ISS

Institute of Steel Structures

Newsletter
January 2025

National Technical University of Athens
School of Civil Engineering

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Institute of Steel Structures - NTUA / January 2025

Designed & formatted by: **Aikaterini Michaltsou**

Front cover: **Inspection of steel roof by the ISS team**

Welcome to the winter 2025 issue of ISS-NTUA Newsletter!

Dear students, colleagues, alumni and friends,

As we prepare for the new academic semester, our team at ISS-NTUA is reflecting on our recent accomplishments and planning for the future.

In the present issue of our bi-annual Newsletter, we are focusing on diploma and graduate theses that have been completed recently, paying credit to our excellent new generation of young engineers.

Prof. Thanopoulos summarizes several theses he has supervised, on the structural behavior, analysis and design of arch bridges, comprising one of his favorite research topics. The theses by Aikaterini Grammatikou, Varvara Skourti, Konstantinos Fasoulakis, Dimitrios Kazantzidis, Dimitrios Platanas, Eirini Mparouta, Vasileios-Minoas Bampatsikos, Panagiotis Fotas, Adam-Alexander Malavazos-Siekierka and Anna Demertzi are included in the presentation, identifying the benefits of this highly efficient structural typology.

Next, two theses on structural steel reuse as a more efficient and environmentally friendly approach in handling old steel structures, supervised by Prof. Gantes, are briefly presented by their authors. Ilias Chatzidimitriou describes general principles of steel reuse, followed by a case study of converting the steel structure of an outdoor theater into a transmission tower. Sokratis Sideris focuses on the reuse of decommissioned tubular wind turbine towers, presenting two case studies of transforming tower sections into a footbridge and a water tank.

Last but not least, a brief review of the progress achieved by the team led by Prof. Vamvatsikos on the seismic fragility assessment of industrial facilities is presented, highlighting a virtual oil refinery testbed.

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

Charis Gantes

DONATION

The Stavros Niarchos Foundation Cultural Center (SNFCC) S.A. has generously donated three (3) Friction Pendulum System (FPS) bearings to the National Technical University of Athens, which are similar to the ones that have been used for the seismic isolation of the main buildings of the cultural complex, namely the National Opera and the Library of Greece. One of these bearings has been sent to the Institute of Steel Structures and is currently displayed at the laboratory. There it will be available for the students to visit in the context of the Experimental and Bridge Design courses, where the basic principles of seismic isolation can be effectively demonstrated and discussed.

FIELD INSPECTIONS

Continuing its activities of field inspection of existing steel structures, in December 2024 ISS was granted and carried out field inspection and visual structural condition assessment of representative sign bridges in "Attiki Odos", the Athens peripheral motorway.

INVITED LECTURES

Prof. Gantes was invited speaker in two recent international meetings, where he delivered keynote lectures on the research activities of ISS in the structural design of tubular steel wind turbine towers:

- 5th International Workshop on Advanced Structures, Southeast University, Nanjing, China, 28-29 March 2024.
- XXX Jubilee Conference of Lightweight Structures in Civil Engineering, Warsaw University of Technology, Warsaw, Poland, 5-6 December 2024.

Prof. Vamvatsikos delivered two invited lectures on issues of seismic design and risk assessment:

- Vamvatsikos D., 1st International Conference on Civil and Environmental Engineering for Resilient, Smart and Sustainable Solutions – CEES2024, Al-Khobar, Saudi Arabia.
- Vamvatsikos D., 18th World Conference on Earthquake Engineering – 18WCEE, Milan, Italy.

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:

- Carlos Molina Hutt, “Seismic design for functional recovery performance, 2026 NEHRP provisions progress update”, 24 September 2024.
- Marcial Blondet, “The nylon rope mesh seismic reinforcement system for adobe dwellings: lessons from Peru”, 26 September 2024.
- Alexandros A. Taflanidis, “Reduced order modeling applications for computationally efficient uncertainty propagation for seismic vulnerability assessment”, 25 October 2024.
- Amilkar Oikonomou, “Steel structures for offshore wind farms”, 20 December 2024.

PUBLICATIONS

In 2024 the members of the Institute have published 23 papers in international journals. For a full list of publications please visit: http://labmetalstructures.civil.ntua.gr/cms/en/research/publications

Arch bridges

<u>Introduction</u>

Arch bridges are designed based on the simple but fundamental principle that the vertical loads of the span are transferred to the abutments through the compression of the arch. As a direct result, simple materials with significant compressive resistance (e.g. stones) could be used for this type of structure and arch bridges are among the oldest in the world and certainly the ones with the largest spans. Surviving arch bridges date as far back as the ancient years (Fig. 1) with many impressive structures being built during the Roman era (Fig. 2).

Fig. 1 Arkadiko or Kazarma Bridge, Peloponnese. Built during the Mycenaean era, ca. 1300 – 1190 BC [1, 3]

Nevertheless, with the introduction of modern materials, namely cast iron, reinforced concrete, prestressed concrete and structural steel, the possibilities of arch bridges were greatly enhanced, thus reaching very large spans with the record-holders being Pingnan Third Bridge (575 m, steel, completed in 2020) and, quite recently, Longtan Tianhu Bridge (600 m, concrete, completed in 2024). As a result, even in the present day, arch bridges comprise a significant percentage of the world's medium and large span bridges, being second only to cable-stayed and suspension bridges.

