ISS

Institute of Steel Structures

Newsletter

January 2023

National Technical University of Athens
School of Civil Engineering

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Institute of Steel Structures - NTUA / January 2023

Designed & formatted by: **Aikaterini Michaltsou**

Front cover: **L-stub testing**

Welcome to the new issue of ISS-NTUA Newsletter!

Dear readers,

January is a month of resolutions and, as such, we tend to glimpse into the future with anticipation and optimism, as we set our personal and collective goals for the forthcoming year. In doing so, we inevitably assess our experiences from the previous year. And what a year it has been! During 2022 we witnessed a significant growth in most sections of the construction industry, like commercial, touristic and residential buildings, infrastructure and energy, with the flagship of the Ellinikon project starting to take form and capturing the public eye. This growth is hopefully expected to continue or even accelerate in 2023, which is good news for civil engineers in general, steel people in particular and, of course, our graduates and alumni who can get good jobs within our country after more than 10 years of combined economic and pandemic crisis.

In this spirit, at the Institute of Steel Structures of the National Technical University of Athens we set our new goals for 2023 and also look back at a few key moments of the last semester that we would like to share with you in this edition of our Newsletter.

Ms. El Dahr, Dr. Lignos and Prof. Vayas present the comparative results of a programme that has been developed for vibrational monitoring and system evaluation, which could evolve into a valuable tool for structural health monitoring.

Prof. Gantes, Dr. Lignos, Mr. Katsatsidis and Mr. Papavieros report on the test results of the 18 full-scale tests of L-stub specimens which have been extracted from a tubular ring connection of a typical wind turbine tower. The project was commissioned by ATES Wind Power, located in Izmir, Turkey.

Dr. Orestis Ioannou is the latest addition to our all-star PhD team, after the successful defence of his Thesis titled "Design of cladding to mitigate blast effects on the supporting structure". You can read about the possibilities to utilise the cladding properties to reduce the demands on the main structure in a literally explosive subject.

The aging and maintenance of the road infrastructure is a global phenomenon, which could not but affect Greek roads. A major operator in Greece, which is responsible for the operation and maintenance of hundreds of kilometres of motorways and the surrounding infrastructure, assigned ISS with the task of inspecting and assessing the condition of four pedestrian steel bridges overpassing a principal motorway. Dr. Melissianos, on behalf of the whole ISS team, describes the methods developed and implemented for the inspection with rich photographic material from the field.

Dr. Gkatzogiannis and Prof. Gantes outline the state-of-the-art and their initial findings regarding the simulation of residual stresses due to welding in large civil engineering structures, in what seems to be a very promising work.

Hoping you will enjoy reading our Newsletter, we wish you a happy and productive year!

Pavlos Thanopoulos

E-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. The 2022 lectures included:

1. Dr. Stefanos Gkatzogiannis, “Simulation of welding residual stresses with the finite element method”, 21 March 2022.
2. Mr. Georgios Papageorgopoulos, “Mixed and encased in reinforced concrete steel structures for residential use”, 21 March 2022.
3. Dr. Pinelopi Kyvelou and Dr. Nicolas Chadjipantelis, “3D printing of steel structures / The first 3D printed steel bridge”, 14 April 2022.
4. Professor Maxime L’Héritier, “The iron skeleton of Notre-Dame de Paris - An archaeometallurgical perspective”, 15 December 2022.

FORTHCOMING CONFERENCE

The 10th Hellenic National Conference on Steel Structures, organized by the Hellenic Steel Structures Research Society, will take place in Athens on 19-21 October 2023, following cancellation of the originally planned dates due to Covid-19. For more information please visit: http://www.eeme.ntua.gr/

FACULTY RETIREMENT

Prof. Tasos Avraam retired on 31 August 2022. Dr. Avraam came from his native Cyprus to NTUA as an undergraduate student in 1974, and remained since then as doctoral student, scientific associate and faculty member, continuously until his retirement. His main research field was on static and dynamic stability of steel structures, with emphasis on analytical methods. He made very valuable contributions to the educational, research and administrative activities of the Institute of Steel Structures and the School of Civil Engineering. He will be greatly missed, even though we all look forward to his continued involvement with ISS.

