the-Art of Civil Engineering Award that rewards the industry's most gifted practitioners who review and interpret state-of-the-art methods, theories, and ideas for the benefit of their colleagues.

https://www.asce.org/career-growth/awards-and-honors/asce-state-of-the-art-of-civil-engineering-award

The award will be presented to Vasileios during the ASCE 2024 Convention in Tampa, FL in October 2024.

The awarded paper is "Onshore Buried Steel Fuel Pipelines at Fault Crossings: A Review of Critical Analysis and Design Aspects," ASCE Journal of Pipeline Systems Engineering and Practice, September 2022. doi:

https://doi.org/10.1061/(ASCE)PS.1949-1204.0000661

The study offers a state-of-the-art review of three aspects: the calculation of the design fault displacement, aspects of the numerical modeling, and the alternative pipe protection measures. Firstly, the deterministic and probabilistic approaches for estimating the design fault displacement are discussed and compared to showcase the corresponding advantages and disadvantages, but mainly to inform and alert designers about the achieved level of safety and conservatism in each approach. Secondly, the code expressions for computing the properties of the soil springs are compared to the latest research findings, highlighting their limitations. Moreover, in the case of employing a 3D model, the available options for calculating the equivalent springs that replace the remaining pipe length beyond the modeled length are presented. Finally, the available and proposed seismic countermeasures are examined systematically for the first time. The focus is on the utilized mechanism for pipe strain reduction, the applicability of each measure, and the required effort for numerical modeling. A set of preliminary criteria is developed (categorized into design, construction, and procurement) for the selection of the appropriate measure in practice.

NORDIC STEEL AWARD

Sofia Antonodimitraki, member of ISS pursuing a joint PhD in collaboration with the University of Liège, won the "Best Paper Award" at the Nordic Steel Construction Conference 2024 for her research paper entitled "Effect of Joints on the Buckling Resistance of Angle Members Made of S460 Steel – Experimental Investigations". The conference was held in Luleå, Sweden between 26-28 June 2024. Co-authors of the paper are M.Z. Bezas, J. Maesschalck, O. Anwaar, I. Vayas and J.F. Demonceau.

The work presents a series of buckling tests on steel angles bolted on one leg at their extremities. The aims of the study were the better understanding of the structural behaviour of such members and the collection of reliable data for the validation of numerical and analytical models. The final goal of this ongoing research is the development of rational design rules for angles with various support conditions. The experimental campaign was carried out at the framework of the "New Steel" project funded by ELIA Group, Belgium and ArcelorMittal, Luxembourg.

An extended abstract of this work can be found in the January 2024 ISS Newsletter, while the full paper can be accessed at https://doi.org/10.5281/zenodo.12384699.

Further advancements concerning the development of a numerical model able to reproduce the physical tests can be found in the following pages of the present issue.

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, researchers and practicing engineers.

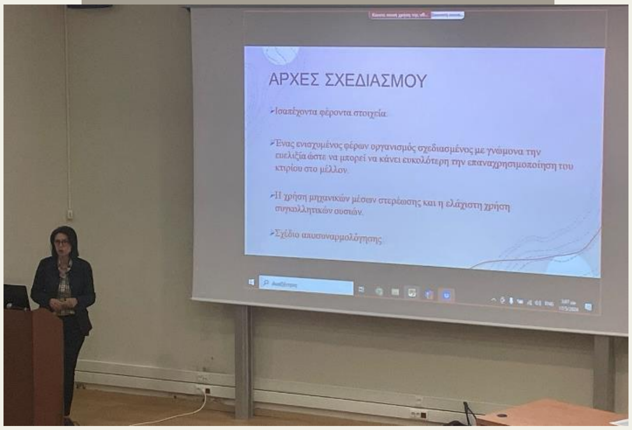
On 21st March 2024, Mr. Charis Bouras, from Rijkswaterstaat, the Ministry of Infrastructure and Water Management in the Netherlands, shared his experience on "Design and reconstruction of old steel bridges".

On 3rd June 2024, two very interesting lectures were delivered by colleagues from Opole University in Poland: "Soil-steel underground structures (culverts, bridges, pipes, tunnels)" by Prof. Damian Beben, and "Fire safety of buildings and installations" by Dr. Krzysztof Drozdzol.

Educational, research and technological activities of Greek universities in the field of steel structures

ISS had a strong representation in a workshop organized by the Hellenic Research Structures Research Society and the Democritus University of Thrace (DUTh) on the "Educational, Research and Technological Activities of Greek Universities in the Field of Steel Structures". The workshop took place on Friday, May 17, 2024, in the Civil Engineering building of DUTh, in Xanthi. It was attended by students and faculty and was also broadcast online. ISS representatives included Ioannis Vayas, Charis Gantes, Dimitrios Vamvatsikos, Pavlos Thanopoulos, Andreas Spiliopoulos and Maria-Eleni Dasiou. In addition to NTUA and DUTh, delegations from the Aristotle University of Thessaloniki (AUTh) and the University of Thessaly (Uth) also participated in the workshop. The presentations included the following:

Educational activities on steel structures at DUTh	D. Tzourmakliotou, DUTh
Presentation of activities on steel structures at AUTh	E. Efthymiou, AUTh
Presentation of activities on steel structures at UTh	E. Mystakidis, UTh
General presentation of NTUA-ISS	Ch. Gantes, NTUA
Educational activities of NTUA-ISS	P. Thanopoulos, NTUA
Research activities of NTUA-ISS	D. Vamvatsikos, NTUA
Principles of sustainable design of steel structures	D. Tzourmakliotou, DUTh
Shape memory alloys in civil engineering	M. Ntina, AUTh
Cyclic plasticity & low-cycle fatigue	S. Karamanos, UTh
Field inspections and assessment	A. Spiliopoulos, NTUA
Behavior of steel structures at high temperatures	D. Pantousa, UTh
Steel-timber hybrid systems	Tz. Voyiatzis, AUTh
Monumental structures	M.-E. Dasiou, NTUA
Seismic response of multi-story steel buildings	K. Mpantilas, DUTh
Aluminum: material properties and applications	E. Efthymiou, AUTh
Transmission towers – Racks – Fatigue of bridges	I. Vayas, NTUA
Dumbbell-shaped hysteretic dampers for seismic retrofit of RC structures	O. Pecorari, UTh
Wind energy support systems	N. Stavridou, AUTh
Design of steel and composite bridges	P. Thanopoulos, NTUA
Risk assessment	D. Vamvatsikos, NTUA
Wind turbine towers – Pipelines – Photovoltaic structures	Ch. Gantes, NTUA



The commitment of all participants for further cooperation towards the advancement of steel structures in Greece was expressed.

by Charis Gantes

State of the Art of
Civil Engineering Award

Onshore buried steel fuel pipelines at fault crossings: A review of critical analysis and design aspects

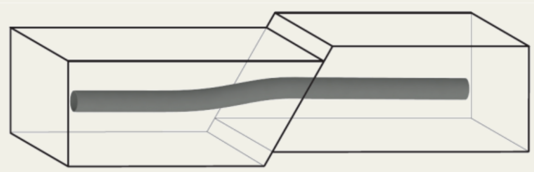
Introduction

Onshore buried steel pipelines have been proven to be the most efficient and cheap mode of transporting fuel from the wells, to the storage facilities and process plants, and finally to the customers. These transmission large-diameter pipelines' structural and operational integrity is essential for the safety and prosperity of society and the economy. A seismically-induced pipeline failure may result in injuries or fatalities, environmental pollution, monetary losses, and downtime of the energy supply chain.