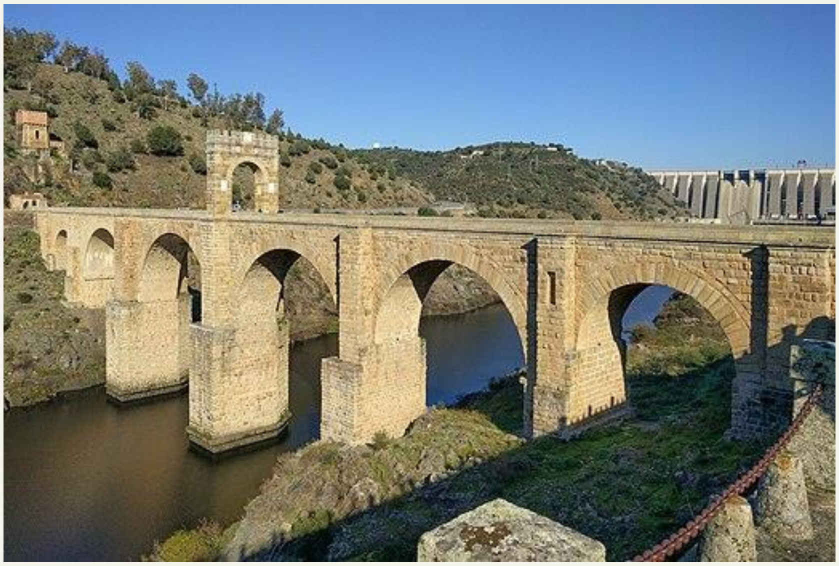


Fig. 2 Alcántara Bridge, Spain. Built during the Roman era, 104 – 106 AD [2, 3]

With the introduction of tensile rods and high-strength cables it became possible to break free from the traditional type of arch bridges where the deck is completely above the arch, thus getting their name as **deck arch bridges**. By placing the deck within or completely below the arch, therefore hanging part or all of it, respectively, from the arch, the **through arch bridges** were created. A special type of the latter are **tied-arch bridges**, where the deck is below the arch but also connected to it at its ends. As a result, the significant horizontal support forces that are related to the arch behaviour are not transferred to the abutments but to the main beam itself, which is often called a tie due to this additional function. This behaviour offers obvious advantages by minimising the requirements on the substructure, making this type of bridge ideal for areas within the urban fabric, rivers or valleys where one or multiple span bridges can be constructed. Although tied-arch bridges are relatively smaller than typical arch bridges, the record span of Qilu Yellow River Bridge (420 m, steel, completed in 2024) is also very promising.

It is obvious that, even though arch bridges are among the oldest ones in the world, they still provide the best solution for certain spans, as is evident from their continuous development worldwide and in China, in particular. Based on this observation, it has always been a firm belief of the teaching staff of NTUA that this type of bridge is a great example that can be used to introduce students to bridge design. This is the case because, besides basic analysis and dimensioning, which is similar in simpler types of bridges, various other aspects of bridge design can be demonstrated, like global stability checks, erection process, maintenance issues etc. To that end, many semester projects have been carried out during our undergraduate studies, which in return led a brave few to selecting similar projects for their Diploma Thesis, undergraduate or postgraduate.

The scope of the Theses that were concluded during the last few years is presented in this article, in order to demonstrate the wide range of interest that has been exhibited by our students. The following figures and the full text of the Theses can be found in the Digital Library of NTUA [4], by searching the name of the Authors. The software used for the structural analysis is SOFiSTiK, with the exception of V. M. Bampatsikos (Fig. 5a) who used MIDAS Civil.

Pedestrian bridges

A simple yet widely used application of arched structures are pedestrian bridges, due to their efficient behaviour and impressive aesthetic results. A limitless variation of arch and cable configurations can provide from cost-effective and practical solutions to landmark structures, based on the requirements of the Owner. Students are usually inspired by an actual structure and try to re-apply it in a similar case study. During this process, they will select a location for the bridge considering the limitations that are applicable (e.g. type of obstacle, foundation area, constructability) and decide on the final geometry and architectural form of the bridge. Then they will perform the full preliminary design of the bridge by designing all structural members for the Ultimate and Serviceability Limit States, including global buckling failure of the arch and vibration due to pedestrian traffic, which can be of major importance for this type of bridges.

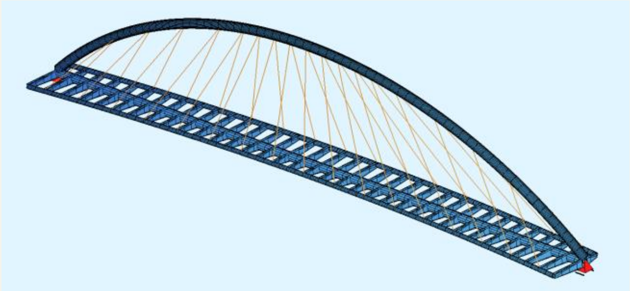


Fig. 3a Steel pedestrian bridge with inclined arch [68 m] (Aikaterini Grammatikou, 2022)

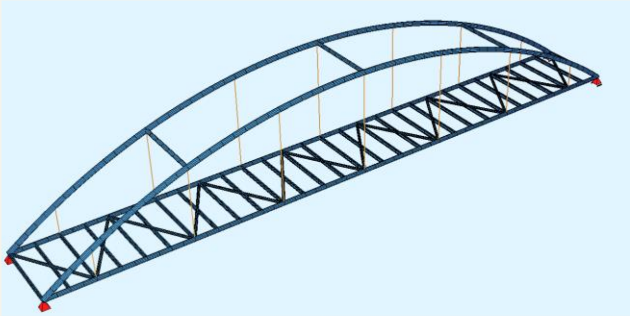


Fig. 3b Tied-arch footbridge at the sea front [42 m] (Varvara Skourti, 2022)

Finally, the design of connections and method of construction are briefly explored, with indicative solutions that could probably be further explored during the full design of the bridge (Fig. 3a, b). In one instance, the structural assessment of an existing pedestrian bridge was performed, where the level of corrosion and level of structural adequacy were evaluated and strengthening measures were proposed (Fig. 3c).

Fig. 3c Structural assessment of an existing arch pedestrian bridge in Corinth [48.50 m] (Konstantinos Fasoulakis, 2024)

<u>Road and railway bridges</u>

In a similar way, arch bridges with road or rail traffic have been designed for various configurations. In this case, additional aspects are investigated, like distribution of concentrated loads, fatigue resistance and deck slab design. To that end, numerical models of varying detail are used (Fig. 4).

