ISS

Institute of Steel Structures

Newsletter

July 2022

National Technical University of Athens
School of Civil Engineering

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Institute of Steel Structures - NTUA / July 2022

Designed & formatted by: **Aikaterini Michaltsou**

Front cover: **The SmartNetHouse project**

Welcome to the fourth issue of ISS-NTUA Newsletter!

Dear readers,

Students are recovering from exams, professors are recuperating from grading, in-person meetings are back in vogue, and the dreaded hybrid conference is disappearing fast. So, I guess summer 2022 is here at last. As you are going through your beachwear, take a look at what has happened at the Institute of Steel Structures NTUA.

Ever heard of nethouses? Well, they look like greenhouses, but instead of a transparent material cover they employ actual nets, fine enough to keep the insects out, but still let the moisture and the air in. Dr Adamakos and planning-to-be-Dr Mantas are reporting on the SmartNetHouse project, testing conventional and novel configurations of nethouse covers for improved capacity.

Never visited an ancient temple in need of weather protection? This would be the Temple of Apollo Epicurius at Bassae. Take a look at its protective shelter and the condition assessment performed by Prof. Gantes and Dr. Lignos.

How about damage-free steel connections for seismic resistant structures? This is the province of the FREEDAM+ project, a valorisation project under the Research Fund of Coal and Steel undertaken by soon-to-be-Dr Antonodimitraki, Prof. Thanopoulos and Prof. Vayas.

Interested in cultural heritage monuments? Look no further than the ARCHYTAS project, instrumenting and investigating the Tower of the Winds in the Athens Agora, and the Temple of Aphaia in Aegina. Dr. Melissianos, Dr. Lachanas and yours truly are happily blabbering away on how we can monitor monuments, perform fast assessments of their expected performance, and help them last a lot longer than their builders intended.

What about the young generation? Two of our own have successfully defended their theses. Recently-minted-Dr. Tsarpalis worked on the seismic performance of automated rack-supported warehouses. If you have never seen these behemoths, think logistics at their grandest scale, with racks the size of football fields and robots efficiently transporting the goods in and out. Even-more-recently-christened-Dr. Lachanas took upon him the investigation of the seismic performance of simple rocking oscillators. This is a fundamental problem of earthquake engineering, only viewed from the probabilistic lens that it sorely needed.

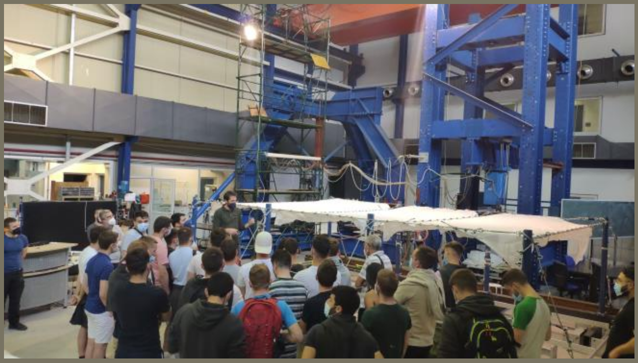
Ever felt a bridge vibrate? Well, now you can read about in-situ monitoring by a reliable and inexpensive measurement system developed in-house with off-the-shelf components, as reported by planning-to-be-Dr. El Dahr, Dr. Lignos and Prof. Vayas.

If all of this was not enough, just wait for what we have in plan for the next edition of our newsletter. In the meantime, enjoy your vacations and don't forget your sunscreen.

Dimitrios Vamvatsikos

VISITS

On 3 May 2022, a group of students from the University of Reims visited the Institute of Steel Structures at NTUA. Among their curriculum activities is to organize a study trip in a foreign country.



For the class of 2023, Greece was chosen, because of its great potential for technical and cultural enrichment.

NEW RESEARCH PROJECT

ISS participates in AMOSS, a new research project funded by the Greek Foundation for Research and Innovation, that started in June 2022 and will have a 3-year duration. Principal aim of AMOSS (Additively Manufactured Optimized 3D Printed Steel Structures) is to combine structural optimization, advanced nonlinear finite element analysis and fundamental principles of steel design, in order to develop optimized steel components and systems, and then employ additive manufacturing for their realization. In the project ISS will undertake numerical and experimental aspects related to structural steel design.

UPGRADING OF THE EVRIPOS BRIDGE

The Institute of Steel Structures has been granted a research project with the title "Upgrading of the Evripos Bridge". The bridge connects the mainland with the Island of Evia, the 2nd largest in Greece, at its narrowest distance in the city of Chalkis. It is a movable, 42.0 m span steel truss bridge built around 1960. The bridge is composed by two halves, connected in the middle through pins. In order to move, the pins disengage, allowing each half bridge to slide into a tunnel on each side of the opening. The truss is composed of the 21.0 m cantilever and 8.40 m behind it that is hidden in the tunnel to provide the back support of the cantilever, while the front support is provided by piles.

By means of experimental, numerical and analytical methods, duly supported by in situ monitoring, the project intends to collect all existing data, estimate the remaining life of both the steel bridge and the reinforced concrete tunnels, propose restoration measures in order to extend their life and set up a maintenance manual.

DUTCH OPEN STUDENT STEEL AWARD

We are pleased to announce that the postgraduate student of the School of Civil Engineering at NTUA, Konstantinos Mantas, participated with his postgraduate thesis in an international competition organized by TU Delft. Between 23 submitted papers, his article was among the 6 selected for presentation and after a relevant public vote he finally took 4th place. The DOSS Award (Dutch Open Student STEEL Award) is the annual international prize for master students, graduating in civil engineering at technical universities from all over the world. This year the DOSS Award celebrated its second edition.

The SmartNetHouse Project: Design of nethouse systems

Nethouses are steel structures that constitute an alternative solution for the greenhouses in order to protect the high value horticultural production against climatic hazards by using an agricultural membrane-net as cladding material. Up to now, they are not designed for snow loads and as a result the majority of the installed nethouses are either unsafe or overdesigned structures. The Institute of Steel Structures at NTUA in cooperation with the Agricultural University of Athens aim to develop an optimal design methodology for nethouse systems examining the possibility of installing them in areas where significant snow loads are expected.

