NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF CIVIL ENGINEERING
DEPARTMENT OF STRUCTURAL ENGINEERING
INSTITUTE OF STEEL STRUCTURES

Charis J. Gantes

INTERACTION BETWEEN EDUCATION, RESEARCH AND PRACTICE IN STRUCTURAL STEEL DESIGN

DCEE 2016

5th International Workshop on Design in Civil and Environmental Engineering

Sapienza University of Rome, ITALY

October 6-8, 2016

Table of contents

On the nature of structural design

David P. Billington, "The Tower and the Bridge: The New Art of Structural Engineering", Princeton University Press, 1983.

"My major objective in this book is to define the new art form of structural engineering and to show that numerous engineering artists are creating such works in the contemporary world. The disciplines of structural art are efficiency and economy, and its freedom lies in the potential it offers the individual designer for the expression of a personal style motivated by the conscious aesthetic search for engineering elegance".

On the nature of structural design

Art ...

Performing Arts Centre
Abu Dhabi

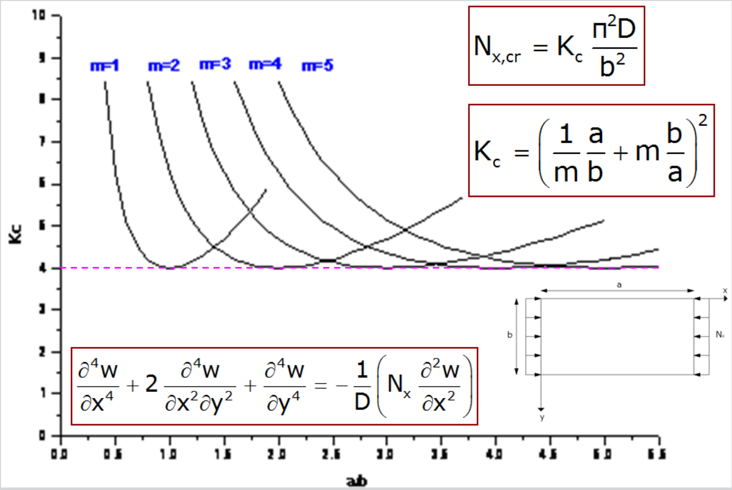
Guggenheim Museum
Bilbao

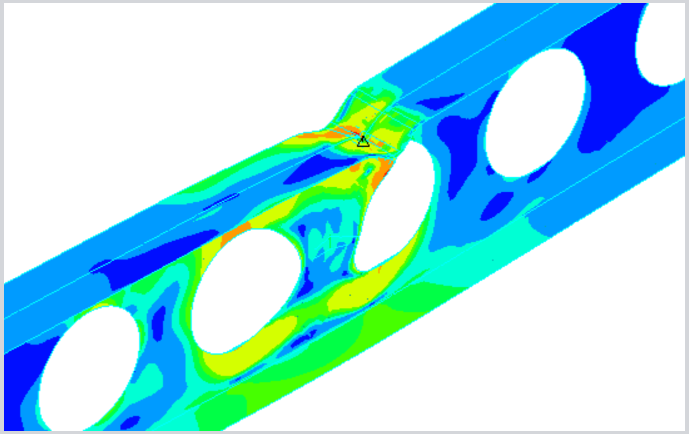
International Forum
Tokyo

On the nature of structural design

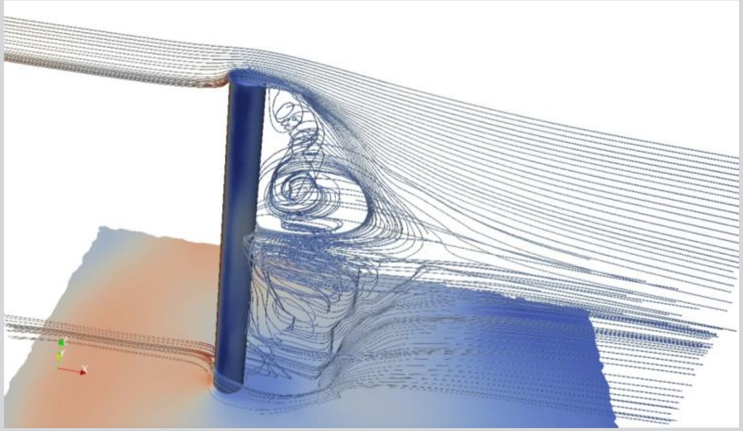
Science …

Analytical solution of linearized plate buckling





Nonlinear Finite Element Method simulation



Computational Fluid Dynamics simulation

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OCTOBER 2016

On the nature of structural design

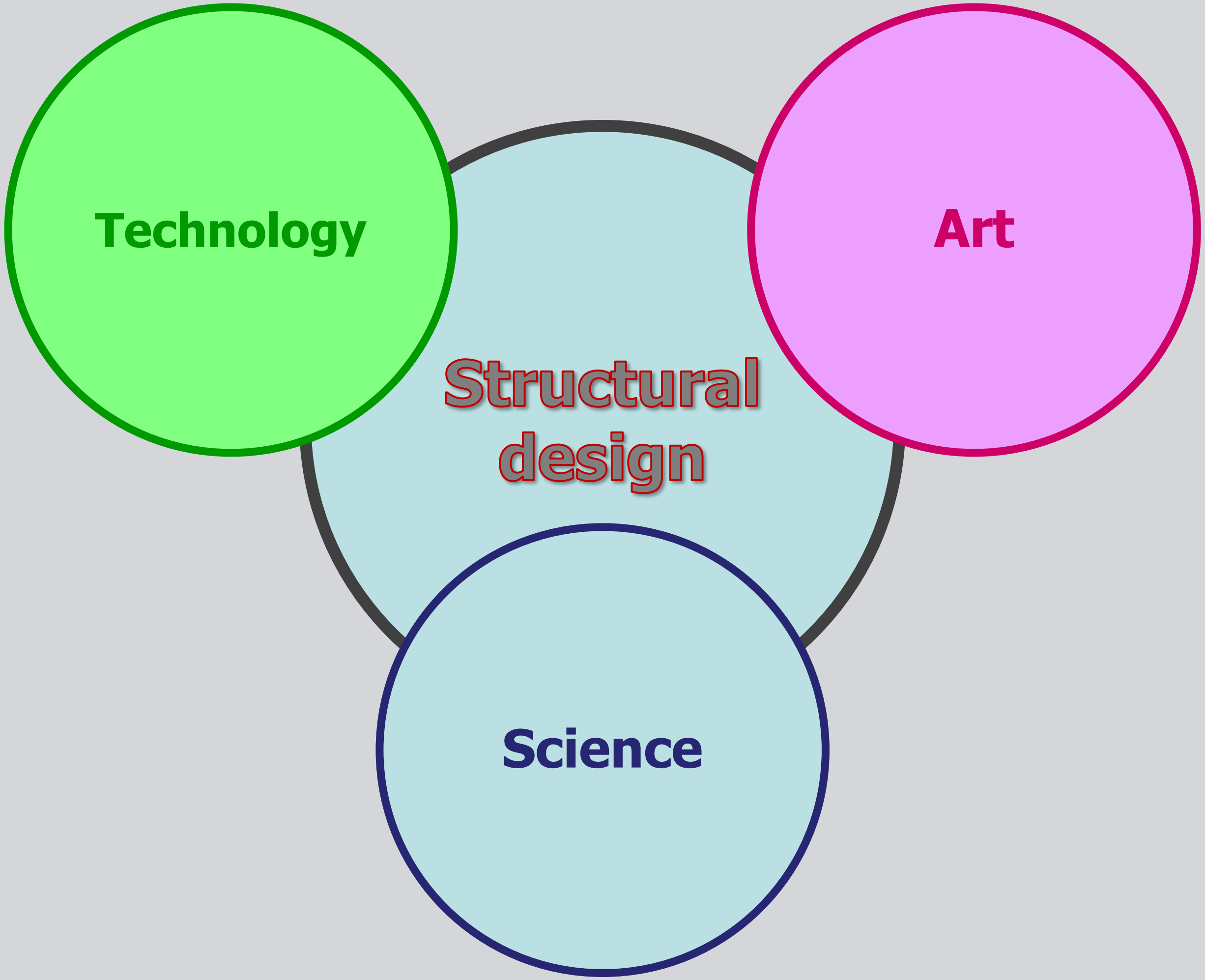
Technology …

Availability and capacity of cranes for erection

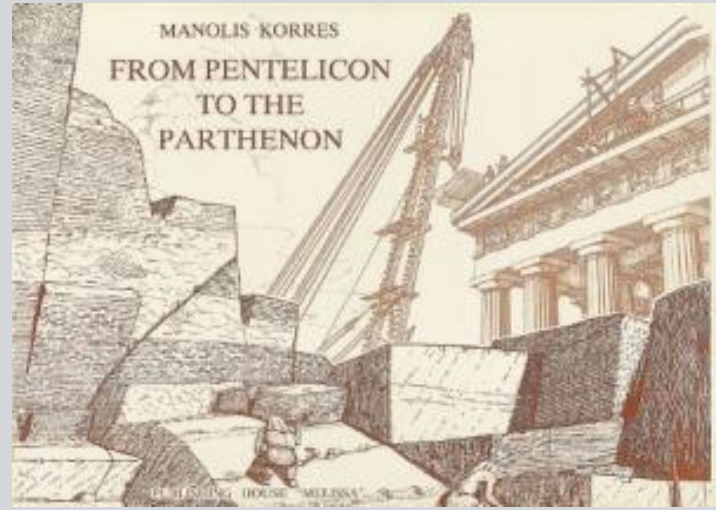
Transportability constraints

Constructability constraints

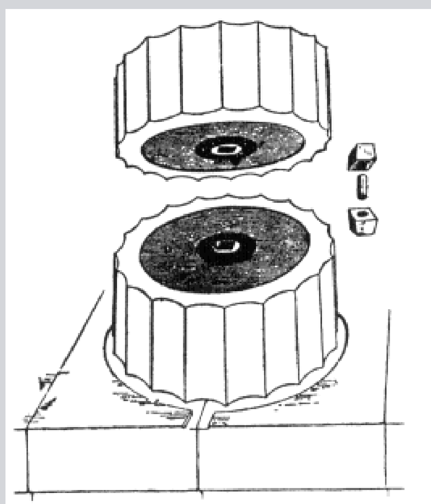
On the nature of structural design

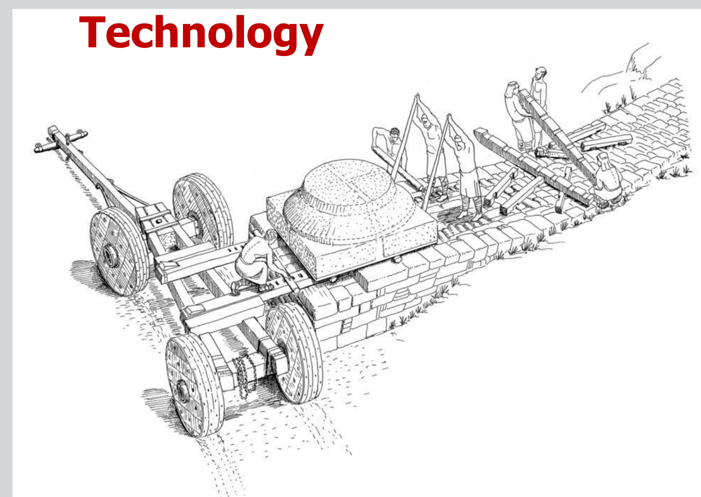


On the nature of structural design
The example of Parthenon



Science





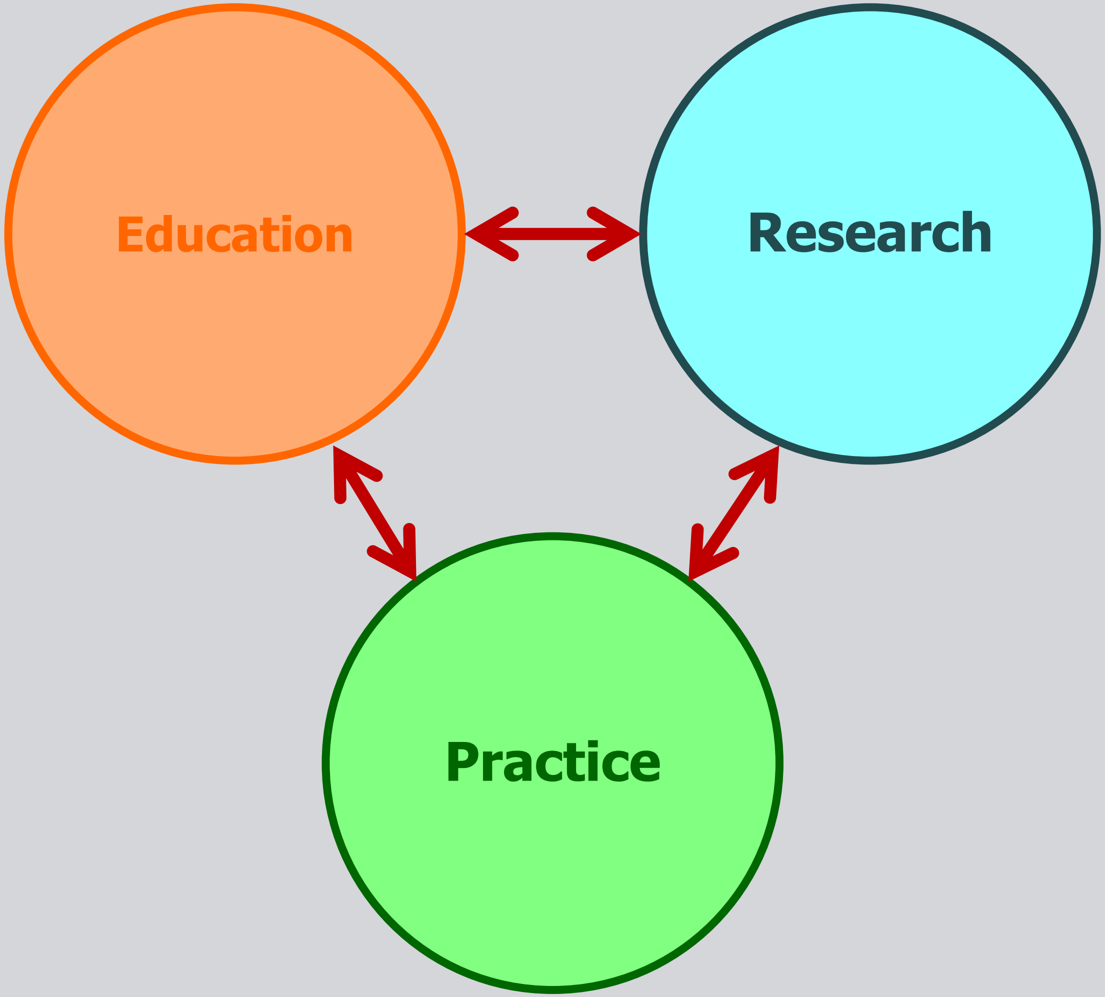
On the role of structural engineering faculty members

American Society of Civil Engineers, Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future, 2nd edition, 2008.

"The four characteristics that the model civil engineering faculty member should have are:

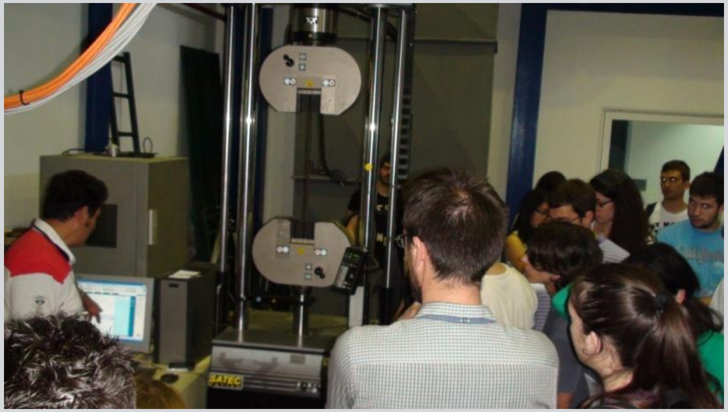
- **Be a scholar**
- **Be an effective teacher**
- **Have relevant practical experience**
- **Be a positive role model"**

On the role of structural engineering faculty members



Institute of Steel Structures

- Teaching
  - 10 undergraduate courses
  - 5 graduate courses



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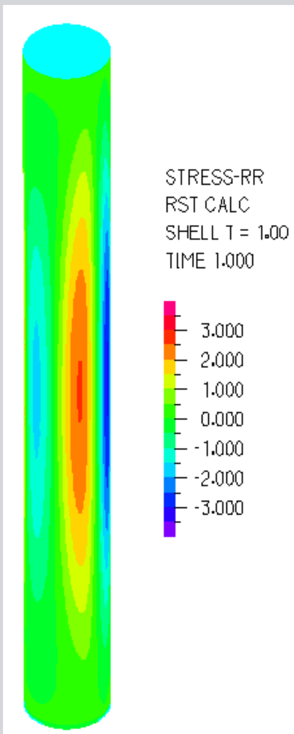
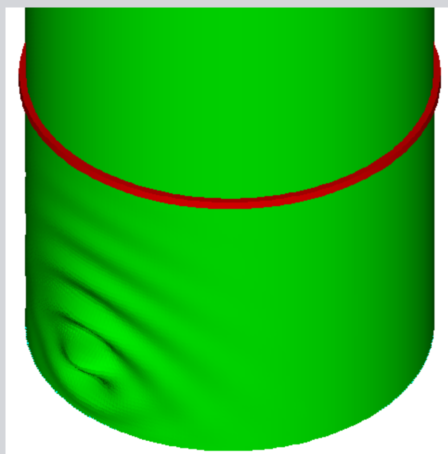
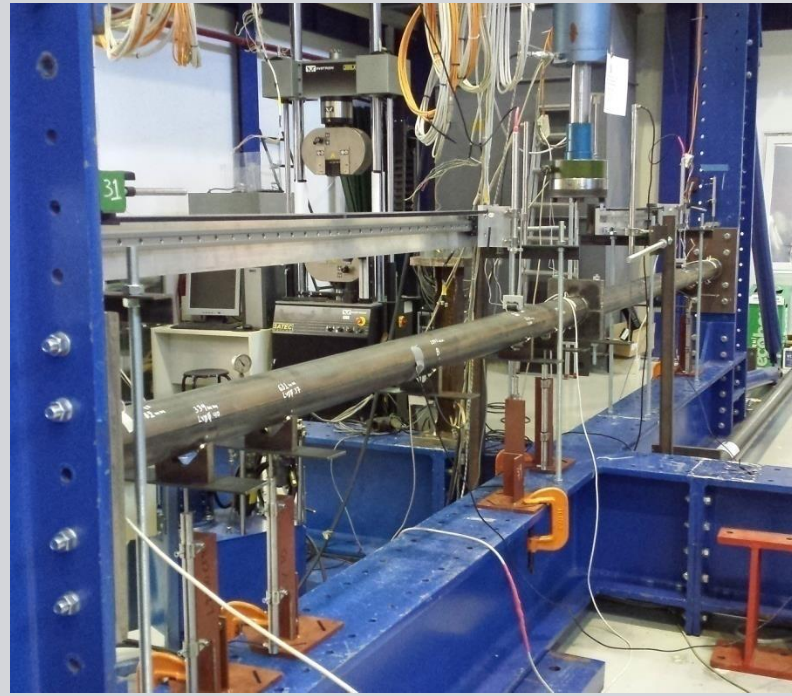
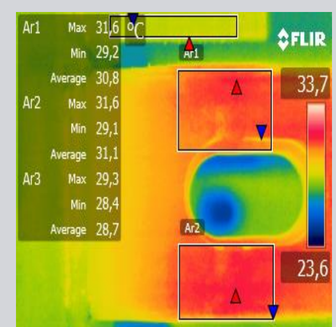
- **Research**
  - **Experimental**
  - **Numerical**









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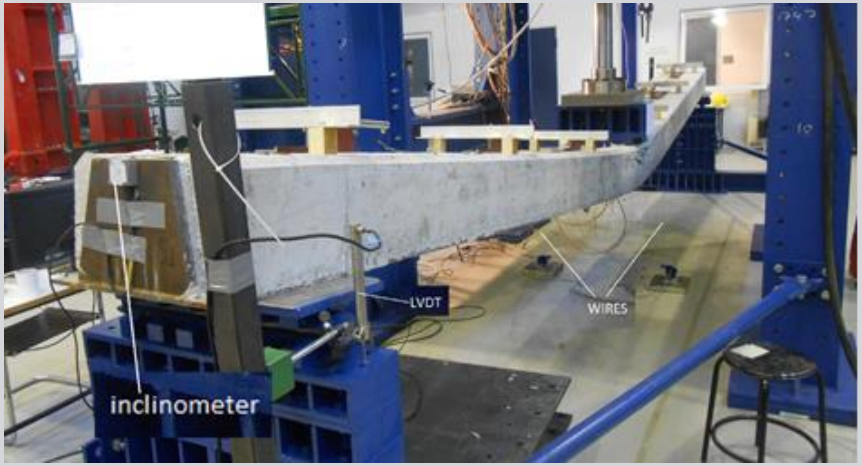
- Cooperation with industry

  Research for product development



Delta-beams (PEIKKO Group Corporation)

Institute of Steel Structures

❑ Cooperation with industry

Consulting for special design projects

Power plant in Samrah, Jordan

Steel gates of New Panama Canal

Entrance Canopy of Athens Olympic Complex

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❑ Service to the community

Member of CEN Project Team SC3/T1 of Part 1-1 of Eurocode 3 (development of 2nd generation of Structural Eurocodes).

1st meeting of the Project Team SC3.T1

University of Stuttgart
Institute for structural design

November 26th, 2015

NOTES AND ACTIONS ARISING FROM THE 1st MEETING

List of attendees

Alain BUREAU	(AB)	PT Leader
David POPE	(DP)	PT Member
Charis GANTES	(CG)	PT Member
Markus KNOBLOCH	(MK)	PT Member
Ulrike KUHLMANN	(UK)	SC3 Chairperson
Ove LAGERQVIST	(OL)	PT Member
Andreas TARAS	(AT)	PT Member

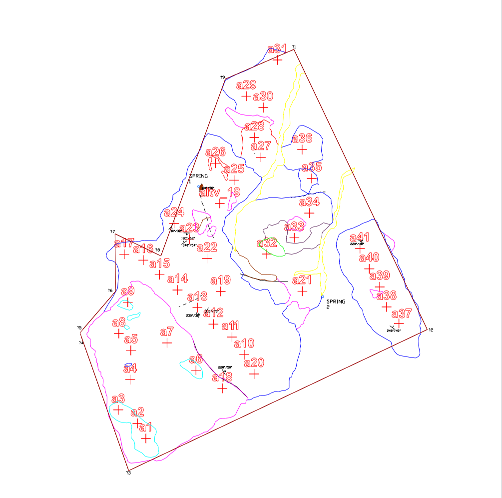
Editor-in-Chief

IASS Journal

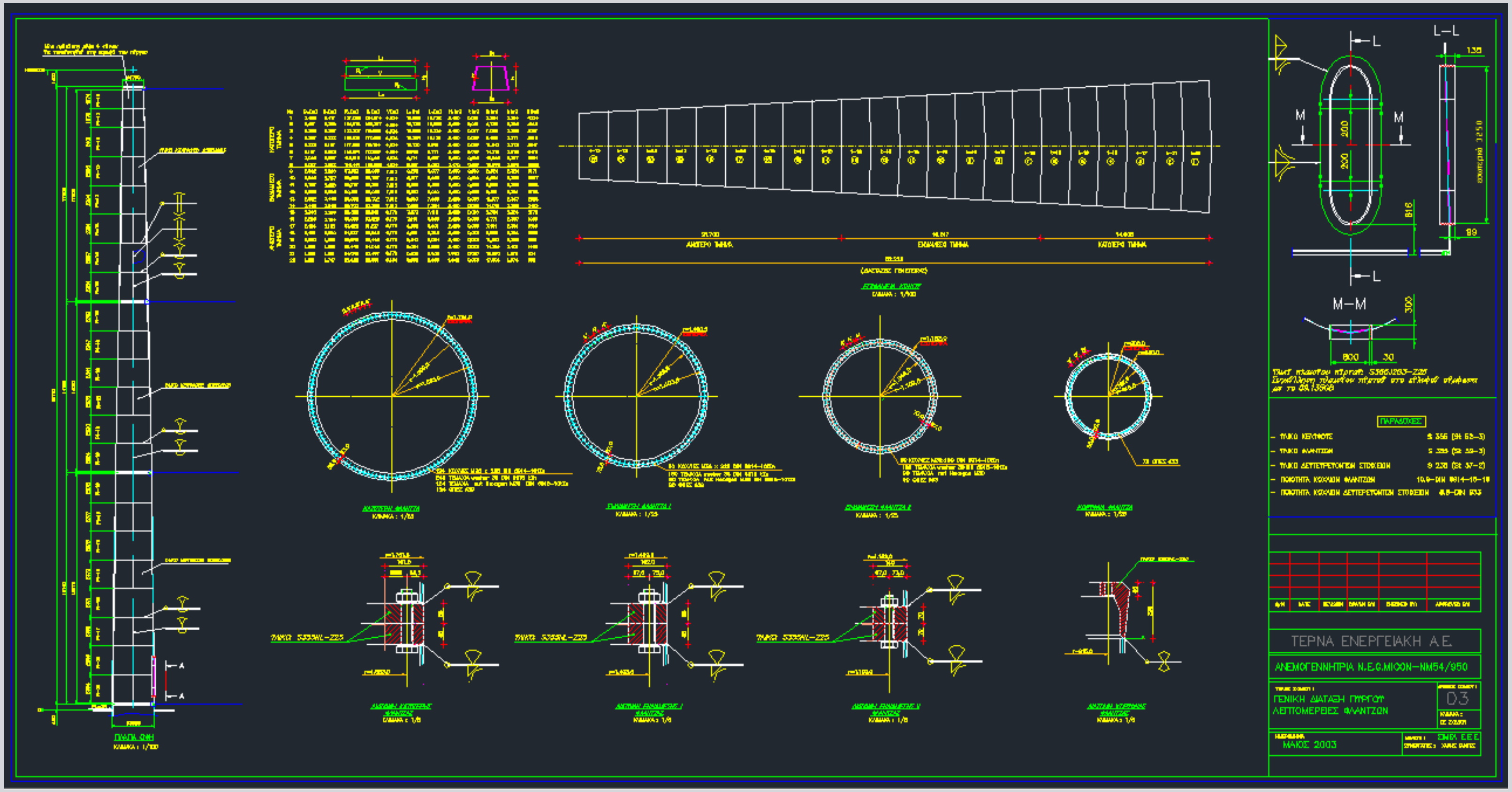
Wind turbine towers
Design example

Main structural design objectives:

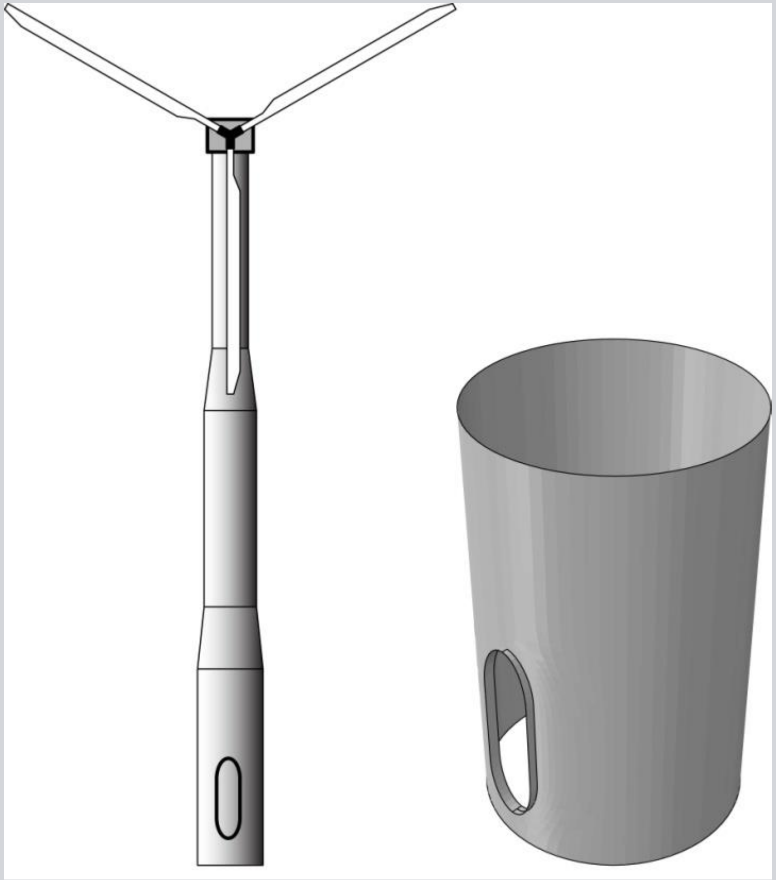
- ❑ Optimize cross-section over height
- ❑ Avoid local buckling
- ❑ Avoid fatigue of connections
- ❑ Strengthen manhole opening
- ❑ Avoid critical range of frequencies



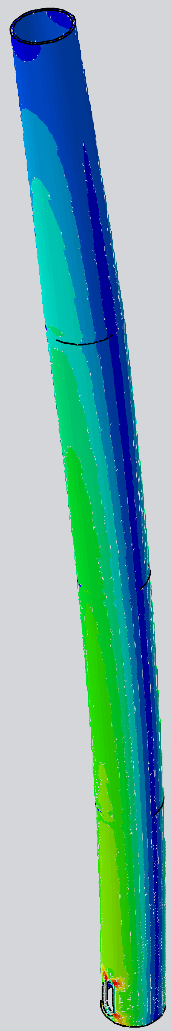
Wind turbine towers
Design example



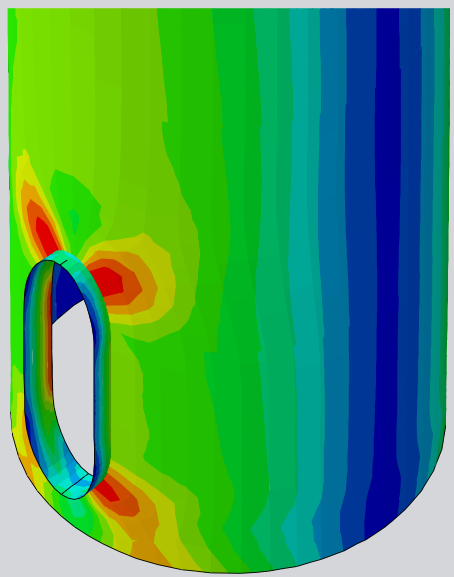
Optimization of stiffening of manholes

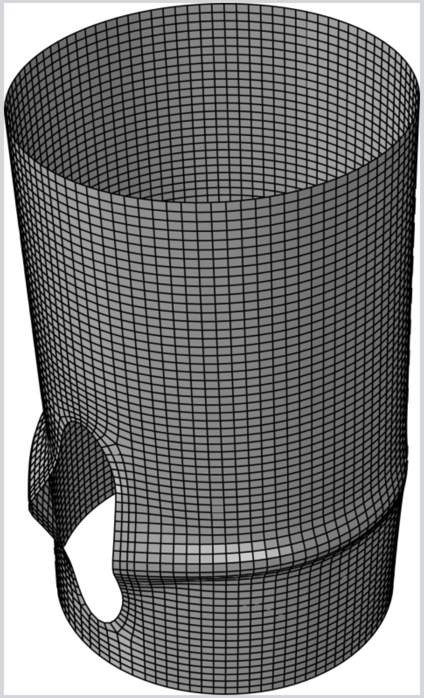


Wind turbine towers
Description of problem



From the doctoral thesis of Christoforos Dimopoulos





Influence of manholes

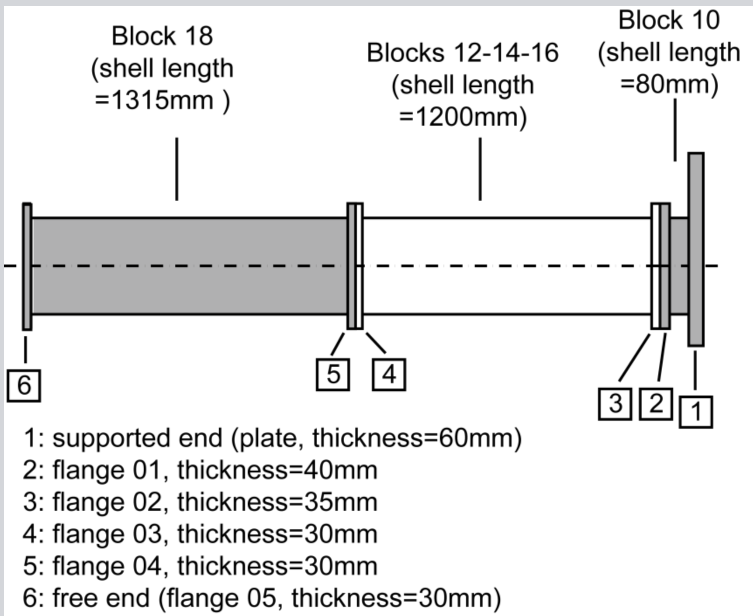
- ❑ **Stress concentrations**
- ❑ **Local buckling**

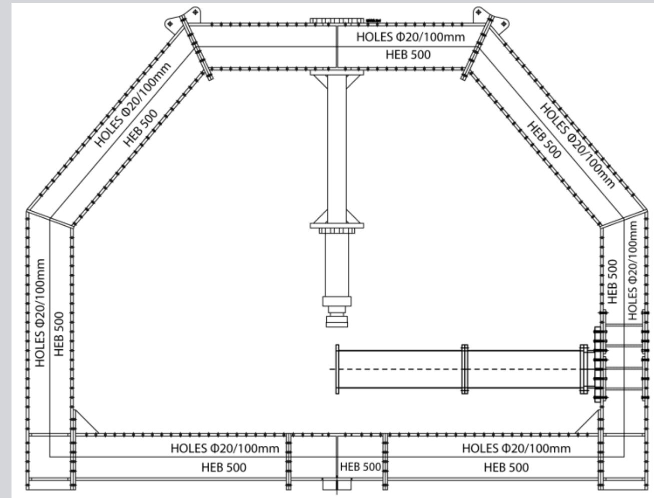
Wind turbine towers
Reinforcement of manholes

- **Objective of stiffening**
  - **To control local stresses**
  - **To provide adequate lateral support to the shell thus establishing adequate resistance against local buckling**
- **Research objective**
  - **Evaluation of the efficiency of different stiffening schemes of manholes at wind turbines towers**
- **Methodology**
  - **Experimental study and parallel numerical simulation for calibration**
  - **Parametric numerical study**
  - **Design guidelines**

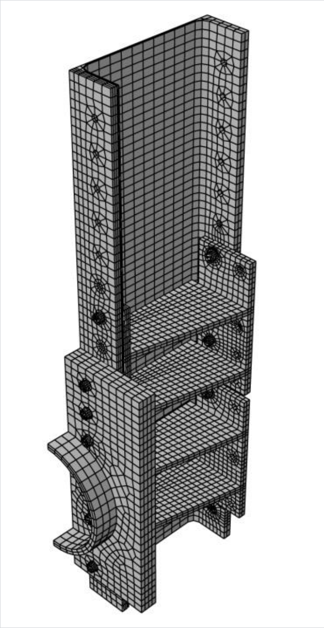
Wind turbine towers
Experimental work

Geometry of specimens

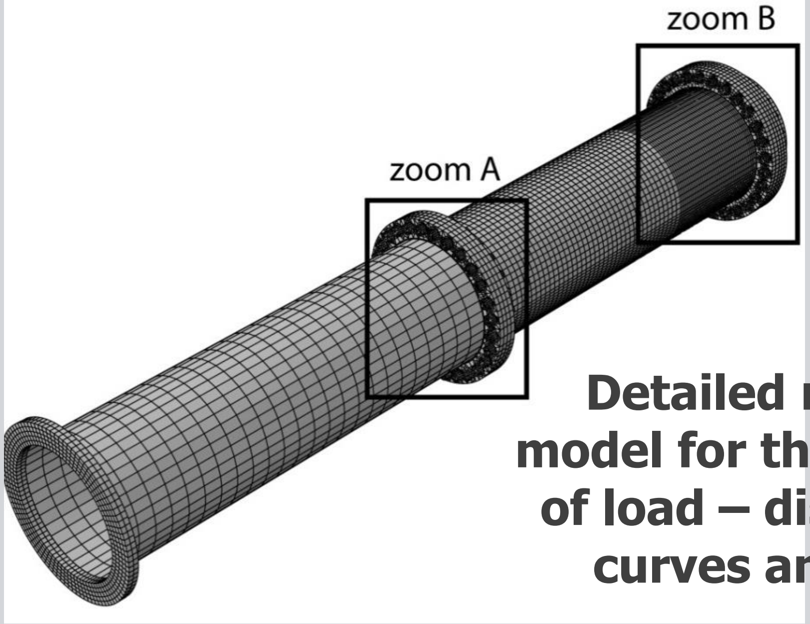




Wind turbine towers
Numerical model



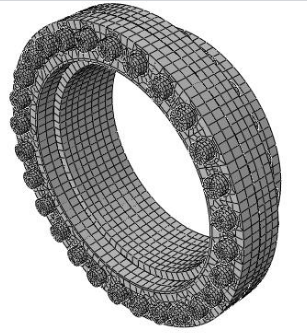
Simplified numerical model for the estimation of support (testing frame) flexibility



Detailed numerical model for the estimation of load – displacement curves and strains

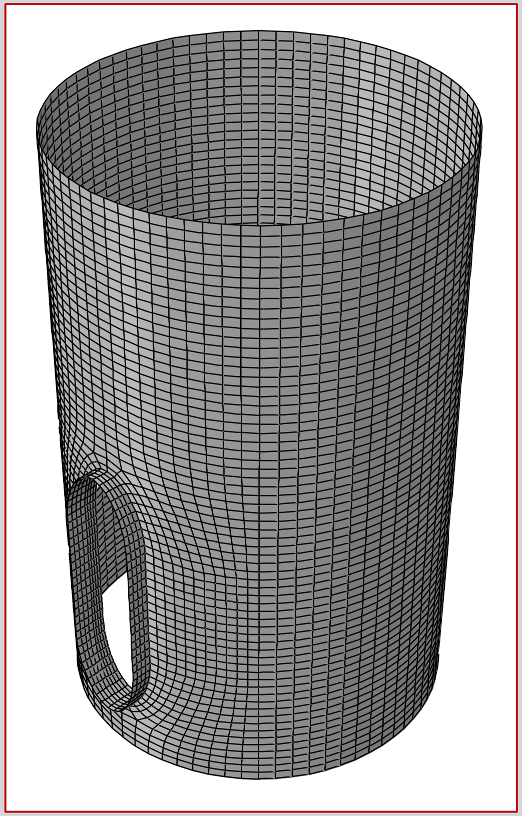
Zoom A

Zoom B

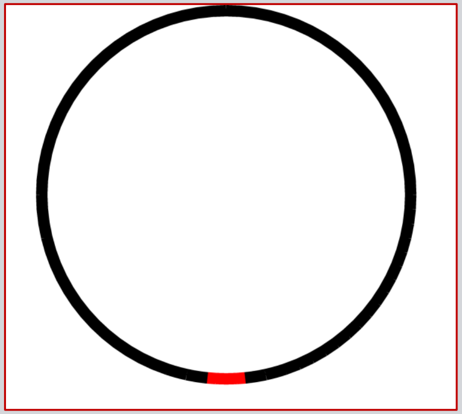


56 bolts and 4 flanges under contact

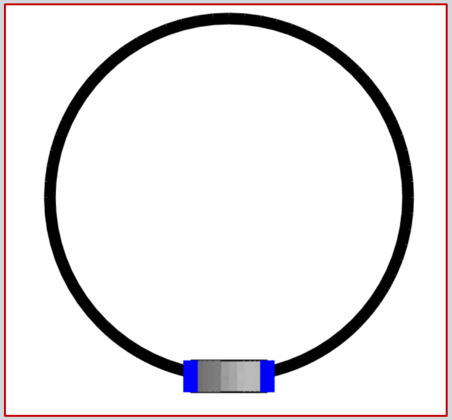
Wind turbine towers
Manhole reinforcement



Stiffeners considered as flanges under compression and classified as category 1 cross-sections according to EC3 provisions



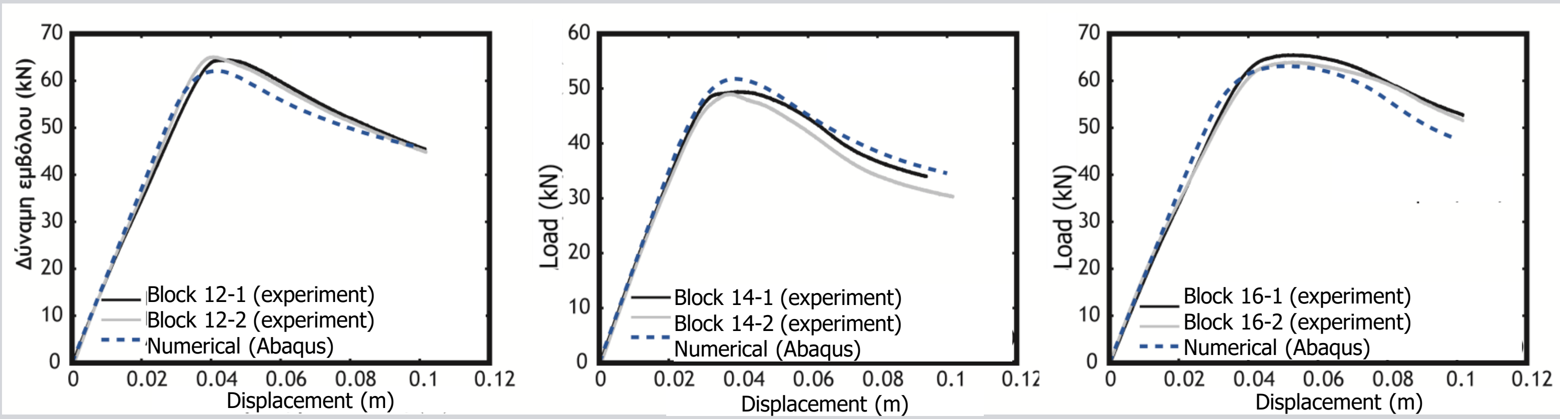
Area of manhole A_0



Area of frame stiffener A

Wind turbine towers

Comparison of experimental & numerical results

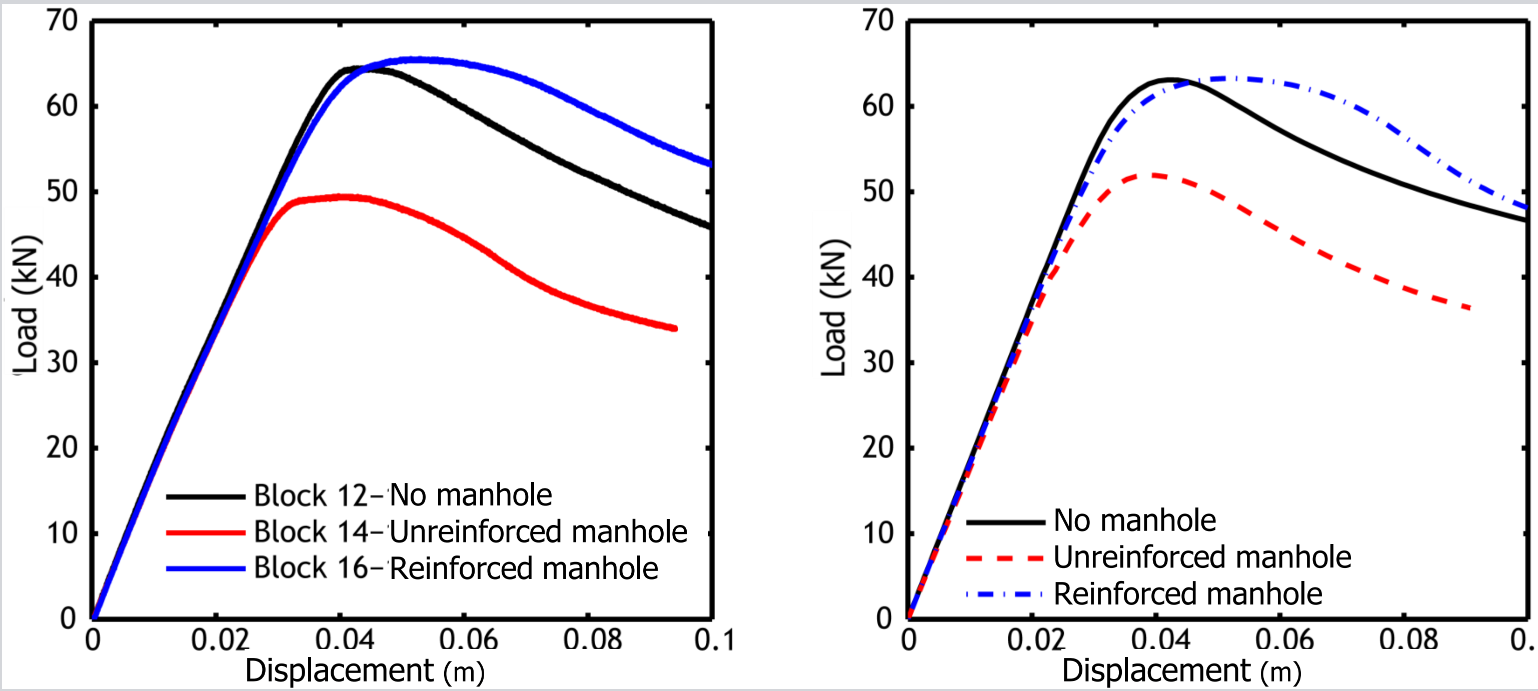


No manhole

Unreinforced manhole

Reinforced manhole

Wind turbine towers
Influence of manhole and stiffening



Experimental **Numerical**

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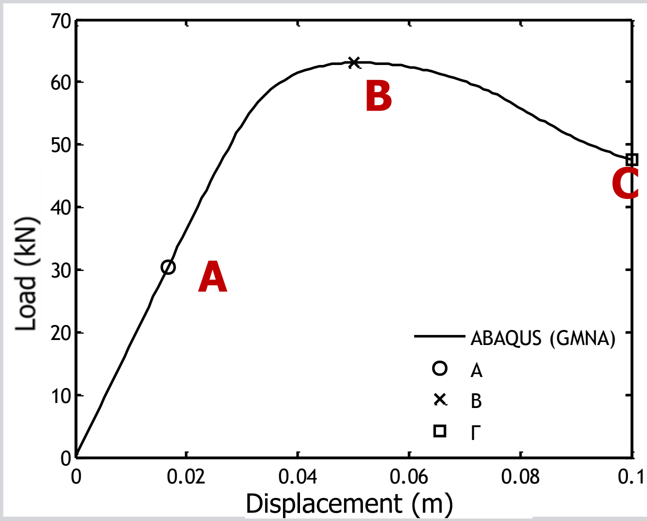
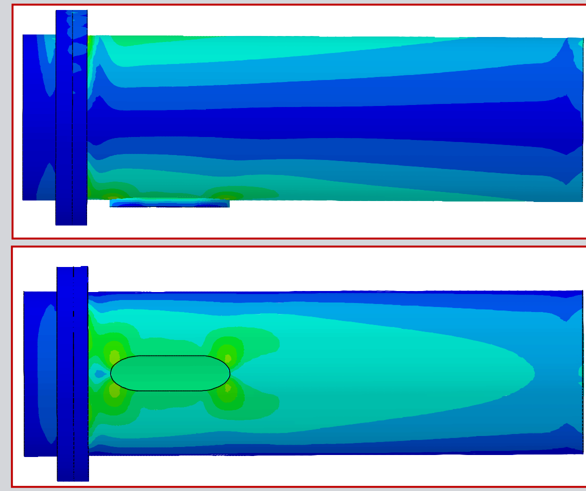
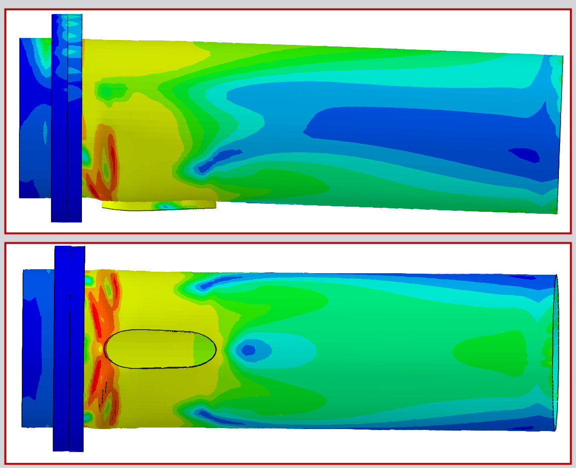
Wind turbine towers
Numerical analysis results