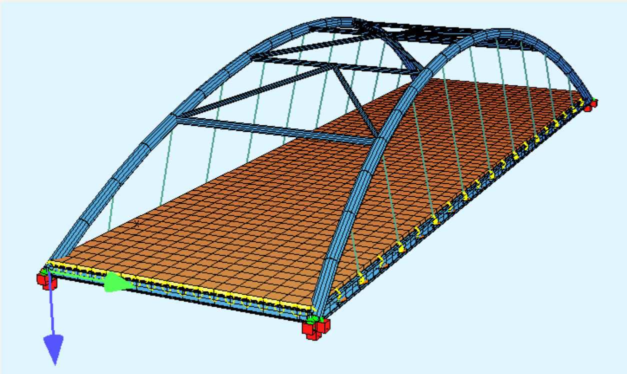


Fig. 4a Tied-arch road bridge [60 m] (Dimitrios Kazantzidis, MSc, 2024)

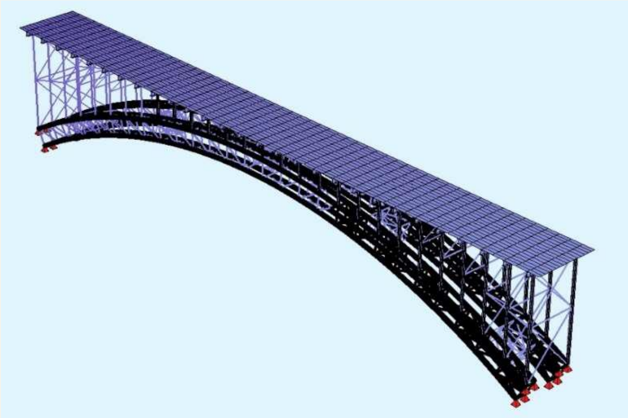


Fig. 4b Deck arched truss road bridge [224 m] (Dimitrios Platanas, 2024)

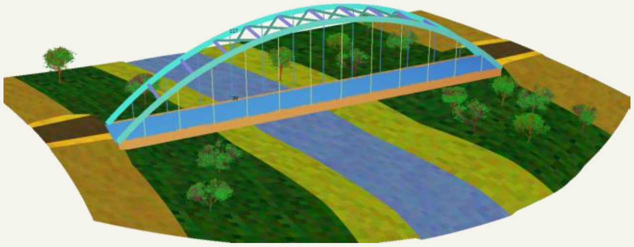


Fig. 4c Tied-arch railway bridge [150 m] (Eirini Mparouta, MSc, 2023)

<u>Innovative designs</u>

In some cases, a rather unconventional design is selected, in order to explore a more impressive and architecturally challenging structure. For these bridges, emphasis is given in the detailed presentation of the bridge, utilising BIM models and 3D renders, as necessary. As these tend to be more complicated structures, structural design tends to be less detailed (Fig. 5).

Fig. 5a Through bridge with two consecutive diagonal main arches [2×100 m] (Vasileios-Minoas Bampatsikos, MSc, 2023)

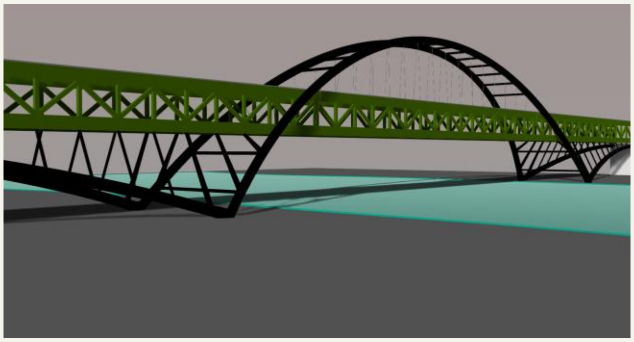


Fig. 5b Through arch bridge with double deck [250 m] (Panagiotis Fotas, 2024)

<u>Research</u>

As it has been demonstrated, the design of an arch bridge can be complicated and certain issues arise where some investigation is required in order to either clarify aspects of the analysis and design due to ambiguity of the codes, or to identify the advantages and disadvantages of certain configurations over others. For tied-arch bridges, aspects that have been examined are:

- The influence of the concrete slab in the analysis and design of the tie and vice versa (Fig. 6a).
- The detailed calculation of the wind loads using Autodesk Computational Fluid Dynamics (CFD) Software, as longer arch bridges are not covered by the Eurocodes (Fig. 6b).
- The characteristics of various cable configurations, with emphasis on the advantages of the network cable configuration.

Other topics that are subject of ongoing investigation are the dynamic behaviour of hangers under wind loading and the distribution of concentrated forces on the beams of a grillage model.

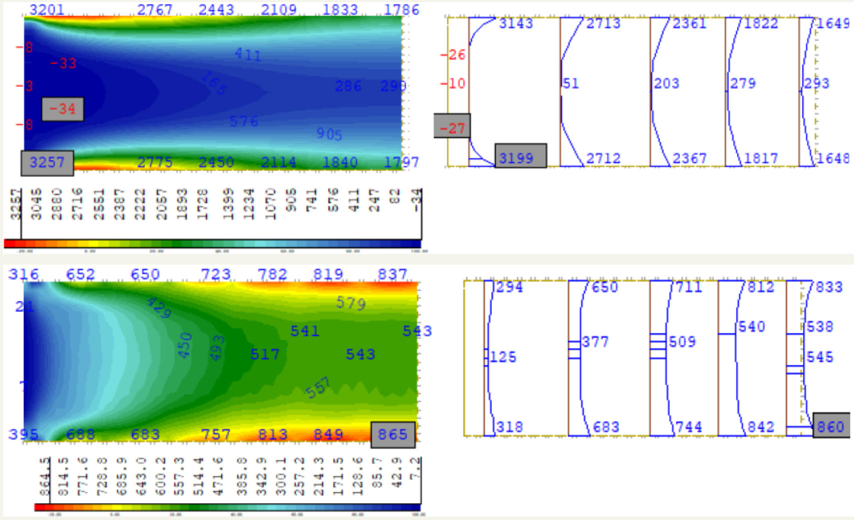


Fig. 6a Various investigations on the behaviour of a tied-arch bridge with road traffic and tramway [150 m] (Adam-Alexander Malavazos-Siekierka, MSc, 2023)