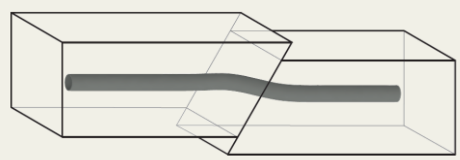
The investigation of past earthquake-related failures of pipelines has revealed that tectonic fault activation leads to most catastrophic failures. In such a case, the buried pipeline is forced to follow the ground movement, which might be a few meters, by developing excessive deformation and consequently very high stresses and strains.

The pipeline mechanical response due to faulting depends on the fault type. The pipe is subjected to bending and tension or compression in the case of normal (Fig. 1a) or reverse (Fig. 1b) fault type, respectively, while it is mainly subjected to bending in the case of strike-slip (Fig. 1c) type. The advancement of pipeline safety against natural hazards and in particular earthquakes remains a hot topic for society, the pipeline community, and the regulatory authorities. There is significant research effort on the assessment of buried continuous pipelines subjected to tectonic faulting.

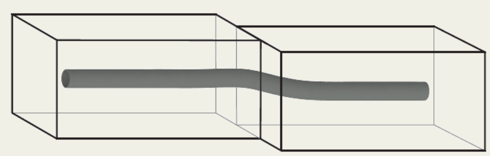
Nevertheless, three analysis and design aspects need to be further investigated and understood by researchers, designers, and pipe operators: (1) the estimation of the design fault displacement, (2) the critical details of the typically employed numerical modeling techniques for the analysis of pipelines, and (3) the available seismic countermeasures for the pipe protection.



(a) pipeline deformation due to normal faulting



(b) pipeline deformation due to reverse faulting



(c) pipeline deformation due to strike-slip faulting

Fig. 1 Pipeline deformation caused by (a) normal, (b) reverse, and (c) strike-slip fault rupture (the left block is the moving and the right is the stationary one)

Design fault displacement

Current international codes lack specific provisions for the computation of the design fault displacement, which is the earthquake load on the structure in the form of imposed displacement. This displacement is typically estimated via empirical fault scaling relations, featuring a deterministic approach that leads to an unknown level of conservatism and safety as only the dimensions of the fault are considered, while the actual earthquake recurrence rate on the fault is neglected. On the other hand, the employment of a full probabilistic analysis, typically the probabilistic fault displacement hazard analysis (PFDHA), requires a significant amount of specialized seismological data.

To provide a deeper understanding of these two approaches, a buried pipeline is considered to be intercepted by a short (38.41km length) normal fault with a high recurrence rate of 0.0425year^{-1} (mean annual number of earthquake events above magnitude 5.5), which is located close to Athens, Greece. The results are presented in Fig.2. The obtained values of fault displacement from the probabilistic analysis for specific return periods of 475, 2500, and 5000 years are presented in the first three bars. Then, the obtained values from three alternative sets of empirical fault scaling relations [Wells and Coppersmith (1994): WC1994, Leonard (2014): L2014, Thingbaijam et al. (2017): TMG2017] are presented in the last three bars, where the displacement is calculated based only on the fault length. Ignoring the fault productivity leads to an unknown level of safety and conservatism, while at the same time being not compatible with code requirements for designing at predefined levels of return period.

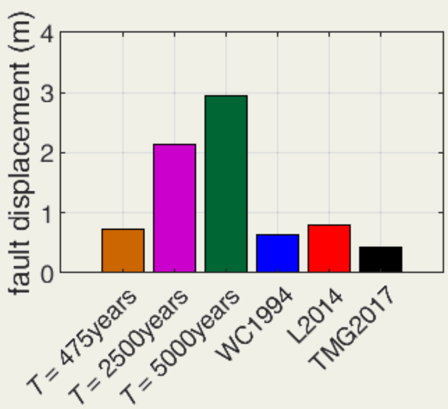


Fig. 2 Pipeline deformation caused by (a)normal, (b)reverse, and (c)strike-slip fault rupture (the left block is the moving and the right is the stationary one)

Numerical modeling

The structural response of the pipeline is typically assessed by employing numerical modeling techniques namely, a beam-type model or a continuum model.

Beam-type model:

The pipe is meshed into beam-type elements and the surrounding soil is modeled with nonlinear translational springs. Stress and strains are calculated at integration points on the cross-section and along the elements. This approach is routinely applied for the design via commercial software and is also presented in relevant codes.

The critical aspect of pipe modeling as a beam resting on a foundation is the force-displacement relations of each soil spring. The ongoing research efforts reveal that the current expressions in codes require further improvement. Therefore, the engineer should be aware of the code assumptions and restrictions because in some cases these curves may lead to either conservative and expensive or unsafe design depending on the soil properties and loading conditions at hand.

Continuum model:

The pipe is discretized into shell elements and the surrounding soil into 3D solid elements. The pipeline-soil interface is modeled with contact elements, as well as the interface between the two soil blocks. This approach allows the assessment of pipe local instability, any potential cross-section ovalization, and the implementation of advanced soil material laws. However, it is significantly time-consuming and requires a lot of computational power. Therefore, only a part of the pipeline can be modeled, i.e., the model length is limited and the pipe segments beyond this length up to the anchoring points should be represented by equivalent springs that model the axial deformation of the pipe. There are limited published studies that offer a roadmap to calculate these equivalent axial translational springs. The designer is required to select an approach based on the available data and the level of detail required.

Seismic countermeasures

The general recommendation during the pipeline route selection process is to avoid areas prone to geohazards, such as fault crossing. Yet, this cannot be always achieved in practice, for example, due to physical obstacles or the requirement to avoid environmentally sensitive areas. Thus, in case of a pipeline-fault crossing, specific seismic countermeasures are required to minimize as possible the development of excessive strains. The protection measures can be grouped into three categories based on the mechanism employed to achieve pipe strain reduction: (A) pipe strengthening, (B) soil friction reduction, and (C) complex measures.

The selection of the appropriate protection measure is based on a set of criteria given the current legislation and the pipe owner's specifications. A set of categorical criteria is defined to group the parameters that drive the selection and formulate a set of preliminary selection criteria, namely design, construction, and procurement.

The criteria are elaborated in Table 1.

