ISS

Institute of Steel Structures

Newsletter

July 2021

National Technical University of Athens
School of Civil Engineering

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Institute of Steel Structures - NTUA / July 2021

Designed & formatted by: **Aikaterini Michaltsou**

Front cover: **The Bailey Bridge at Feneos Village, Greece**

Welcome to the 2nd Newsletter of ISS-NTUA!

Dear readers,

This 2nd ISS Newsletter presents recent activities of the Institute in the balance between experiment and analysis, theory and practice. As structures become older, issues of field testing, health monitoring and structural assessment become increasingly important and the Institute is frequently called to provide services of this kind.

The Institute's latest news are presented first, followed by our most recently completed PhD thesis on the behavior of cold-formed angles used for lattice towers. The next article presents shaking table results of buildings equipped with low-cost dissipative and easily replaceable systems improving the economy and feasibility of their post-earthquake maintenance, performed in the frame of the European research project DISSIPABLE. Results of the very successful European research project ANGELHY are presented then, in which the Institute, as coordinator, cooperated with a number of European Companies, Institutes and Universities.

Next, field measurements and accompanying analyses on the dynamic behavior of a prefabricated steel truss bridge are summarized. Then, a recent field test of two steel cladding panels subjected to blast loading is briefly presented. The final article is devoted to a condition assessment of an airplane maintenance hangar and several old steel buildings at a Fire Brigade Training Center.

Allow me to say that after almost 35 years' academic service, I enter in September into retirement. During these years the Institute evolved from a minor chair to a significant European teaching and research Institution. This was possible due to the gain of experimental capabilities, after moving to the University campus in 2003 and the commitment and good cooperation and teamwork between all its staff, whether faculty, technical, administrative or PhD candidates. I'm confident that this spirit will continue in the future, for the Institute to keep its place as a center of excellence.

Ioannis Vayas

NTUA Civil Engineering School ranked 4th globally for 2021

The Civil Engineering School of the National Technical University of Athens was ranked 4th globally (2nd in Europe) according to Shanghai Ranking's Global Ranking of Academic Subjects (GRAS) 2021, being the best performance of any Higher Education School in Greece. GRAS use a range of objective academic indicators and third-party data to measure the performance of world universities in respective subjects, including research output, research influence, international collaboration, research quality, and international academic awards.

E-LECTURES

The Institute of Steel Structures at NTUA in cooperation with the Steel Structures Research Society continued the tradition of organizing lectures addressed to students and practicing engineers. To comply to Covid-19 safety measures we switched to an e-lecture format, which proved to also have positive aspects, in attracting a larger than usual audience.

In January 2021 Prof. I. Vayas coordinated presentations by Prof. Emeritus G. Ioannidis, Mr. M. Sofras and Dr. X. Lignos on the "Standard EN1090-2 - Execution of Steel Structures" covering aspects of project execution, industrial processing and corrosion protection.

In April 2021 Prof. E. Mistakidis coordinated presentations by Prof. I. Vayas, Mr. T. Dimitriou and Mr. A. Spiliopoulos on the "Construction and Tests of Floisvos Pedestrian Bridge", including vibration monitoring, fabrication and detail design.

NEW RESEARCH PROJECT

ISS participates in ADDOPTML, a new MSCA-RISE-2020 Marie Skłodowska-Curie Research and Innovation Staff Exchange project (http://addoptml.ntua.gr/), that started in May 2021 and will have a 4-year duration. Principal aim of ADDOPTML (ADDitively Manufactured OPTimized Structures by means of Machine Learning) is to create and test an holistic optimum design – additive manufacturing process of civil structures by a multi-disciplinary team of academic experts and SMEs from Belgium, Cyprus, Germany, Greece, Italy, Jordan, Netherlands and Spain. The role of ISS in the project will be:

- To contribute to the development of optimization algorithms for steel structures based on fully nonlinear finite element analyses (GMNIA).
- To perform tension tests of 3D printed steel coupons towards formulating constitutive relations.
- To design deployable structures for emergency applications employing 3D printed joints.
- To validate this design by performing experimental testing of 3D printed specimens.

DONATION

ISS accepted the donation of technical books and archival material from the office of the late Fotis Zoulas, one of the most prominent structural steel design engineers in Greece, who passed away recently. The material will be available to students and structural engineers in the ISS library.