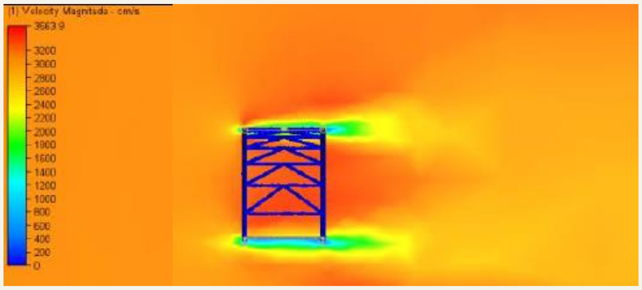


Fig. 6b Investigation of the wind effects on a tied-arch bridge using CFD software [160 m] (Anna Demertzi, 2024)

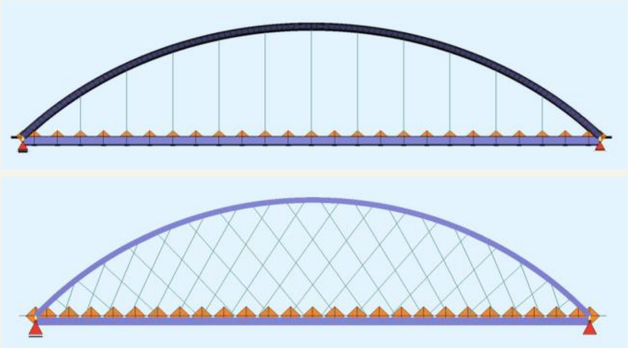


Fig. 6c Alternative hanger arrangements of a tied-arch bridge [100 m] (Lida Damoraki, 2024)

Acknowledgements

I would like to thank the afore-mentioned students for their contributions and especially for our fruitful collaboration over the past few years, which served the purpose of learning about arch bridges and investigating various aspects of their behaviour.

References

[1] Arkadiko Bridge (accessed 13/1/2025): https://en.wikipedia.org/wiki/Arkadiko_Bridge
[2] Alcántara Bridge (accessed 13/1/2025): https://en.wikipedia.org/wiki/Alcántara_Bridge
[3] 10 Oldest bridges in the world: https://www.oldest.org/structures/bridges/
[4] Digital Library of NTUA: https://dspace.lib.ntua.gr

by Pavlos Thanopoulos (supervisor)

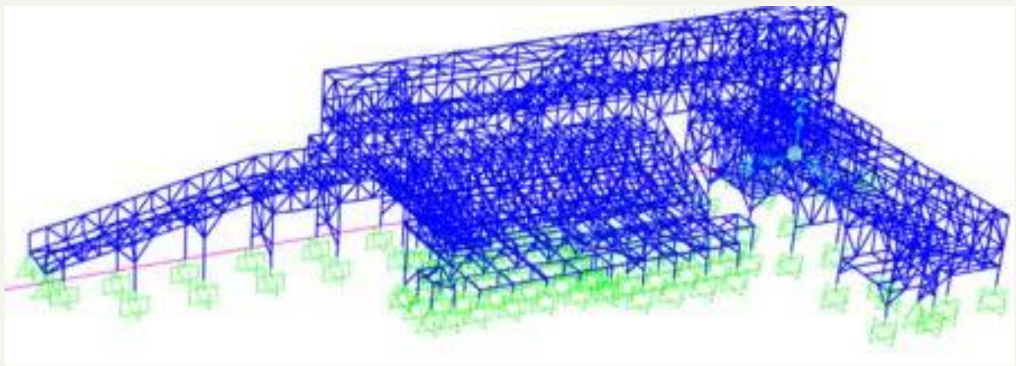
Fundamental principles of steel structures reuse and a case study

This thesis on steel reuse, carried out by Ilias Chatzidimitriou and supervised by Prof. Gantes, consists of two main parts.

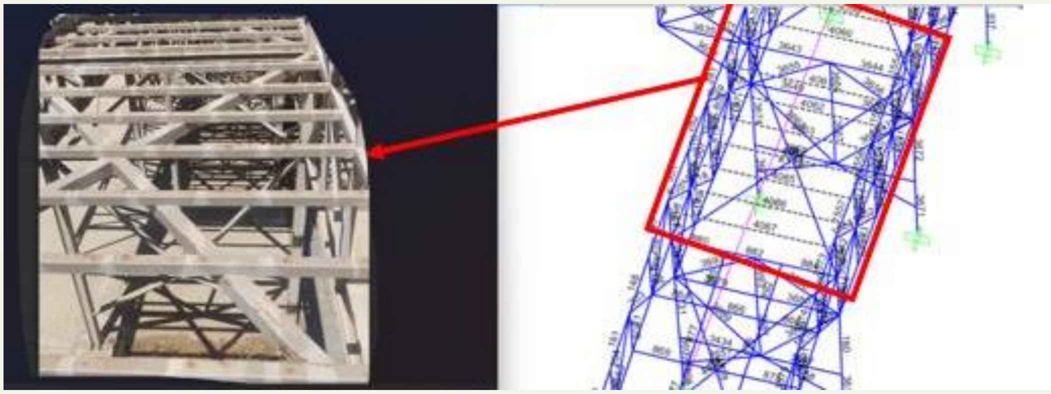
The first part encompasses comprehensive bibliographic research, exploring the principles and practices of steel reuse in construction. It emphasizes prioritizing reuse over recycling, as reuse significantly reduces energy consumption and emissions by avoiding the reprocessing stage. Given that the construction sector accounts for nearly 40% of global energy use and waste in Europe, adopting reuse strategies is crucial. While reuse can sometimes entail higher costs, it remains an excellent solution from the sustainability point of view.

In the second part a case study is presented, focusing on the deconstruction of an outdoor theatre made of steel, located at NTUA Zografou Campus, and the design of a transmission tower utilizing 100% reused materials from the theater's structure.

This work highlighted the potential for sustainable practices in the steel construction industry and emphasized the importance of reusing materials to reduce environmental impact.