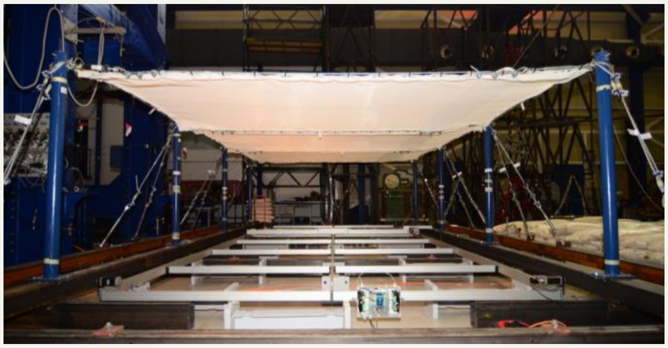


Fig. 1 **Side view of experimental set-up of flat configuration**

In May 2022, a series of large scale (1:2) tests of a tensile nethouse structure was conducted, investigating the response of the structure under distributed vertical loads. Tensile nethouse was composed of pretensioned steel cables in two directions. The main horizontal cables were suspended from steel columns and restrained by inclined anchorage cables. The structural behavior of the nethouse was tested for two different roof angles θ (θ=0, θ=20^{o}) and each segment was 2x4m.

Experimentally, imposing a uniformly distributed load may be a challenge. This issue becomes even more complicated in the case that the imposed area is an extremely flexible surface, such as a membrane. For the implementation of the uniformly distributed load, bags of sawdust/wood shavings were selected. The sawdust, as a bulk material, can follow the large deformations of the flexible surface, applied in layers. The vertical deformations of the membrane, before and after prestressing, but also after application of each load layer were measured using a laser scanner. The cable forces were measured by means of load cells placed at their end points.

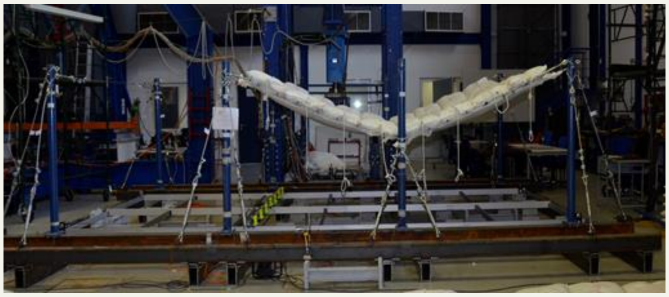


Fig. 2 **Experimental set up of duopitch configuration**

ISS participates in SmartNetHouse with the doctoral candidate Konstantinos Mantas, post-doctoral researcher Konstantinos Adamakos and faculty member Dr. I. Vayas

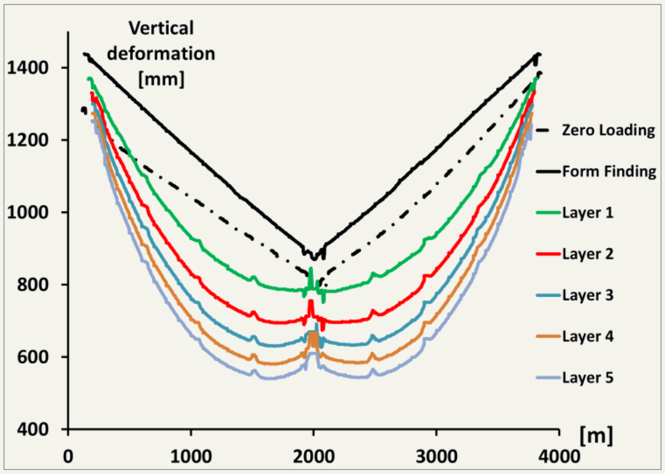


Fig. 3 **Vertical deformation of duopitch nethouse**

by Konstantinos Mantas
& Konstantinos Adamakos

Structural condition assessment of the shelter protecting the Temple of Apollo Epicurius at Bassae

The Temple of Apollo Epicurius was dedicated to the god of healing and the sun and was built towards the middle of the 5th century B.C. It is located within the sanctuary of Bassae in the mountains of Arkadia, in southern Greece. It is one of the best-preserved monuments of classical antiquity and an evocative and poignant testament to classical Greek architecture. The temple appears to have been forgotten for almost 1700 years until it was rediscovered in the 18th century and attracted intense interest from scholars and artists. Since 1986 it has been included in the UNESCO Heritage List [1].

The greatest threats to the property stem from inherent weaknesses in the building structure and the adverse effects of climate and environment, including extreme temperatures, strong wind, water and seismic activity. In 1987 a protective shelter was constructed, to minimize damage caused by the extreme weather conditions and provide more favorable conditions for major restoration work. The shelter comprises a pretensioned, cable-supported membrane roof, shown in photo 1.

Photo 1. Exterior view of the shelter, 2021

The shelter has suffered significant damage due to aging and harsh environmental conditions in the area (photos 2). Examples of damage include local wear of the membrane, corrosion of steel components, partial loosening of stay cables, and loosening of foundation anchors, which are essential to maintain the pretension of the superstructure.

Photo 2 a, b, c. Indicative structural damage, 2021

As part of the efforts to evaluate structural damage and take appropriate decisions between strengthening or replacement of the shelter and its foundations, a site visit was conducted, accompanied by preliminary measurements (photo 3), aiming at developing a comprehensive proposal of additional field measurements encompassing the foundation as well as the superstructure.

Photo 3. Preliminary measurements of cable tension

Moreover, a preliminary numerical investigation of the superstructure was conducted, indicating adequacy of the member cross-sections for the assumption of no damage, and confirming very good compliance of numerically obtained action effects to the hand calculations of the original shelter design.

The recent investigations were undertaken by consulting company GEOPER. Structural and geotechnical engineering consulting services were provided by Christos Papadopoulos and Dimitris Egglezos, respectively. Numerical modeling was conducted by Christos Alamir. ISS participated with Prof. C. Gantes and Dr. X. Lignos who consulted on numerical modeling, field measurements and condition assessment of the superstructure.