ISS VIDEO

A short 4 minute video presenting ISS is available in YouTube: https://youtu.be/shlXDxV52yY

ISS IN SOCIAL MEDIA

Since June 2021, you may also find ISS in Linkedin: https://gr.linkedin.com/in/iss-institute-of-steel-structures-ntua-15a8b3214

PUBLICATIONS

In 2020 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

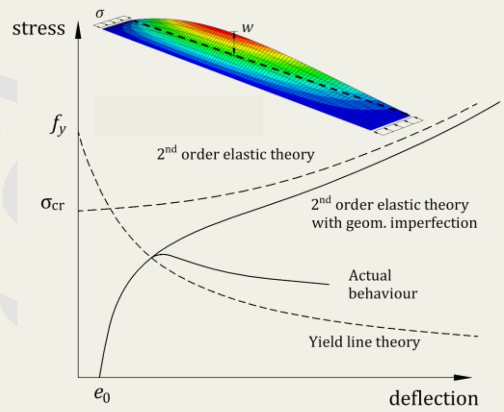
PhD Defense of Zacharias Fasoulakis

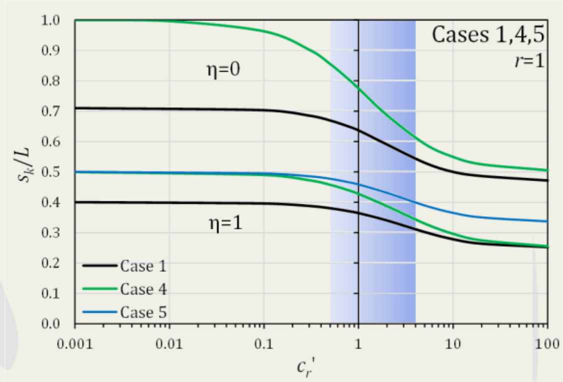
In May 2021, Zacharias Fasoulakis successfully defended his PhD dissertation "**Investigation on the behaviour of members from cold-formed angle sections used for lattice towers**".

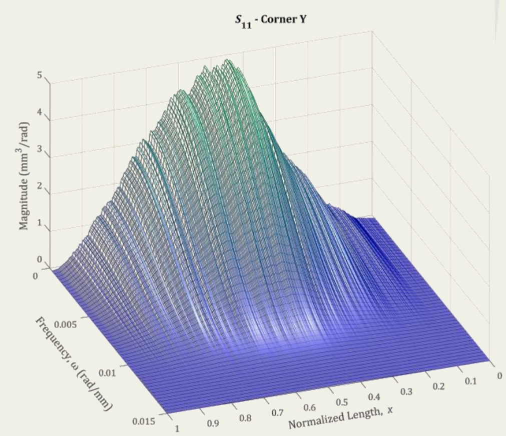
Steel lattice towers with members from angle sections are the dominant structural type for the needs of energy transmission. This thesis endeavours to bridge the gap towards an improved capacity assessment of lattice towers. A joint analytical-experimental-numerical study is undertaken in order to provide comprehensive and efficient design tools for the capacity of bracing members from cold-formed angle sections with bolted ends.

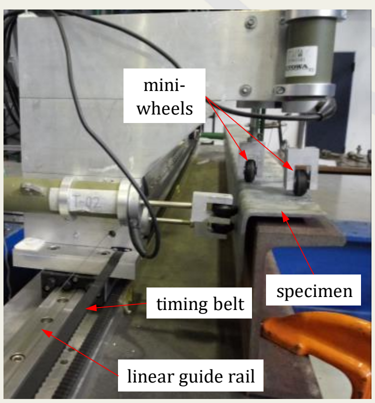
Simple yet reliable expressions are proposed by employing analytical approaches in order to realistically capture local and global buckling behaviour of angle-section columns, taking into account the effects of the bolted connection. The experimental study carried out offers up-to-date test results for cold-formed angle-section columns with single-bolted connections. The comparative results denote a fair prediction of EN 1993-3-1. Detailed imperfection measurements are measured by an in-house built imperfection plotter. A thorough numerical study via finite element analyses frames the tests, considering geometric and material nonlinearities. Accordingly, the buckling behaviour of X-braces is investigated.

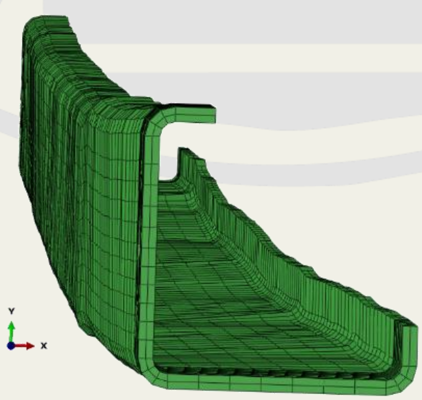
Further research using stochastic mechanics aims to capture the probabilistic estimation of the buckling capacity of bolted members from plain or lipped angle sections with stochastic geometric imperfections. Additional uncertain parameters are also included, namely material properties and lateral wind pressure. The resulting density distributions reveal the influence of each parameter (and their combinations) on the buckling load variability and can be used also for probabilistic assessment. Finally, a reliable computational model of an actual transmission lattice tower with braces from cold-formed angle sections is developed. The proposed modelling of the tower takes into account slippage effects for single-bolted or double-bolted connections of the bracing members, as well as accurate buckling performance.