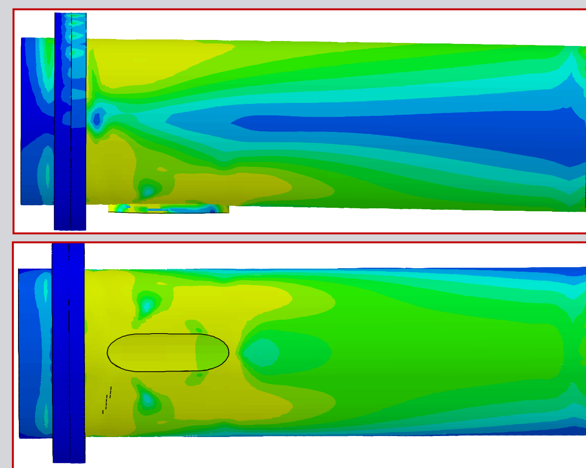
A



C

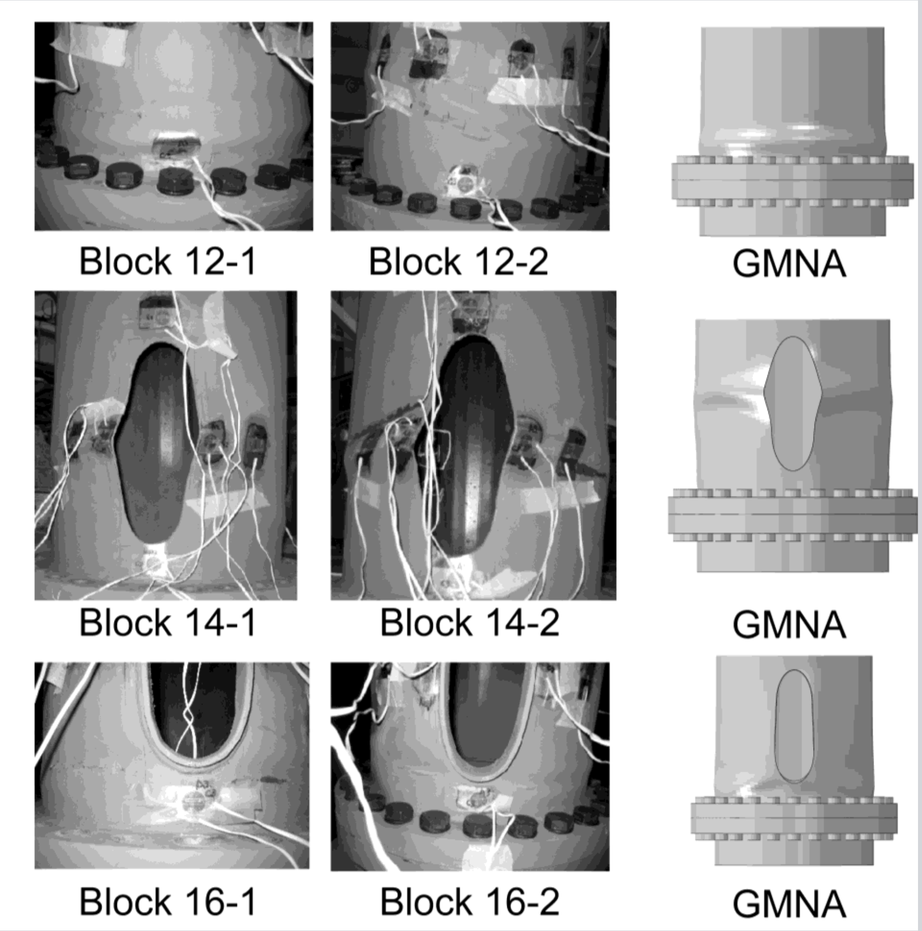


B



Wind turbine towers
Experimental / numerical results

Deformation after collapse

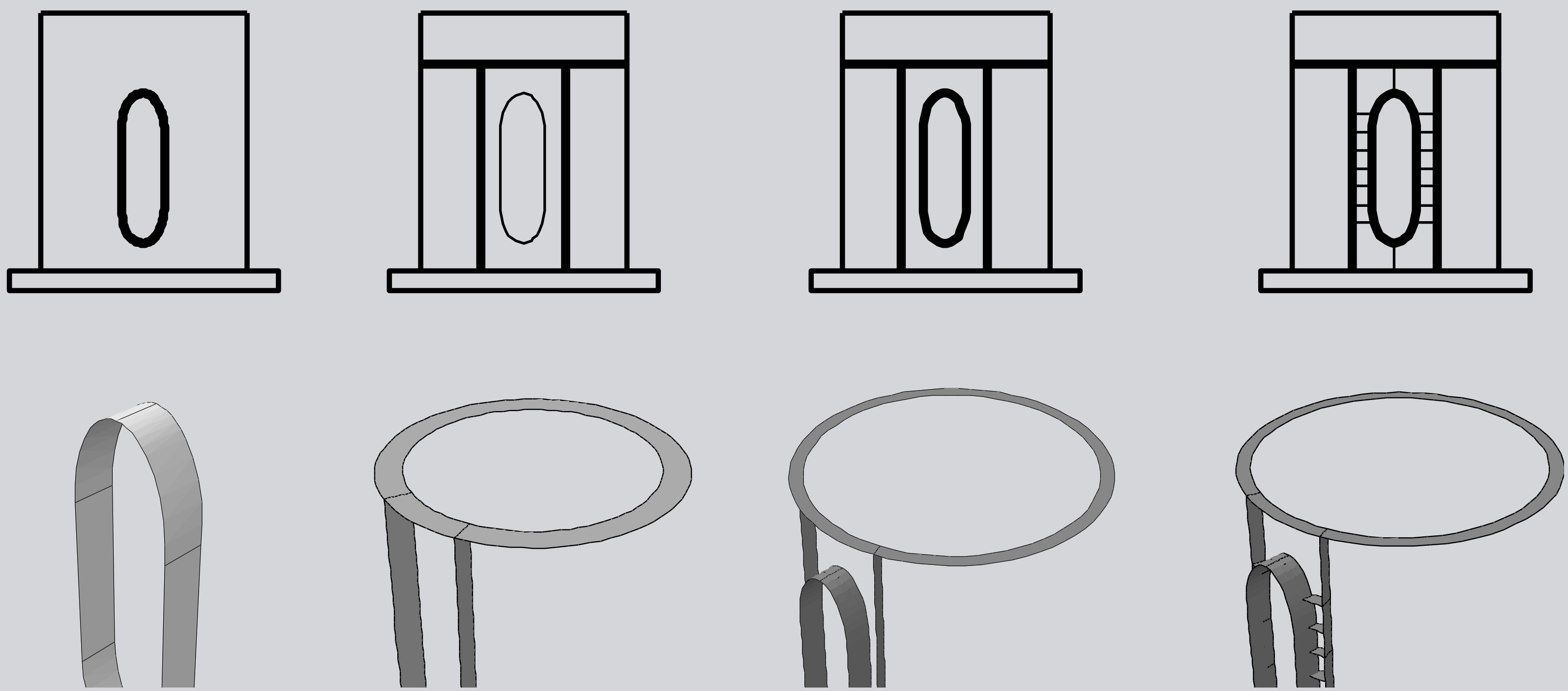


No manhole

Reinforced manhole

Unreinforced manhole

Wind turbine towers
Alternative stiffening schemes



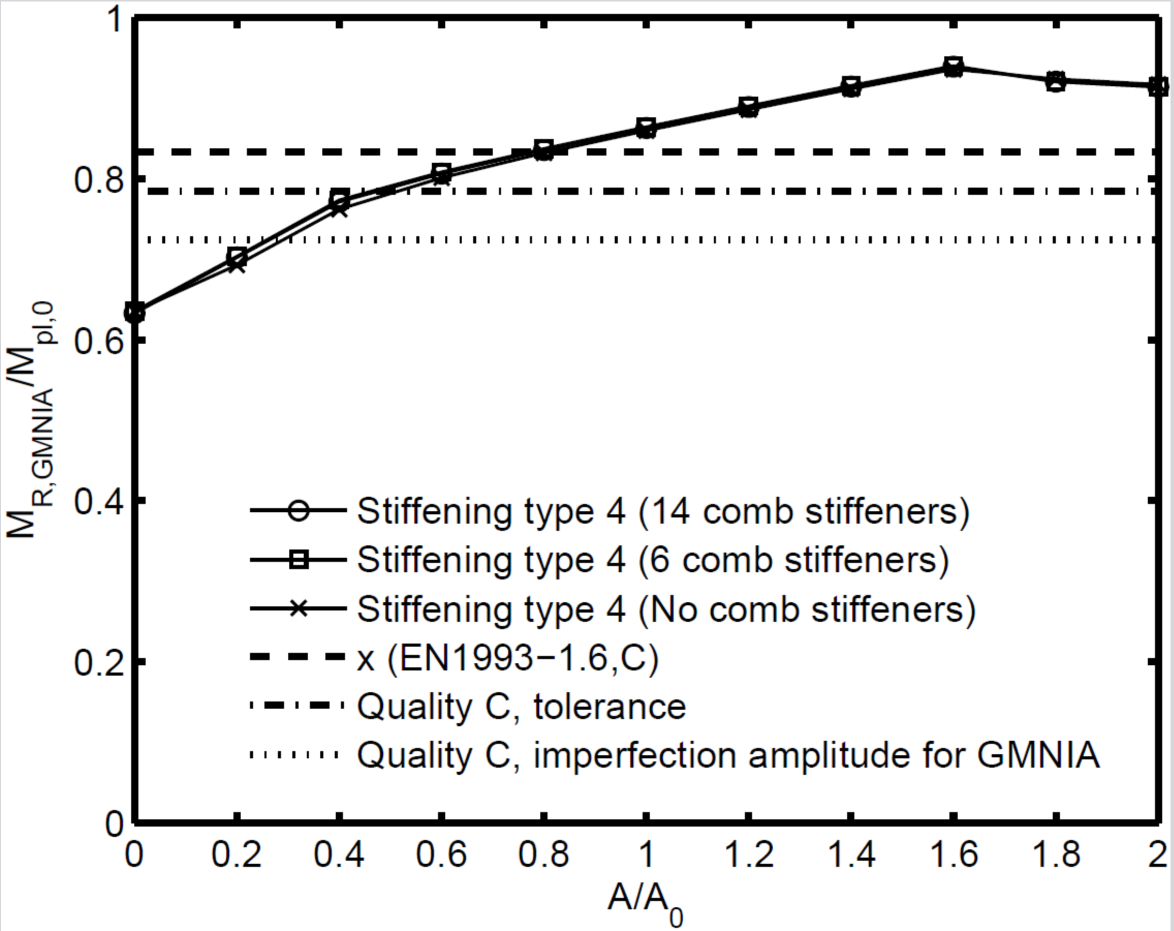
Frame stiffener

Stringer stiffener

Frame & stringer stiffeners

Frame & stringer stiffeners with extra stiffeners in between

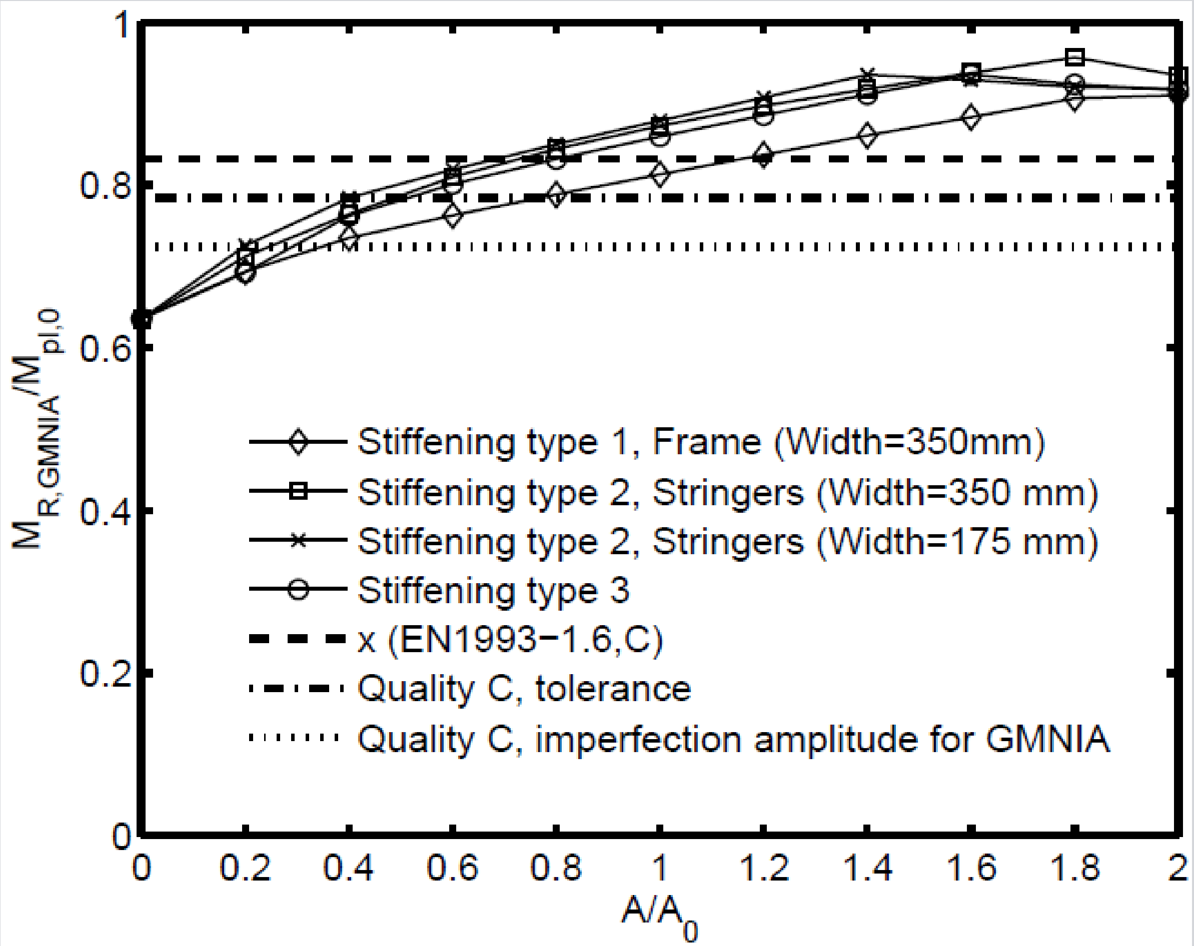
Wind turbine towers
Alternative stiffening schemes



Negligible influence of additional stiffeners

Wind turbine towers

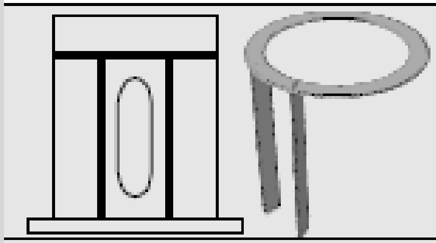
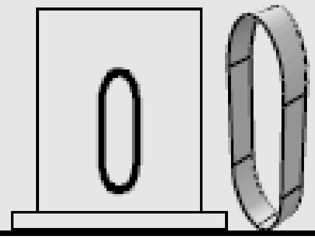
Comparison of alternative stiffening schemes



Required A/A_0 ratio for different stiffening types

Wind turbine towers

Dimensioning of alternative stiffening schemes

Stiffening type	Quality A	Quality B	Quality C
	A/A_0=0.6 (b/t= 2.979,b=175mm) A/A_0=0.6 (b/t= 11.916,b=350mm)	A/A_0=0.6 (b/t= 2.979,b=175mm) A/A_0=0.8 (b/t= 8.937,b=350mm)	A/A_0=0.8 (b/t= 2.234,b=175mm) A/A_0=0.8 (b/t= 8.937,b=350mm)
	A/A_0=1.2 (b/t=1.49,b=175mm) A/A_0=0.8 (b/t=8.937,b=350mm)	A/A_0=1.2 (b/t=1.49,b=175mm) A/A_0=1.0 (b/t=7.15,b=350mm)	A/A_0=1.4 (b/t=1.277,b=175mm) A/A_0=1.2 (b/t=5.958,b=350mm)

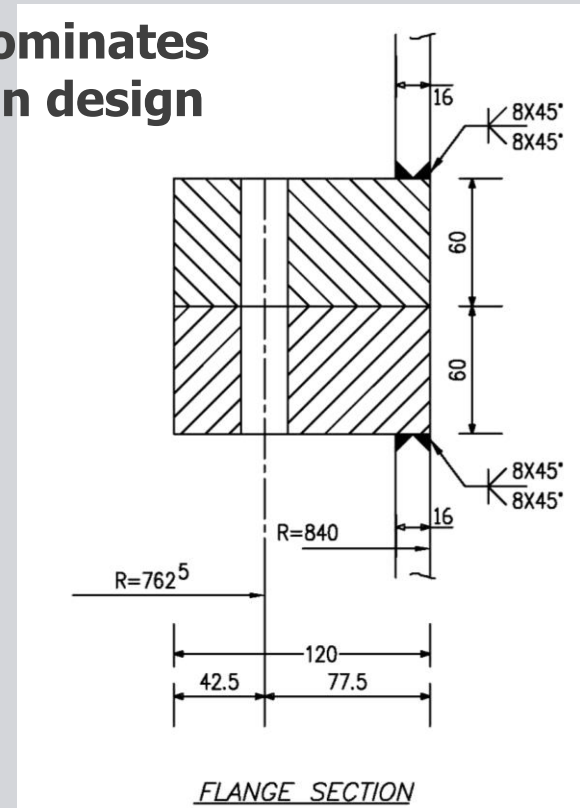
Required A/A_0 ratio for stringer and frame stiffeners

Wind turbine towers

Numerical modeling of connections for fatigue design

Typical connection between adjacent shell parts

Fatigue dominates connection design

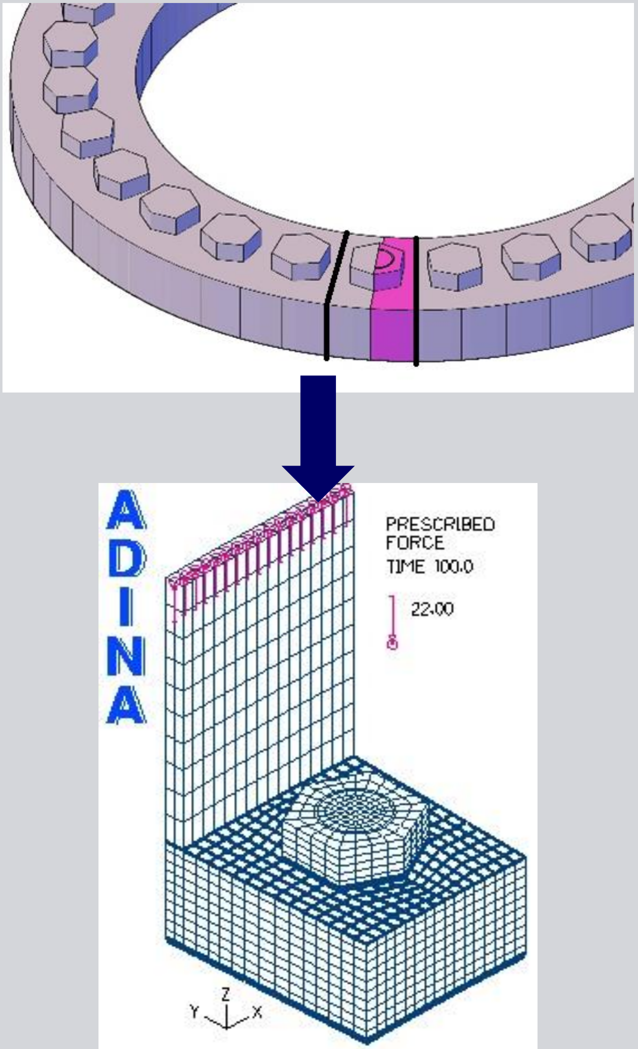


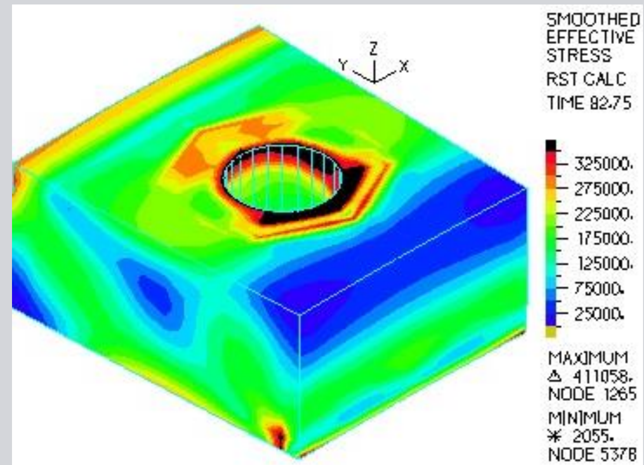
From the doctoral research of Konstantina Koulatsou

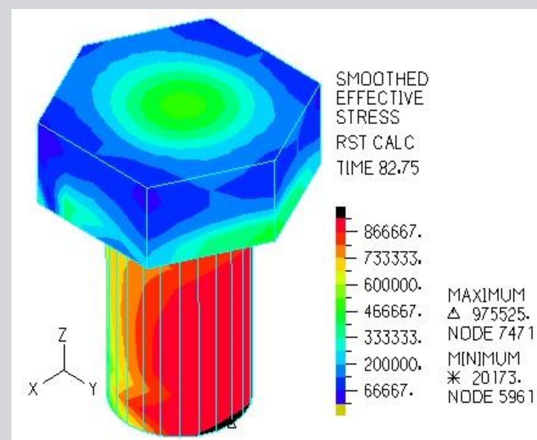
Wind turbine towers

Numerical modeling of connections for fatigue design

1st level of modeling

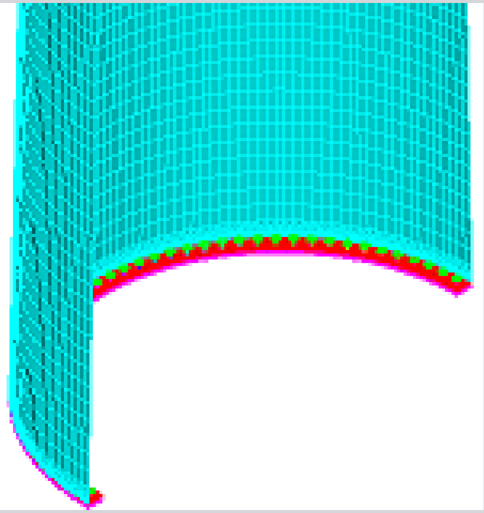


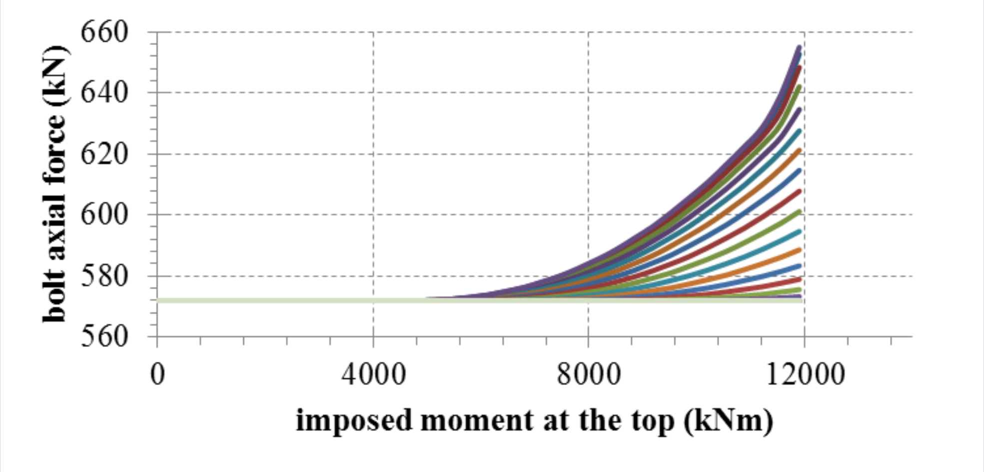


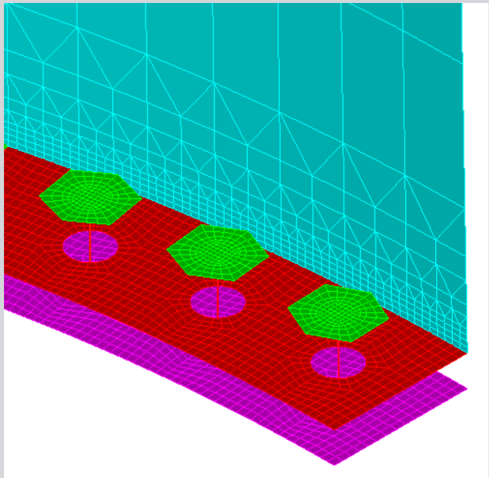


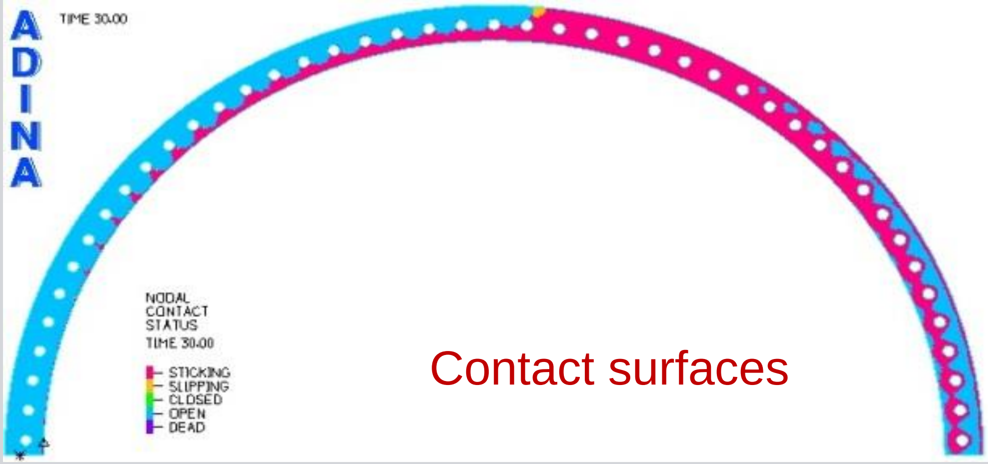
Wind turbine towers
Numerical modeling of connections for fatigue design