REFERENCE:
[1] Temple of Apollo Epicurius at Bassae, https://whc.unesco.org/en/list/392/

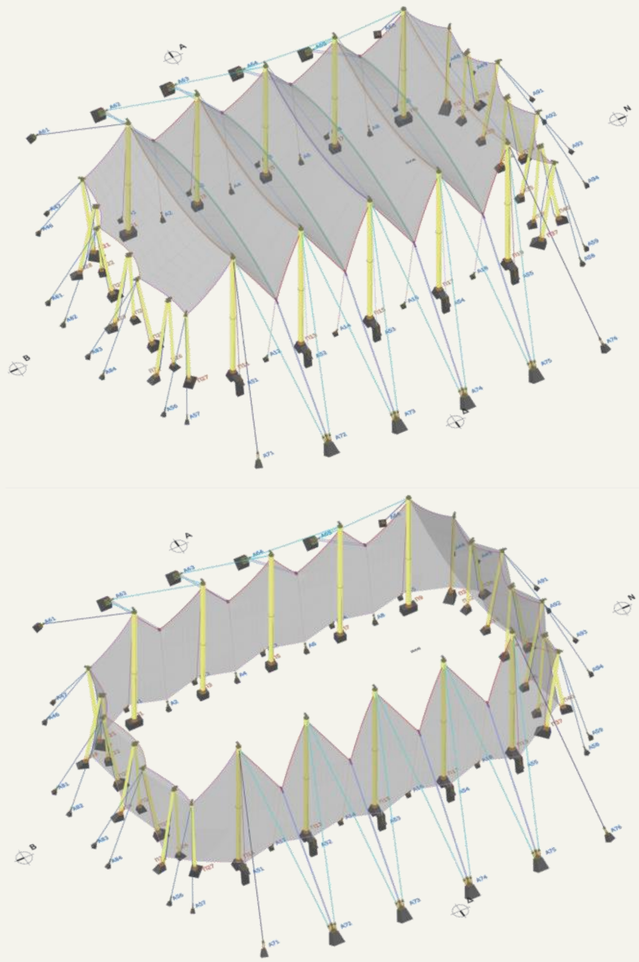


Fig. 1 Structural configuration of superstructure (above: roof membranes, below: wall membranes)

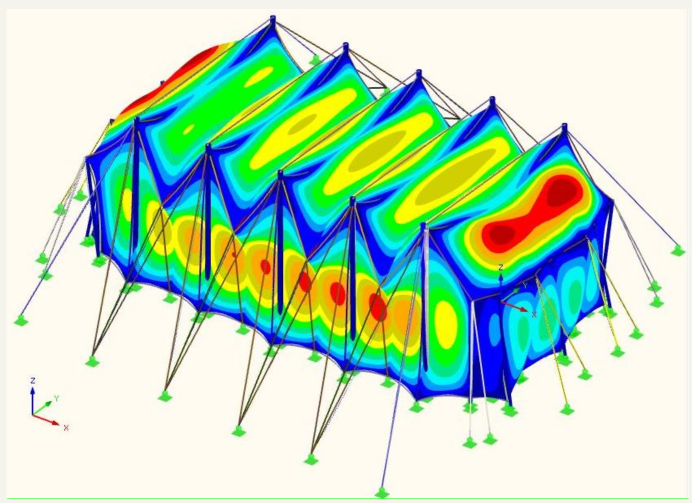


Fig. 2 Deformed shape of superstructure due to wind loading

by Charis Gantes

FREEDAM-PLUS project: Valorisation of knowledge for FREE from DAMage steel connections

The FREEDAM+ project is an RFCS funded project, which started in July 2020 and concluded in June 2022. Fifteen partners from 13 European countries were involved. The ISS participated with the faculty members Prof. Ioannis Vayas and Lecturer Pavlos Thanopoulos and the Doctoral Candidate Ms. Sofia Antonodimitraki. The aim of the project was the valorisation and dissemination of the knowledge that had been obtained on FREEDAM joints during the homonymous RFCS project where they were originally introduced.

The FREEDAM beam-to-column joints integrate friction dampers, which are able to absorb the seismic energy during a destructive seismic event, leaving the connections as well as the structural members almost without any damage. This, obviously, increases the safety of the building and decreases the costs related to damage repair after rare seismic events or exceptional loads.

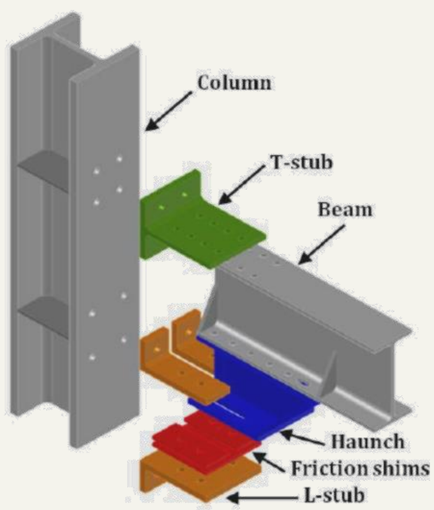


Fig. 1 Components of FREEDAM joints [1]

The components of a typical FREEDAM joint are depicted in Fig. 1. The main benefit of this configuration is the possibility of prefabrication, ensuring better quality control of the treatment of the friction surfaces and of the pre-tensioning of the bolts, which govern the behaviour of FREEDAM joints.

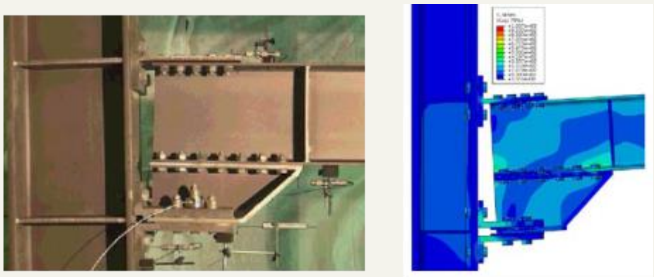


Fig. 2 Exprerimental and numerical investigation of FREEDAM joints [1]

The behaviour of FREEDAM joints has been studied extensively through experimental and numerical investigations both at sub-assembly (Fig. 2) and at a full-scale structure level (Fig. 3).

Fig. 3 Test of a real scale steel structure with FREEDAM joints [1]

Based on these investigations, pre-normative design recommendations were drafted during the FREEDAM+ project, in line with the latest versions of EN 1993-1 and EN 1998. Additionally, in order to facilitate practising engineers willing to design buildings with FREEDAM joints, worked examples and a design tool, available in both pc software and mobile app format (Fig. 4), were developed.