NTUA Theatre (Investigated for deconstruction and element collection)

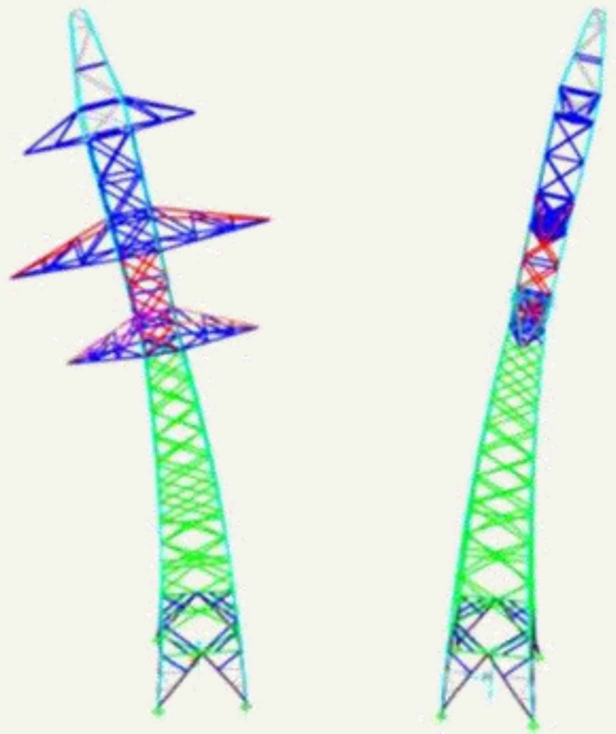


Element identification between SAP2000 and site

A database of all collected elements from the theatre was created using an Excel spreadsheet. Another Excel spreadsheet was used to store information related to the new labels assigned to the reused elements for their new purpose in the transmission tower.

Through this thesis and the above application, it was demonstrated that reuse practices can be implemented for the construction of a new steel structure, either involving 100% of the elements or making partial use.

Utilization ratios of the reused element structure. This optimal design was based on exclusive use of available elements in the theatre structure.



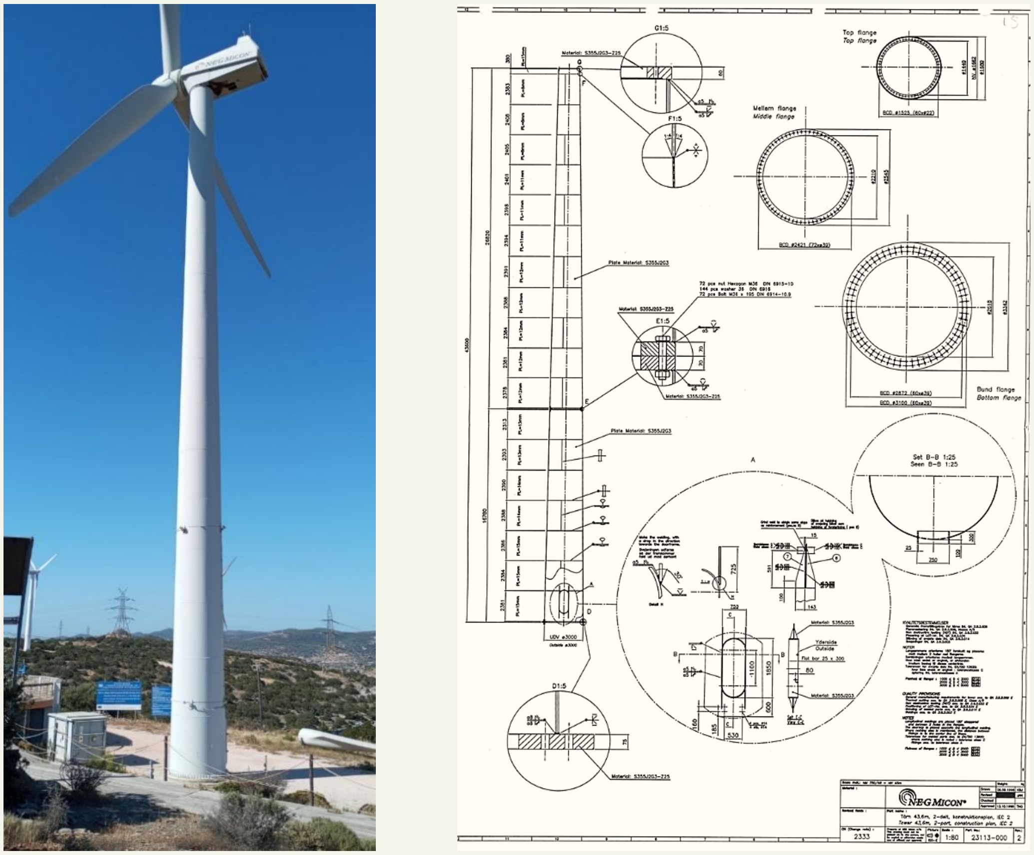
First two vibration modes of the tower

AI machine learning models using convolutional neural networks (CNNs), that were developed and applied to identify corrosion and cracks.

by Ilias Chatzidimitriou

Examples of wind turbine towers reuse

While recycling steel offers well-known benefits, the growing demand for more economical and sustainable structures has shifted attention toward steel reuse as a more efficient and environmentally friendly approach. Wind turbine towers, made of steel, represent an excellent example of structures that could potentially be repurposed for alternative applications. The typical lifespan of a wind turbine is approximately 25 years, after which it is usually decommissioned. In this diploma thesis by Sokratis Sideris, supervised by Prof. Gantes, strategies for repurposing steel from wind turbine towers at the end of their service life are explored. Specifically, potential applications for a NEGMICON 700KW wind turbine model are investigated, drawing on data and visual materials provided by the Greek Center for Renewable Energy Sources and Saving (CRES).



(a) (b)

Fig. 1 (a) The actual wind turbine in the demonstration Wind Park of Lavrio and (b) a detailed drawing of the tower

<u>Case study – Footbridge:</u> One potential application for the upper section of the tower is its use as structural support for a small footbridge. Specifically, the upper part of the tower is cut longitudinally, producing two semi-toriconical segments. Secondary beams extend transversely, supporting a timber deck, while bracing members are positioned between the secondary beams for additional stability. To enhance structural integrity, hollow rectangular stiffeners are welded at the intersections between the tower and the secondary beams. The footbridge is mounted on two small bearings at each end, which are supported by concrete walls. To prevent cross-section distortion and local buckling at the ends, semi-circular steel plates are provided. The proposed design successfully satisfied the necessary verifications for all prescribed loads, effectively utilizing the tower's structural capacity.