Table 1. Preliminary selection criteria for pipe protection measures

Category	Criterion
1. Design	1.1 Compatibility with fault
	1.2 Compatibility with pipe–fault crossing geometry
	1.3 Compatibility with pipe cross-section geometry and steel grade
	1.4 Requirement for sophisticated analysis
	1.5 Requirement for experimental verification
	1.6 Compatibility with codes
2. Construction	2.1 Ease of on-site application
	2.2 Requirement for special installation equipment
	2.3 Special requirements for transportation to the construction site
3. Procurement	3.1 Availability in the market
	3.2 Production upon request
	3.3 High cost of purchase
	3.4 High cost of installation

Five protection measures, namely, wall thickness increase (pipe strengthening), pipe placement within culverts and backfilling with pumice (soil friction reduction), and introduction of flexible joints and route changing with high-radius bends (complex) are indicatively examined using the selection criteria of Table 1. The compliance of each measure to every criterion is presented in Table 2, demonstrating that the selection process is a multi-level cost-benefit analysis.

Lastly, it should be taken into account that:

- Protection measures are applied along the entire fault trace uncertainty length, thus affecting the cost-related criteria.
- Weight factors should be applied if necessary, depending on the case at hand. For example, if the crossing is located at a remote mountainous site, the transportation and installation costs might be very high.
- More than one protection measure might be selected to satisfy the design objectives.

This is a summary of the publication: Melissianos, V. E. (2022). "Onshore Buried Steel Fuel Pipelines at Fault Crossings: A Review on Critical Analysis and Design Aspects." ASCE Journal of Pipeline Systems Engineering and Practice, 13(4), 03122002. https://doi.org/10.1061/(ASCE)PS.1949-1204.0000661

Table 2. Illustrative examples of applying the preliminary selection criteria for pipe protection measures

Measure	Design						Construction			Procurement			
	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	3.1	3.2	3.3	3.4
Wall thickness increase	+	+	+	x	x	+	+	x	x	+	x	x	x
Pipe placement within culverts	x[+]	+	N/A	x	x	+	+	+	+	+	+	+	+
Backfilling with pumice	+	+	+	x	x	+	+	x	+	+	N/A	x	x
Introduction of flexible joints	+	+	N/A	+	+	x	+	x	x	+	+	+	x
Route changing with high radius	+	+	+	+	x	x	x	x	N/A	N/A	N/A	+	+

Note: +: yes / compliance / required, x: no / not required, N/A: not applicable

+ Compatible only with strike-slip fault mechanism

by Vasileios E. Melissianos

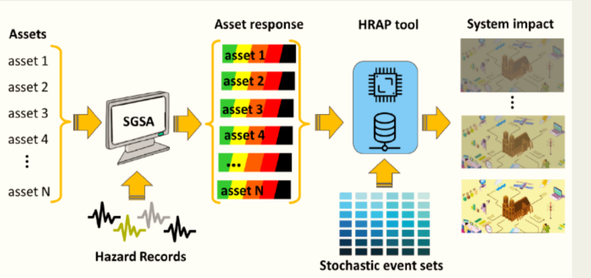
PhD Defense of Akrivi Chatzidaki

In February 2024, Akrivi Chatzidaki successfully defended her PhD dissertation entitled "**Risk and resilience assessment of highways under multiple natural hazards**" under the supervision of Dimitrios Vamvatsikos (Associate Professor NTUA).

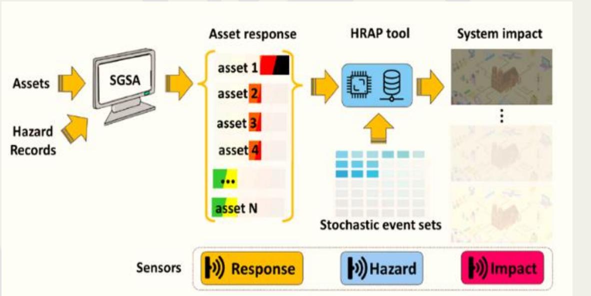
The Thesis focuses on developing a comprehensive framework for multi-hazard risk and resilience assessment of critical infrastructure, named HAPPI, that integrates a database of discrete event simulation results with real-time sensor information. The aim is to offer a holistic tool for pre-event assessment and rapid post-event inspection of critical infrastructure under multiple hazards. This framework is employed in the context of road infrastructure networks and is demonstrated in two case studies, i.e., the Metsovo-Panagia segment of the Egnatia highway in Greece with emphasis on the seismic and the wind hazards and the Taracena-Medinaceli segment of the A2 highway in Spain with emphasis on the wind hazard. In both cases, the impact of Climate Change on the wind hazard is considered. To achieve so, a state-of-the-art methodology is developed for spatially and temporally downscaling the numerical results of climate models in order to generate artificial time-series for wind that have a proper spatial and temporal resolution that allows assessing the risk for civil engineering structures.

The HAPPI framework utilizes multiple hazard and damage/loss scenarios, thus enabling rapid damage and consequence identification. To enhance the assessment resolution, a component-based approach is adopted for the critical highway assets that allows evaluating damage scenarios for individual structural components (such as piers of a bridge) and propagate them to assess the asset-level performance. For less influential assets, an asset-level treatment is followed to quantify damage and consequences at the global level of the entire structure. The asset interdependencies are then considered to assess the system-level consequences, which are quantified in terms of repair losses, downtime, and actions that the road operator shall take until repair actions have finished, i.e., close any lanes and/or reduce the speed limit in the open ones.

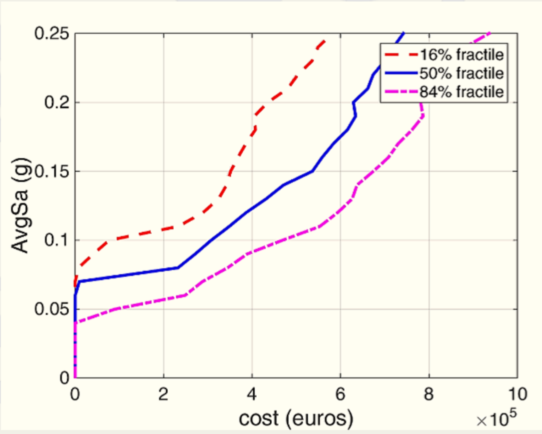
Overall, the proposed methodology comprises a unique approach for multi-hazard risk and resilience assessment of critical infrastructure networks. It allows tracing back the consequences after an event to individual components/assets and can help road operators establish inspection prioritization protocols and manage associated incidents, facilitating the rapid assessment of the state of the highway and optimal recovery to full functionality. The outcomes aim to be integrated into holistic decision support tools that can facilitate informed decisions of the stakeholders before and after potentially catastrophic events and can help the road operators efficiently inspect, maintain, and safely operate road infrastructure networks, efficiently mitigating and managing risks.



HAPPI framework for long-term pre-event risk assessment. All scenarios of asset response, stochastic events, and system impact are taken into account



HAPPI framework for short-term trans/post-event scenario risk assessment. Faded scenarios of asset response, stochastic events, and impact relay the incorporation or response, hazard, and impact sensors, respectively, reducing the uncertainty by pruning realizations that do not conform to observations.



Distribution of repair cost for the G1 bridge of Egnatia Odos for increased levels of the intensity measure, i.e., AvgSa.