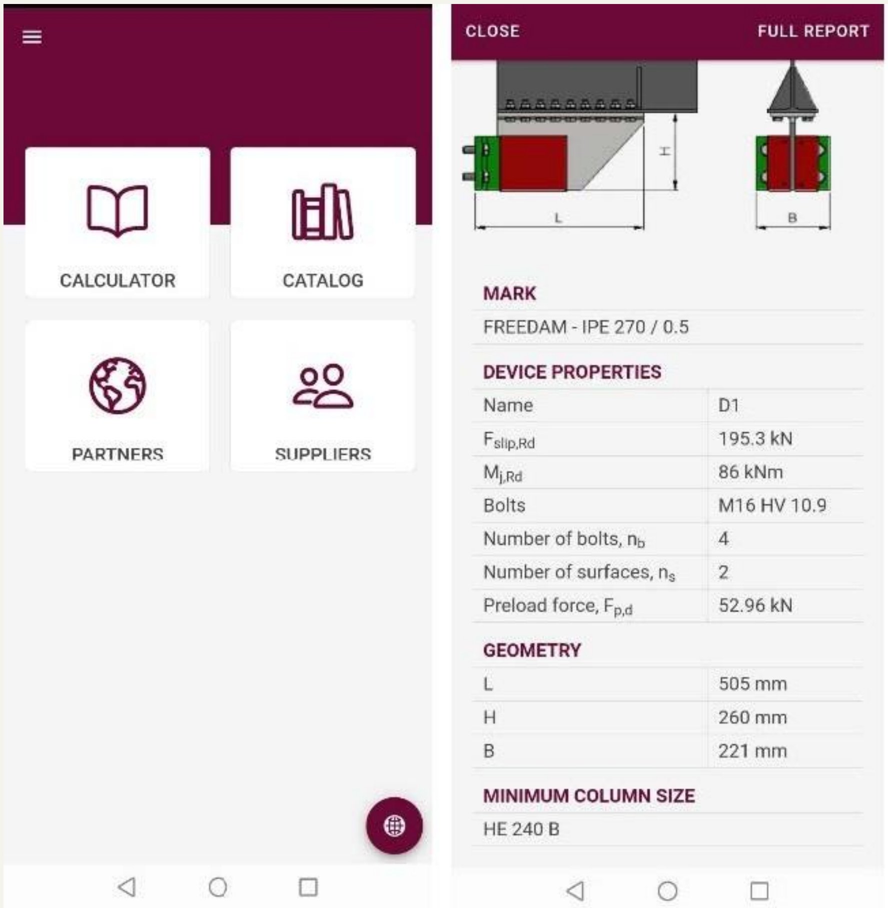


Fig. 4 Environment of the FREEDAM design tool [1]

Robustness issues of buildings equipped with FREEDAM joints in an accidental column loss scenario were also investigated with various approaches of varying complexity (Fig. 5).

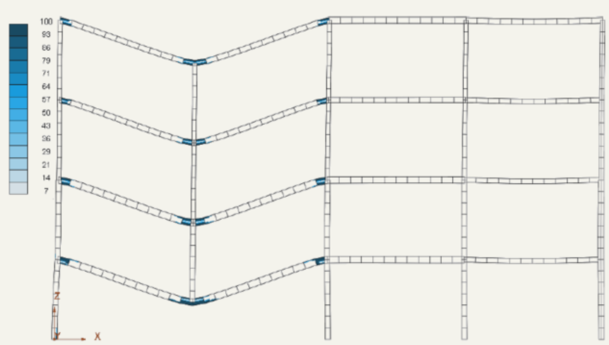


Fig. 5 Deformation and plastic zones of a frame in a column loss scenario [1]

Finally, to make the knowledge accessible to all interested parties (academic institutions, engineers and construction companies) involved in the construction sector, all the results of the research activities, the design guidelines and the worked examples were assembled into a single volume [1]. The volume was translated in 13 different languages and is available online [2]. To disseminate the knowledge, workshops and webinars were also organised in the countries of the project partners. For Greece, the webinar was hosted by the Steel Structures Research Society on 19/5/2022 and is available on their YouTube channel [3]

Further information about the project, as well as videos from the experimental tests on FREEDAM joints can be found on the website [2] and the YouTube channel of the project [4]. The FREEDAM+ App is available in both App Store and Google Play.

REFERENCES

[1] FREEDAM-PLUS: Valorisation of knowledge for FREE from DAMage steel connections, “Seismic design of steel structures with FREE from DAMage steel connections”, in V. Piluso and M. Latour (eds), ECCS, 2022

[2] FREEDAM+ website: https://www.steelconstruct.com/eu-projects/freedam-2/

[3] SSRS YouTube channel: https://www.youtube.com/channel/UCUmoC9xo4FvxYEIHjLrfzpg

[4] FREEDAM YouTube channel: https://www.youtube.com/channel/UCpn9ndskAcwgZTForCl-Xvw

by Sofia Antonodimitraki, Pavlos Thanopoulos, Ioannis Vayas

ARCHYTAS: Archetypal telemetry and decision support system for the protection of monumental structures

The ARCHYTAS research project is co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE. The project started in Aug. 2018 and will be completed in Jul. 2022. Six partners are involved with three industrial partners, the NTUA being the academic partner, and the Ministry of Culture and Sports of the Hellenic Republic. The main objective of the project is the development of an intelligent platform for remotely monitoring monumental structures, promptly diagnosing their potential for instability and making subsequent decisions on taking remedial actions.

The protection of cultural heritage is a difficult and ever-evolving task as authorities attempt to tackle the steady onslaught of extreme natural hazards and continuous weathering deterioration. At present, most Mediterranean countries have their share of monumental structures whose structural condition is relatively poor and are in danger of sustaining non-recoverable damage or even losing their structural integrity. Protecting endangered monuments from environmental actions, such as the dominant seismic and pluvial flooding hazards that are prevalent around the Mediterranean Basin is a challenge that only becomes more daunting when tackled within severe budgetary constraints. Finding ways to maximize the impact of every euro spent is of paramount importance, especially within a crisis environment. Such structures are priceless and, consequently, the application of novel engineering solutions needs to be handled with care, involving archeologists, restoration specialists, architects and structural engineers to ensure optimal outcomes. All the above elements highlight the need for an intelligent decision-support platform for the prioritization of rehabilitation actions, before or after a damaging event takes place.

The ARCHYTAS platform is the core of the intelligent decision-support system for the protection of monumental structures and consists of four conceptual entities:

- End-user: The end-user of the platform is the Ministry of Culture and Sports, where certified personnel can access the platform, handle the data, and assess the potential risks to the monuments.
- Sensors: The sensors are installed in the monuments and provide the data to the web-cloud to perform the risk calculations.
- Computational models: Hazard and vulnerability computational models run offline and generate data that is stored in the web-cloud to be used for risk assessment.
- Web-Cloud Middleware: The core of the platform is hosted in the web-cloud, where sensor data are stored, risk assessment calculations are performed, the platform's website and warning engine are provided with data.