SCHOOL VISIT

On 22nd November 2022, pupils from Leonteios Athinon High School visited the Institute of Steel Structures. They were informed by the faculty about civil engineering and also visited the laboratory area.

WORKSHOP

On 19th May 2022 a workshop on “Damage-free steel connections – FREEDAM connections” took place. The participating ISS members were Ioannis Vayas, Dimitrios Vamvatsikos, Pavlos Thanopoulos and Sophia Antonodinitraki.

PUBLICATIONS

In 2022 the members of the Institute have published 26 papers in international journals. For a full list of publications please visit: http://labmetalstructures.civil.ntua.gr/cms/en/research/publications

Comparative analysis among different operational modal analysis-based platforms for structural health monitoring purposes

A LabVIEW program has been developed for vibrational monitoring and system evaluation. It is capable of calculating the natural frequencies, damping and displacement parameters of a structure. To validate the program, a steel cantilever beam with a cross-section of 80mm x 6 m and a length of 1.86 m was subjected to experimental modal testing involving hammer excitations at its free end. Vibrational measurements were performed along with displacement calculations (Fig. 1).

Fig. 1 Displacement transducer and accelerometer mounted on the cantilever beam

Sensors were mounted on the edge of the beam, and the measurements were recorded at perturbation. A BDI accelerometer with an accuracy of +/-2g was installed to record acceleration data, then used to calculate natural frequencies, damping ratio and displacement, and a displacement transducer KYOWA DT-100A was parallelly mounted on the free end of the beam, used for displacement calculation for the sake of comparison. The displacement evaluation is based on a double integration of recorded acceleration data, applying a high pass filter.

The evaluated parameters were also estimated using ARTeMIS modal analysis software for comparison purposes. The developed program was capable of detecting eigenfrequencies, damping and displacement from acceleration data. Displacements were calculated with an error of less than 5%, overperforming ARTeMIS in the available filtering order. The results are summarized in Table 1 for the first two modes.

The reported response confirmed that the proposed framework achieves the desired performance, as it successfully identifies the system state and modal parameters.

by Reina El Dahr, Xenofon Lignos, Ioannis Vayas

Table 1 Summary of results

Parameters	Manual calculation	LabView	ARTeMIS
Natural Frequency	1.41Hz / 8.86Hz	1.44Hz / 8.21Hz	1.39Hz / 8.14Hz
Damping		11% / 2.3%	11.29% / 2.37%
Displacement	69.9mm	65.9mm	62.7mm

Ultimate capacity of full-scale L-stub specimens

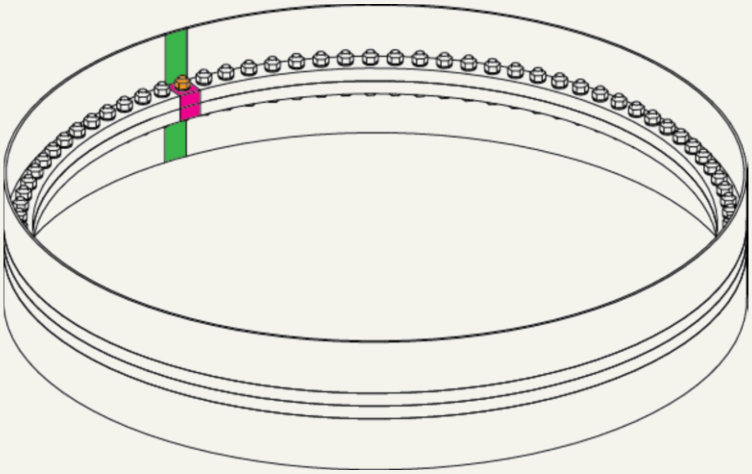
Experimental static tension tests of full-scale L-stub specimens comprising parts of tubular wind turbine tower ring flange connections have been performed at the Institute of Steel Structures NTUA in the period July to September 2022. The tests were commissioned by ATES Wind Power, Izmir, Turkey, who prepared the specimens from actual tower wind turbine tower components.