Buckling resistance of S460 angles with various support conditions Numerical investigations

Best Paper Award

Although angles are being studied for more than a century [1], their structural behaviour is not yet fully comprehended, which is reflected by the known inaccuracies [2], [3] of the relevant design standards [4]. This is the reason why research on angles made of various steel grades and with various support conditions is still ongoing. ISS contributes, in the framework of the PhD thesis of the doctoral candidate Sofia Antonodimitraki, to a research project called “New Steel”, which includes experimental, numerical and analytical investigations on the buckling behaviour of S460 angles. Partners of the project are the University of Liege, the ELIA Group and the ArcelorMittal.

An experimental campaign on the buckling resistance of S460 angles bolted on one leg at their extremities was recently completed and part of the results were published in [5]. A numerical model able to reproduce the physical tests has also been developed. The model was built in ABAQUS software with 3D solid finite elements. The size of the elements was determined to achieve the highest efficiency with acceptable accuracy through mesh sensitivity analyses. The interactions between the different surfaces at the end joints were modelled in detail using appropriate contact properties.

A small pretension force was applied in the bolts corresponding to snug-tightening condition. A bi-linear material model was used for steel whose properties were determined through coupon tests. Both geometric imperfections and residual stresses were included in the model with their actual amplitudes as measured in the Laboratory. For the evaluation of the ultimate resistance of the specimens, geometrically and materially nonlinear analyses were executed applying the loading under displacement control at the top of the specimen as done during the physical test. A graphical representation of the simulation procedure is presented in Fig. 1.

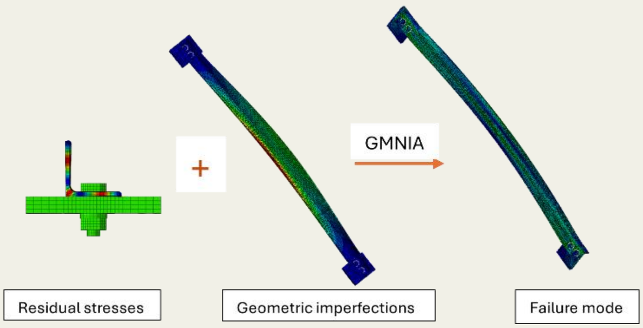


Fig. 1 Simulation procedure

The validity of the model was verified though comparisons to the experimental results in terms of initial stiffness (Fig. 2), failure mode (Fig. 3) and ultimate resistance (Fig. 4).

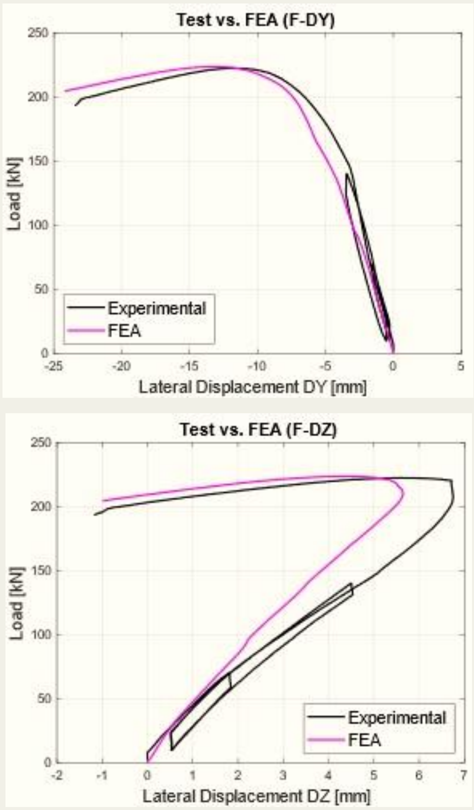


Fig. 2 Comparison of Load-Horizontal displacement curves

Fig. 2 depicts the comparison between the experimental and numerical Load-Horizontal displacement curves. A good agreement between the test and the numerical results can be observed.

Moreover, the model is able to catch both the global as well as the local failure modes exhibited by the specimens, as shown in Fig. 3.

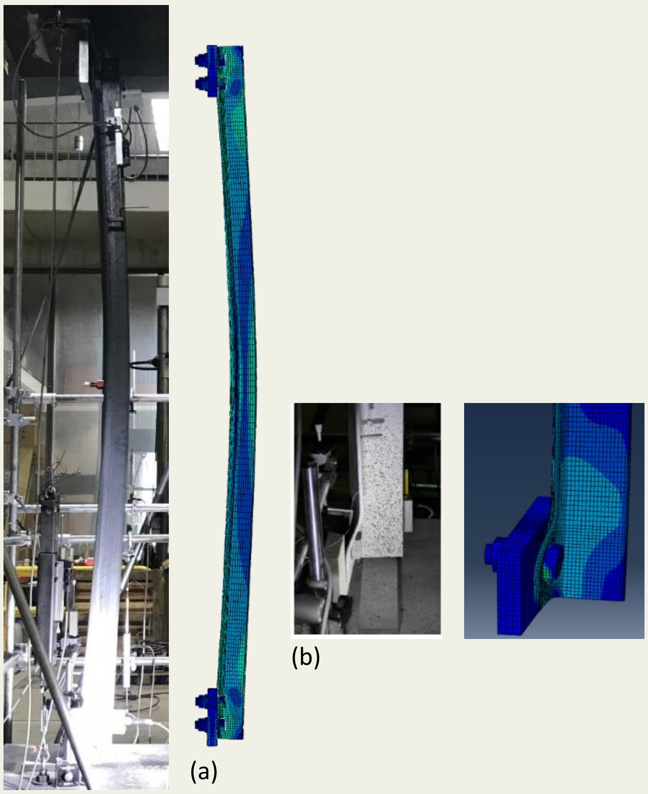


Fig. 3 Global (a) and local (b) failure modes appeared during the test and the simulation

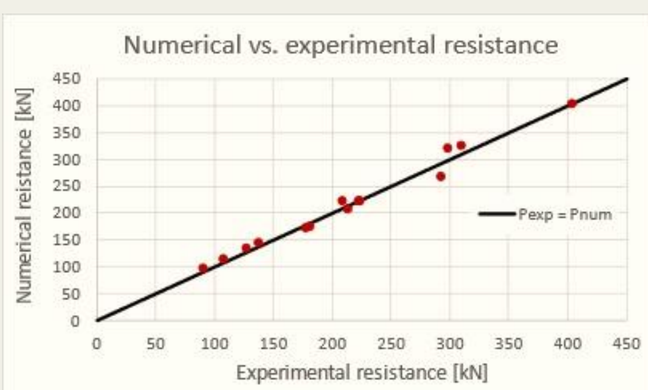


Fig. 4 Comparison between the experimental and numerical resistance of the specimens

Finally, the comparison between the experimentally and the numerically obtained resistances is illustrated in Fig 4. The numerical results are very close to the experimental ones with the maximum error being less than 10%, which is acceptable for engineering purposes.

The research is ongoing; the validated numerical model will be used for parametric analyses which will allow to investigate the influence of a wider range of parameters on the behaviour of angle members with various support conditions and to extend the experimental data set. Analytical formulae aiming to predict with enhanced accuracy the buckling resistance of angle members with various support conditions are being developed and their validity will be assessed through comparisons to the experimental and numerical results.

REFERENCES

[1] A. H. Stang and L. R. Strickenberg, "RESULTS OF SOME COMPRESSION TESTS OF STRUCTURAL STEEL ANGLES" ,1922.