The DISSIPABLE Project
Design and analysis of shaking table specimens with dissipative components (FUSEIS & INERD)

The DISSIPABLE project started in June 2018 comprising 8 partners from the academia and industry. The overall objective of the project is to promote buildings equipped with low-cost dissipative and easily replaceable systems, improving the economy and feasibility of their post-earthquake maintenance. To this end, DISSIPABLE is re-visiting the components and systems previously developed by the proposal's beneficiaries in past RFCS projects since 2001 (INERD, FUSEIS, MATCH). Using the experience collected so far, their design is being upgraded to make these systems feasible and economic for commercial applications, as well as to prove their repairability.

The performance of the upgraded systems is being quantified both analytically and experimentally. Given the impracticality and high costs of performing a pilot/demonstration test for a multi-storey full-scale building under real seismic actions, the technical approach of the project is based on a two-way demonstration:

- Hybrid testing based on numerical/physical simulation based on dynamic 2D sub-structuring in full-scale.
- Shaking table testing of half-scaled 3D buildings under real-time three-dimensional seismic excitations.

The shaking table tests have been conducted in the Laboratory of Earthquake Engineering of NTUA since October 2020 and are expected to be concluded by Autumn 2021. The shaking table specimens were half-scaled composite structures with two-storeys, two bays in the longitudinal direction and one bay in the transversal direction.

The test procedure included the definition of the natural frequencies of the structure and the earthquake loading for each performance level. In total, four performance levels of earthquake loading were examined (namely DL, SD, NC, NC+sd).

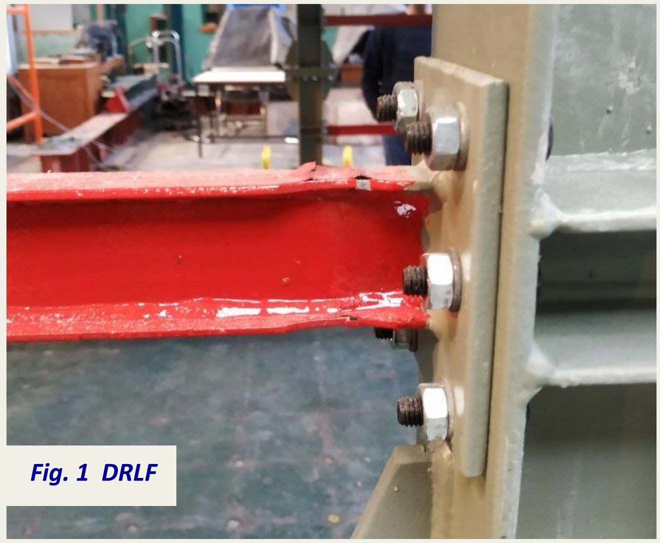


Fig. 1 DRLF

The dissipative systems that were examined are the following:

- DRBrC (also known as INERD or DRD1)
- DRLF (also known as FUSEIS beams or DRD2)
- DRBES (also known as FUSEIS-2 or DRD3)

Fig. 2 DRBrC

After the completion of each test, the specimens were repaired, namely the damaged dissipative components were replaced with new ones. Afterwards, the test was repeated in the repaired specimen.

Despite the fact that the evaluation of the results is ongoing, the initial conclusions on the examined dissipative systems indicate significant ability to dissipate seismic energy and remarkable repairability.

ISS participates in DISSIPABLE with the doctoral candidate Konstantinos Papavasileiou, and faculty members Dr. I. Vayas, Dr. P. Thanopoulos and Dr. D. Vamvatsikos. The design of the shaking table tests is conducted under the guidance of Dr. H. Mouzakis, the scientific coordinator of the NTUA team.

REFERENCES

1. Fully dissipative and easily repairable devices for resilient buildings with composite steel concrete structures - DISSIPABLE, 2017.
2. Design and Analysis of Shaking Table Specimen DRLF-DRBrC, DISSIPABLE, 2020.

by Pavlos Thanopoulos
& Konstantinos Papavasileiou

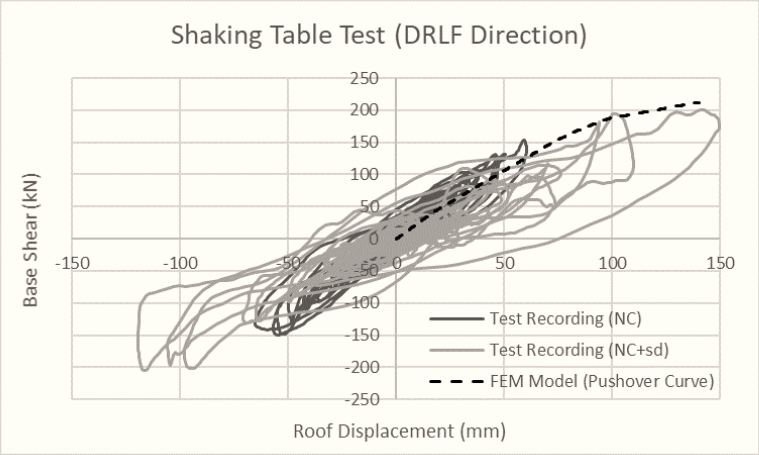


Fig. 3 Test calibration results

Fig. 4 NTUA Specimen configuration

ANGELHY: Design of steel and hybrid lattice towers

The ANGELHY research project, is an RFCS funded project focused on steel lattice towers, that started in July 2017 and was completed with great success in the end of December 2020. Seven partners were involved, with participants from academic institutes and industry from four European countries. The main objectives of the project were the establishment of analysis methods for lattice towers and the development of design rules for steel and hybrid angle sections, as well as built-up members composed of angles.