It is well known that L-stubs are basic constituents of such connections, corresponding to one bolt, as illustrated schematically in Fig. 1. During operation of a tower, such ring flange connection is subjected to combined axial compression, due to gravity loads, and predominant bending, due to eccentricities and - mainly - due to wind actions. As a result, part of the tower section is in compression and another part in tension. Of interest in the present investigation is a typical pair of L-stubs corresponding to the location with higher tension, in which the flanges are pulled apart by the corresponding webs, and their detachment is prevented by the prestressed bolt between them.

neck and web, performed with/without preheating, was investigated.

Accordingly, six specimen types were fabricated and tested. Three tests of each type were performed, for repeatability, thus 18 tests in total were carried out. The specimens were in full scale with the dimensions of an actual tower, with the dimensions shown in Fig.2, comprising 77mm thick flanges, 18mm thick webs, both made of S355NL steel, and M36 grade 10.9 nominally prestressed bolts.

Charpy V-Notch (CVN) results were obtained for core drill samples in the axial flange direction at -20°C and were found in the range between 6J and 18J for the low quality flanges and approximately equal to 200J for the good quality flanges. For all specimens, the flange was welded to the web with SAW welding, while for some of specimens, a MAG repair welding pass was applied after SAW, either with or without preheating. Pairs of welded specimens were bolted together with prestressed bolts, applying a torquing moment of 1920 Nm + 90° turn.



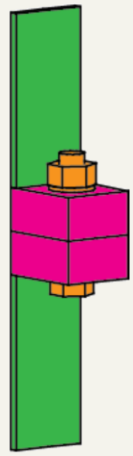


Fig. 1 Ring flange connection and typical pair of L-stubs

The objective of the tests was to compare the behavior of specimens fabricated using flanges will low Charpy values, to the one of specimens fabricated using flanges will normal Charpy values (within specifications). In addition, the effect of repair of the weld between flange

The specimens were placed in a suitably arranged testing frame, and were connected at their bottom to the frame and at their top to the actuator, using custom-designed auxiliary components fabricated by ATES. Imposed displacements were applied with a rate of

0.1mm per second by means of a hydraulic actuator of type Anaptixis 2.53-2.14MN, with stroke 500mm, which was controlled by a NI PXI-SCXI National Instrument control system, that was also used for the recordings. The load reactions were recorded by a load cell of type Anaptixis Mod. LC2.5MN, and the displacements by a displacement meter (wire type) Firstmark Controls NC27522USA. The testing set-up with one of the specimen pairs in place is shown in Fig. 3.