[2] M. Kettler, A. Taras, and H. Unterweger, "Member capacity of bolted steel angles in compression – Influence of realistic end supports," *J Constr Steel Res*, 2017.

[3] M. Reininghaus and M. Skottke, "Druckbeanspruchte Winkelprofile mit Ein-Schrauben-Anschluß Bemessung nach den Normen DIN 18800-2 und EC 1993-3-1 (Türme und Maste)," *Stahlbau*, 2005.

[4] CEN, "EN 1993-3-1: Eurocode 3: Design of steel structures - Part 3-1: Towers, masts and chimneys – Towers and masts," Brussels, 2006.

[5] S. Antonodimitraki, M.Z. Bezas, J. Maesschalck, O. Anwaar, I. Vayas, J.F. Demonceau, "Effects of joints on the buckling resistance of angle members made of S460 steel-Experimental investigations," in *Nordic Steel Construction Conference*, Lulea, Sweden, Jun. 2024.

by Sofia Antonodimitraki

DY.RE.B.

Investigating the dynamic behaviour of reconfigurable buildings by means of numerical analyses and experimental investigations

Introduction: This article presents an update on the progress of the DY.RE.B. research project, part of the ONISILOS program at the University of Cyprus. This project is supported by the author's Marie Skłodowska-Curie Grant and the ONISILOS COFUND fellowship.

Project's objective: Over the past decade, significant advancements have been made in the architectural and robotics applications for reconfigurable buildings. Professors Marios C. Phocas and Eftychios G. Christoforou, the fellowship hosts, have been instrumental in contributing to this field. DY.RE.B. aims to further these developments by leveraging the fellow's expertise in structural engineering and numerical analysis to address gaps in knowledge concerning structural design and the practical implementation of such structures.

Case study - Reconfigurable research pavilion: Within the DY.RE.B. project, a temporary, reconfigurable research pavilion is examined. The aim is to conceptualize a structure that can be deployed, transformed, and dismantled safely and efficiently by a small group of users (scientists) while withstanding harsh climatic conditions.

The pavilion's structural system features a central pillar and strategically placed linkage bars to ensure reconfigurability and structural stability (see Fig. 1). Reconfiguration is achieved by sequentially unlocking the joints of the linkage bars and adjusting the height of the central pillar through external actuation. All components of the bearing system are made of structural aluminum EN AW 6061 to maximize the structure's lightweight characteristics.

Project progress: DY.RE.B., currently in its 10th month, is scheduled to last 24 months. As of now, WP1 (Selection of investigated scenarios) has been completed. Concurrently, WP3 (Numerical investigation of the reconfigurable structure) and WP4 (Numerical investigation of the joints) are ongoing. Experimental investigations of the structure's scale prototypes (WP2) and of the conceptualized reconfigurable joints at full scale (WP5) are scheduled for the second year of the project.

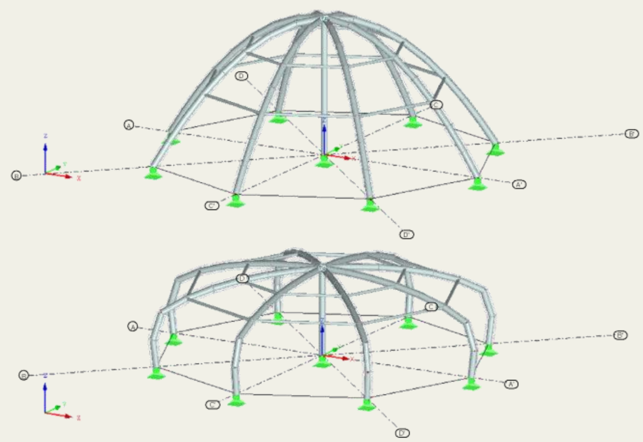


Fig. 1 Reconfigurable structural system in two configurations considered (isometric view)

First results and upcoming dissemination: *Thus* far, aside from preliminary tasks, several significant results have been achieved. These findings focusing on the structural design of reconfigurable temporary structures and the optimization of their reconfiguration sequences will soon be presented in peer-reviewed papers at forthcoming conferences and symposia. More specifically:

1. **Structural design of reconfigurable and temporary spatial structures according to Eurocodes**
   - Authors: S. Gkatzogiannis, M. C. Phocas, E. G. Christoforou

- Conference: ACEM24 - The World Congress 2024 on Advances in Civil, Environmental, and Materials Research, Seoul, August 19 – 22, 2024, full paper accepted for publication
- Focus: Addressing the challenge of designing reconfigurable structures within the framework of existing structural design codes, traditionally tailored for permanent, fixed-shape structures. The study explores adaptations necessary to accommodate the unique demands of reconfigurability, temporary usage, and ease of erection. Finite Element Analyses (FEA) evaluate structural behavior in configurations approximating paraboloid and ellipsoid shapes, adhering to Eurocode guidelines while discussing deviations necessitated by these unique requirements.

2. **Efficient structural design of reconfigurable spatial structures by adopting aerodynamic shapes**
   - Authors: S. Gkatzogiannis, M. C. Phocas, E. G. Christoforou, C. J. Gantes
   - Symposium: IASS Symposium 2024 – Redefining the Art of Structural Design, ETH Zurich, August 26 – 30, 2024, full paper accepted for publication
   - Focus: Investigating the structural benefits of adapting reconfigurable spatial structures to aerodynamic shapes to mitigate internal forces and displacements under high wind speeds. The study utilizes Finite Element Analyses (FEA) to compare the responses of an axisymmetric structure in paraboloid and ellipsoid configurations with an optimized aerodynamic form, demonstrating potential efficiency gains and highlighting the need for further detailed numerical analyses

3. **Application of vertical effective crank–slider approach in reconfigurable buildings through computer-aided algorithmic modeling**
   - Authors: L. Irodotou, S. Gkatzogiannis, M. C. Phocas, E. G. Christoforou
   - Conference: eCAADe – Education and Research in Computer Aided Architectural Design in Europe, Nicosia, September 9 – 10, 2024, full paper accepted for publication
   - Focus: Advancing robotic mechanisms like the vertical crank-slider for reconfigurable circular section buildings, employing computer-aided algorithmic modeling to optimize structural kinematics. The study defines target shapes through rigorous geometric analyses, incorporating architectural, construction, and structural criteria to enable swift and controlled reconfigurations. This approach enhances preliminary design efficiency and elevates performance-based outcomes in reconfigurable building projects.

4. **Motion sequence optimization of a reconfigurable building to increase its energy efficiency**
   - Authors: S. Gkatzogiannis, M. C. Phocas, E. G. Christoforou
   - Conference: OPTARCH2024 - 2nd International Conference on Optimization Driven Architectural Design, abstract accepted, full paper to be submitted
   - Focus: Investigating the structural benefits of adapting reconfigurable spatial structures to aerodynamic shapes to mitigate internal forces and displacements under high wind speeds. The study utilizes Finite Element Analyses (FEA) to compare the responses of an axisymmetric structure in paraboloid and ellipsoid configurations with an optimized aerodynamic form, demonstrating potential efficiency gains and highlighting the need for further detailed numerical analyses.