The conceptual architecture of the platform is illustrated in Fig. 1, where the modules are presented with green color, the sensors with orange, and the database with yellow. The platform architecture supports the seamless flow of data from sensors and computational models to the end-user, as well as the interaction with the end-user. The Middleware is the core of the platform and is located in the web-cloud. It comprises a Web Server that interacts with the rest of the platform modules and part, the Database and the Risk Assessment Engine. The Webserver provides the required functionality, in the form of RESTful web services, to (i) the Sensor Data Module that records the measurements from the sensors installed in the monuments, (ii) the system’s Website where information for the monuments and measurements are presented, and (iii) the Warning Engine. The Web Server also receives data to be stored in the Database by the

Hazard Assessment Module and the Vulnerability and Fragility Assessment Module. The ARCHYTAS system will be implemented to two emblematic monuments of Classical Antiquity: the Horologion of Andronikos Kyrrhestes in Roman Forum of Athens (Fig. 2) and the Temple of Aphaea in Aegina island (Fig. 3).

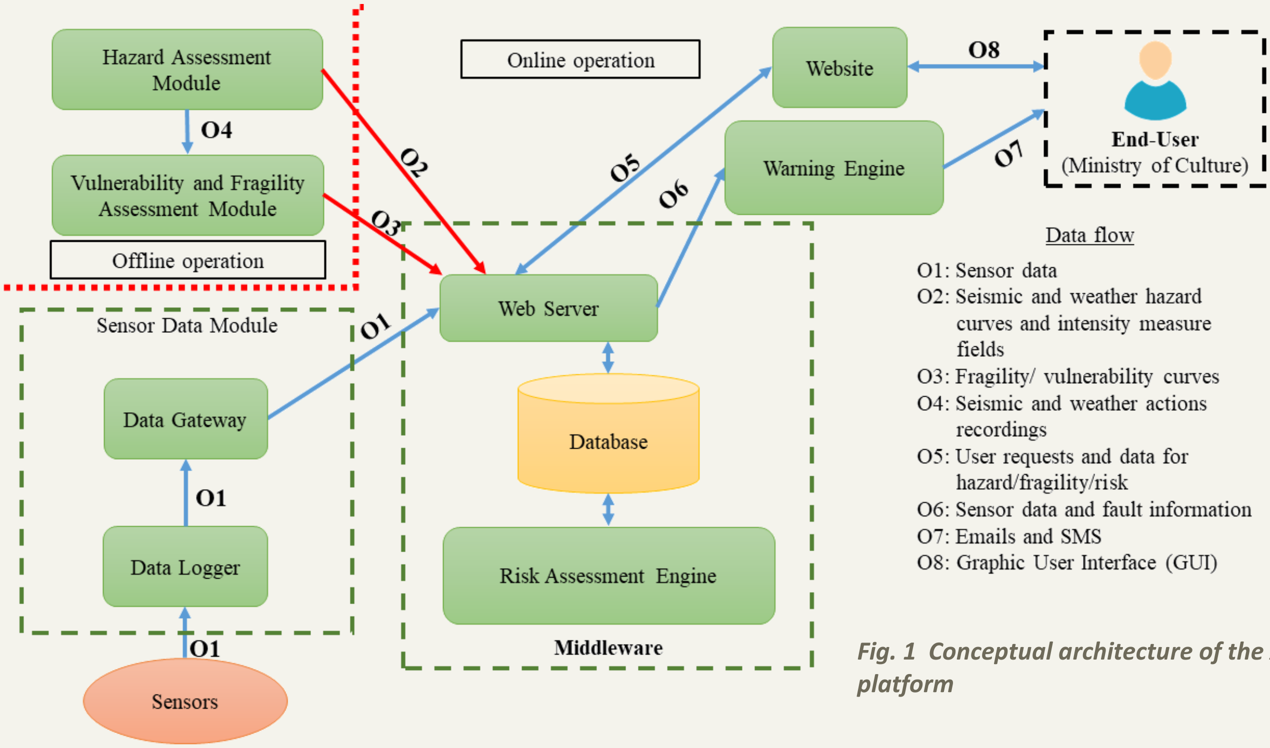


Fig. 1 Conceptual architecture of the ARCHYTAS platform

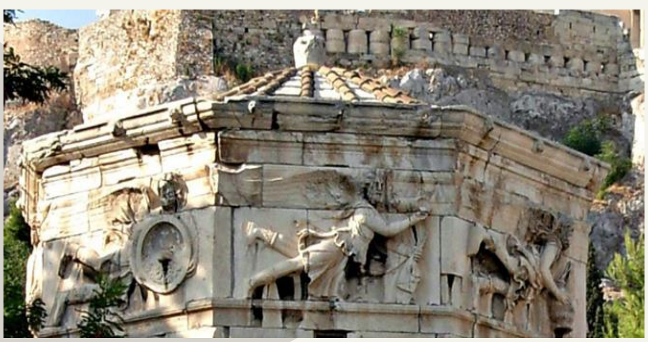


Fig. 2 The Horologion of Andronikos Kyrrhestes in Roman Forum of Athens

The ARCHYTAS platform is a viable approach for supporting decision-making for pre-event or post-event rehabilitation actions for cultural-heritage sites. It supports multiple monuments at the same, or at spatially distributed sites. It allows integrating models of different levels of complexity and fidelity within a homogeneous flexible risk assessment framework with true multi-hazard capabilities. In the ever-present fiscal constraints and under a changing climate, it represents a way forward to achieve efficient resource management for protecting our cultural heritage.

Fig. 3 The Temple of Aphaea in Aegina Island

by Vasileios E. Melissianos, Christos G. Lachanas, Dimitrios Vamvatsikos

PhD Defense of Dimitrios Tsarpalis

The seismic behaviour of steel racking systems has been objective of the Institute's research efforts throughout recent years. In the middle of 2022, **Dimitrios Tsarpalis** successfully defended his PhD dissertation **"Ductile seismic design, performance assessment and taxonomic characterization of steel racking systems"**. In this work a combined numerical and analytical approach, calibrated by existing experimental results, was implemented to assess the seismic behaviour of racks.