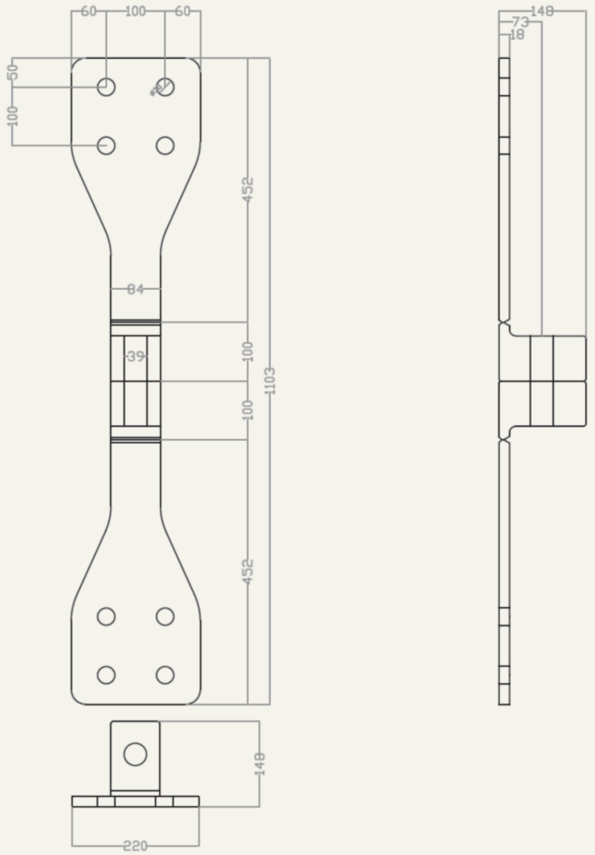


Fig. 2 Dimensions of L-stub specimens

Typical photos of failed specimens are shown in Fig. 4. A comparison of measured load-displacement curves of all tests is presented in Fig. 5, while the ultimate loads and corresponding displacements of all tests are plotted in Fig. 6. The main findings are summarized below:

- In all tests the bolt failed first, exhibiting either tensile rupture of the bolt shank or shearing of the threads.
- In most tests the ultimate load ranged between 485kN and 500kN, while in two tests it slightly exceeded 500kN, reaching 506kN in one case. It is noted that the nominal tensile strength of the bolt is equal to 735kN (without partial factor).
- Considering that the bolt experiences significant bending, in addition to tension, it is not surprising that failure occurred at a smaller load than the bolt's nominal tensile strength.
- The ultimate load exhibited small variability in all tests, while the corresponding displacement had a larger variability, ranging between 6.6mm and 11.2mm.
- No obvious dependence of the response to neither the type of flange in terms of CVN values nor the weld repair was observed.

Fig. 3 Overview of testing setup

The tests were performed by Dr. Xenophon Lignos, Mr. Stelios Katsatsidis and Mr. Spyros Papavieros under the supervision of Prof. Charis Gantes.

by Charis J. Gantes, Xenofon Lignos, Stylianos P. Katsatsidis, Spyridon Papavieros