These forthcoming publications underscore the DY.RE.B. project's commitment to pushing the boundaries of structural engineering and design methodologies, aiming to advance the field of reconfigurable buildings with practical insights and innovative solutions.

Upcoming secondments:

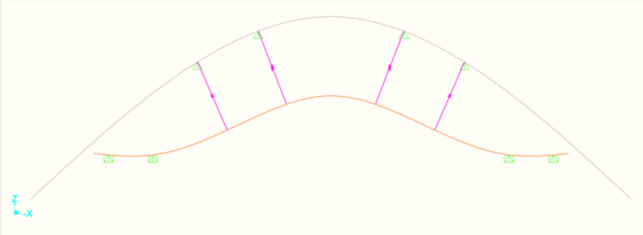
Two secondments are planned within the framework of DY.RE.B. for the fellow. The first secondment will take place between November 2024 and January 2025. The fellow will be hosted at the Institute for Lightweight Structures and Conceptual Design at the University of Stuttgart by Jun.-Prof. Dr.-Ing. Maria Matheou. The second secondment is planned to occur between March and September 2025. It will be hosted by Prof. Charis Gantes at the Institute of Steel Structures at the National Technical University of Athens.

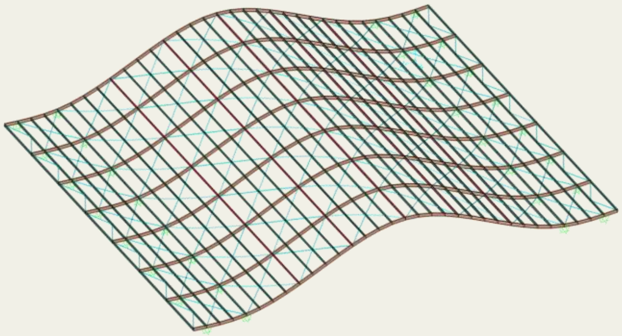
by Stefanos Gkatzogiannis

Integrated project in structural engineering

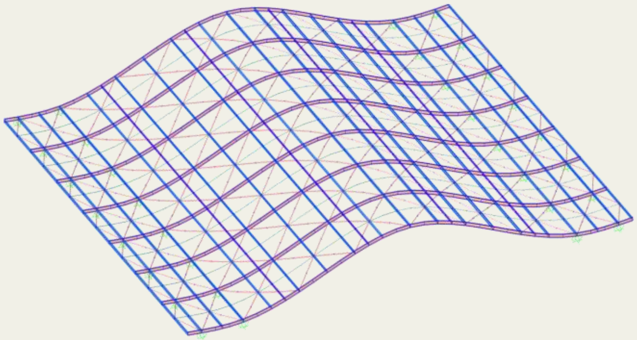
DESIGN OF AN AIRCRAFT MAINTENANCE HANGAR

As part of this project a steel roof suspended from two arches by means of inclined cables was proposed. The main reason for this approach, in addition to architectural aesthetic considerations, was the large span (~80m) and height (~24m) required to host aircrafts like AIRBUS-350 and BOEING-747.

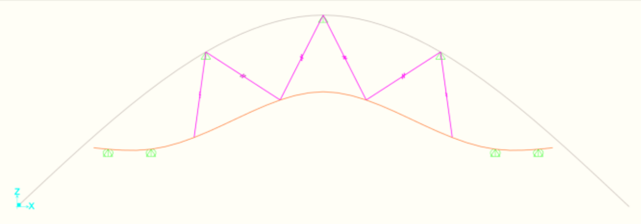




Renders are made using Sketchup/V-Ray

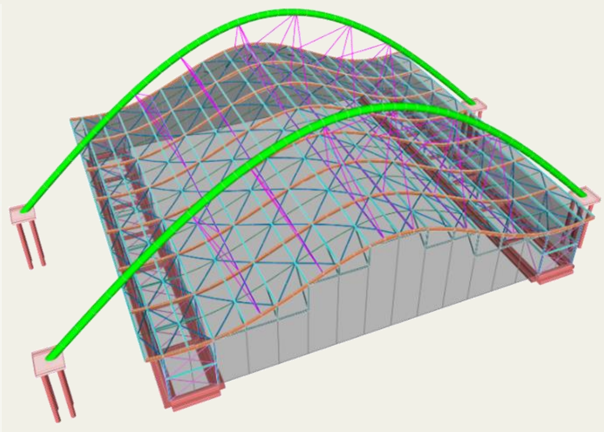


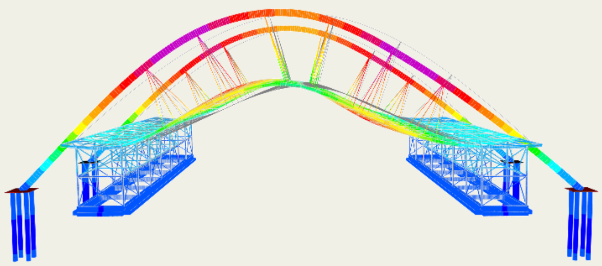
The optimal geometry of the cables and roof structure was obtained after analysing and evaluating different possible arrangements.

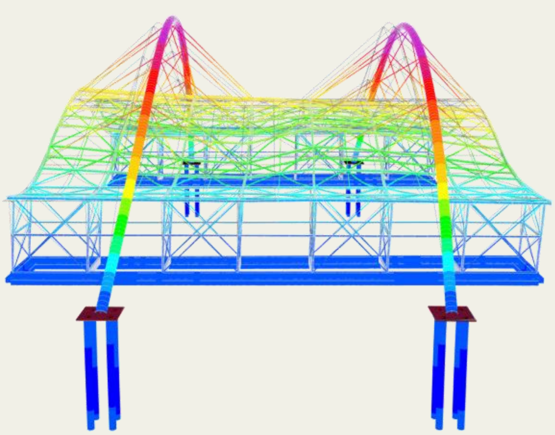


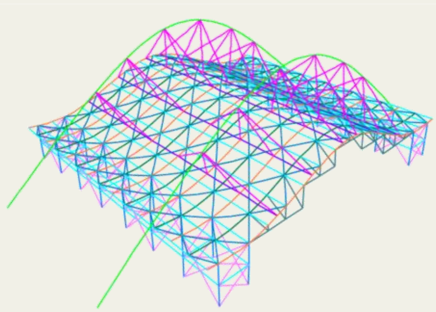
For this process and the global analysis of the structure the FEA software SAP2000 was used. In the numerical models, both stiffness and large displacements nonlinearities were taken into consideration to better predict the cables' response. The actions accounted for, comprised self-weight of the structure, cables' prestress force, E/M equipment weight, snow, wind, temperature and seismic actions. Soil elastic support was also estimated and taken into account in the model.