Within the framework of the project the main structural typologies for telecommunication and transmission towers were identified. Six case studies with simple and refined analysis and design methods were analysed. The provisions of the European codes concerning design of angles and closely spaced built-up angle sections were critically reviewed and discrepancies were detected.

A number of experimental tests on steel and hybrid angle members as well as on complete large-scale parts of lattice towers were performed to create an appropriate data-base for calibration of numerical models and further elaboration of design rules. Experimental investigations included 12 buckling tests on the largest available angle profiles made of High Strength Steel, 5 bending and 16 buckling tests on hybrid members composed of angle profiles strengthened by FRP plates, 16 buckling tests on built-up angle members in three configurations and 6 full-scale pushover tests on telecommunication tower's parts composed of steel or hybrid angle members. Tests on hybrid members and full-scale tests were performed in the Laboratory of ISS.

Appropriate numerical models were developed and parametric studies were performed to explore the contribution of the main parameters influencing the response of steel and hybrid angle members or built-up members and validate the proposed design formulae. Four levels of numerical modelling were studied for lattice towers and probabilistic models for wind and ice loads were developed considering inherent uncertainties of those actions.

Fig. 1 Objectives of the ANGELHY project

A summary of construction recommendations for hybrid members was formulated, including general requirements, necessary equipment and guidelines for FRP application.

Finally, new design rules duly validated by results of experimental and numerical studies were proposed. They refer to new consistent rules for equal angle profiles, extending the application to classification, cross-section and member design for compression and bending, similar rules for hybrid sections and members as well as new unified rules for built-up members that through consideration of the shear stiffness eliminate existing conditions of minimum distance between packing plates. Proposals were also made for four possible analysis and design methods for lattice towers with increasing refinement and a new failure mode, a "leg instability mode" was detected in the project and covered by appropriate design rules.

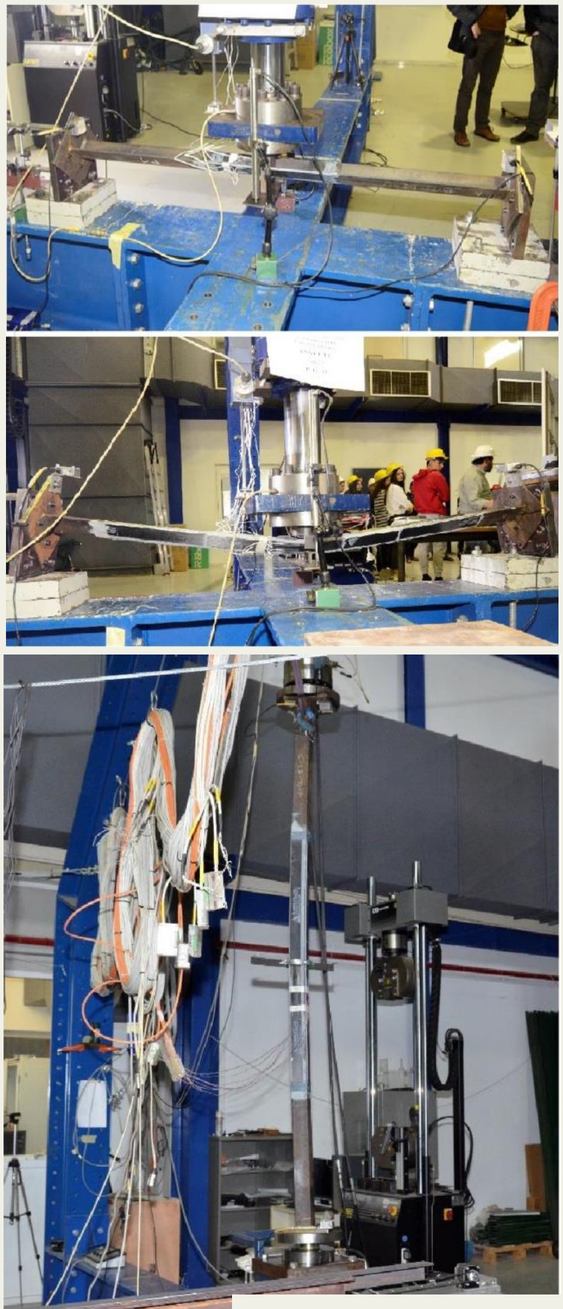


Fig. 2 Tests on hybrid angle members

A performance-based design procedure was introduced to assess the safety of existing towers and tower lines taking into account the impact of ageing and the uncertainties of loading conditions. This procedure allows, in combination with cost estimations, a decision-making concerning upgrading/ strengthening of the existing or building a new line.