Fig. 4 Specimens after testing

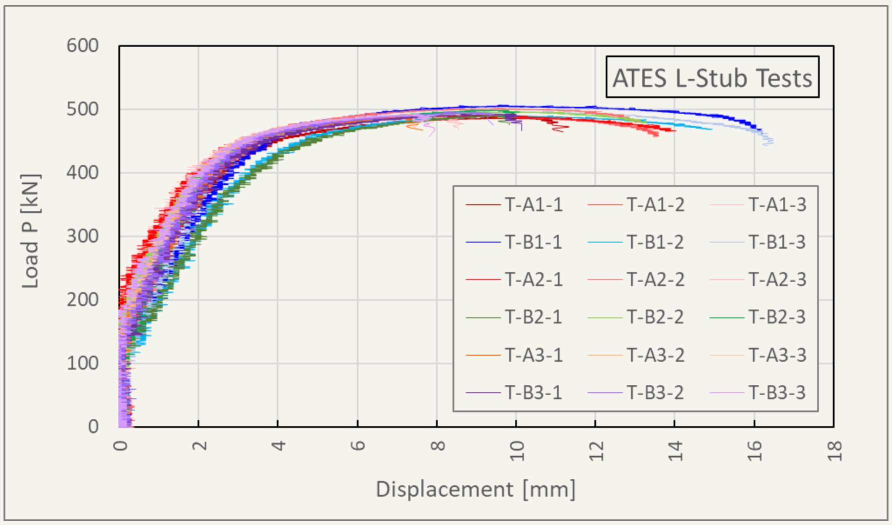


Fig .5 Load-displacement curves of all tests

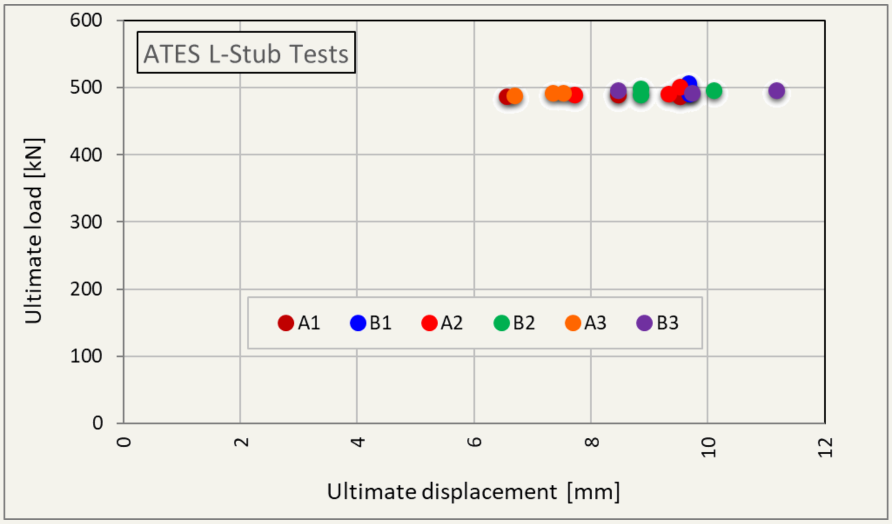
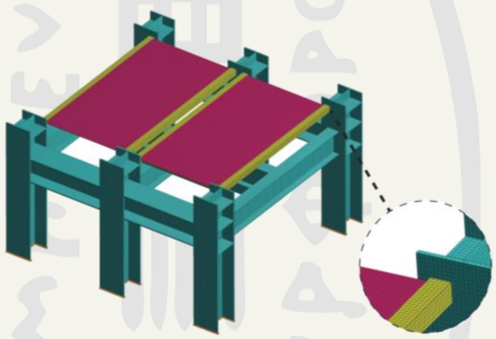


Fig. 6 Ultimate loads and corresponding displacements of all tests

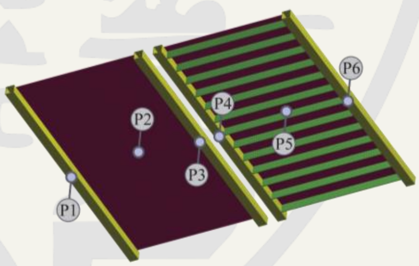
PhD Defense of Orestis Ioannou

In July 2022, Orestis Ioannou successfully defended his PhD dissertation "**Design of cladding to mitigate blast effects on the supporting structure**", supervised by Prof. Gantes. The full text of the thesis is available here: http://dx.doi.org/10.26240/heal.ntua.24068.

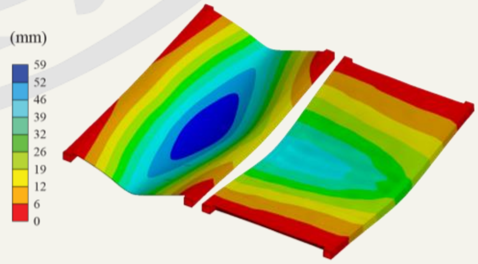
The main aim of the doctoral thesis was to gain insight into the role of building cladding to mitigate blast effects on the supporting structure. This can be achieved by utilizing two different mechanisms, i.e., the mechanism of inertial resistance and the mechanism of plastic energy absorption, which, if properly exploited, may both yield similar beneficial results. More specifically, the initial blast load profile on the cladding is converted from a high-amplitude and short-duration time history into a lower-amplitude and longer-duration time history of the dynamic reactions of the cladding, that are then transferred to the supporting structure. In this way, the load demand on the supporting structure is decreased, thus reducing its deflections, increasing the chances that it maintains its integrity, achieving life safety, and limiting damages. The mechanism of inertial resistance is activated through increased mass and decreased stiffness in the cladding, while the mechanism of plastic energy absorption is activated through plastic strains in the cladding.