2nd level of modeling









Contact surfaces

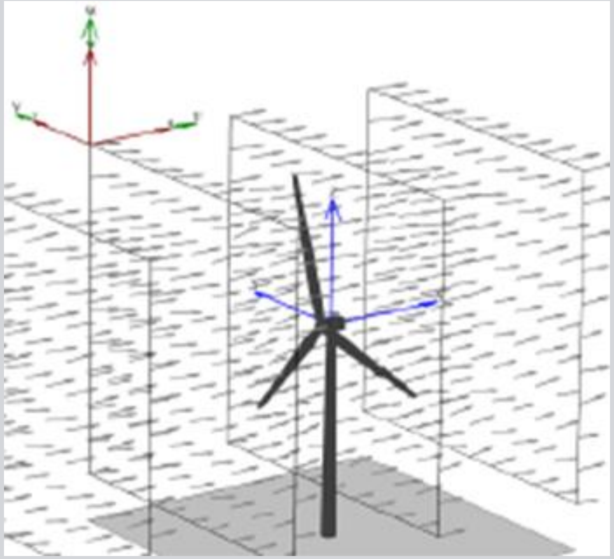
Wind turbine towers

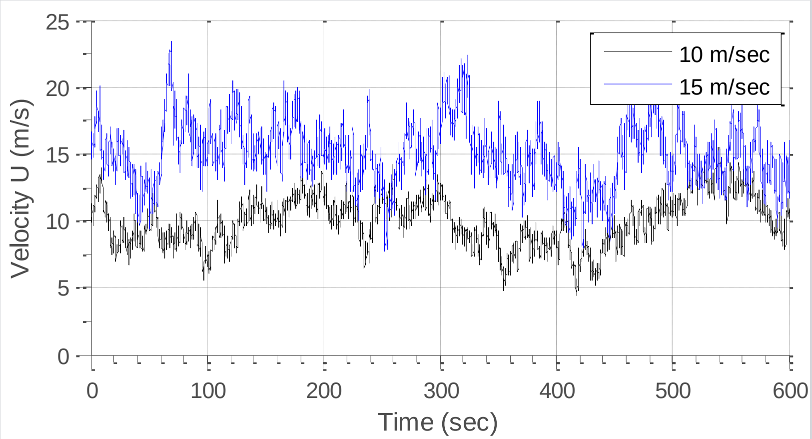
Numerical modeling of connections for fatigue design

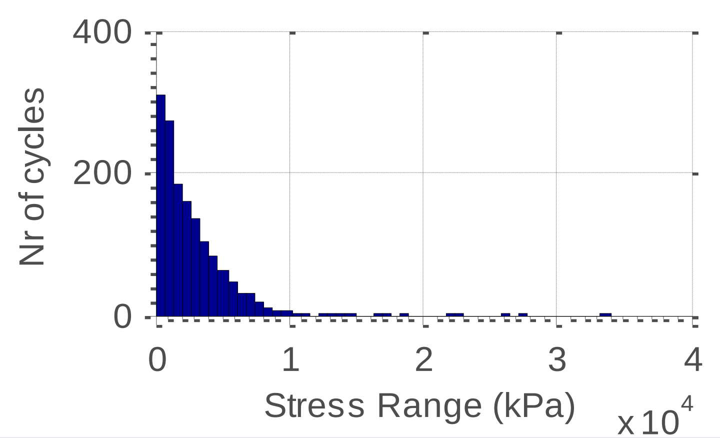
Combining

- **meteorological data,**
- **aeroelastic computer-aided engineering (FAST software)**
- **nonlinear finite element analysis (Adina software)**
- **rainflow counting method**

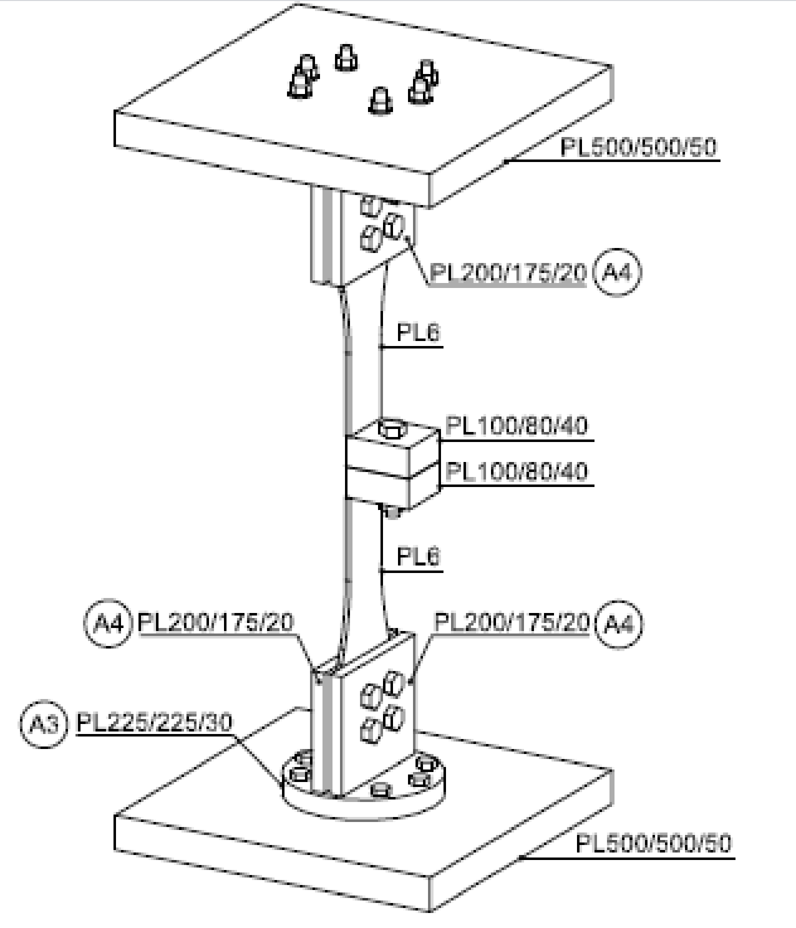
for optimizing connection fatigue design (flange + bolts) and evaluating service life







Tests for S-N fatigue curves in preparation



Wind turbine towers
Publications

Shell buckling and man-hole strengthening

- Dimopoulos, C.A., Koulatsou, K., Petrini, F. and Gantes, C.J., "Assessment of Stiffening Type of the Cutout in Tubular Wind Turbine Towers under Artificial Dynamic Wind Actions", *Journal of Computational and Nonlinear Dynamics (ASME)*, Vol. 10, No. 4, pp. 041004-1 - 041004-9, July 2015.
  http://dx.doi.org/10.1115/1.4028074
- Dimopoulos, C.A. and Gantes, C.J., "Comparison of Stiffening Types of the Cutout in Tubular Wind Turbine Towers", *Journal of Constructional Steel Research*, Vol. 83, pp. 62–74, April 2013.
  http://dx.doi.org/10.1016/j.jcsr.2012.12.016
- Dimopoulos, C.A. and Gantes, C.J., "Experimental Investigation of Buckling of Wind Turbine Tower Cylindrical Shells with Opening and Stiffening under Bending", *Thin-Walled Structures*, Vol. 54, pp. 140-155, May 2012.
  http://dx.doi.org/10.1016/j.tws.2012.02.011

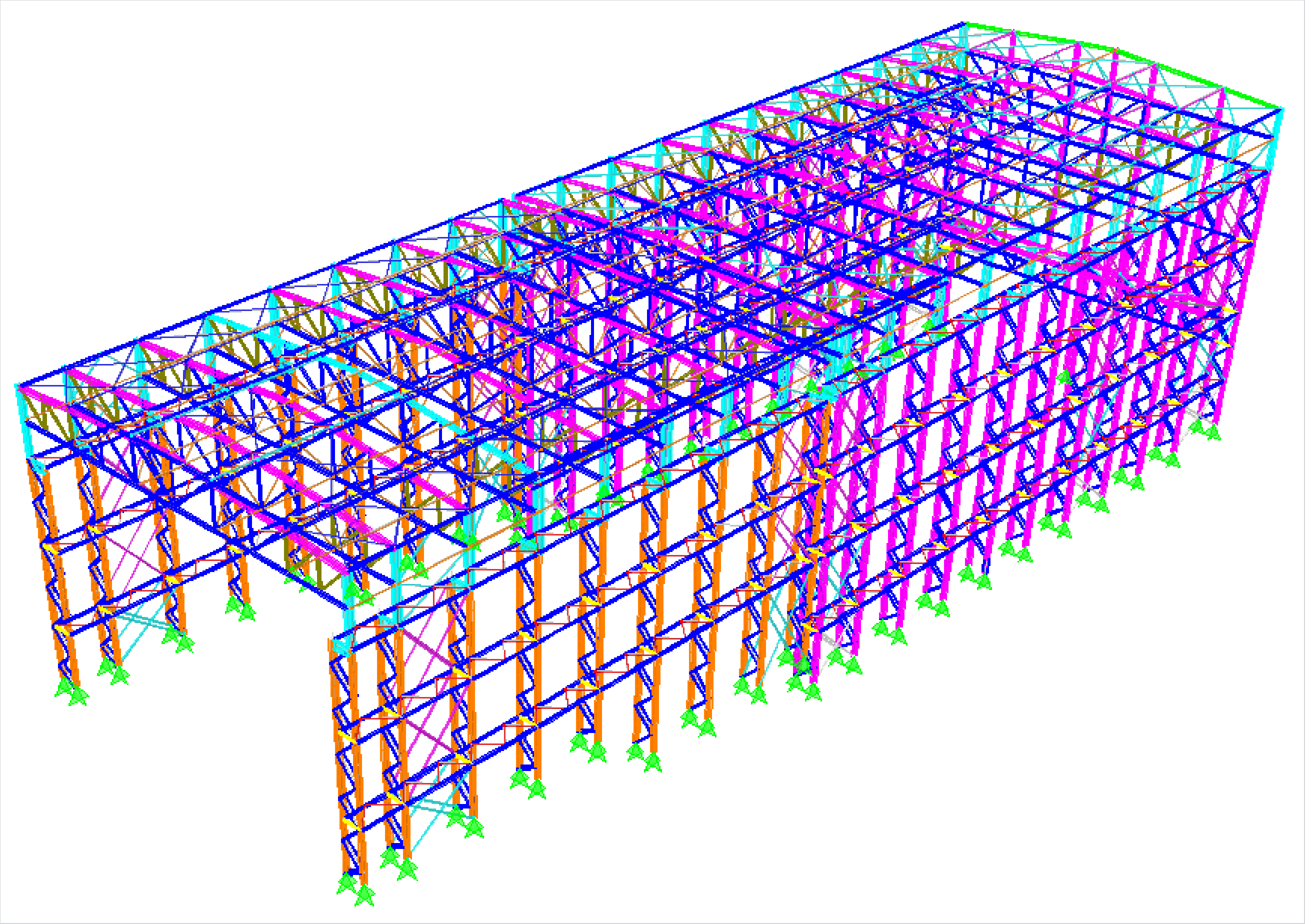
Fatigue of connections

- Ntaifoti, A.I., Koulatsou, K.G. and Gantes, C.J., "Numerical Simulation of Flange-Bolt Interaction in Wind Turbine Tower Connections", *8th GRACM International Congress on Computational Mechanics*, Volos, Greece, 12-15 July 2015.
- Thanasoulas, I., Koulatsou, K.G. and Gantes, C.J., "Nonlinear Numerical Simulation of Bolted Ring Flanges in Wind Turbine Towers", *IASS-SLTE 2014 Symposium*, Brasilia, Brazil, Sep. 15-19, 2014.

Other issues

- Vernardos, S. and Gantes, C.J., "Cross-Section Optimization of Sandwich-Type Cylindrical Wind Turbine Towers", *American Journal of Engineering and Applied Sciences*, Vol. 8, Issue 4, 2015.
  http://dx.doi.org/10.3844/ajeassp.2015.471.480
- Margariti, G., Papadopoulos, A., Barmpas, D., Gantes, C.J. and Gkologiannis, C.P., "Design of Monopile vs Tripod Foundation of Fixed Offshore Wind Turbines via Advanced Numerical Analysis", *8th GRACM International Congress on Computational Mechanics*, Volos, Greece, 12-15 July 2015.

Built-up columns
Design example

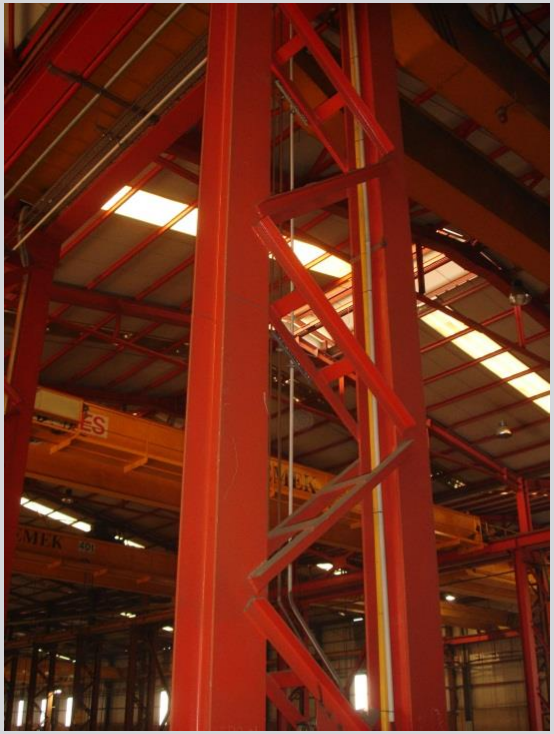


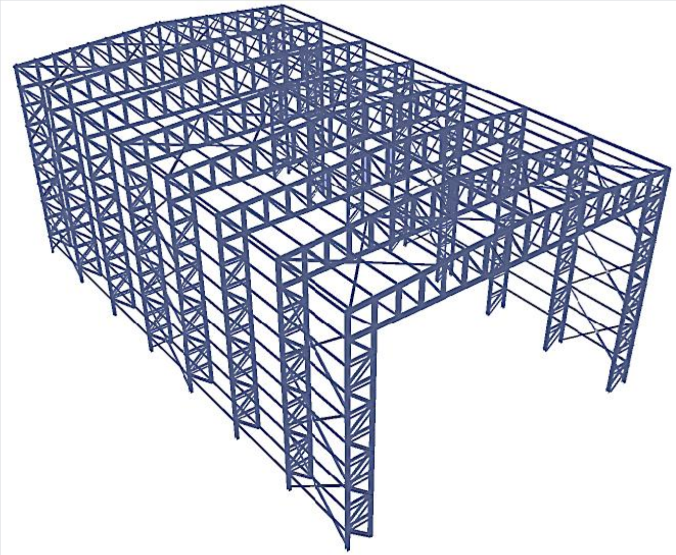
Hellas Gold Facilities in Skouries, Chalkidiki - Flotation bld

Built-up columns
Problem description

Recommended in cases of:

- ❑ Large height / long span
- ❑ Heavy loads





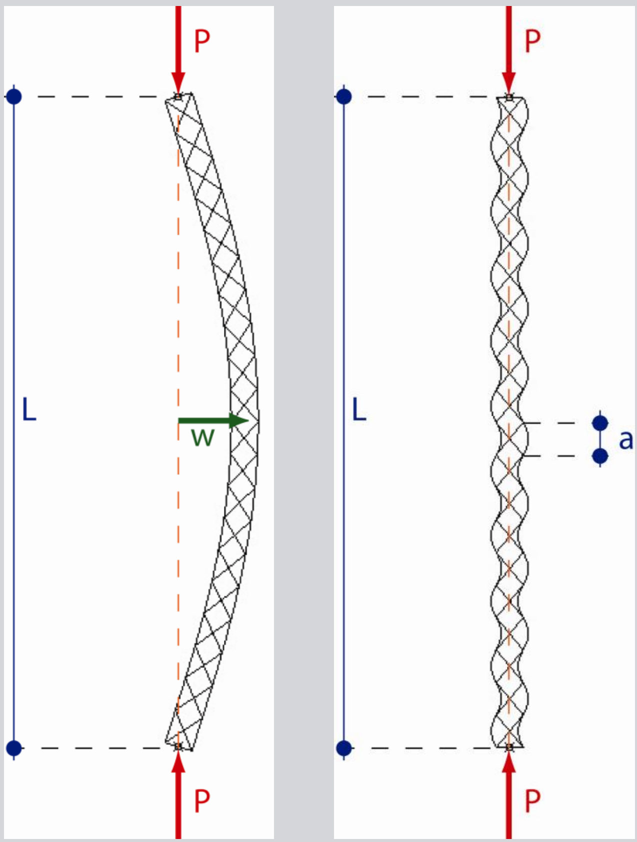
From the doctoral thesis of Kostis Kalochairetis

Research objective:

- ❑ Arbitrary boundary conditions
- ❑ Axial + bending actions
- ❑ Design guidelines

Built-up columns
Interesting issues

- Influence of shear deformation
- Interaction of global buckling, local buckling and plasticity



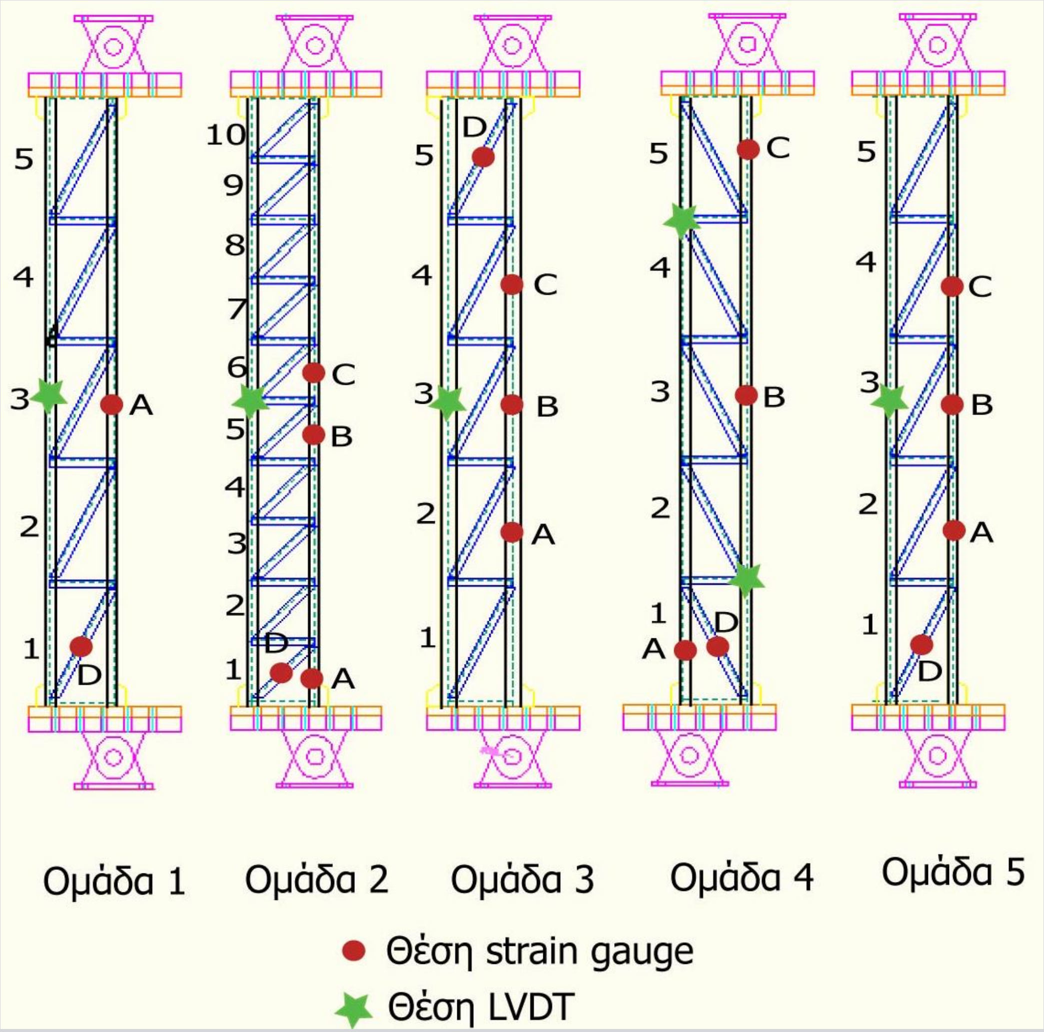
$$P_{cr} = \frac{1}{\frac{1}{P_E} + \frac{1}{S_v}}$$

$$P_L = \frac{2\pi^2 EI_{ch,z}}{a^2}$$

$$P_Y = 2A_{ch} f_y$$

$$x = \frac{P_{cr}}{P_L}$$

Built-up columns
Experimental tests



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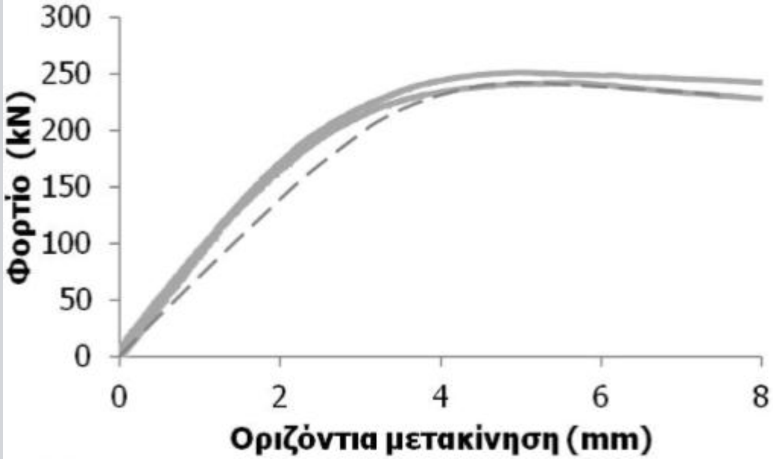
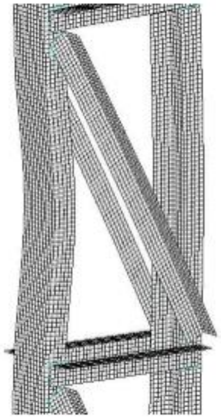
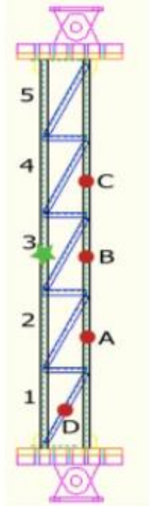
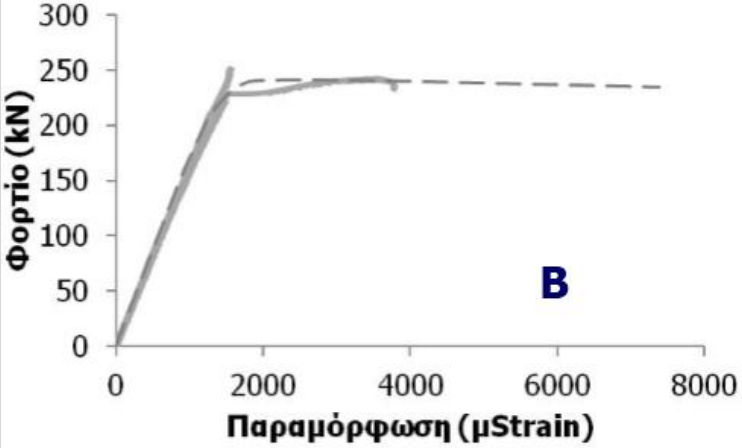
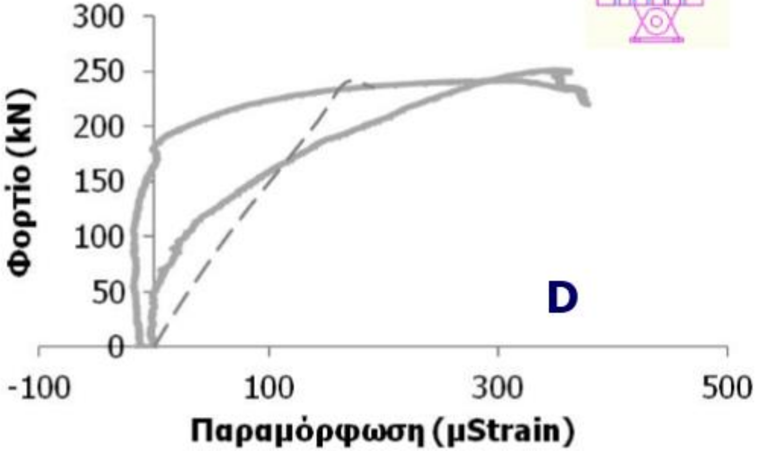
Built-up columns
Comparison between tests & numerical results



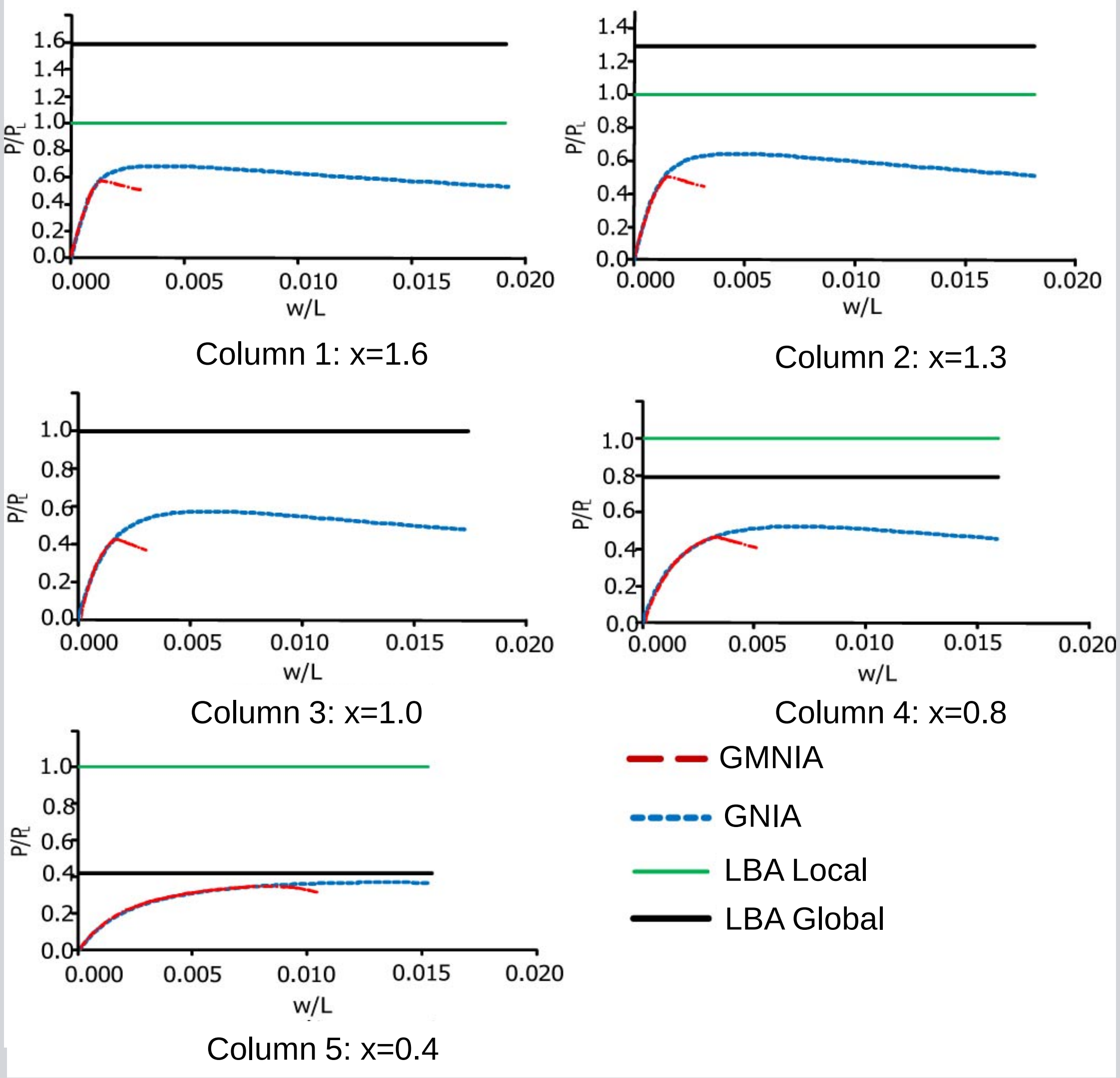








Built-up columns
Interaction



Built-up columns
Publications

- Kalochairetis, K.E. Gantes, C.J. and Lignos, X.A., "Experimental and Numerical Investigation of Eccentrically Loaded Laced Built-Up Steel Columns", *Journal of Constructional Steel Research*, Vol. 101, pp. 66–81, October 2014.

  http://dx.doi.org/10.1016/j.jcsr.2014.04.032
- Gantes, C.J. and Kalochairetis, K.E., "Axially and Transversely Loaded Timoshenko and Laced Built-up Columns with Arbitrary Supports", Journal of Constructional Steel Research, Vol. 77, pp. 95–106, October 2012.