The results of the project were presented to researchers, students and practicing engineers through a webinar. Moreover, a number of papers has been submitted and accepted for publication in conference proceedings, such as Eurosteel 2021, and scientific journals. Finally, contacts were established with European code drafting panels, especially of EN 1993-3 related to towers and masts, to possibly include the proposed design rules in the forthcoming code draft.

Partners of the project were ArcelorMittal Belval & Differdange (Luxembourg), University of Liege (Belgium), COSMOTE (Greece), CTICM (France) and SIKA (France).

ISS was responsible for a significant part of the work performed, including coordination and management of the entire project, with many doctoral candidates, technical staff and faculty members getting involved during this 42 month period.

by Konstantinos Vlachakis

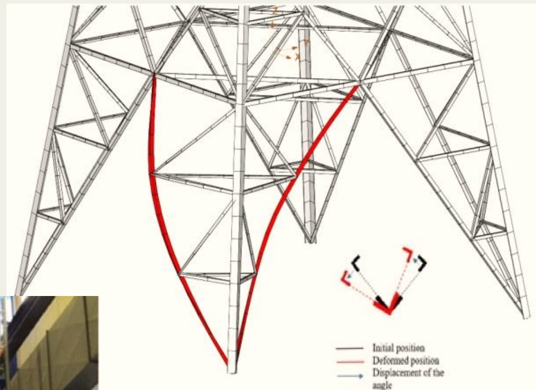


Fig. 4 The "leg instability" mode

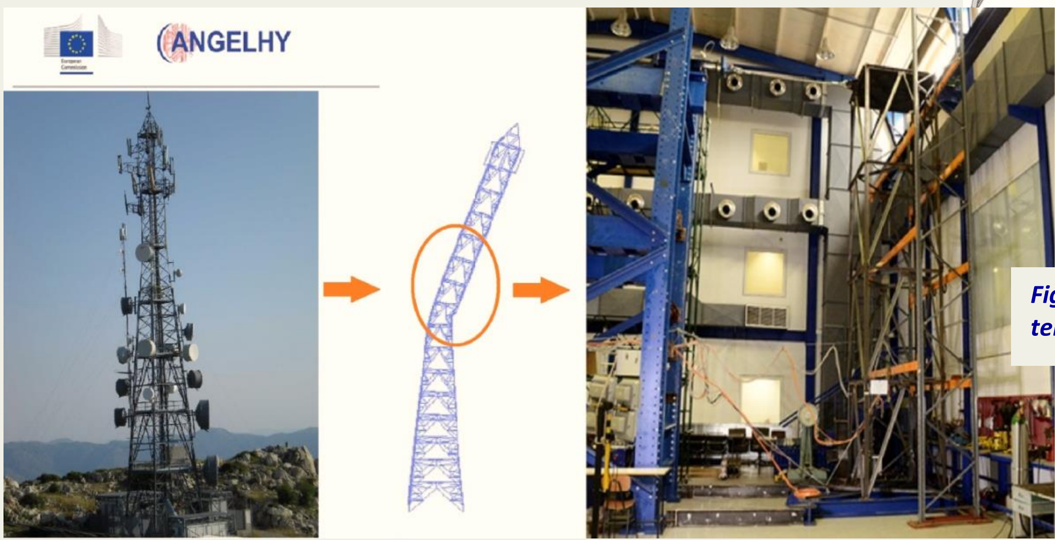


Fig. 3 Full scale tests on telecommunication towers

Traffic-induced vibration measurements of a prefabricated steel bridge

Prefabricated steel truss bridges, such as the well-known Bailey bridge, were developed for temporary use in emergency cases, where the immediate operation of the road network is vital. However, many of the erected Bailey bridges are in use for an extended time period, replacing permanent infrastructures. Consequently, the evaluation of the structural health state of such bridges is a subject that deserves investigation.

Fig. 1 The Bailey Bridge at Feneos Village

An approach for structural condition assessment of existing bridges is based on estimation of their modal parameters based on vibration measurements under operational conditions, and comparison to expected values. In recent years, a well-established practice known as Operational Modal Analysis (OMA) has been developed, which constitutes a powerful tool for such purposes.

In the framework of the doctoral research of Vasileios Papavasileiou, measurements were performed at a Triple-Single type (TS) Bailey bridge near Feneos village at the Corinth Prefecture. The total length of the bridge is 30.48m with an effective width of 3.70m (Fig. 1). Recording the traffic-induced vibration response of bridges using conventional equipment is more expensive compared to the use of the recently developed technology of sensors relying on micro-electromechanical systems (MEMS). Thus, the bridge was equipped with six low-cost MEMS accelerometers (Fig. 2), custom- made for this study, consisting of a microcontroller, an Inertial Unit (IMU) and a data logging card (SD-CARD), that were attached on the two girders by means of high-adhesive force neodymium-magnets (NdFeB).