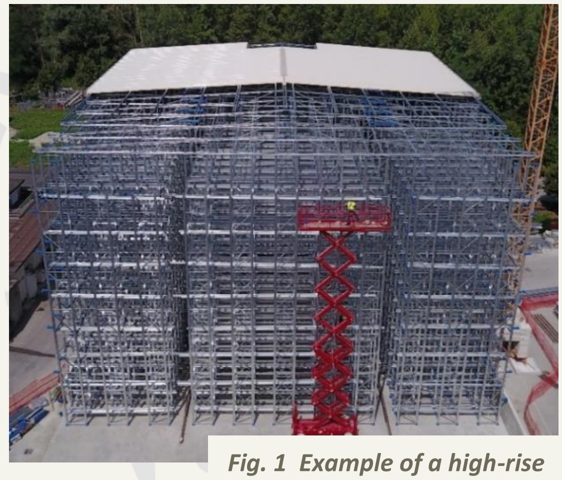


Fig. 1 Example of a high-rise

Steel racking systems are Civil Engineering structures used to store the goods and materials of a warehousing unit. In order to facilitate the construction process and to minimize the cost, racks employ thin-walled profiles with loose connections and, as a result, they are characterized by significant geometric nonlinearities and local buckling phenomena that deteriorate their lateral-loading response. Indeed, past earthquake events have revealed the vulnerability of racks against strong ground motions, underlining the need for novel design approaches in order to increase their resilience. This is true especially for the innovative Automated Rack Supported Warehouses (ARSWs), as they play a dual role in the warehousing process, supporting the wares and at the same time offering protection from the external environment.

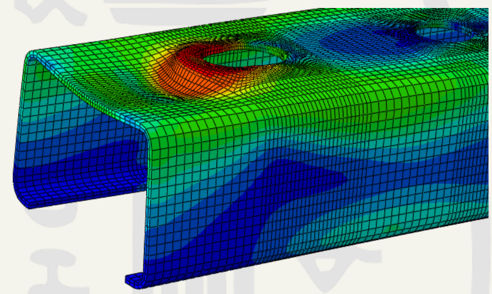
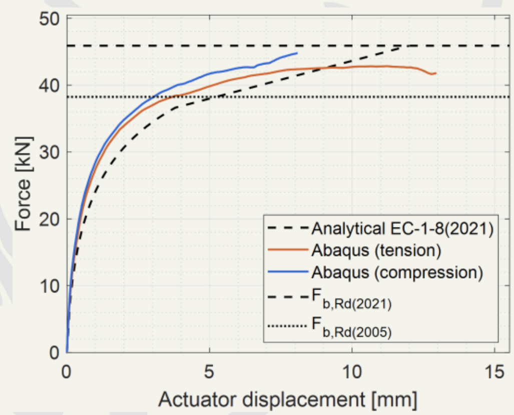
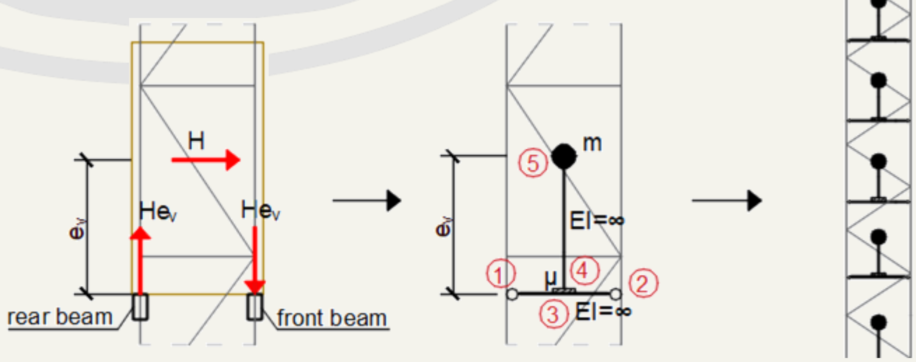


Fig. 2 Finite element analyses on the plastic ovalization of the diagonal bolt hole



The contribution of Dimitrios' work to the advancement of engineering science included the establishment of a uniform taxonomy for steel racking systems, the seismic assessment of five high-rise ARSWs, the introduction of new ductile seismic design approaches, the development of simplified models of ARSWs, and the presentation of comprehensive approaches for the assessment of content sliding. One of the main outcomes is that ARSWs designed according to conventional rack codes are vulnerable to brittle failure modes that hamper their ability to develop reliable ductility. To tackle this issue, the proposed Plastic Ovalization Strategy (POS) relied on the bearing failure of the diagonal bolt hole to dissipate seismic energy, while the rest components were designed with overstrength. Finite element analyses revealed that the ductility of the connection is high, as long as the diagonal is thick enough to avoid local buckling of its web. Finally, to capture the effect of content sliding, it was found that the best option is to introduce complex flat slider elements to simulate the movement of each pallet, while more code-compatible methodologies were developed by increasing the damping ratio of the structure or by reducing the seismic design spectrum.

Fig. 3 Numerical simulation of pallet sliding using complex flat slider elements



After defending his thesis, Dimitris is planning to continue his academic work as a postdoc researcher, while continuing his professional activity as a freelance Risk and Structural Engineer.

PhD Defense of Christos Lachanas

In June 2022, Christos G. Lachanas successfully defended his PhD dissertation entitled "**Seismic response standardization and risk assessment of simple rocking bodies: Cultural heritage protection, content losses, and decision support solutions**" under the supervision of Dimitrios Vamvatsikos (Associate Professor NTUA).

Rocking is a seismic response mechanism that corresponds to a wide range of structures from ancient monuments and cultural heritage assets to vulnerable building contents, whereas it is also found to be an efficient seismic protection mechanism that can be employed for the design of "seismically isolated" resilient structures. This wide applicability of the rocking oscillator has attracted significant interest leading to numerous studies. The vast majority of them, stemming from the extreme nonlinearity of the problem, treat it deterministically aiming to investigate analytically the correlation between the rocking block's characteristics and the excitation's waveform. On the other hand, limited literature exists on the probabilistic treatment of the problem based on the concepts of performance-based earthquake engineering (PBEE). Aiming to offer such an outlook, the thesis deals with standardizing the probabilistic treatment of rocking response for simple rigid bodies via state-of-the-art tools to provide a solid framework for vulnerability studies.

Following the concepts of PBEE, the standardization of the seismic response treatment refers to multiple aspects. It starts from the application of nonlinear dynamic analysis to obtain the seismic response distribution of rocking blocks, offering case-specific tools for applying incremental dynamic analysis to rocking oscillators. Then, a detailed investigation is offered on the potential minimal parametrization of the problem by reducing its dimensionality followed by the investigation for the probabilistic distribution that best fits rocking fragilities. The next step refers to investigating potential optimal intensity measures (IMs) for using them as interface variables in rocking vulnerability studies. One more aspect regards the influence of the vertical component of the ground motion on the rocking response under a probabilistic view, finding that, with the only exception of the uplift neighborhood of stocky blocks, the inclusion of the vertical component does not alter the seismic response statistics. Based on these steps, the final step becomes the presentation of closed-form expressions for the direct estimation of rocking fragilities at any limit-state either for on-ground blocks or for rocking components. Finally, some of the proposed tools are applied to a simple example of regional risk assessment of ancient columns located across Attica, Greece. Overall, the proposed tools cover comprehensively the standardization of the seismic response of rigid rocking bodies, offering a fundamental step for assessing their vulnerability, while they open the path for application to more complex systems having rocking-like behavior.