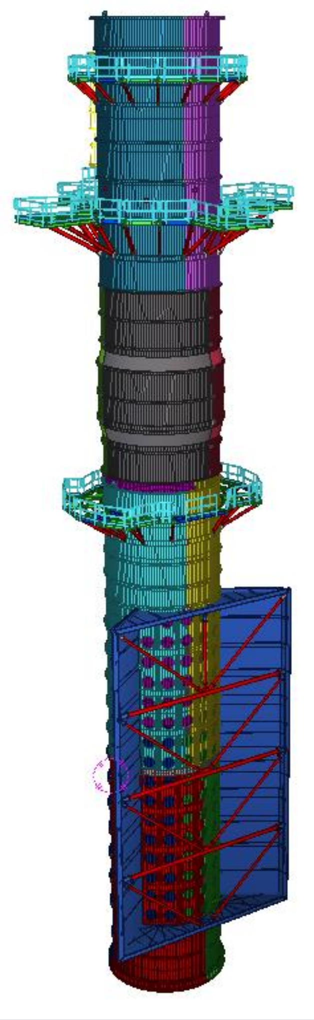
  http://dx.doi.org/10.1016/j.jcsr.2012.05.004
- Kalochairetis, K.E. and Gantes, C.J., "Elastic Buckling Load of Multi-Story Frames Consisting of Timoshenko Members", Journal of Constructional Steel Research, Vol. 71, pp. 231–244, April 2012.

  http://dx.doi.org/10.1016/j.jcsr.2011.11.007
- Kalochairetis, K.E. and Gantes, C.J., "Numerical and Analytical Investigation of Collapse Loads of Laced Built-up Columns", Computers & Structures, Vol. 89, Issues 11-12, pp. 1166-1176, June 2011.

  http://dx.doi.org/10.1016/j.compstruc.2010.10.018

Large-diameter industrial steel chimneys

Problem description



Funding from CICIND - International Committee on Industrial Chimneys (http://cicind.org/)

In recent years the development of combined cycle power plants has led to boiler exhaust stacks with diameters in the order of 7 meters

Steel chimneys are designed shell buckling according to one of the following codes:

- **CICIND: Model Code for Steel Chimneys**
- **EN 1993-1-6: Strength and Stability of Shell Structures**
- **ASME STS-1: Steel Stacks**

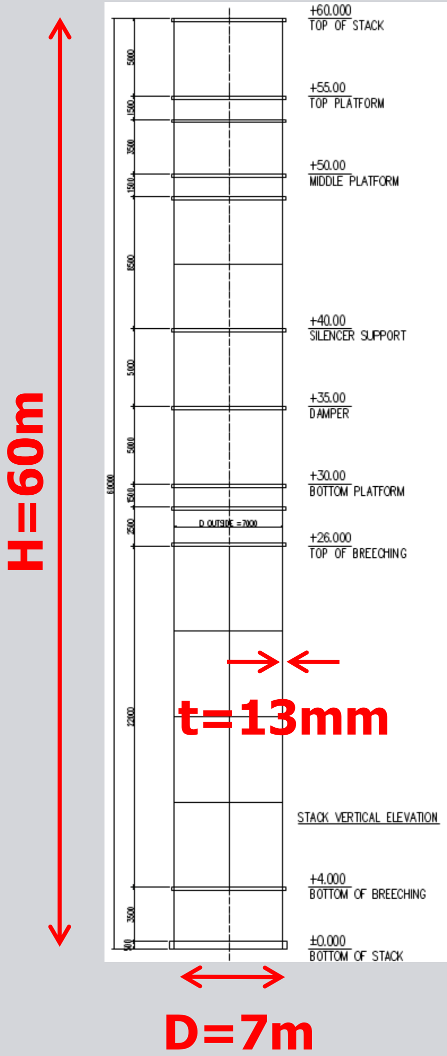
Issues not covered by these codes:

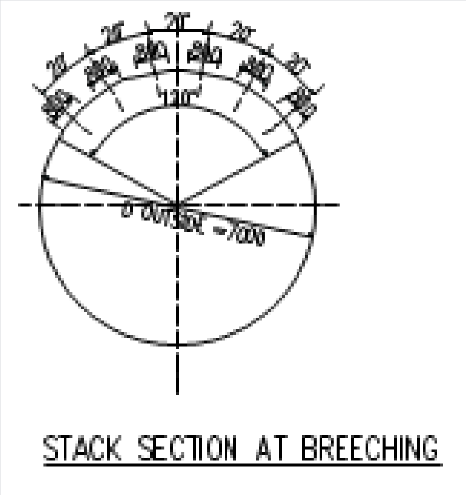
- **Beam vs. shell modeling**
- **Impact of stiffeners**
- **Impact of breeching**

Large-diameter industrial steel chimneys

Problem description

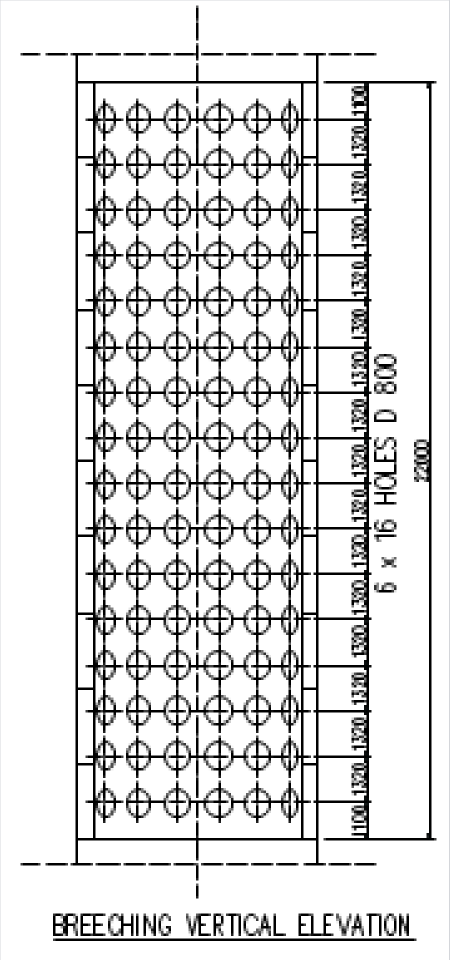
Prototype chimney





- STIFFENERS GENERALLY: L 120/10
- STIFFENER AT CHIMNEY TOP: U 200
- STIFFENERS AT PLATFORM CONNECTIONS: U 200
- STIFFENER AT SILENCER SUPPORT. U 200
- DAMPER FLANGES: 2 PL 400x20 SPACED 500 mm APART

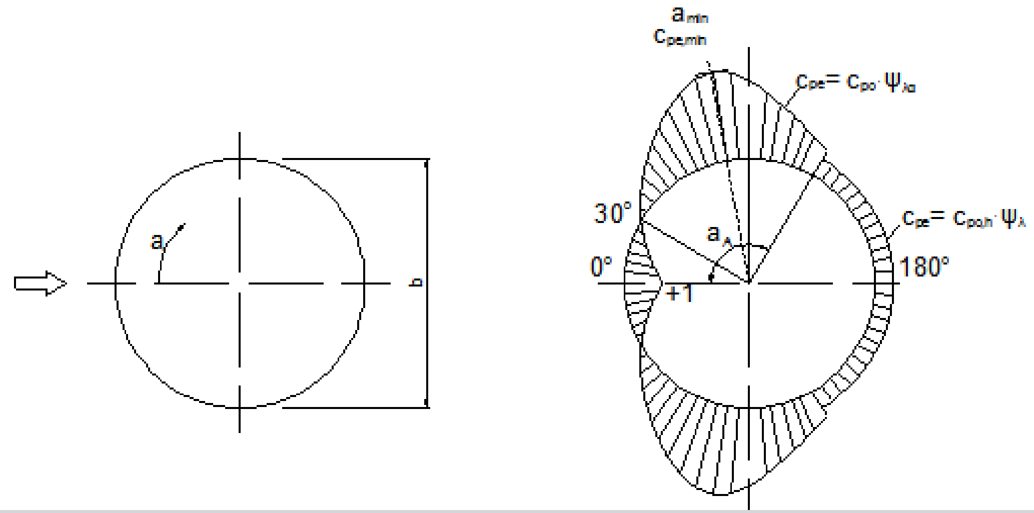
- STEEL GRADE FOR SHELL: S235 JR
- STEEL GRADE FOR STIFFENERS: S235 JR



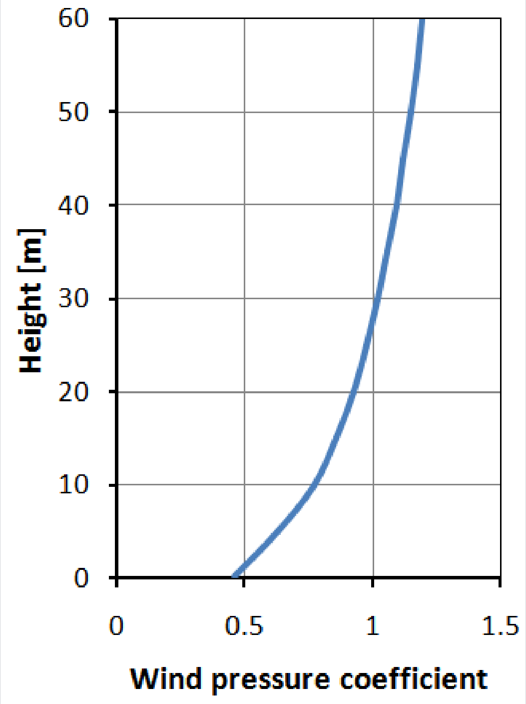
Large-diameter industrial steel chimneys

Problem description

Wind loading distribution



In plan

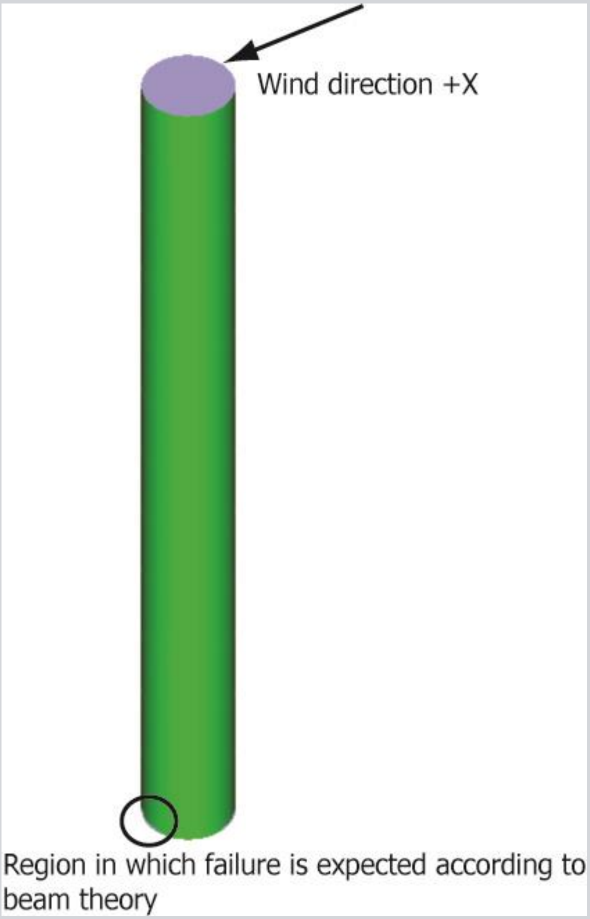


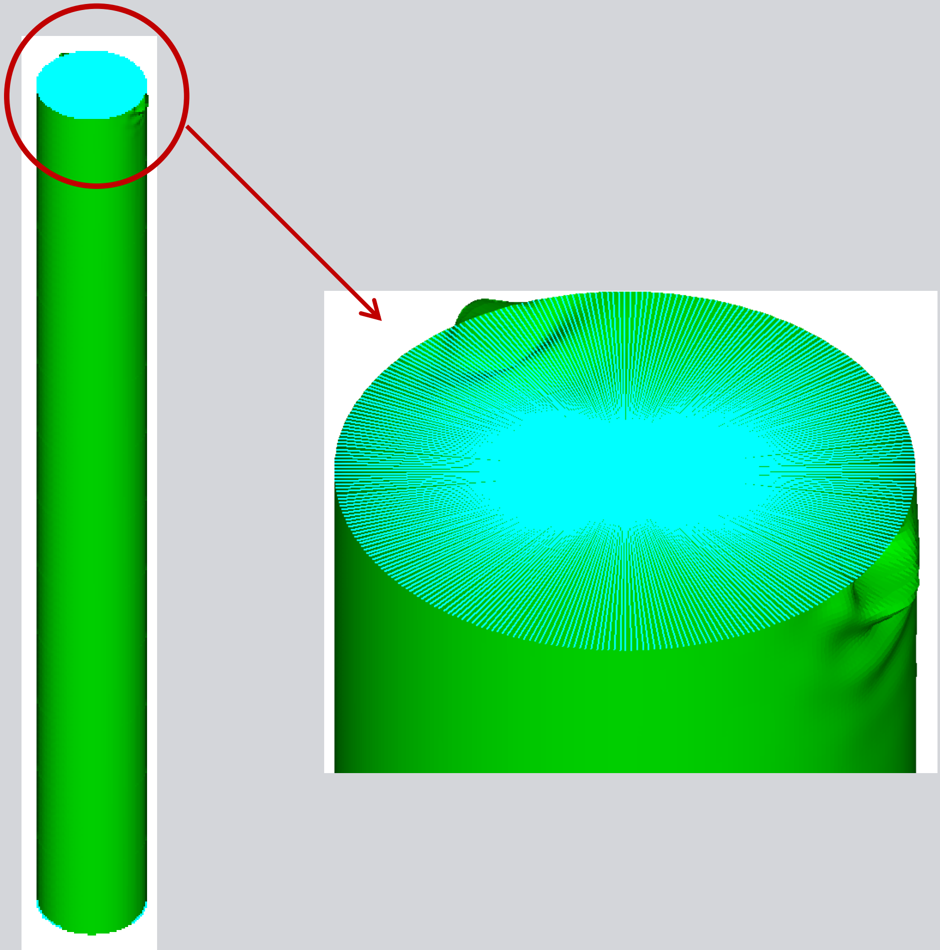
In elevation

Large-diameter industrial steel chimneys

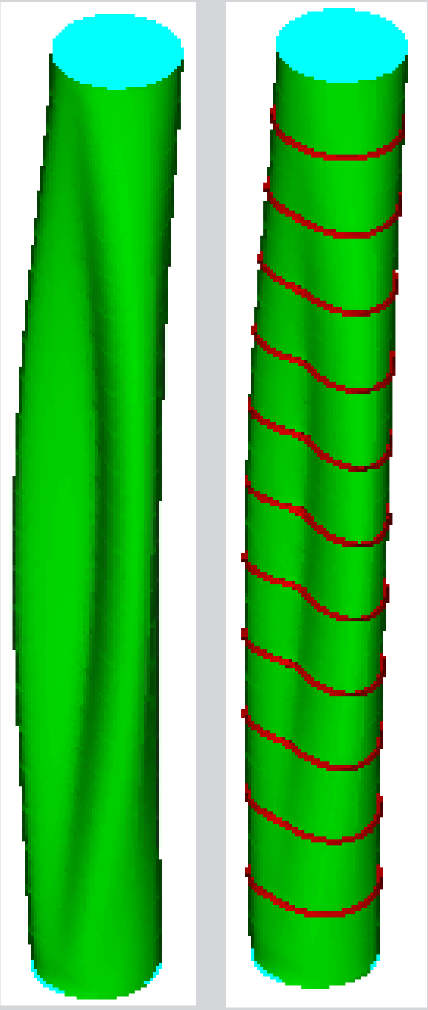
Beam vs. shell modeling

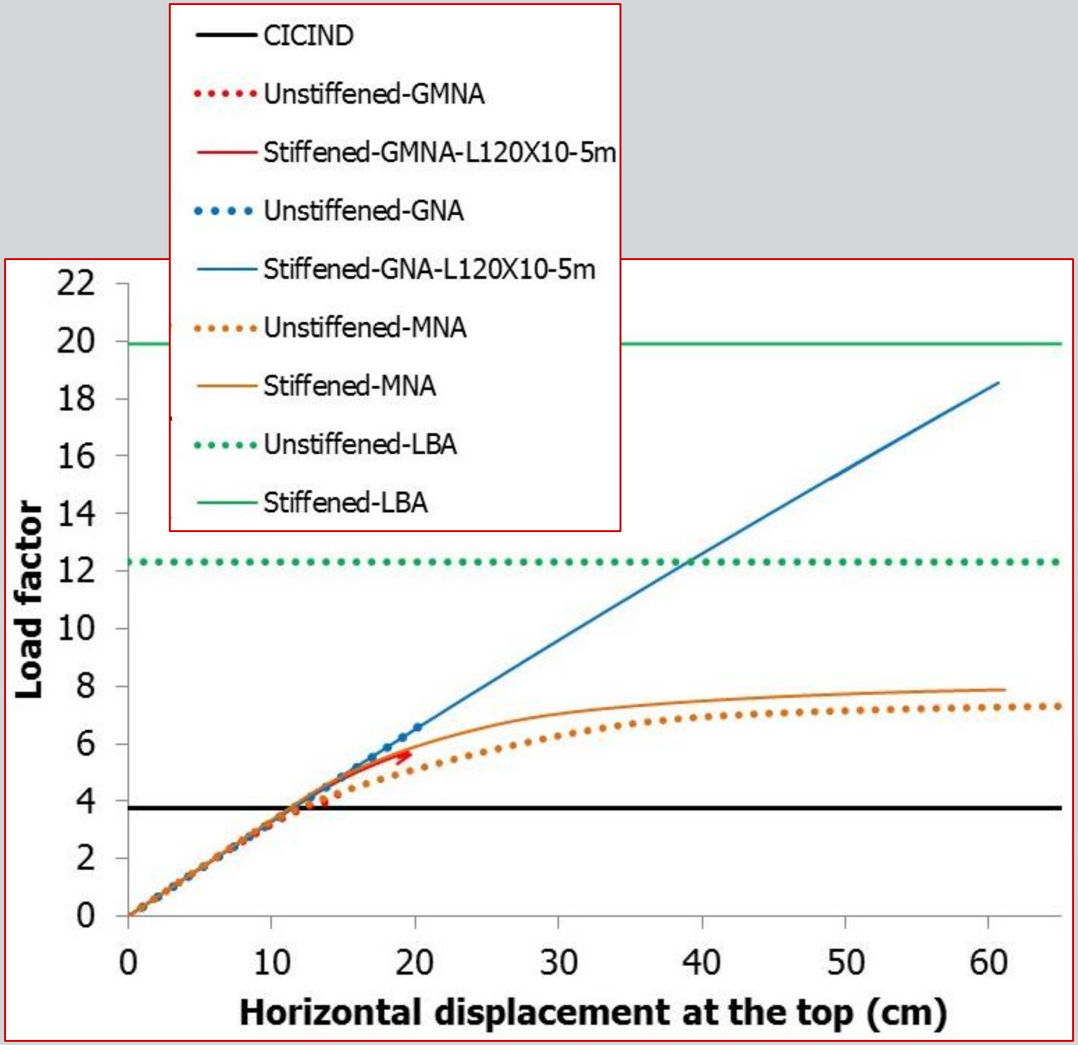
Due to wind pressure distribution, shell-type buckling dominates





Large-diameter industrial steel chimneys
Effect of stiffeners

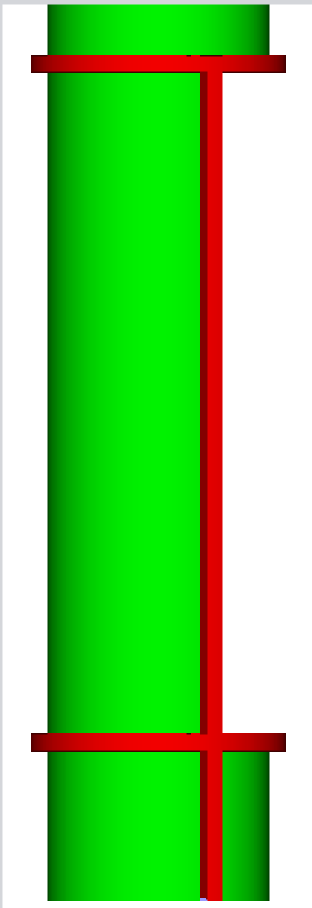




Large-diameter industrial steel chimneys

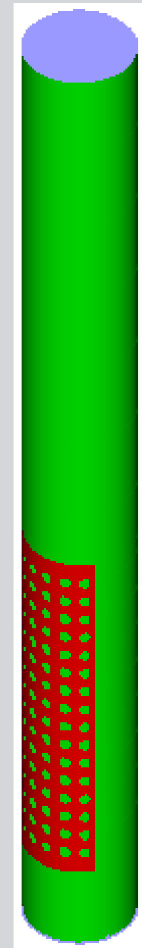
Effect of breeching

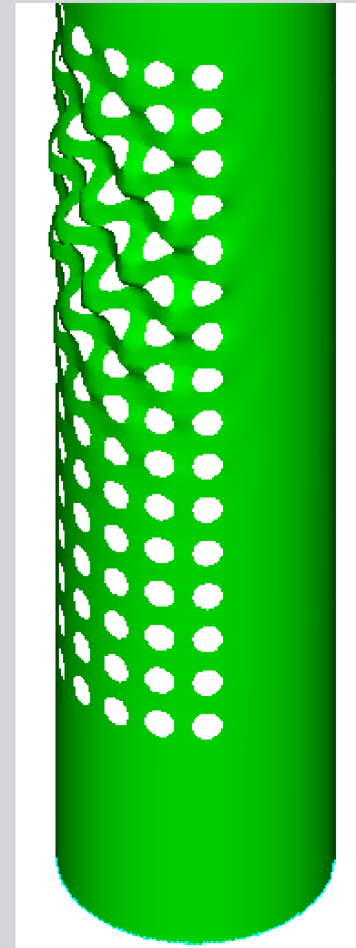
Single large opening



Huge stiffeners are required to compensate loss of strength

Much better performance with small local increase of shell thickness





Array of many small circular openings

Eurocode 3 rules for nonlinear analysis

Problem description

CEN/TC 250

Date: 2015-11

prEN 1993-1-1:2015

CEN/TC 250

Secretariat: BSI

Eurocode 3 — Design of steel structures — Part 1-1: General rules and rules for buildings

Eurocode 3 — Bemessung und Konstruktion von Stahlbauten — Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau

Eurocode 3 — Calcul des structures en acier — Partie 1-1 : Règles générales et règles pour les bâtiments

Eurocode 3 rules for nonlinear analysis

Problem description

5.2 Global analysis

5.2.1 Effects of deformed geometry of the structure

(1) The internal forces and moments may generally be determined using either:

— first-order analysis, using the initial geometry of the structure or

— second-order analysis, taking into account the influence of the deformation of the structure.