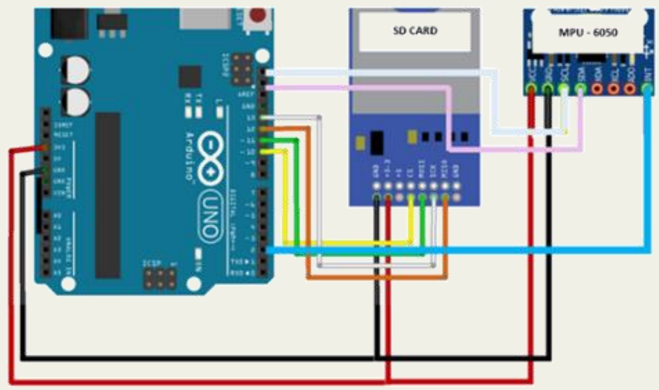


Fig. 2 Wiring diagram of MEMS accelerometer

Data were collected from vibrations caused by twenty-seven passing vehicles of various classes. The recorded raw values were subjected to pre-processing with a 5th order Butterworth filter for further analysis. A comparison between measured and pre-processed vibration responses is presented in Fig. 3.

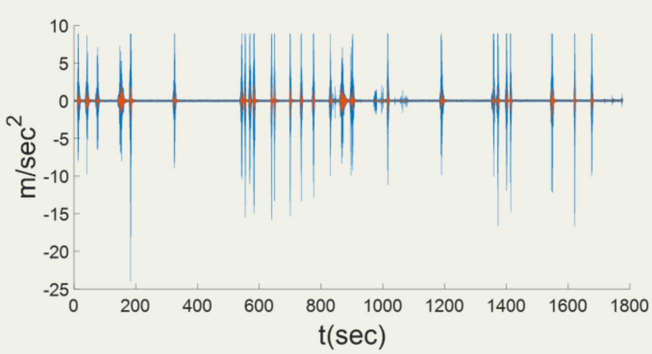


Fig. 3 Acceleration measurements (raw measurements in blue vs filtered measurements in orange) of the sensor at the middle of the bridge (vertical axis)

Moreover, a finite element model (FEM) of the bridge was developed (Fig. 4), adopting all geometrical, structural and material properties. Firstly, a modal analysis was performed and the results of obtained eigenfrequencies and eigenmodes are presented in the first and second columns of Table 1, respectively.

TABLE 1				
	FEM			Traffic Induced Vibration
Mode	Modal		FDD	FDD
	Hz	Mode	Hz	Hz
1	2.758	Vertical	2.753-2.799-2.845	2.766
2	3.187	Torsional	Ø	3.449
3	4.760	Lateral	4.688	4.533 - 4.893
4	7.970	2nd Lateral	Ø	Ø
5	8.913	2nd Vertical	8.776	8.415- 8.615- 8.770

The analysis of recorded data provided an estimation of frequencies that are close but not identical to the numerical estimates. This differentiation is considered to be caused by the operational conditions during the vehicles passage over the bridge, which are affected from both the dynamic properties of the vehicles and the modal parameters of the bridge. In addition, some measured frequencies are attributed to independent vibration of loosened secondary members of the bridge.

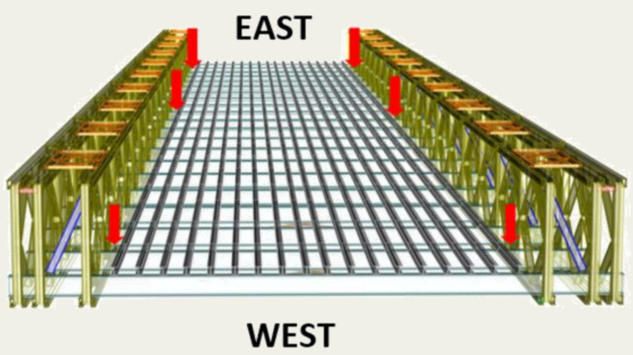


Fig. 4 FEM model (red arrows indicate the position of sensors)

A second set of numerical simulations was carried out, consisting of time history direct-integration analyses, simulating the crossing of twenty-seven vehicle models with the same characteristics as the actual ones. Even though in this case ideal operational conditions were assumed, the obtained frequencies were close to the measured ones. Traffic-induced vibrations and numerical frequency domain analysis results are compared in Fig. 5.

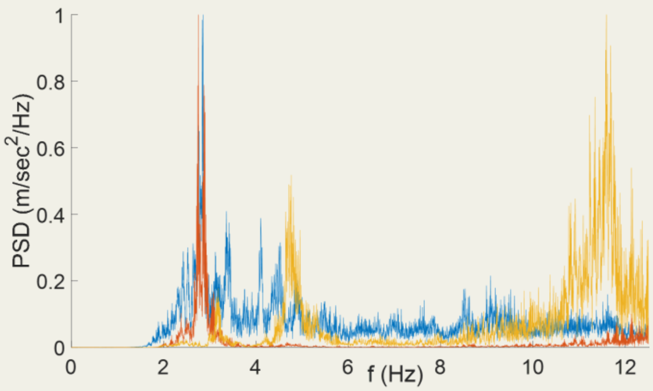


Fig. 5 Power spectral density (Welch's method), (Traffic induced vibration measurements in blue vs FE analysis results in orange and yellow)