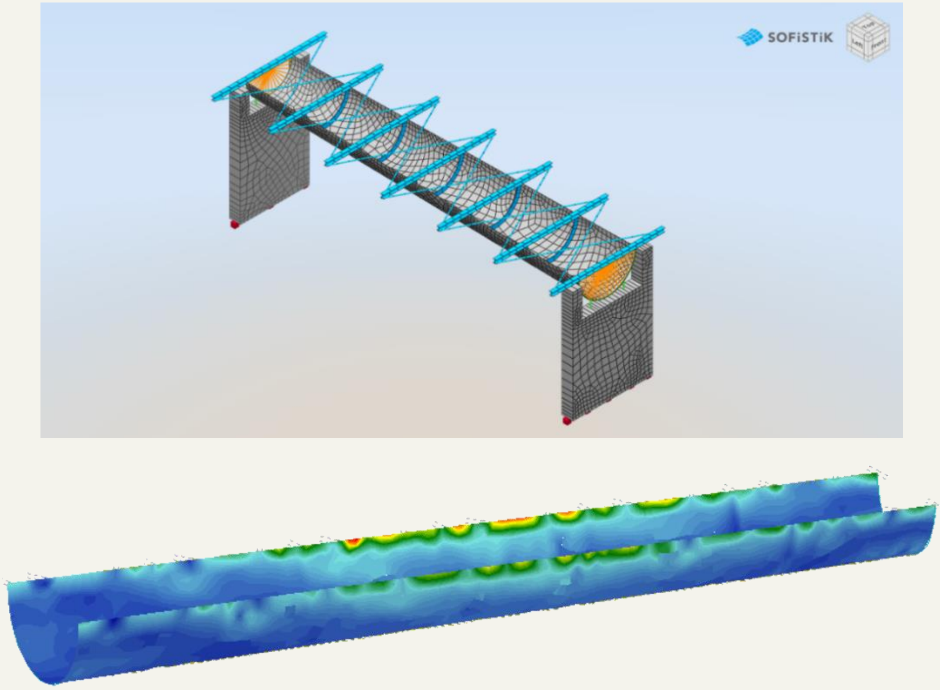


Fig. 2 Finite element model of the footbridge in SOFISTIK 2024

<u>Case study – Fluid storage vessel:</u> In this application the structural behavior of the tower transformed into a fluid storage vessel and subjected to internal pressure, temperature loading, and fatigue conditions is analyzed. The bottom section of the tower is cut transversely, resulting in two toriconical shapes. The design of the vessels complies with ASME and EN13445 standards, while the contained fluids were selected based on operational research. One section, featuring a manhole, is designated to store water for agricultural purposes, whereas the other section is intended to contain pressurized butane.

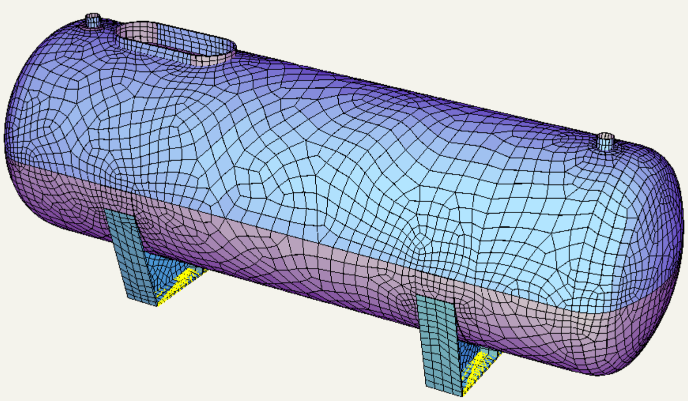


Fig. 3 Horizontal storage tank finite element model in SOFISTIK 2024

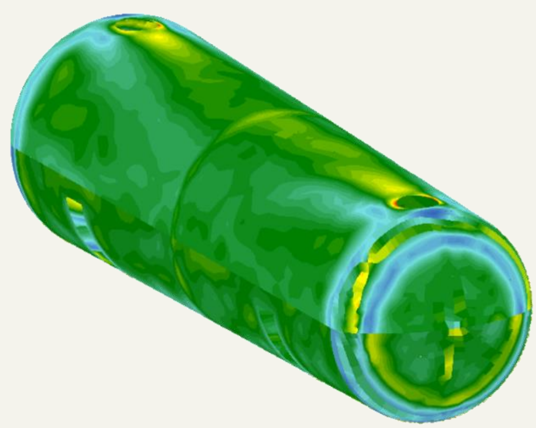


Fig. 4 Stresses of the pressure vessel

The tower demonstrated sufficient capacity to withstand the applied loads, while most practical aspects of the vessel design were partially addressed or discussed. Special attention was given to the pipe openings due to the high risk of explosion. It is also worth noting that, although the pressure vessel application successfully endured the prescribed loads, its feasibility is limited by the absence of non-destructive testing to verify the tower's actual yield strength and fatigue condition. Conversely, the storage tank appears to be a more reliable and practical structural solution, primarily due to its lower strength requirements and reduced risk factors.

by Sokratis Sideris

Seismic fragility assessment of a virtual oil refinery testbed

Introduction

Crude oil refineries are critical infrastructures vital for the smooth functioning of modern society. Refining involves numerous complex physical and chemical processes to produce gaseous and liquid fuels for everyday use. Refineries contain various assets within a confined area, which functionally interact through a dense piping network rather than through structural connections. Therefore, the overall health, resilience, and uninterrupted operation of these systems heavily rely on the structural integrity of individual components/assets.

Strict safety regulations and guidelines govern refineries from design through daily operations and maintenance. Still, earthquake-triggered Natural-Technological accidents in refineries still occur, such as the 1964 Niigata, the 1978 Miyagi, and the 2011 Great East Japan earthquakes, which caused significant environmental, economic, and societal impacts, underscoring the urgent need for more robust seismic risk assessments in industrial facilities. While it is widely agreed that seismic performance assessments for critical infrastructures should adopt a probabilistic approach to account for uncertainties, most research has focused on evaluating the seismic performance of individual refinery assets, such as tanks, chimneys, process towers, pressure vessels, and buildings. Conversely, there is limited research treating refineries as integrated systems.

Refineries are intricate systems, making a system-level study both challenging and costly because specific details are more significant than generalized contributions. Owing to the above, a virtual crude oil refinery testbed is developed with sufficient information to enable researchers to conduct system-level assessments.