(2) The effects of the deformed geometry (second-order effects) should be considered if they increase the action effects significantly or modify significantly the structural behaviour.

(3) First order analysis may be used for the structure, if the increase of the relevant internal forces or moments or any other change of structural behaviour caused by deformations can be neglected. This condition may be assumed to be fulfilled, if the following criterion is satisfied:

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 10 \quad \text{for elastic analysis}$$
$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 15 \quad \text{for plastic analysis} \qquad (5.1)$$

where

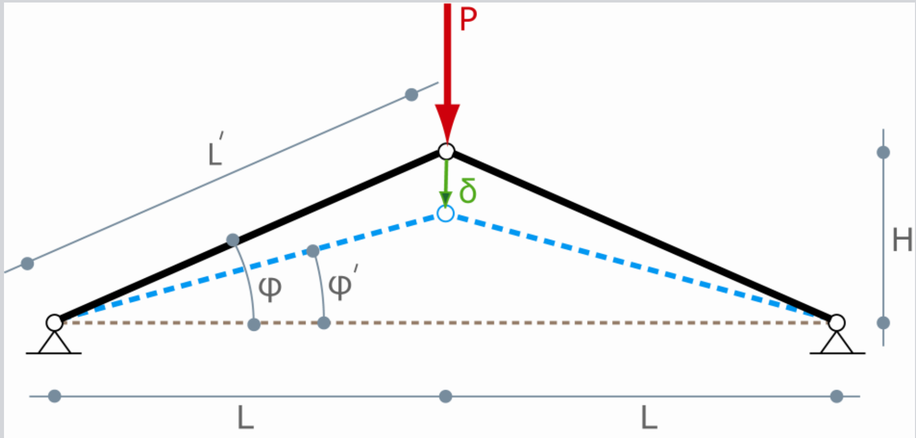
α_{cr} is the factor by which the design loading would have to be increased to cause elastic instability in a global mode;

F_{Ed} is the design loading on the structure;

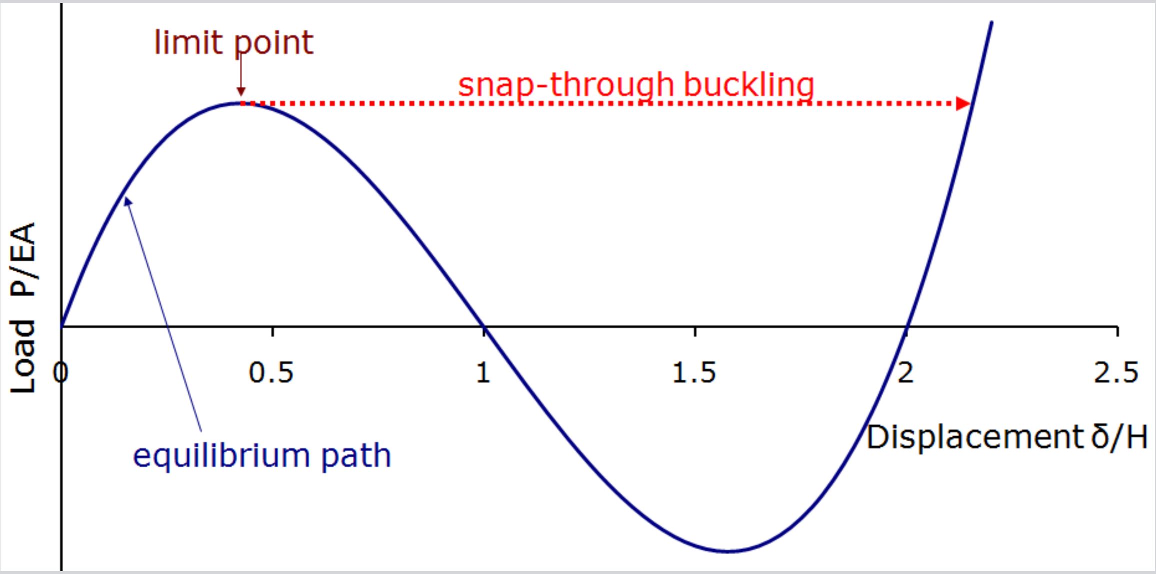
F_{cr} is the elastic critical buckling load for global instability mode based on initial elastic stiffnesses.

Eurocode 3 rules for nonlinear analysis

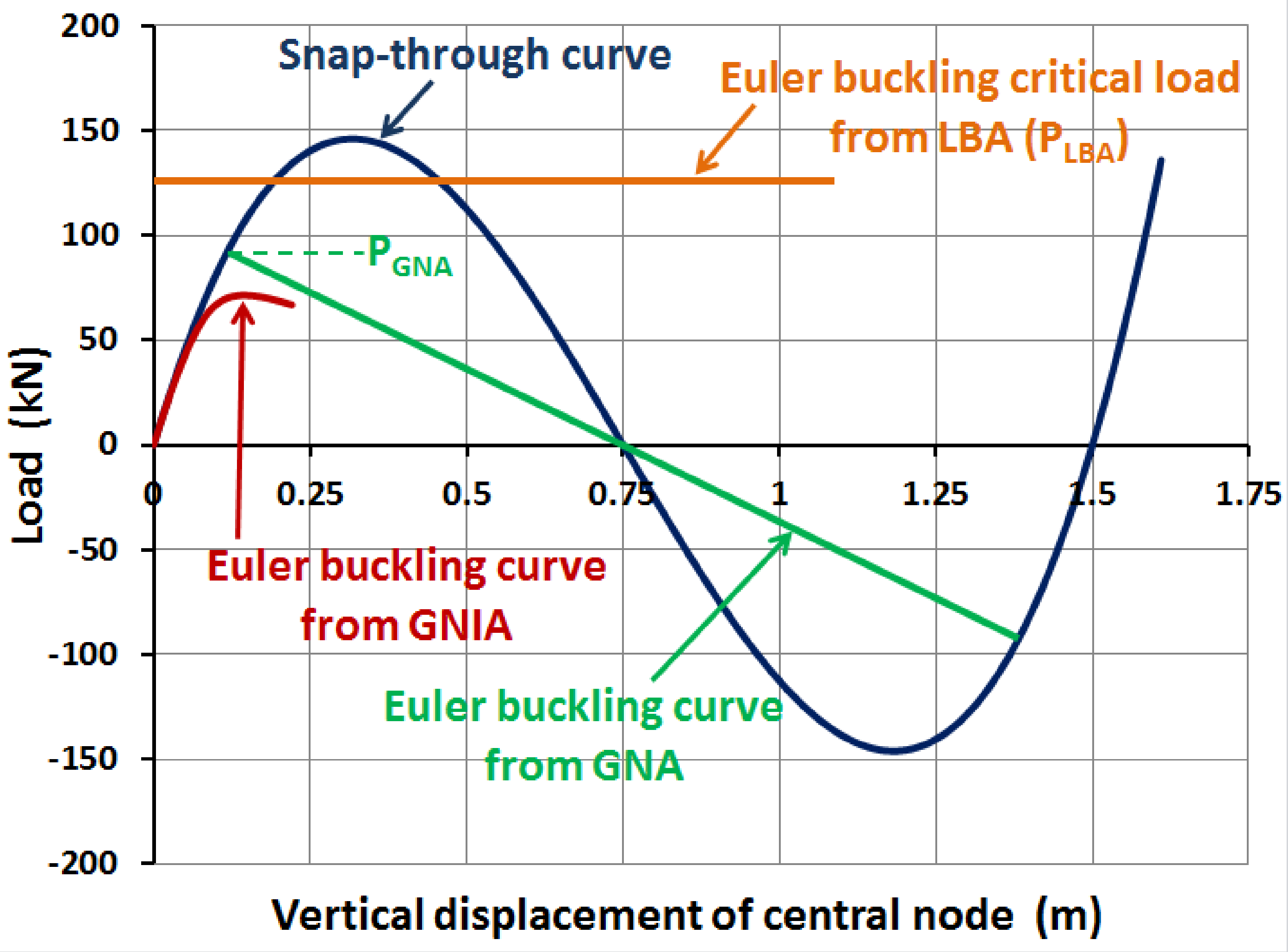
Example of von Mises truss



From the doctoral research of Maria Livanou



Eurocode 3 rules for nonlinear analysis
Example of von Mises truss



Eurocode 3 rules for nonlinear analysis

Example of von Mises truss

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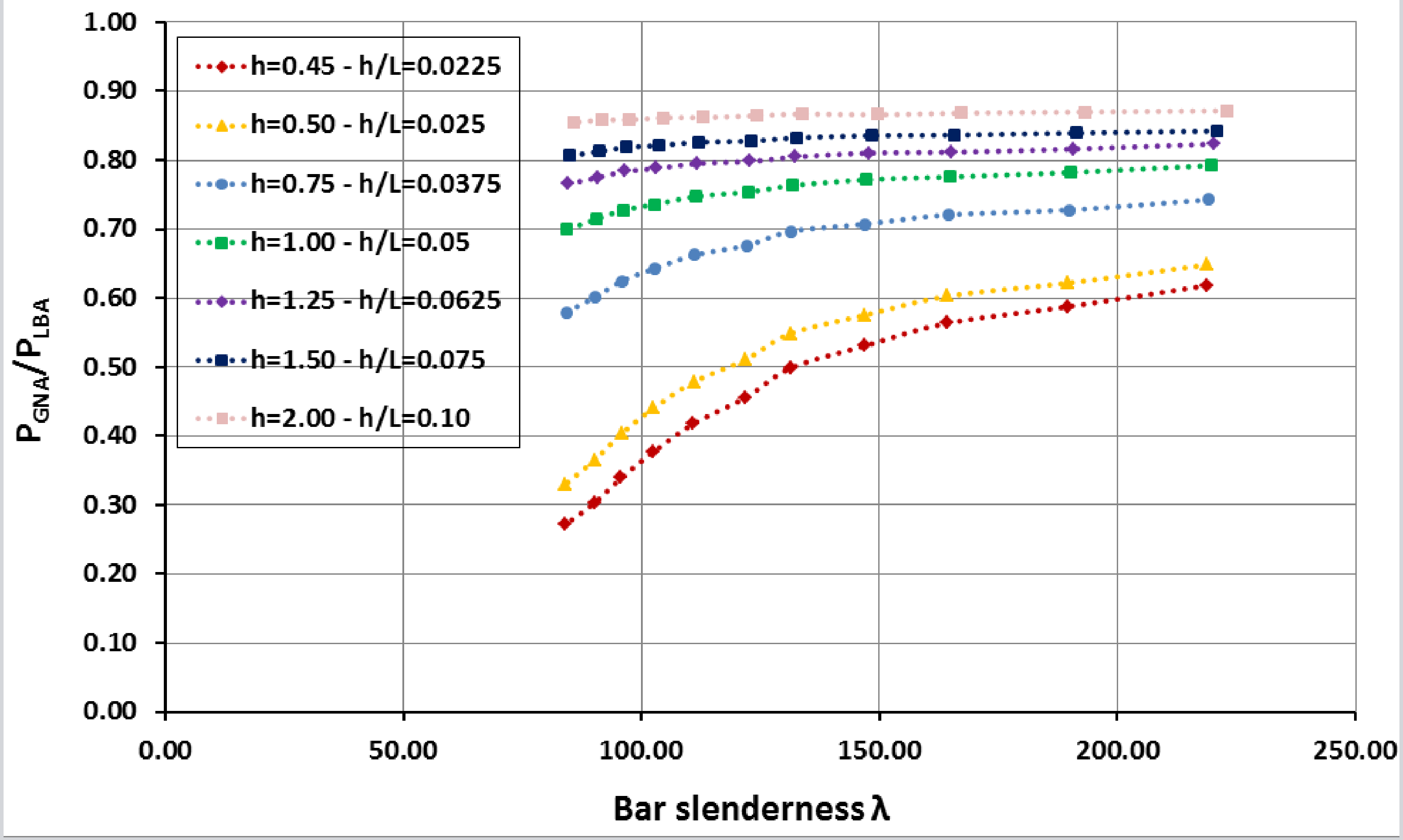
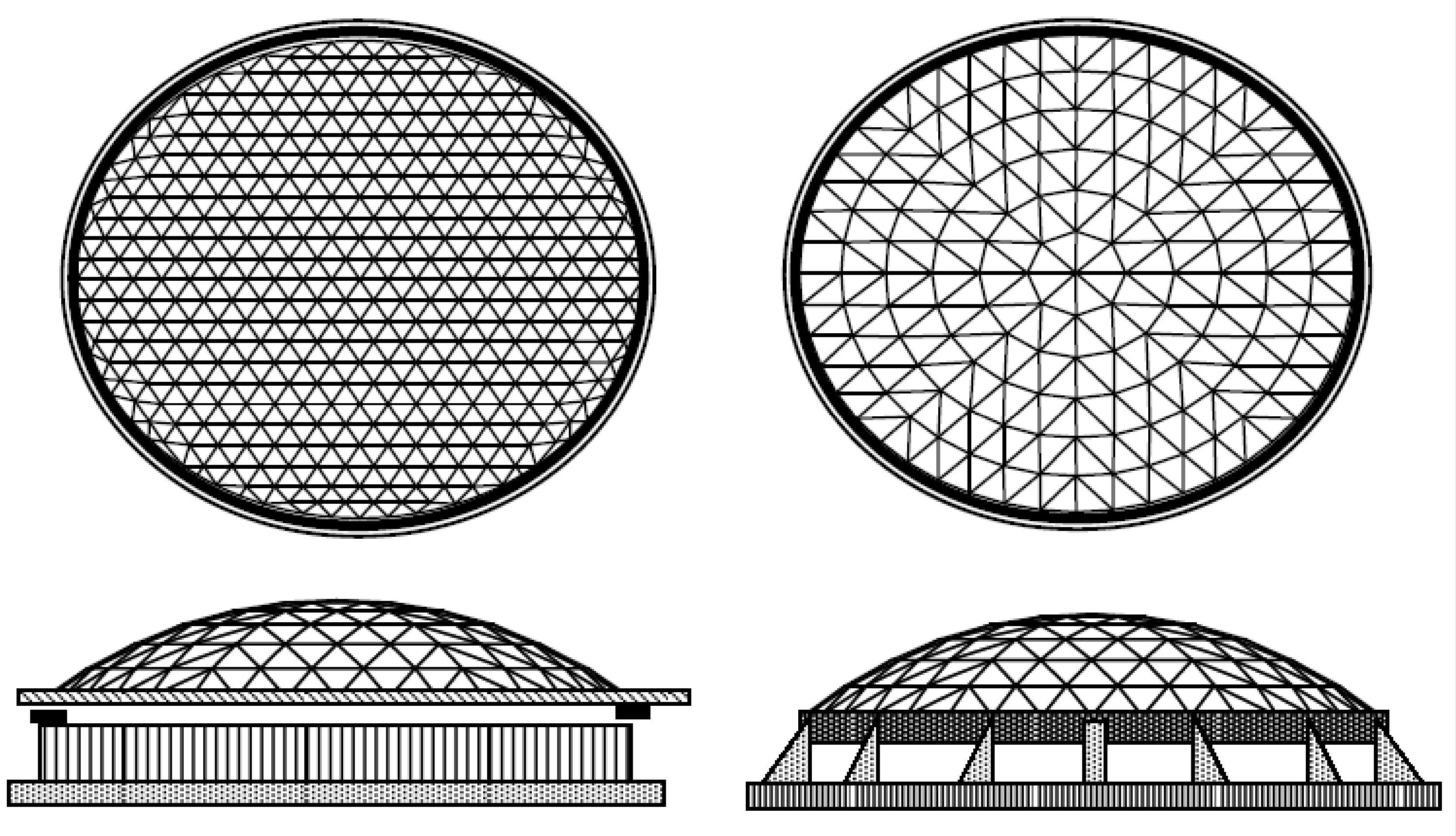


Eurocode 3 rules for nonlinear analysis
Possible extensions

Extension of conclusions to reticulated shells



Aristotle's Lyceum protection hangar
Architectural proposal

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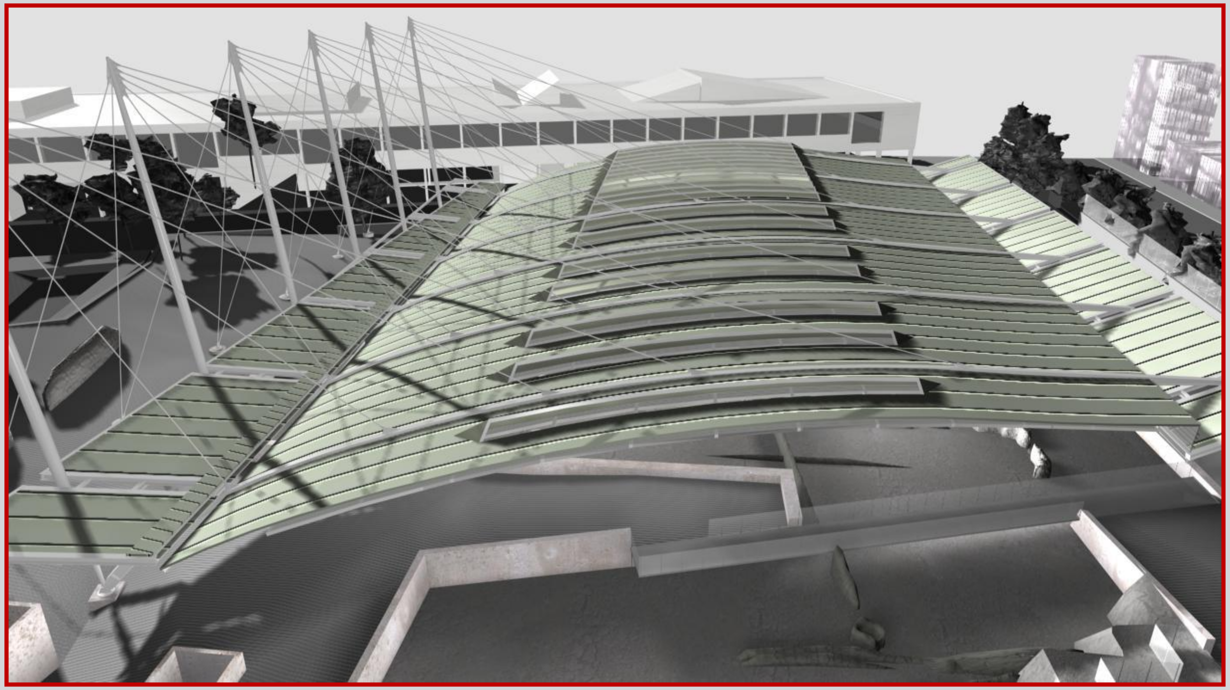


K. Karadimas

D. Loukopoulos

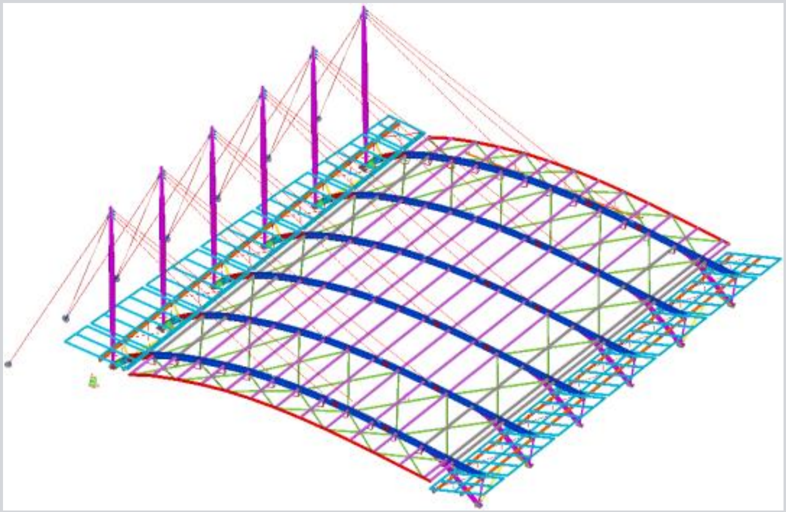
K. Vrettou

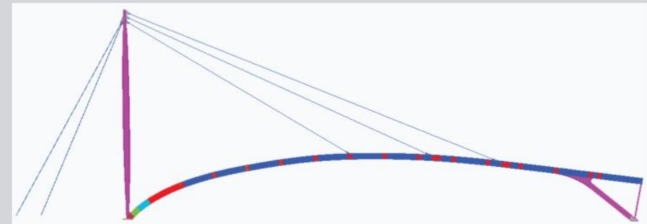
Ch. Papadimitriou

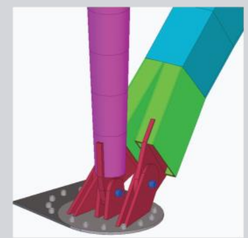
Architectural design team

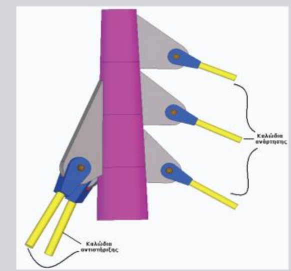
L. Stavropoulou

Aristotle's Lyceum protection hangar
Description of structural system









Steel roof consists of 6 parallel arch shaped main frames and is suspended by cables from 6 pylons.

Pylon ⇨ circular hollow section, varying over the height

Arch-shaped main frames ⇨ welded I section strengthened with sideplates near the support

Aristotle's Lyceum protection hangar

Pylon design

Circular hollow section, varying over height

All cross section are classified to class 1 or 2 in order to avoid local buckling

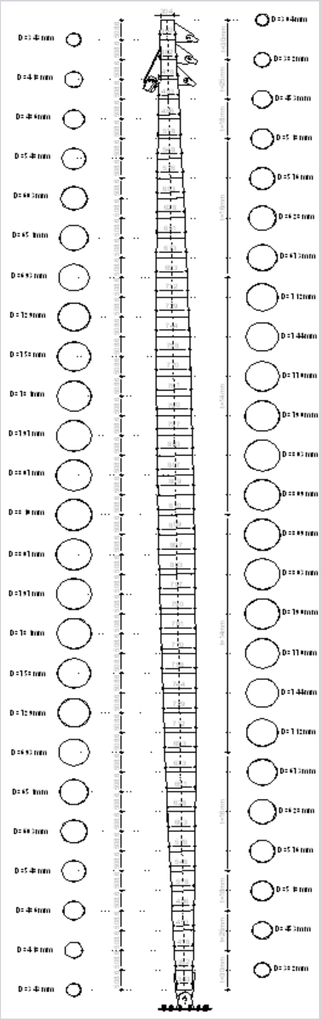
Height of pylon

h=25m

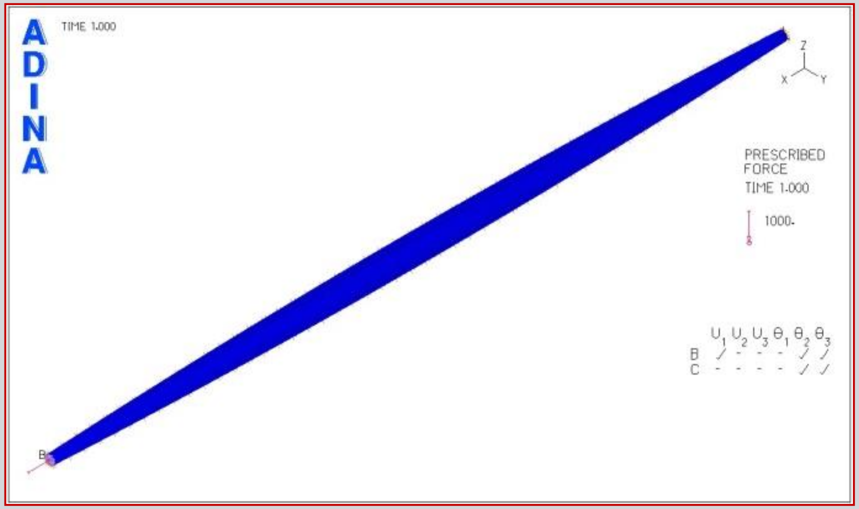
Pylon sections

- **max**
  D=800mm/t=14mm
  (middle section)
- **min**
  D=300mm/t=30mm
  (end sections)

x (mm)	D (mm)	tεπιλ (mm)
0	300.0	30
500	339.2	
1000	376.8	
1500	412.8	25
2000	447.2	
2500	480.0	18
3000	511.2	
3500	540.8	16
4000	568.8	
4500	595.2	16
5000	620.0	
5500	643.2	16
6000	664.8	
6500	684.8	14
7000	703.2	
7500	720.0	14
8000	735.2	
8500	748.8	14
9000	760.8	
9500	771.2	14
10000	780.0	
10500	787.2	14
11000	792.8	
11500	796.8	14
12000	799.2	
12500	800.0	