In this context, a combined numerical, analytical and experimental investigation of the capacity of cladding to mitigate blast effects has been performed. The investigation has been conducted along four distinct lines of action. In the first one, the influence of cladding mass, stiffness, ultimate resistance and ductility on the supporting structure is theoretically explored. In the second, the influence of cladding membrane action on the supporting structure is researched. Next, the results of the theoretical investigation are verified with the experimental investigation of two steel cladding types and the respective numerical models are validated. Finally, a methodology is proposed for the calculation of the potential of any cladding to mitigate blast effects on the supporting structure, when subjected to a variety of blast loadings. Hence, the originality of the doctoral thesis and its contribution to the advancement of engineering practice is multilevel. Novel scientific findings have been obtained and guidelines for structural engineers have been formulated about the properties that cladding should have in order to offer increased mitigation potential capabilities.



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.



Structural condition inspection of steel pedestrian bridges

The Institute of Steel Structures NTUA has been granted in May 2022 a project to inspect 4 steel pedestrian bridges of a major motorway in Greece. The inspected structures comprised bridges with various structural systems, such as a bridge with castellated main beams, single-span arched bridge, and a truss bridge.

Fig. 1 Check for geometrical deviation

Fig. 2 Visual inspection of bolted connections

The objectives of the inspection were: (a) Identification of any structural damage, (b) Qualitative evaluation of the effects of damage on the structural condition, (c) Recommendations for additional measurements, laboratory tests, and numerical modeling of the structure, if required, and (d) Recommendations for repair and rehabilitation actions, as well as for future regular inspection schedule.

The inspection team of ISS developed and carried out a set of checks for the structural condition assessment of each bridge. In more detail:

(1) Visual inspection of the entire structure to detect and record any apparent failure or geometrical deviation (Fig. 1), and assess their importance based on EN 1090-2.

(2) Visual inspection of bolted connections to detect and record any failed or missing components (Fig. 2).

(3) Check of bolt tightening at snug-tight level (Fig. 3).

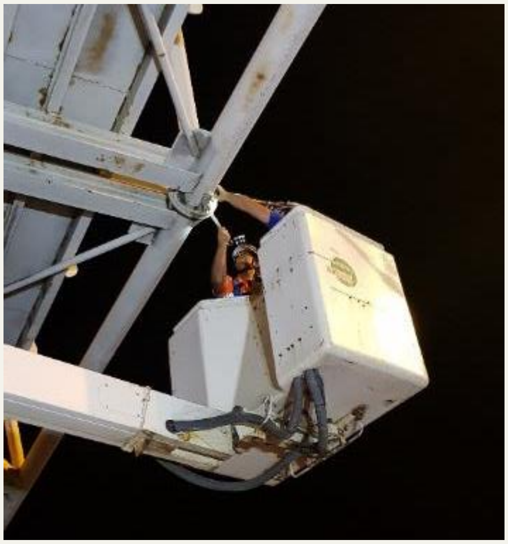


Fig. 3 Check of bolt tightening at snug-tight level

(4) Visual inspection of welded connections to identify and record any apparent failure and propose non-destructive testing, where needed (Fig. 4).

Fig. 4 Visual inspection of a welded connection

(5) Detection of locations subjected to corrosion (Fig. 5) and taking pictures with a digital microscope (Fig. 6) in order to classify the corrosion of metal surfaces based on ISO 8501-1.

(6) Measurement of paint thickness using a gauge operating on the magnetic principle of eddy current (Fig. 7) for comparing the paint thickness to the provisions of ISO 12944-5 with reference to the maintenance period and the corrosive environment (ISO 12944-2).

(7) Measurement of steel deck thickness using an ultrasonic thickness gauge to identify any thickness loss (Fig. 8).

Fig. 5 Detection of location subjected to corrosion

Fig. 6 Taking pictures with a digital microscope

Fig. 7 Measurement of paint thickness

Fig. 8 Measurement of steel deck thickness

by Vasileios E. Melissianos, Charis J. Gantes,
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Simulation of welding residual stresses in large civil engineering structures

State-of-the-art

Although the theoretical background for the numerical simulation of welding residual stresses has been established earlier, research and practical investigations increased exponentially in the previous two decades. This is when sufficient computational power for the estimation of residual stress fields in 3D problems was made available. Most existing models for the detailed simulation of weldments of small-scale specimens (total length of weld beads up to few meters), both in research-related projects and practical investigations, have thus far been developed. Welding simulations for instance, have been widely applied for the optimization of mechanical components in the automotive industry.