In conclusion, the bridge was found to be in relatively good operational condition, based on the comparison between traffic-induced vibrations and numerical simulation results. However, the identified frequency differences indicate that the bridge should be checked for loosened connections.

by Vasileios Papavasileiou

Steel cladding subjected to blast loading

In May 2021 a field test of two steel panels subjected to blast loading was conducted as part of the PhD research of Orestis Ioannou. The two panels were placed side by side and the blast was induced by approximately 2.5 kg TNT at a standoff distance of 2.40 m. The dimensions of each panel were 0.70 m × 1.40 m, both were simply-supported on SHS 50/2 purlins along their long edges, and the difference between them was their geometric configuration. Namely, panel A consisted of a 2 mm thick steel plate with 5 mm x 48 mm stiffeners spaced at 110 mm, while panel B consisted only of a 4 mm thick solid steel plate. The purlins were attached rigidly to steel moment frames in both directions, anchored to a 4.0 m × 2.7 m × 0.5 m reinforced concrete ground slab. Numerical analyses conducted with LS-DYNA and ANSYS had indicated that the stiffer panel A exhibits during blast smaller deflections than the more flexible panel B. However, the deflections of the supporting structure are lower in the case of the panel with solid plate than in the case of the panel with stiffeners. The numerical analyses were Nonlinear Transient Finite Element Analyses (NTFEA) with material and geometric nonlinearity as well as consideration of strain rate effects.

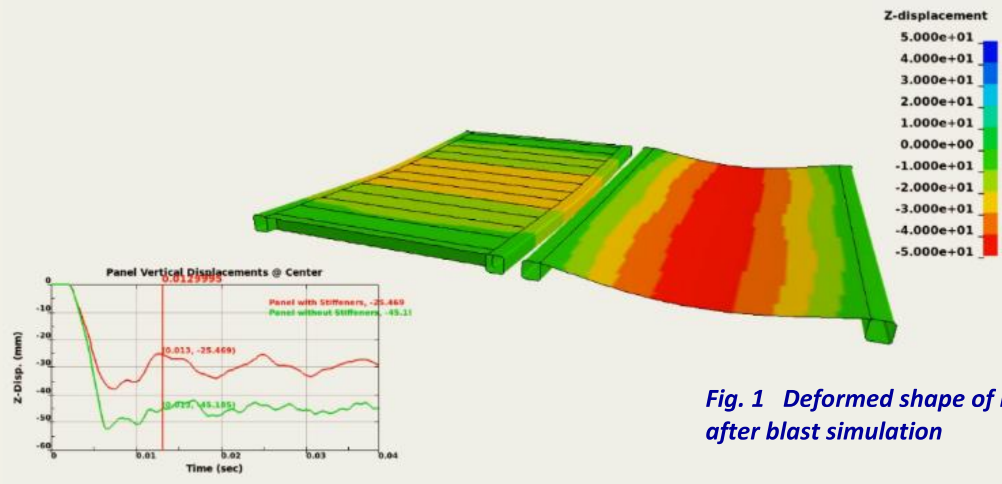


Fig. 1 Deformed shape of numerical model after blast simulation

The main purpose of the experiment was to confirm the numerical results, focusing on the effects of panel configuration to the supporting structure, as a way to reduce overall blast consequences. In the aftermath of the explosion, it was indeed observed that the purlins of the panel with stiffeners suffered significant inelastic deformation, while this was not the case for the flexible solid plate panel that exhibited such deflections itself but not its purlins.

It was thus confirmed that by appropriate cladding design the response of the supporting structure can be controlled to a significant extent, providing interesting insight into the role of cladding stiffness, mass and resistance in blast design. As predicted, the experimental setup remained elastic during blast testing and is reusable.

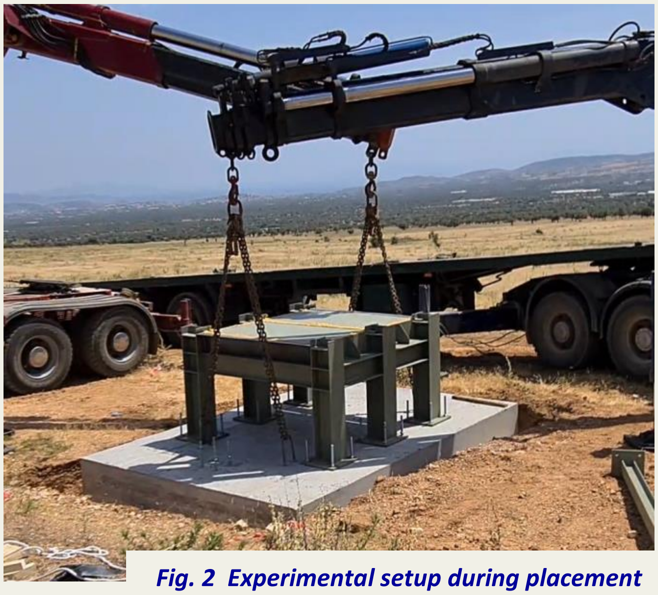


Fig. 2 Experimental setup during placement

Maximum deflections occurring during the test at the center of the panels and the corresponding purlins were recorded through single-value displacement comb devices. Furthermore, permanent deflections due to inelastic response of the panels and the corresponding beams were measured after the explosion.