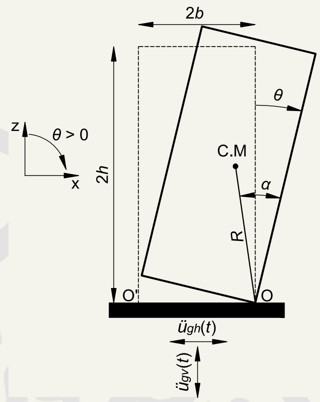
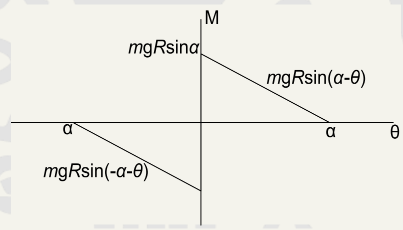


Fig. 1 Planar rectangular rocking block on a rigid base being subjected to ground excitation (above), Moment-rotation diagram of a rocking block (below).



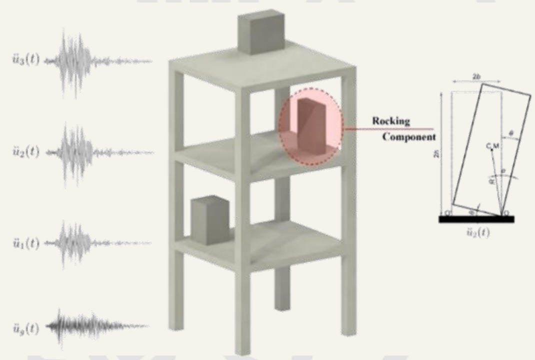


Fig. 2 Generic representation of rocking components located at different floor levels

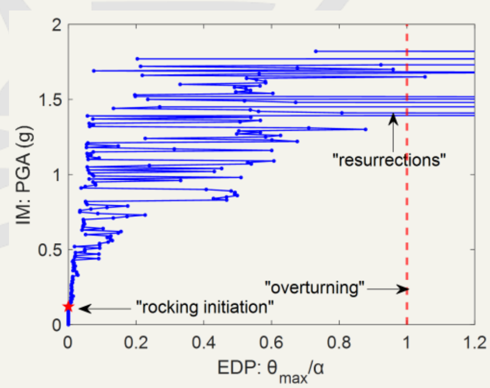


Fig. 3 Typical IDA curve of a rocking block for a single ground motion

Development of a reliable displacement measurement system using acceleration responses

Estimating the displacement of a civil engineering structure is considered crucial in assessing its system state and analyzing its dynamic performance. However, the majority of available displacement measuring techniques are considered expensive and impractical to adopt in large constructions, as they necessitate fixed reference benchmark points. To address such shortcomings, accelerometers can be introduced for displacement calculation, as they record minimal noise and can be mounted on complicated structures.

In this study, we have employed accelerometers to record the accelerations and displacements and compute the eigenfrequency of a rectangular cross-section cantilever beam subjected to dynamic loading. A high-pass filter was used in order to exclude low-frequencies and noise, so that a clear dynamic reaction is properly predicted from acceleration measurements. A comparative analysis between different sensors was adopted, mainly the displacement transducer (DT) and BDI accelerometer to validate the proposed displacement estimation methodology. Next, a manual calculation was performed to compute the eigenfrequency according to the beam mode shape.

Fig. 1 Displacement transducer and BDI Accelerometer mounted on the beam tested under laboratory condition

I. Motivation

Bridges are subjected to dynamic testing and long-term assessment to validate their design, analyze their system state and detect any damage using vibrational investigation. It is crucial to analyze the dynamic performance in terms of acceleration data to evaluate the dynamic properties including damping ratio, mode shapes and eigenfrequencies and displacement data to determine the bridge load carrying capacity. In health monitoring, measuring the acceleration is considered as a straightforward method, whereas displacement calculation is more challenging. Generally, to detect displacements, displacement transducers are adopted, yet employing them inquires fixed reference benchmark points, which is not easy to realize on bridges. These challenges arise particularly when bridge constructions have limited or prohibited access underneath them, for example if they are over rivers or congested highways, so that it is difficult to mount conventional displacement sensor network cost-effectively. Due to the accelerometers ease of handling and set up, and in order to have minimal recorded noise, numerous researchers have considered the indirect estimating techniques of converting the acceleration to displacement as a useful option to overcome all difficulties imposed by displacement sensors. Displacement estimation necessitates double integration of acceleration data, where errors can be made by estimating initial conditions for calculation purposes. Therefore, a high-pass filter is used in order to exclude low-frequencies and noises, so that a clear dynamic reaction can be properly predicted from acceleration.

II. Experimental benchmark procedure

Sensors were mounted on the edge of a steel cantilever beam 0.08 x 0.006 m^2 with a total length of 1.86 m, and measurements were recorded at perturbation. Excitations were generated by arbitrary point loads exerted by human finger pressing on the edge of the beam. The beam was stimulated 8 times, each time by non-constant intensity. Data from a trademark triaxial accelerometer BDI and a displacement transducer were recorded and saved on a PC. BDI accelerometer has high accuracy with +/-2g.

The adopted displacement transducer from KYOWA electronic instruments was of type DT-100A with capacity of measuring displacements ranging between 0 and 100mm. Both sensors were calibrated before the experiment.

Fig. 2 Beam fixed from one end and free from one end

The proposed methodology consists of (i) changing the recorded data from time to frequency domain using Fast Fourier Transform, (ii) applying a high pass filter to filter the noise from the recorded acceleration data, and (iii) estimate the time domain through inverse Fourier transform to double integrate and get the displacement of the structure. The calculation process was coded on LabView.

III. Results

First, a comparison between the results of the displacements recorded by the displacement transducer and the twice integrated accelerations retrieved from the mounted accelerometer was performed on LabView software. The collected data of 44565 samplings with a sampling frequency of 500Hz and a sampling rate of 0.002 were saved in a text file.

The beam behaved differently at each of the 8 excitations corresponding to a different displacement response for each excitation intensity. The 6th stimulation triggered the most intensified response, as shown in figure 3 with a recorded displacement of 69.93mm. Acceleration time domain was recorded by the mounted accelerometer for the 8 excitations as shown in figure 4. FFT was applied showing two peaks at 1.45Hz and 8.217Hz. To compensate for the noise, High pass Elliptic Filter of second order was adopted with cut-off frequency of 0.4Hz.