In civil structural engineering practice though, the influence of residual stresses on the mechanical behavior of structures (fatigue, instabilities etc.), is considered indirectly in the empirical, analytical design equations of welded components and joints, along with other imperfections, see for instance the imperfection factors for buckling suggested by Eurocode 3. A consideration of the residual stress fields by means of numerical investigations prior to subsequent numerical analyses of such structures could help structural engineers achieve deeper understanding of the structures' failure mechanisms in research applications and significantly less conservative but safe design in practice. With the majority of the structures investigated by civil structural engineering being much larger than those described above though, existing simulation models cannot be applied in their case due to numerical capacity restrictions.

The problematic of simulating welding residual stresses in large structures

Several topics arise when large structures are considered in welding simulations and the engineer has to make assumptions to reduce the numerical workload.

- How coarser can the mesh in the weldment area be modelled? Steep temperature gradients are present adjacent to the weld centerline. As they can result in steep gradients in the residual stress profiles as well, fine mesh is usually applied at the area. Reducing the mesh density can compromise the accuracy.
- Use of shell elements? The use of shell elements instead of 3D solid brick-alike elements is a possibility, especially when structures like wind turbines or silo bins are considered. However, when multi-pass welds are modelled, the simulation of a shell may neglect significant through-depth temperature distributions at the weld bead.
- Can the weld source model be simplified retaining an acceptable level of accuracy? The Goldak double-ellipsoidal model has been established, since its publication in 1984, as the state-of-the-art model for modelling the moving weld heat source of metal arc welding. Although it is ideal for detailed 3D simulations of smaller components, its requirement for an even finer mesh in the weld area burdens its application to large structures. It is possible that simpler models for the weld heat source can achieve a better balance of accuracy-computational effort (time).
- Reducing weld passes: In previous investigations, especially in the first steps of computational welding mechanics, simplifications were made for the simulation of residual stresses even for small components, due to restricted computational resources. Quite often, multi-pass weldments were simulated as single ones. However, the influence of such a simplification has not been quantified.

Ongoing investigations at the Institute of Steel Structures

A series of numerical analyses is currently carried out at the Institute of Steel Structures (ISS) of NTUA in order to check the feasibility of the above-mentioned assumptions and quantify their influence on the estimated welding residual stresses. This is envisioned to be a first-step towards the establishment of a validated engineering approach for the consideration of welding residual stresses in global models of real-scale civil engineering structures.

The following alternatives are under investigation:

- Hybrid shell-solid FE models with the latter being applied only at the weldment area of a component to allow for sufficiently accurate modelling of the weld process. Shell elements are applied for the rest of the geometry to reduce computational time.
- Simplistic modeling of the moving heat source (shape and number of weld passes), more suitable for global models, maintaining a level of acceptable accuracy.
- Combination of small- and real-scale models, with the former highlighting areas of steep temperature or residual stress gradients and in extension required mesh densities for the latter ones.

At first, investigations are carried out on small-scale specimens (see Fig. 2 and 3) in order to quantify the influence of modelling simplifications on the estimated residual stresses. Later, a real-scale component, i.e. an assembly of two cans from a wind turbine tower designed in [1], a Master Thesis carried out at the ISS and co-supervised by the two authors of the present article, will be simulated exemplarily to check the feasibility of the selected approach (Fig. 1).

First results

The results of the present investigations are planned to be announced at the EUROSTEEL 2023 conference [2].

REFERENCES

[1] Skourti O. M.; *A Review of the Available Technologies and Structural Design Practices for Offshore Wind Turbines*, MSc Thesis, Institute of Steel Structures, NTUA, 2022.