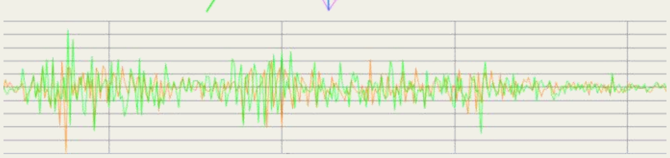
For the seismic analysis, Equivalent Static Analysis was performed instead of Response Spectrum Analysis to consider nonlinearities. Afterwards, results were assessed with Modal Analysis and Nonlinear Dynamic Analysis according to EN1998-1. Because the FEA modeling requirements are different for loads acting as static and dynamic, 2 numerical models were used.



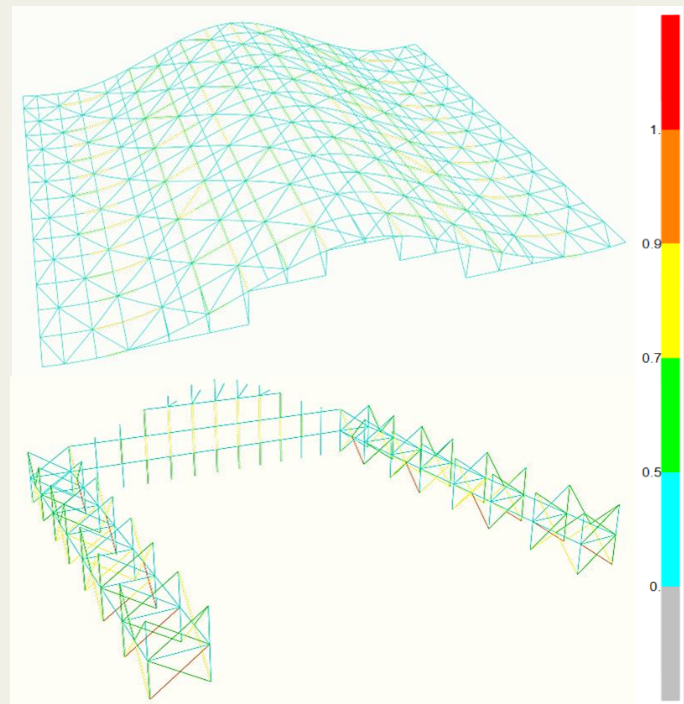




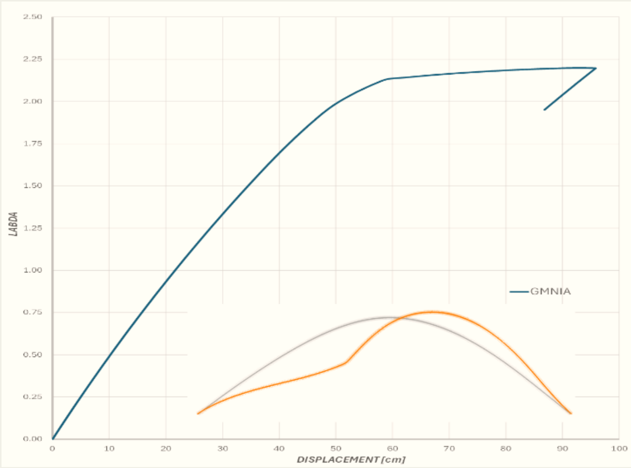




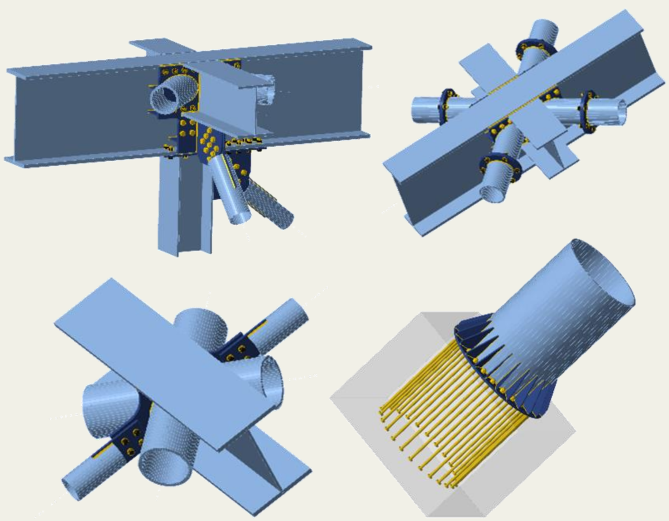
The analysis results indicated that combinations with wind as primary action were the critical ones. For that reason, the structure was designed for static loads and was then checked to also cover dynamic loads and capacity design requirements according to EN1993-1 and EN1998-1. The material used in this structure was steel S355 and the main sections were HEA300 for the columns, HEA700 and HEA400 for the primary and secondary beams, CHS168.3/5 and CHS139.7/5 for the vertical bracings, CHS219.1/10 for the horizontal bracings and CFCHS1600/40 for the arches.

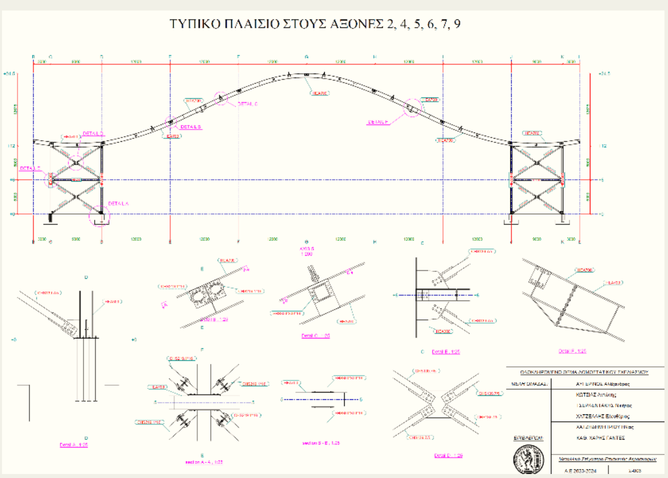


A point of interest was the analysis and design of the arches, and in particular their out-of-plane buckling capacity. With a shape that is not completely covered by Eurocodes and the importance of the lateral support provided by cables for structural integrity, more advanced analyses were required. For that purpose, a Collapse Analysis (GMNIA) was carried out on the general-purpose FEA software ADINA. Adopting elastic support conditions and critical load combinations from the global model, it was shown that the arches had an o verstrength of ~1.75 buckling. This collapse load is hardly possible because the cables would have failed beforehand, hence the arches' sections and geometry were considered as adequate.