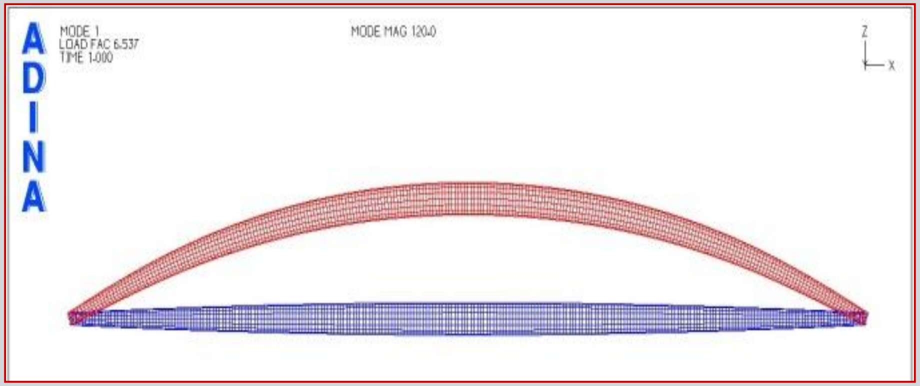
Aristotle's Lyceum protection hangar
Pylon design



Modeling ⇨ beam elements

shell elements

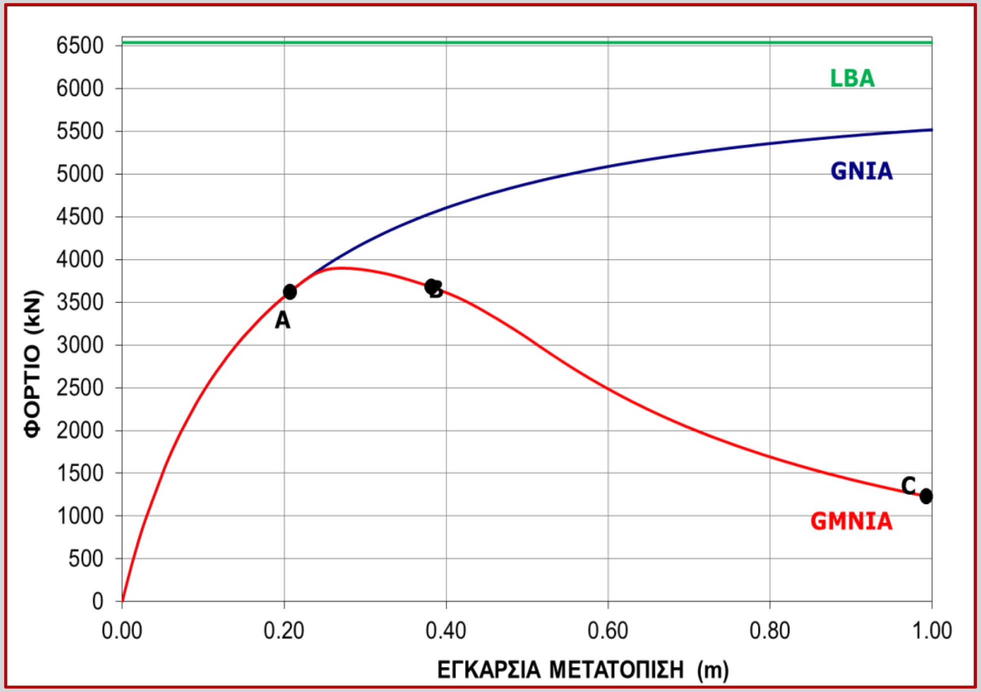
- **No local buckling among the first ten modes.**
- **First (flexural) buckling mode as imperfection pattern.**

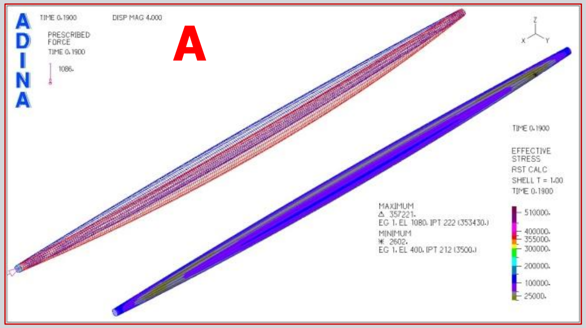


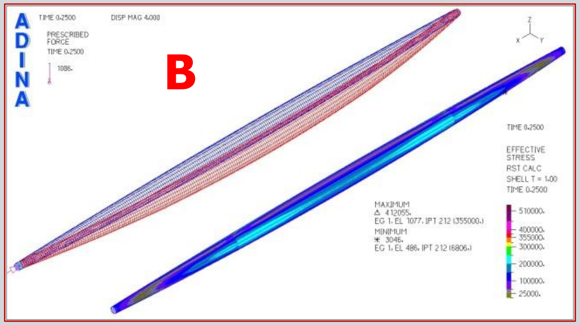
First critical buckling mode

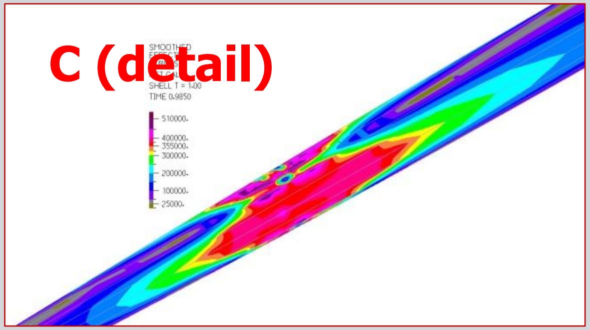
Aristotle's Lyceum protection hangar

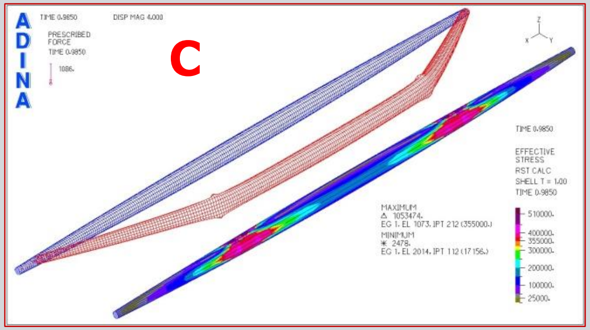
Pylon design



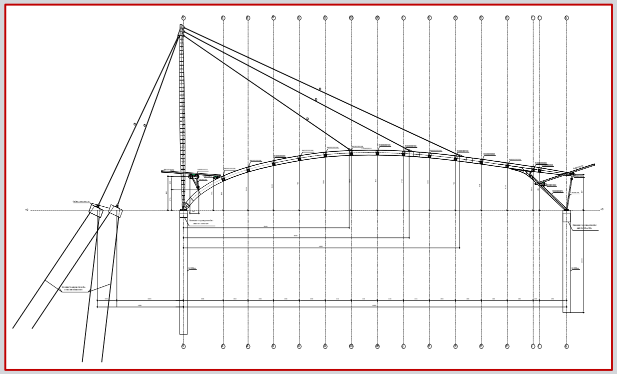


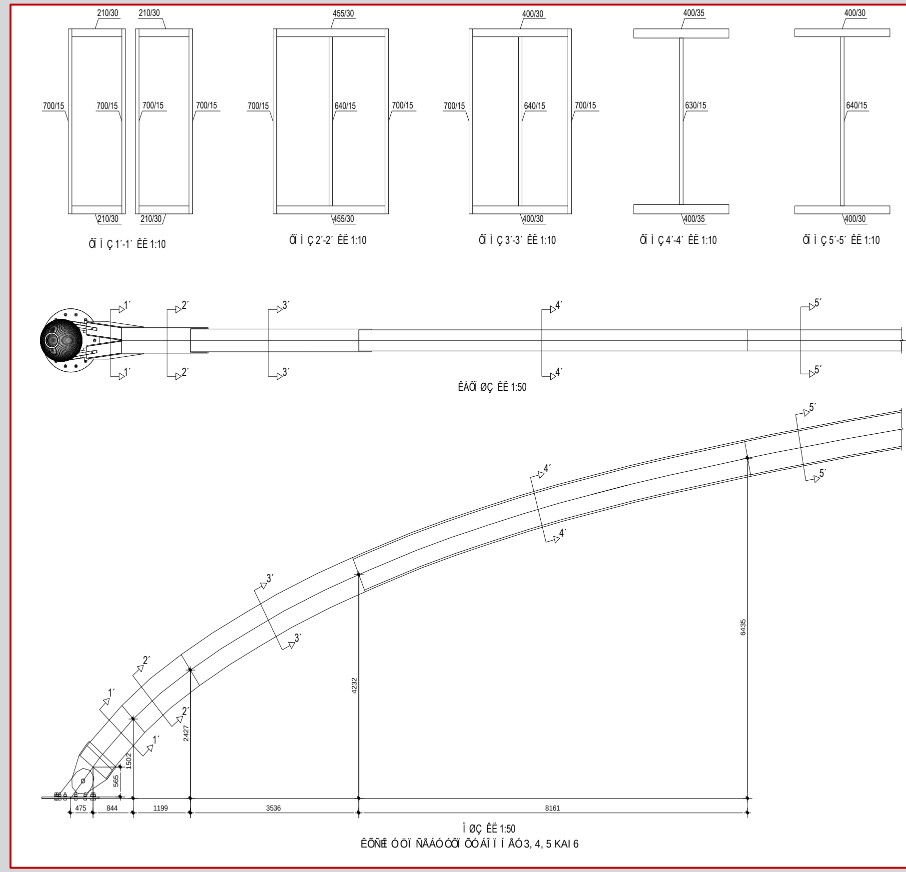






Aristotle's Lyceum protection hangar
Main frame design





Cross sections from pylon to column:

- Double RHS700/210/15/30
- RHS700/455/15/30
- RHS700/400/15/30
- I630/400/15/35

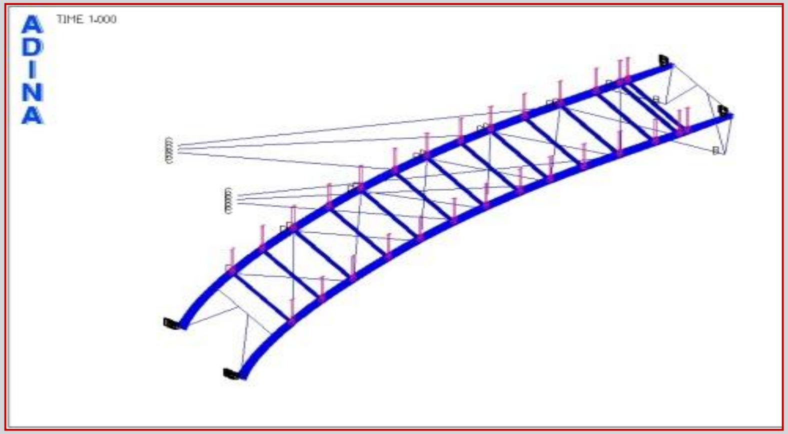
Cross sections of class 1 or 2 were used in order to avoid local buckling

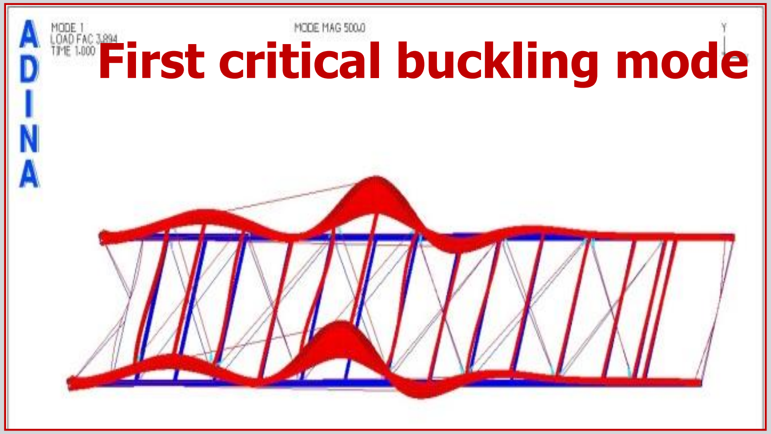
Aristotle's Lyceum protection hangar

Main frame design

Modeling

- Two main frames with shell elements
- Transverse and braced connection members with beam elements
- Retaining cables with nonlinear, tension only, prestressed truss elements





- No local buckling among the first ten modes.
- The first global buckling mode (lateral-torsional) as imperfection pattern.

Aristotle's Lyceum protection hangar
Main frame design

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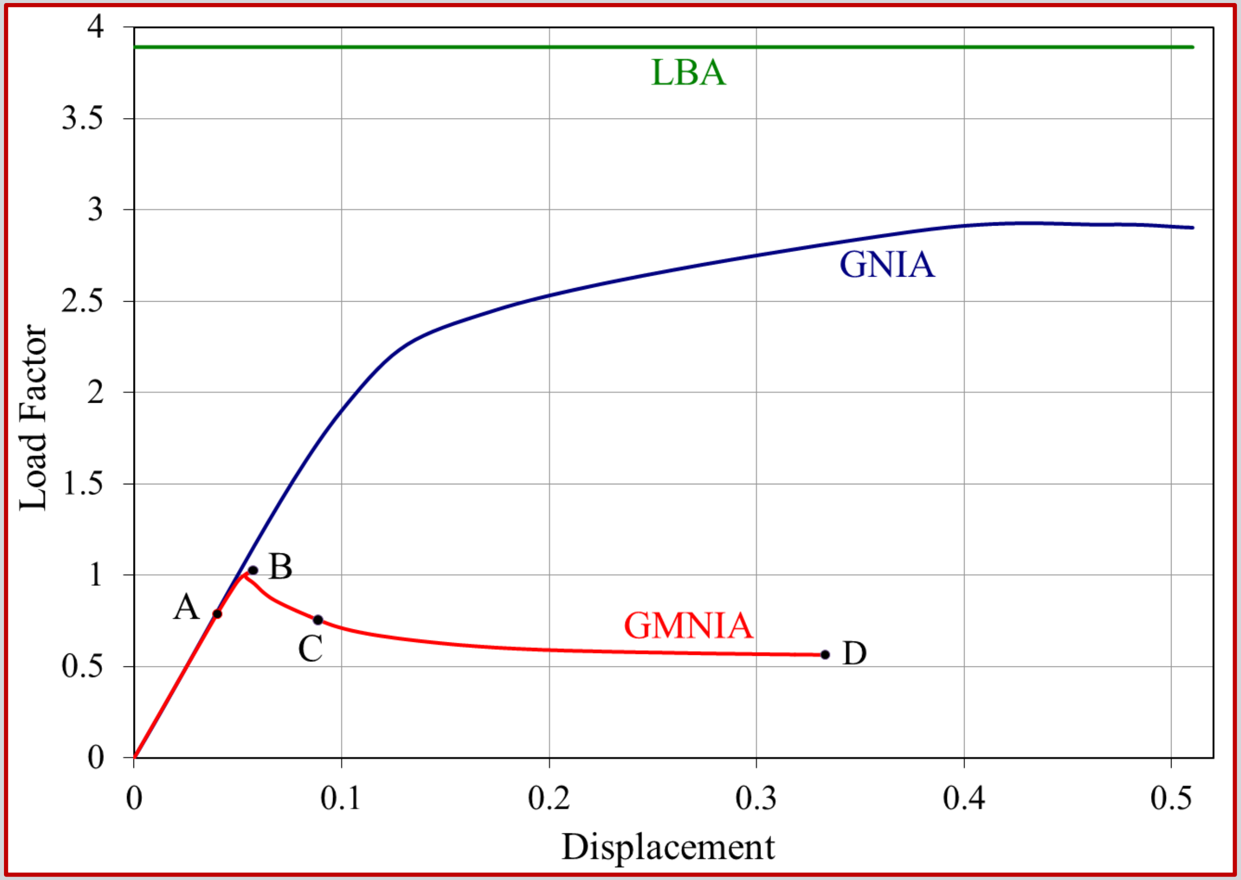
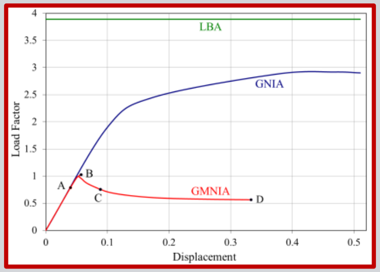
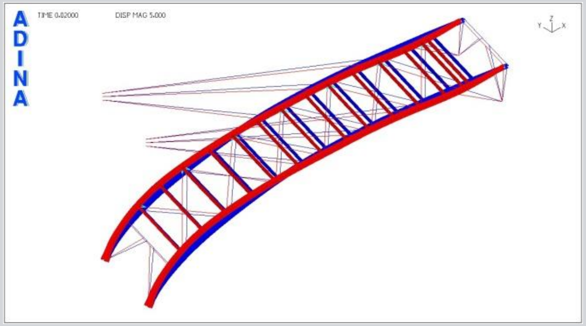
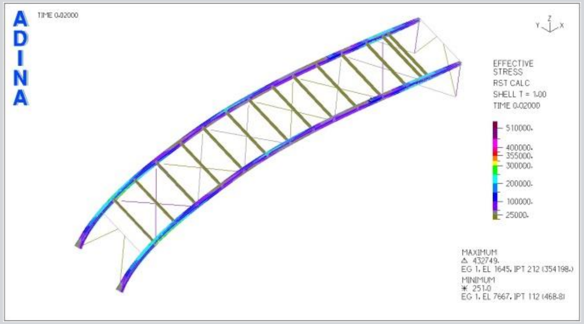


Equilibrium paths from different types of analysis

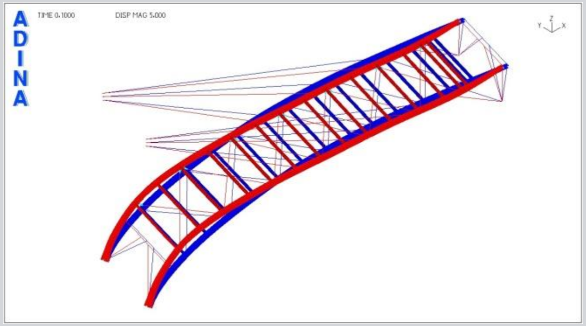
Aristotle's Lyceum protection hangar
Main frame design

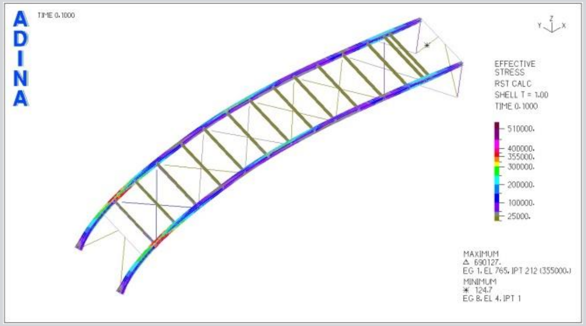






Point A--deformation | **Point A-stresses**

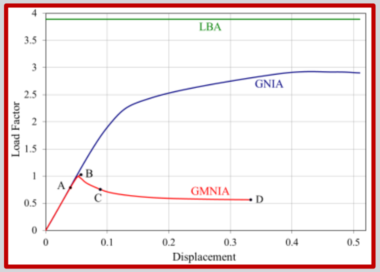


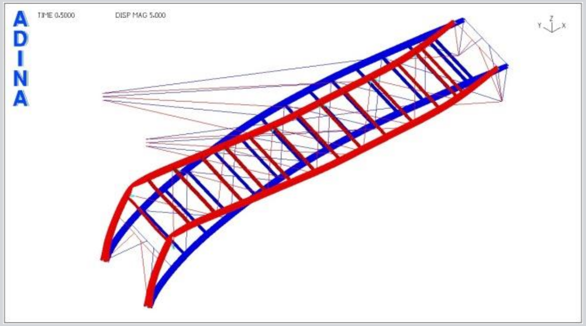


Point B-deformation | **Point B-stresses**

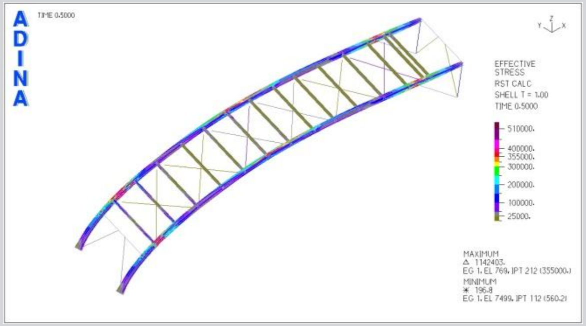
Deformation and stress distribution at characteristic points (1/3)

Aristotle’s Lyceum protection hangar
Main frame design

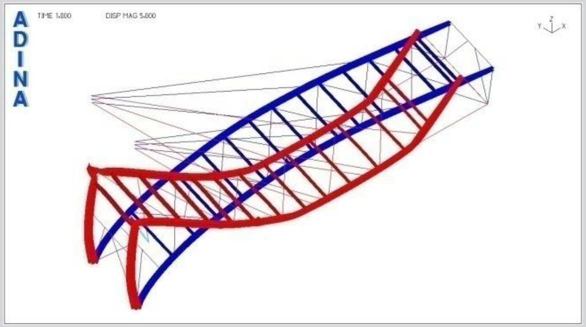




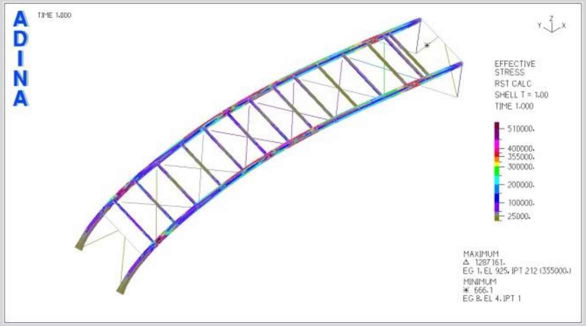
Point C-deformation



Point C-stresses



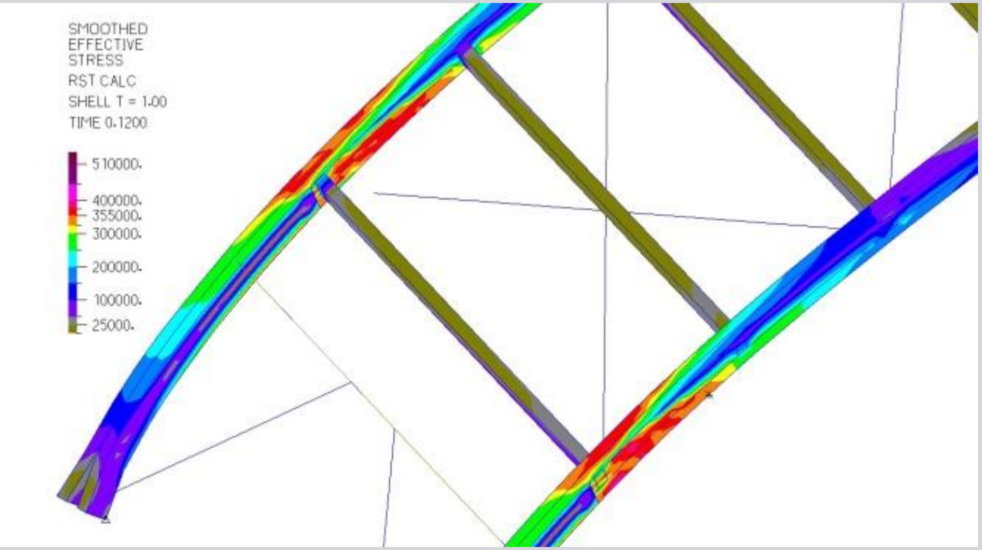
Point D-deformation



Point D-stresses

Deformation and stress distribution at characteristic points (2/3)

Aristotle's Lyceum protection hangar
Main frame design

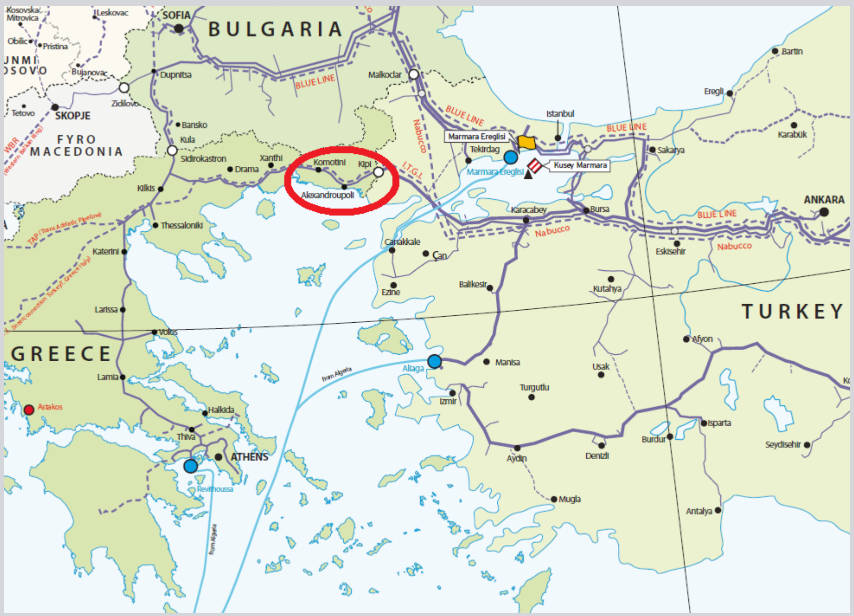


Point D-stresses (detail)

Deformation and stress distribution at characteristic points (3/3)

Buried pipelines for fuel transport
Problem description

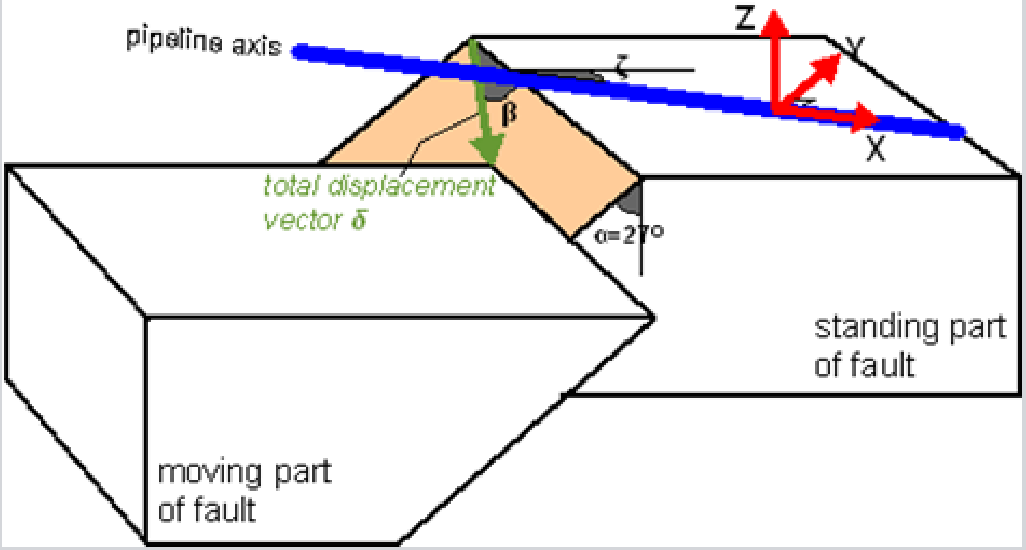
High Pressure Natural Gas Pipeline
Komotini – Alexandropoulis – Kipi

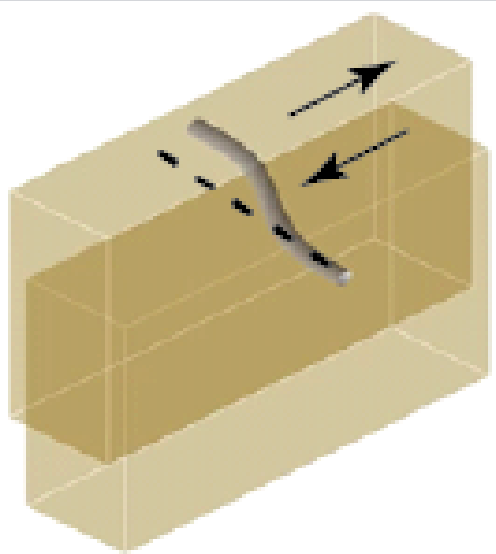


Buried pipelines for fuel transit
Problem description

Scope:

To evaluate the consequences of potential landslides or fault activation, triggered by an earthquake, and to propose protection measures.