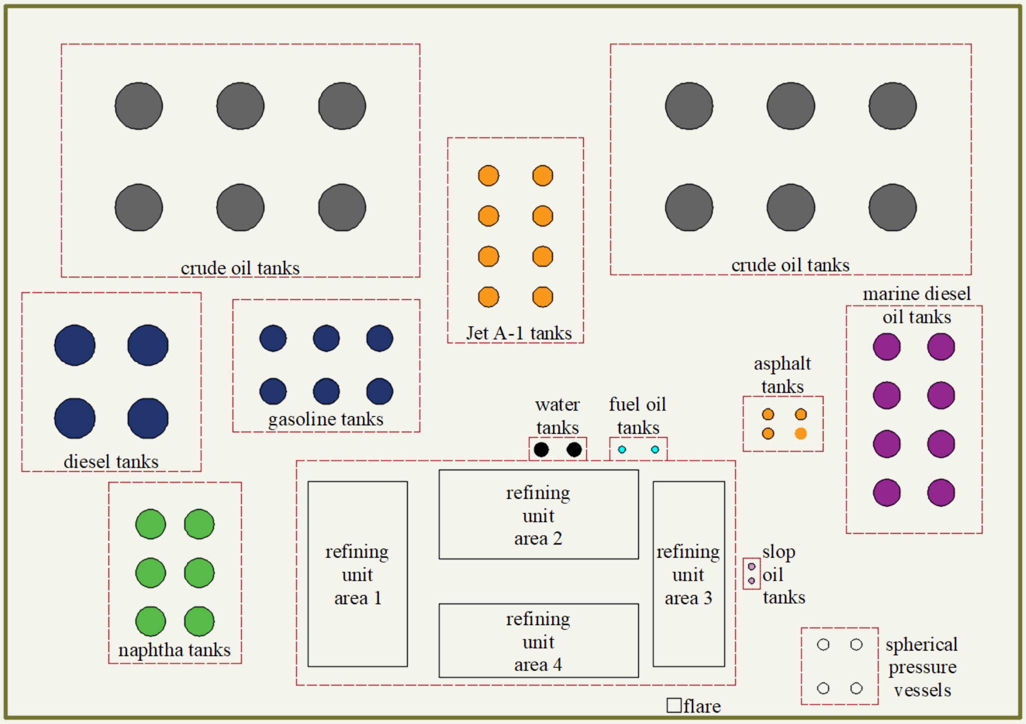


Fig.1 Exposure model: plan view of the case study oil refinery

Exposure model

A typical mid-sized crude oil refinery, in terms of functionality and production, is offered as the testbed. The refinery plan view is shown in Figure 1. The key steel structures encountered in the refinery, being also critical assets at risk, are liquid storage tanks, process towers, chimneys, equipment-supporting buildings, spherical pressure vessels, and the main flare (Figure 2).

Seismic hazard

The refinery is located in a major industrial zone in west Attika region, Greece. The OpenQuake engine was used to probabilistically assess the seismic hazard by employing the 2013 European Seismic Hazard Model.

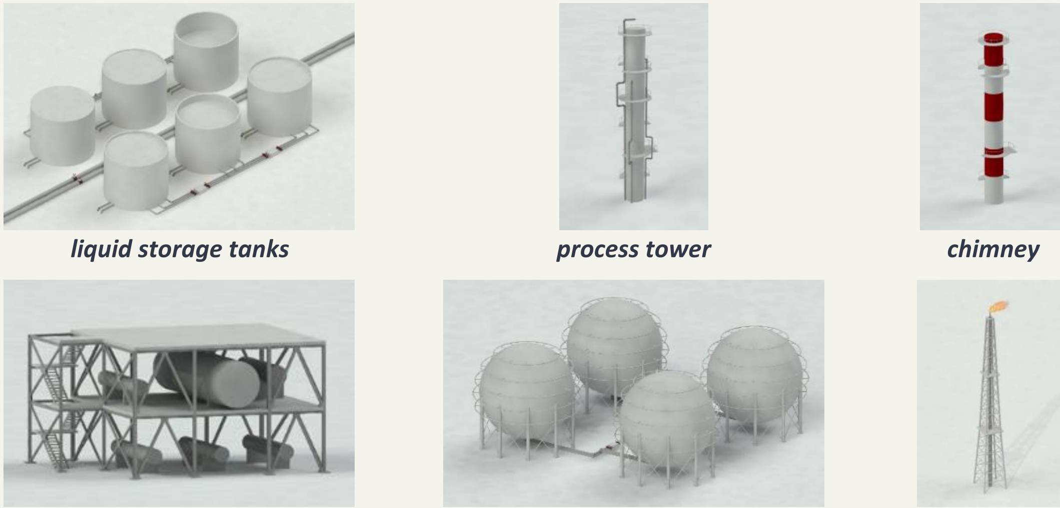


Fig.2 Critical steel structures at risk encountered in the refinery testbed

For structural demand estimates, a set of 30 hazard-consistent ground motion records was selected from the NGA-West2 database, considering a 2% probability of exceedance over 50 years.

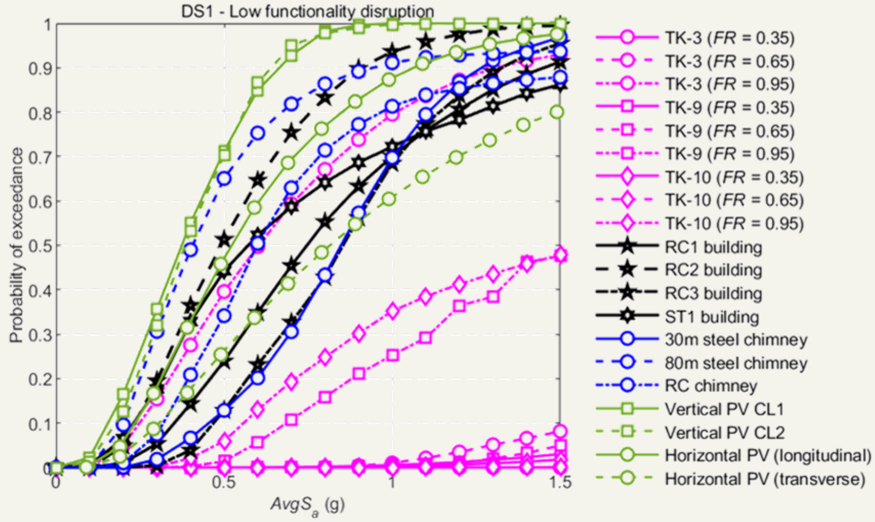
Fragility analysis

Reduced-order and surrogate numerical models were developed for the refinery assets using the open-source software OpenSees. Incremental Dynamic Analysis was carried out using the selected set of natural ground motion records. The critical failure modes of each asset type were identified and appropriate engineering demand parameters were selected to assess the structural performance, such as top displacement, interstory drift, floor acceleration, etc.