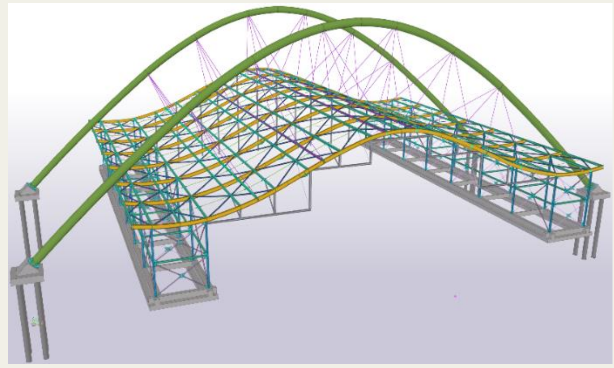


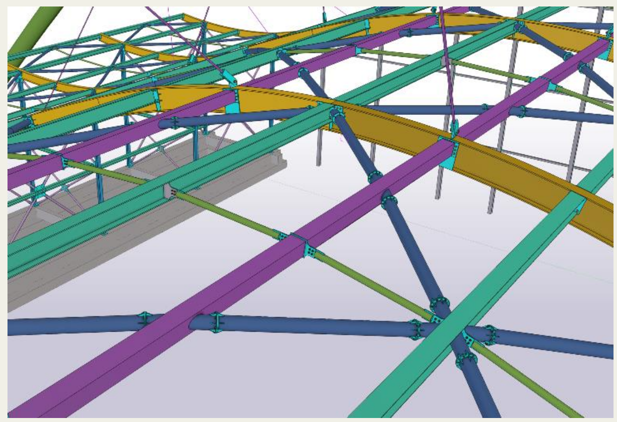
Another point of interest was the design and analysis of steel connections. For that purpose, the FEA software IdeaStatica was used, where the joints were modeled and analyzed.

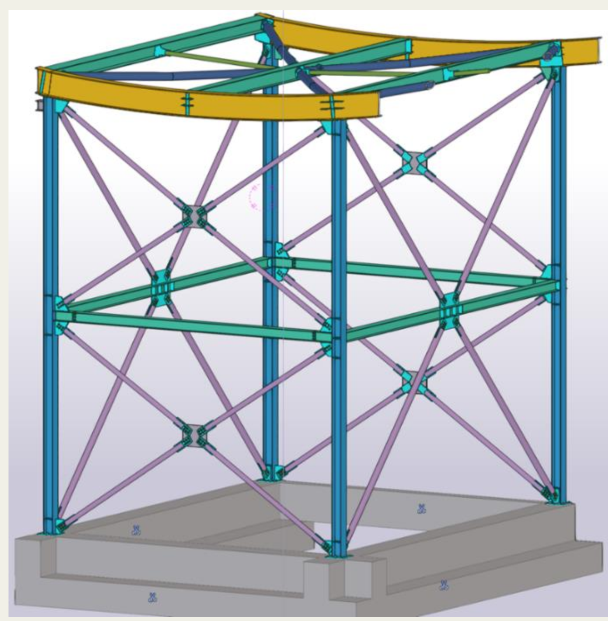




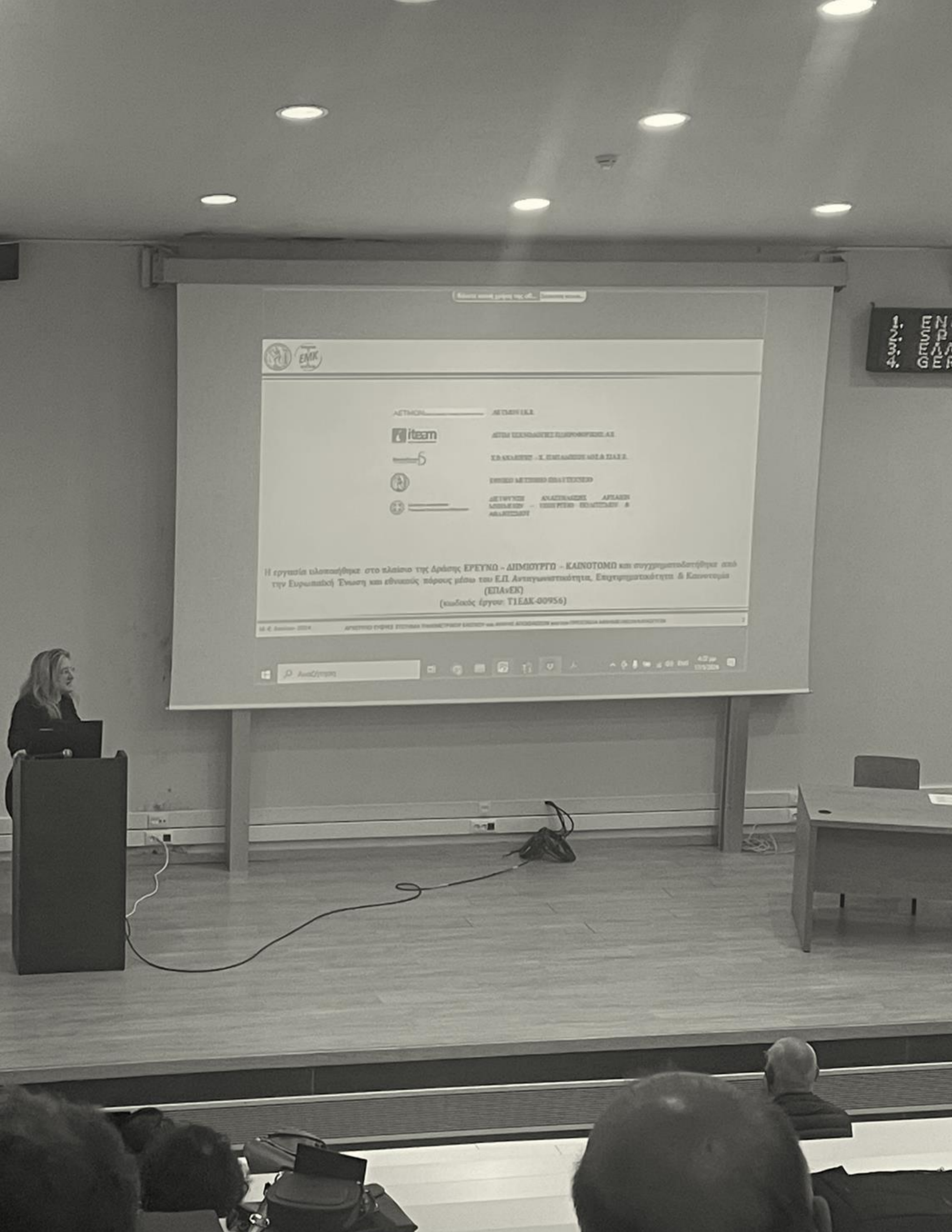
After analysis and design of all parts was performed, the structure was modeled in the BIM software Tekla with the purpose of getting a better insight into the structures geometry and also of exporting structural drawings from it. Some pertinent images and drawings are shown below.







by Alexandros Avgerinos, Antonis Kotsias, Nikitas Tserlentakis, Eleftherios Chatzellis, Ilias Chatzidimitriou
supervised by Prof. Charis Gantes


iteam
Η εργασία υλοποιήθηκε στο πλαίσιο της Δράσης ΕΡΕΥΝΩ – ΔΗΜΙΟΥΡΓΩ – ΚΑΙΝΟΤΟΜΩ και συγχρηματοδοτήθηκε από την Ευρωπαϊκή Ένωση και εθνικούς πόρους μέσω του Ε.Π. Ανταγωνιστικότητα, Επιχειρηματικότητα & Καινοτομία
(ΕΠΑνΕΚ)
(κωδικός έργου: Τ1ΕΔΚ-00956)

ISS Institute of Steel Structures

National Technical University of Athens
School of Civil Engineering
Institute of Steel Structures
9 Iroon Polytechneiou str.
Zografou Campus, 15780
Athens - GREECE