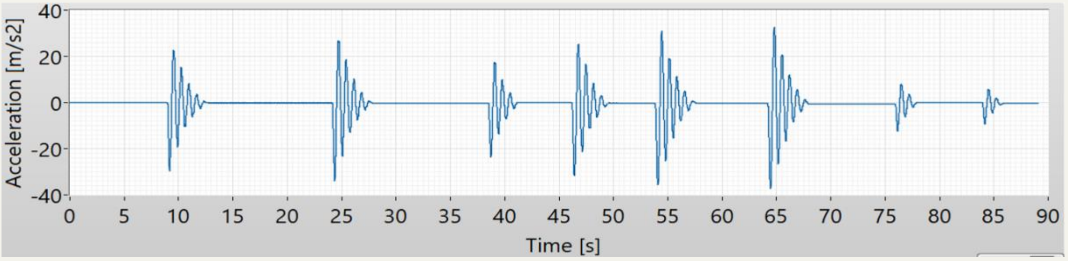


Fig. 3 Displacement time domain recorded by displacement transducer

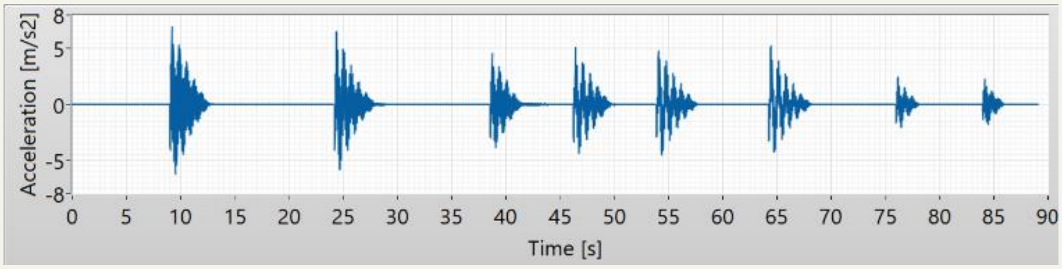


Fig. 4 Filtered acceleration time domain recorded by accelerometer

After twice integrating the acceleration data, we, the calculated displacement estimated from the filtered collected acceleration measurements are plotted in figure 5, in red, while the recorded displacements by the displacement transducer are plotted in blue.

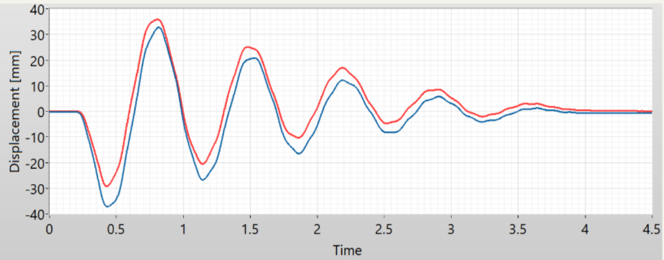


Fig. 5 Displacement time domain collected by displacement transducer (blue) and accelerometer (red)

Both types data were collected in the 6th experiment, where the highest displacement was observed at 64 sec lasting for a duration of 5 seconds. The two graphs showed a smooth overlap.

After comparing the results of the accelerometer and displacement transducer on LabView, one can conclude that both showed very similar displacements, as the collected noise of the accelerometer was removed with filtering. Smoother curves were shown after eliminating the noise. Then the calculated eigenfrequencies after performing FFT from both recordings, by the accelerometer and the displacement transducer, were compared to the manual calculation.

The natural frequency calculated after performing FFT on the results of the displacement transducer was 1.444Hz (figure 6).

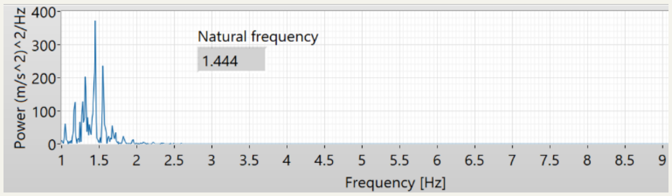


Fig. 6 Power spectral density of the displacement transducer

For the case of the accelerometers, figure 7 demonstrates the power spectral density showing two major peaks at 8.217Hz and at 1.450Hz. The higher peak is caused due to a small tilt induced by the external pressure exerted on the beam in order to perform the experiment, as the load was not applied at the middle of the beam height. It is better to account for the second peak only.

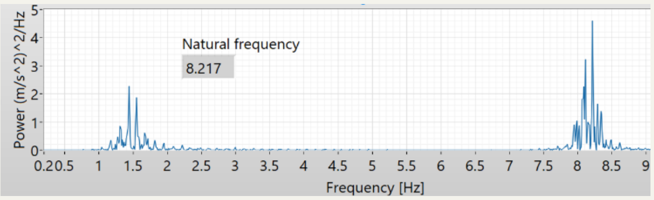
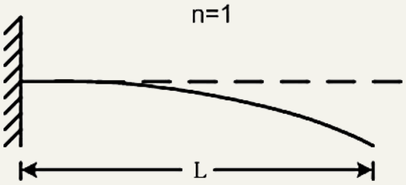


Fig. 7 Power spectral density of the BDI accelerometer

According to Zai et al. in 2011, the equation of the beam eigenfrequency after behaving as mode shape 1 (n=1) is:



$$f_1 = \frac{(1.875)^2}{2\pi L^2}\sqrt{\frac{EI}{\rho A}}$$

Therefore, for L=1.86m, E=2.1E+11Pa, I=(bxh^3)/12 =1.44E-09m^4, ρ=7850 kg/m^3, A=bxh=0.00048 m^2:

$$f_1 = \frac{(1.875)^2}{2\,\Pi\,1.86^2}\sqrt{\frac{(2.1\text{E}+11)(1.44\text{E}-09)}{(7850)(0.00048)}} = 1.449 \text{ Hz}$$

As shown above, both the displacement transducer and the accelerometer were able to detect the eigen frequency of the beam.

IV. Conclusion

In conclusion, the accelerometer results are sufficiently close to the results of the displacement transducer sensor. A trade-off between precision, ease of installation and computational effort should be considered to choose what sensor to adopt, but overall, the suggested methodology provided satisfactory results in terms of accuracy, computational effort, network topology and reduced budget.

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LA PROMOTION 2023 REMERCIE SES
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AU VOYAGE D'ÉTUDES À ATHÈNES

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