[2] Gkatzogiannis S., Gantes C.; *Simulation of Welding Residual Stresses in Large Structures*, abstract submitted at 10th EUROSTEEL, Amsterdam, 12-14 September 2023.

by Stefanos Gkatzogiannis
& Charis Gantes

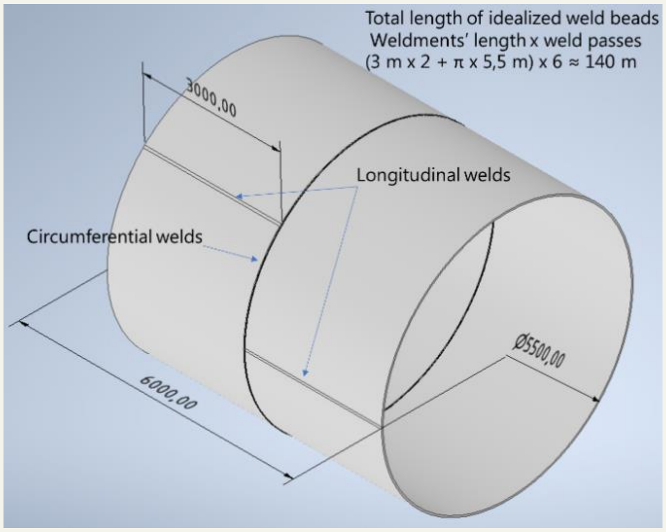

Fig. 1 The two bottom cans of a bottom-fixed offshore wind turbine tower, designed in [1], dimensions are given in mm

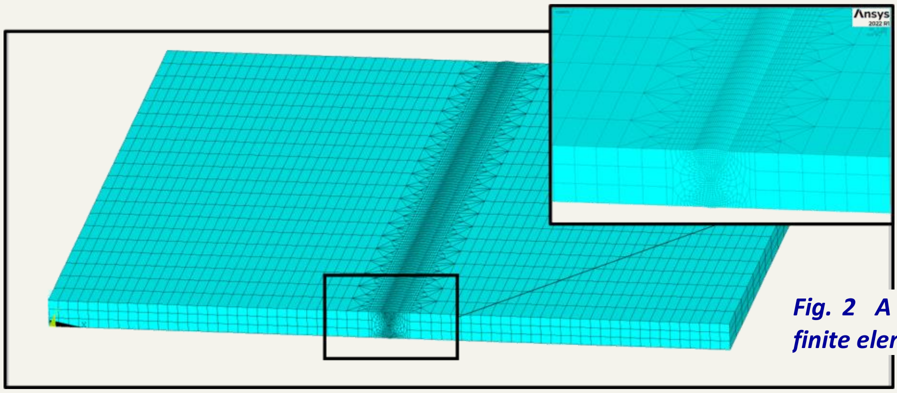

Fig. 2 A 4-pass butt weld modelled with 3D solid finite elements

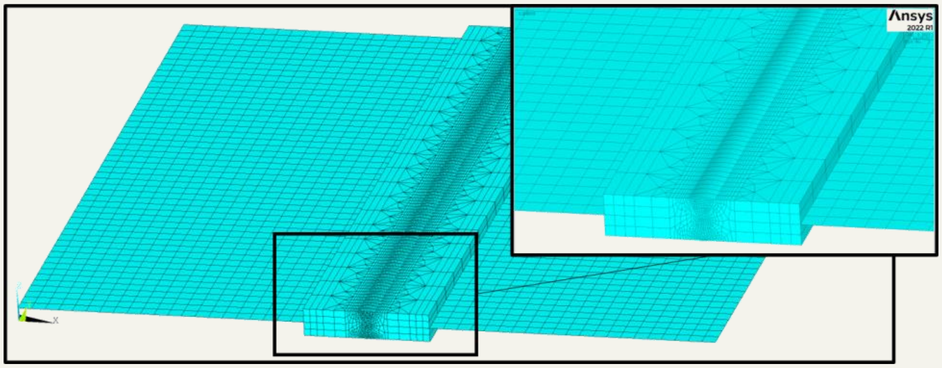

Fig. 3 A hybrid FE model of a 4-pass butt weld, 3D solid elements are applied in the weld area, shell elements are applied on the outer parts of the component

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