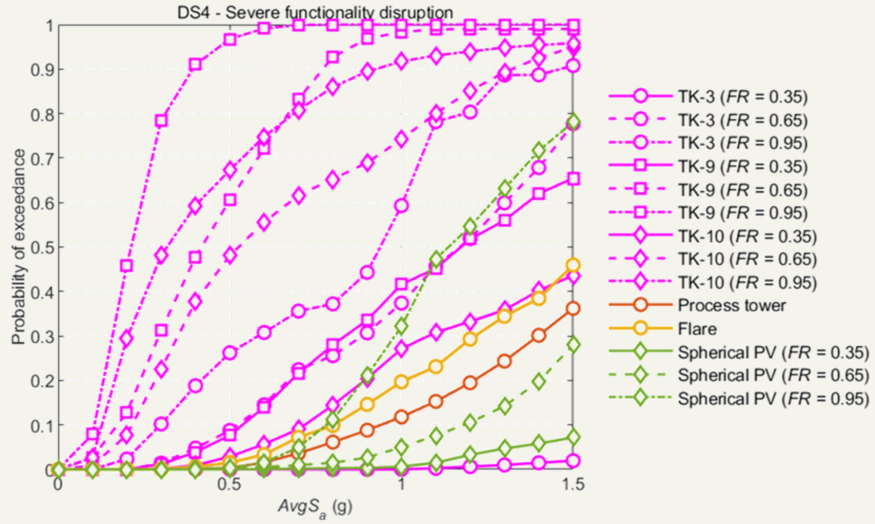
Homogenization of damage states

The impact of the operational or structural failure of a single asset on the overall refinery business differs significantly. Therefore, the asset-level damage states (ds) were consolidated into a set of refinery-level damage states (DS) that more accurately reflect their functional consequences. These global DS range from "none" to "severe" disruption. This homogenization process was performed by considering the significance of each asset in the refining process, the potential business disruption for the entire refinery, the asset location, possible cascading effects, and expert opinion. To illustrate the damage state homogenization process, a characteristic example if offered. If a steel chimney fails due to local buckling of the shell (ds3), the consequences for the refinery would be significant (DS3) because gaseous waste cannot be safely released. This would necessitate halting operations in the section of the refinery served by that chimney. However, since different chimneys may service various parts of the facility, the disruption is somewhat contained. Conversely, the failure of a steel process tower due to local buckling of the shell (ds2) results in a severe reduction in functionality (DS4) because this asset typically has little to no redundancy for the size of the refinery. This failure would directly disrupt the refining process chain, leading to substantial business interruption and downtime until repairs can be completed.

A preliminary qualitative identification of assets that contribute most to the disruption of the refinery business is illustrated in Figure 3 in terms of fragility curves for the refinery-level DS1 [Figure 3(a)] and DS4 [Figure 3(b)]. DS1 is related to low-functionality disruption (refinery is operational at almost 100% capacity) and minor repairs are required, while DS4 is related to severe operational disruption (refinery is partially operational at low capacity and may be shut down) and requirement for extensive repairs and/or replacement of assets. It is evident that: (i) there is considerable variability among assets due to their distinct dynamic and structural properties; (ii) nearly full liquid storage tanks (FR=0.95) and spherical vessels are more vulnerable to seismic damage; (iii) the potential failure of pressure vessels or the anchoring of acceleration-sensitive equipment within buildings or tall chimneys has a higher likelihood of causing low functionality disruption (DS1) compared to other structures; and (iv) liquid storage tanks filled above half their capacity may significantly contribute to severe functionality disruption when compared to other high-rise stacks or spherical vessels. It is important to note that comparing fragilities provides a preliminary assessment of which asset may fail first during an earthquake, potentially impacting refinery operations. Additionally, stakeholders require a reliable link between structural damages and physical consequences (e.g., material release, fire, explosion) in a quantitative manner, though this aspect is beyond the scope of the current analysis.



(a) DS1



(b) DS4

Fig.3 Global damage states: Fragility curves of assets

Conclusions

In support of seismic risk and resilience assessment of industrial facilities, a virtual testbed is offered, which simulates a mid-size refinery in high-seismic Mediterranean regions. This model includes a comprehensive exposure analysis with defined site seismic hazard and fragility for critical refinery assets. It offers essential details about the location and function of each structure, providing earthquake and risk engineers insights into the facility's operations and the interdependencies of its assets, which influence risk estimation. The provided data can serve as a testbed for evaluating various assessment methodologies related to seismic risk in refineries. It allows researchers and engineers to examine the impacts of simplifications, formulations, concept discrepancies, and assumptions without the burden of extensive structural modeling. This focus enables exploration of asset correlation, common cause failures, mitigation strategies, and the complex phenomena resulting from initial damage, including cascading effects and damage spread due to loss of containment and subsequent fires.

Open-source data
https://doi.org/10.5281/zenodo.11419659.

This is part of the publication: Melissianos, V. E., Karaferis, N.D., Bakalis, K., Kazantzi, A.K., and Vamvatsikos, D. (2024). "Hazard, exposure, fragility, and damage state homogenization of a virtual oil refinery testbed for seismic risk assessment." Earthquake Spectra, 1-32.
https://doi.org/10.1177/87552930241272521

by Vasileios E. Melissianos, Nikolaos D. Karaferis, Konstantinos Bakalis, Athanasia K. Kazantzi, Dimitrios Vamvatsikos

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