For the experimental investigation of the response of steel cladding subjected to blast loading, which was conducted by NTUA's Institute of Steel Structures, the explosions were performed by the Land Minefield Clearance and EOD Battalion in the context of the memorandum of cooperation between the National Technical University of Athens (NTUA) and the Engineer Officers' Technical School (EOTS) of the Greek Army. As part of the action, the necessary protection measures against the transmission of COVID-19 were observed. Sponsors and fabricators of the experimental setup were the companies Armos Precast SA (precast reinforced concrete ground slab) and Kataskevastiki J. Dimitriou (steel cladding specimens, main steel support structure). Their support is gratefully acknowledged.

by Orestis Ioannou

Fig. 3 Experimental setup before explosion

Fig. 4 Snapshot of explosion

Fig. 5 Displacement device before and after the explosion

Fig. 6 Permanent deflections after the explosion

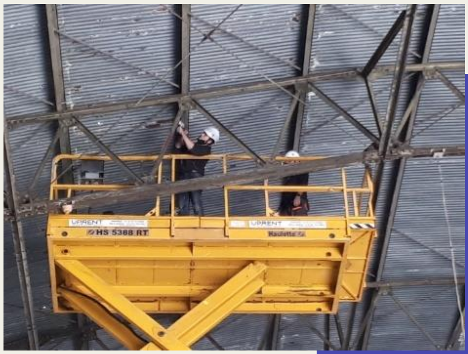
Condition assessment of old steel structures

Old steel structures often exhibit deterioration and damage due to insufficient maintenance, corrosion of members and connections, loss of straightness of bars and flatness of plates, or due to accidental loads such as earthquake, fire of vehicle collision. Even if there is no damage, evaluation of the available bearing capacity is necessary in cases of change of use or of live loads. For this evaluation it is necessary to record and appraise possible damage as well as assess the mechanical characteristics of the materials.

Airplane maintenance hangar at Hellinikon International Airport

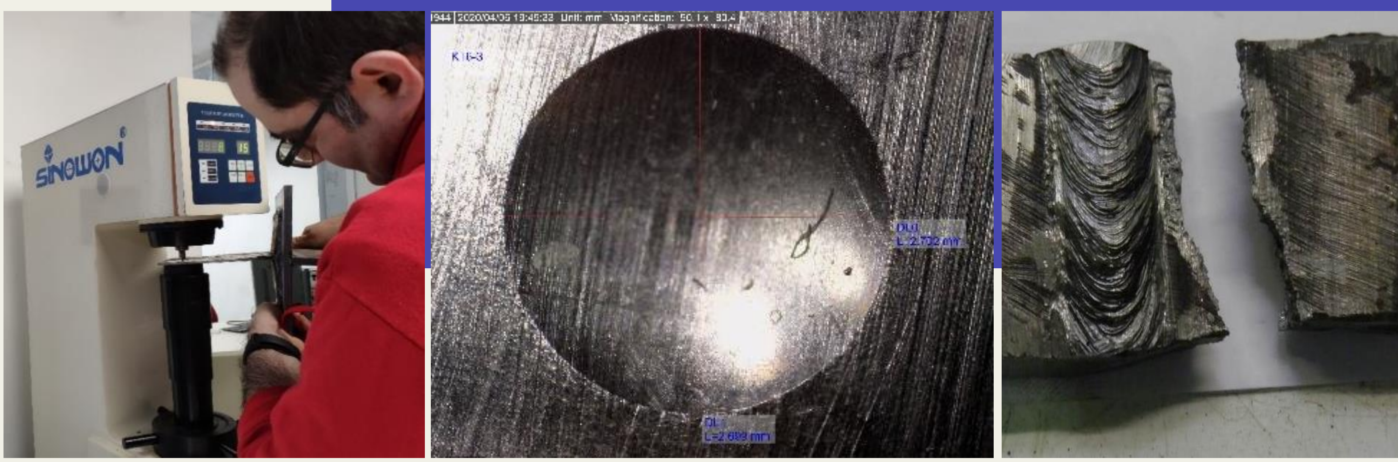
Towards that goal, the research team of the Institute of Steel Structures at NTUA combines a wide range of on-site measurements, laboratory tests and computational simulations. Recent examples of such activity include an airplane maintenance hangar at Hellinikon International Airport and several old steel buildings at the Fire Brigade Training Center in Nea Makri.

by Charis Gantes



On-site measurements

Laboratory testing for material characterization



Laboratory testing for material characterization

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