Buried pipelines for fuel transit
Problem description

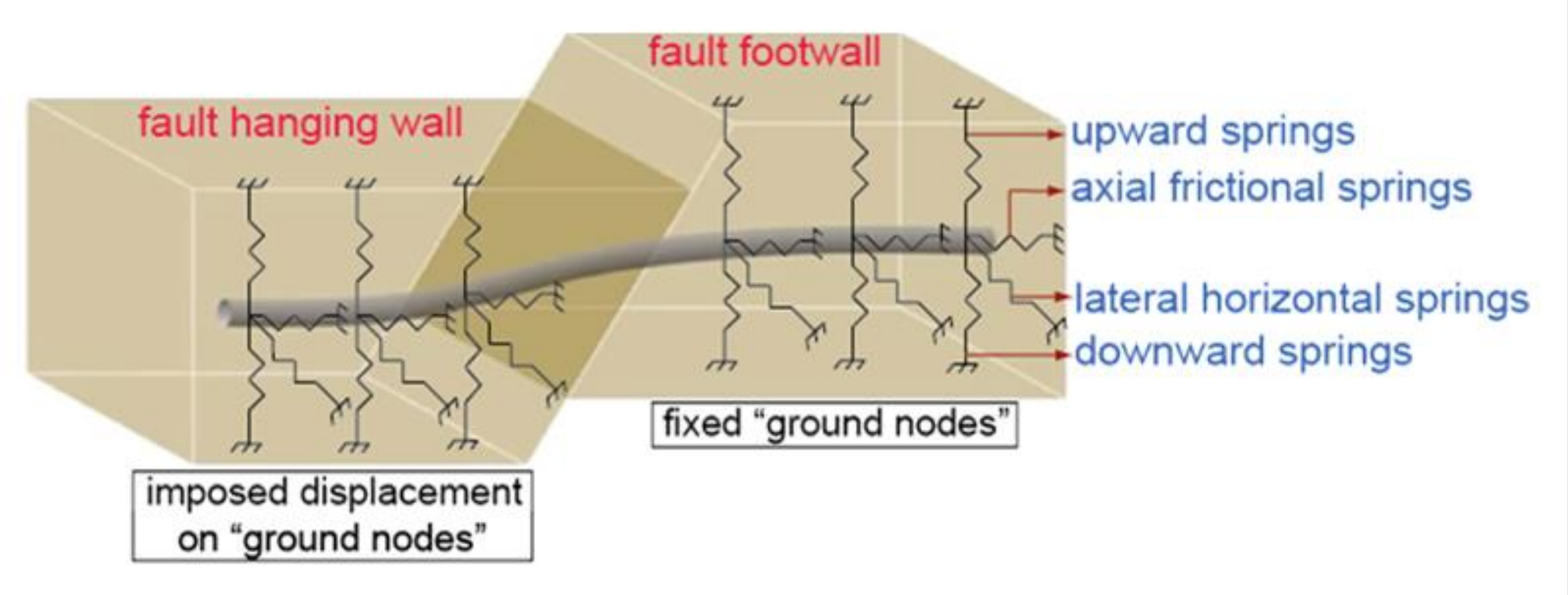
Strain-based problem

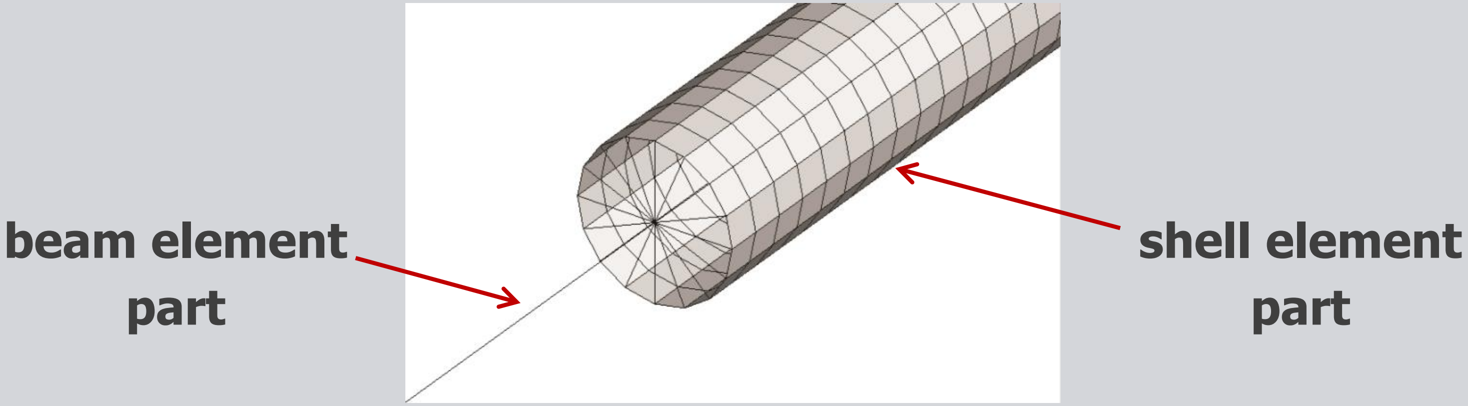
Possible failure modes:

- Local buckling of shell wall
- Tensile fracture of girth welds between adjacent parts
- Upheaval buckling

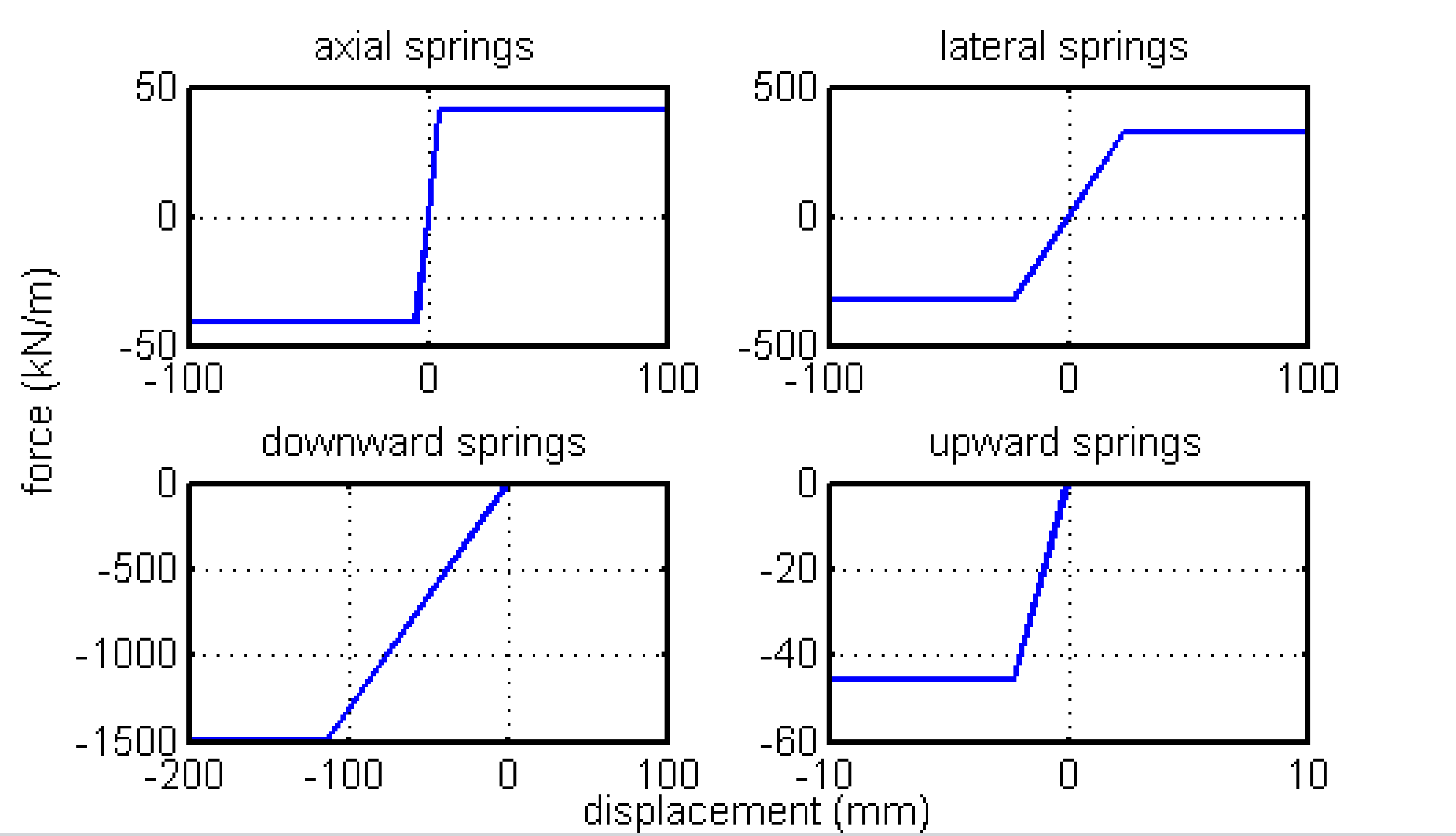
Buried pipelines for fuel transit

Pipeline modeling

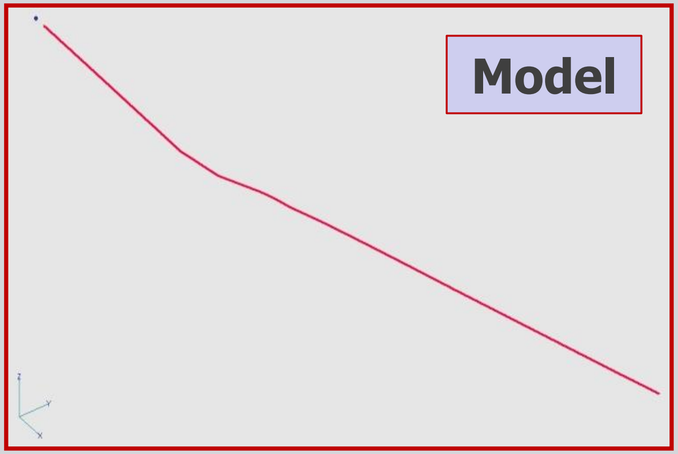


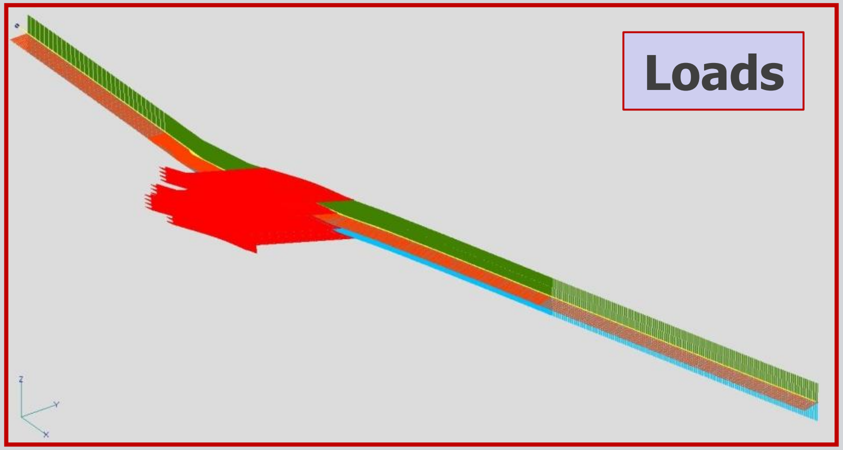


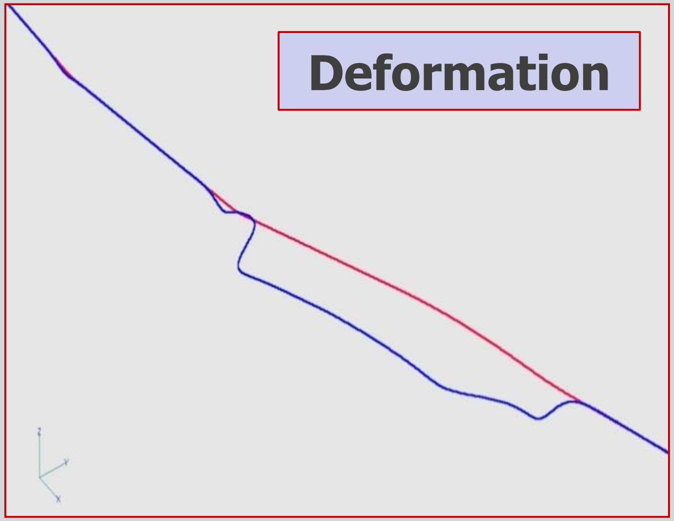
Buried pipelines for fuel transit
Soil modeling

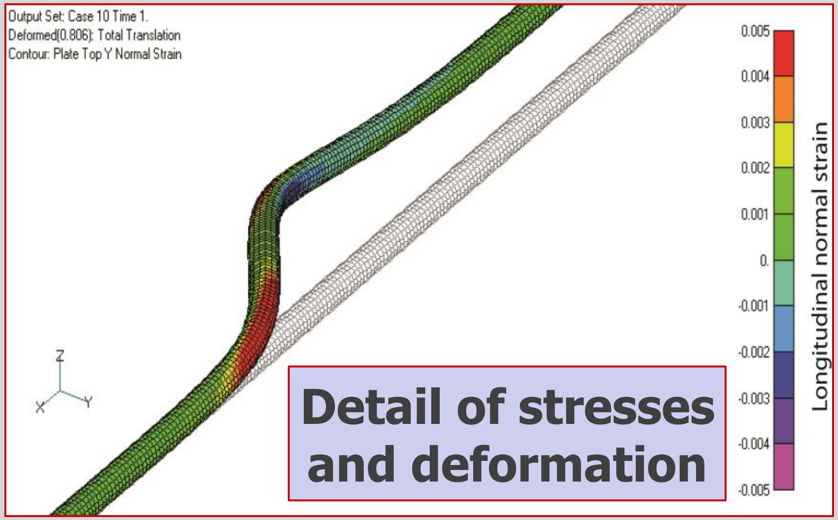


Buried pipelines for fuel transit
Numerical results



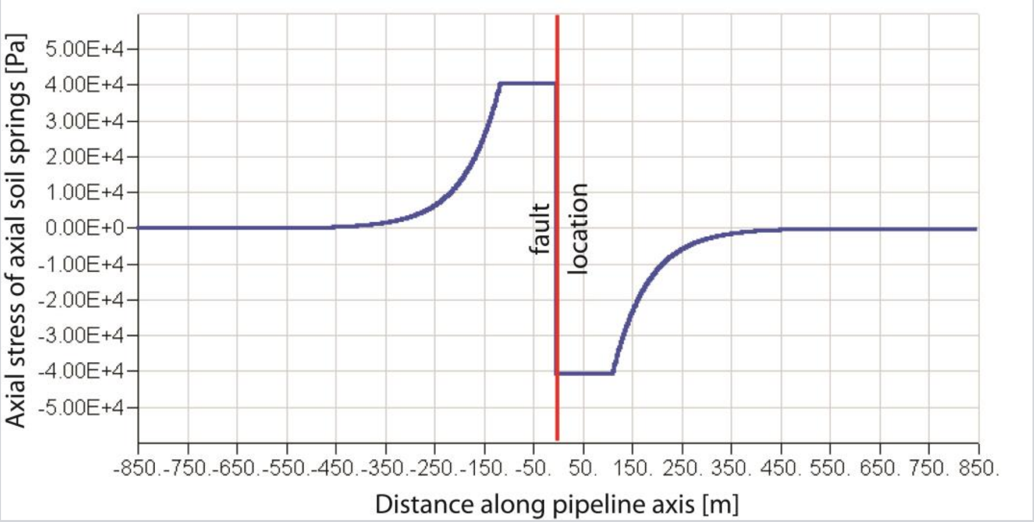


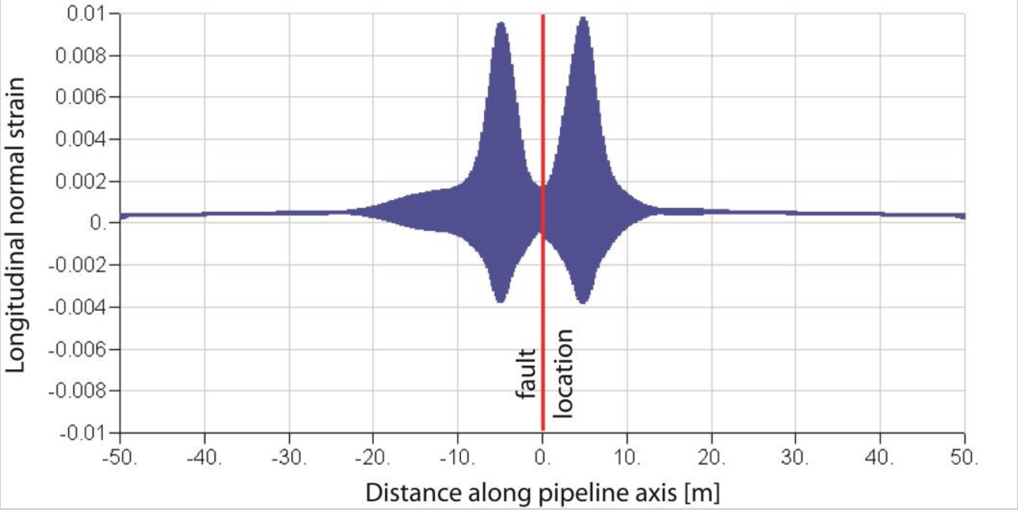




Buried pipelines for fuel transit
Numerical results

Stresses of axial soil springs along the pipeline

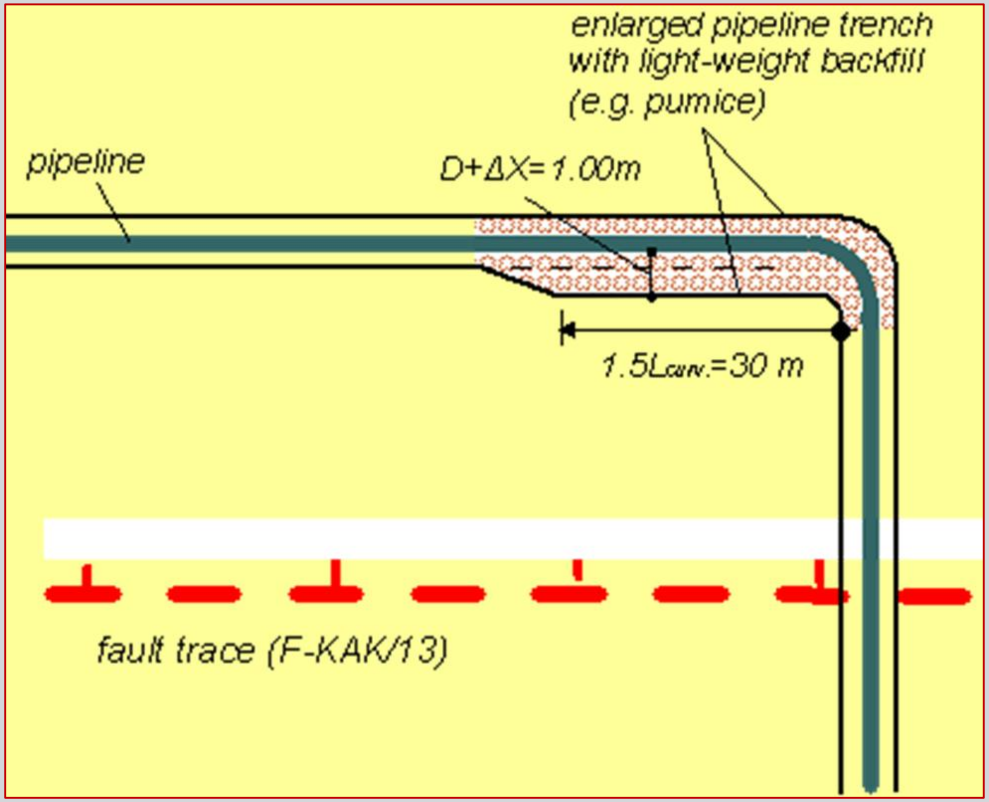




Longitudinal normal strain along the pipeline

Buried pipelines for fuel transit
Proposed measures

- Excavation expansion
- Fill in with soft material

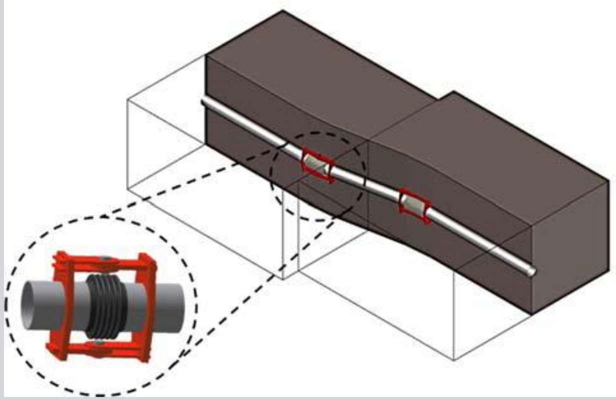


Buried pipelines for fuel transit
Proposed measures

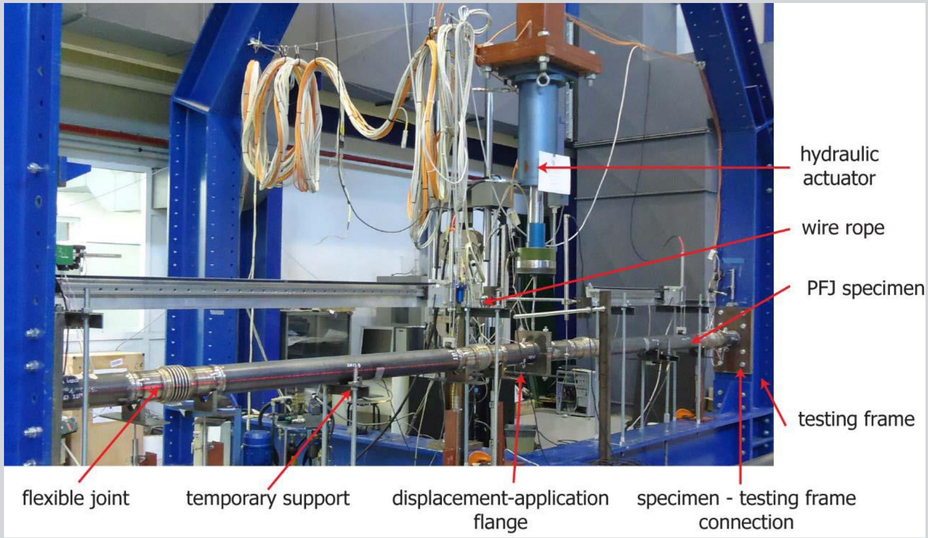
Wrapping of the pipeline with a friction reducing geotextile

Buried pipelines for fuel transit
Proposed measures

Incorporating into the pipeline flexible joints in the vicinity of the fault



From the doctoral thesis of Vasilis Melissianos

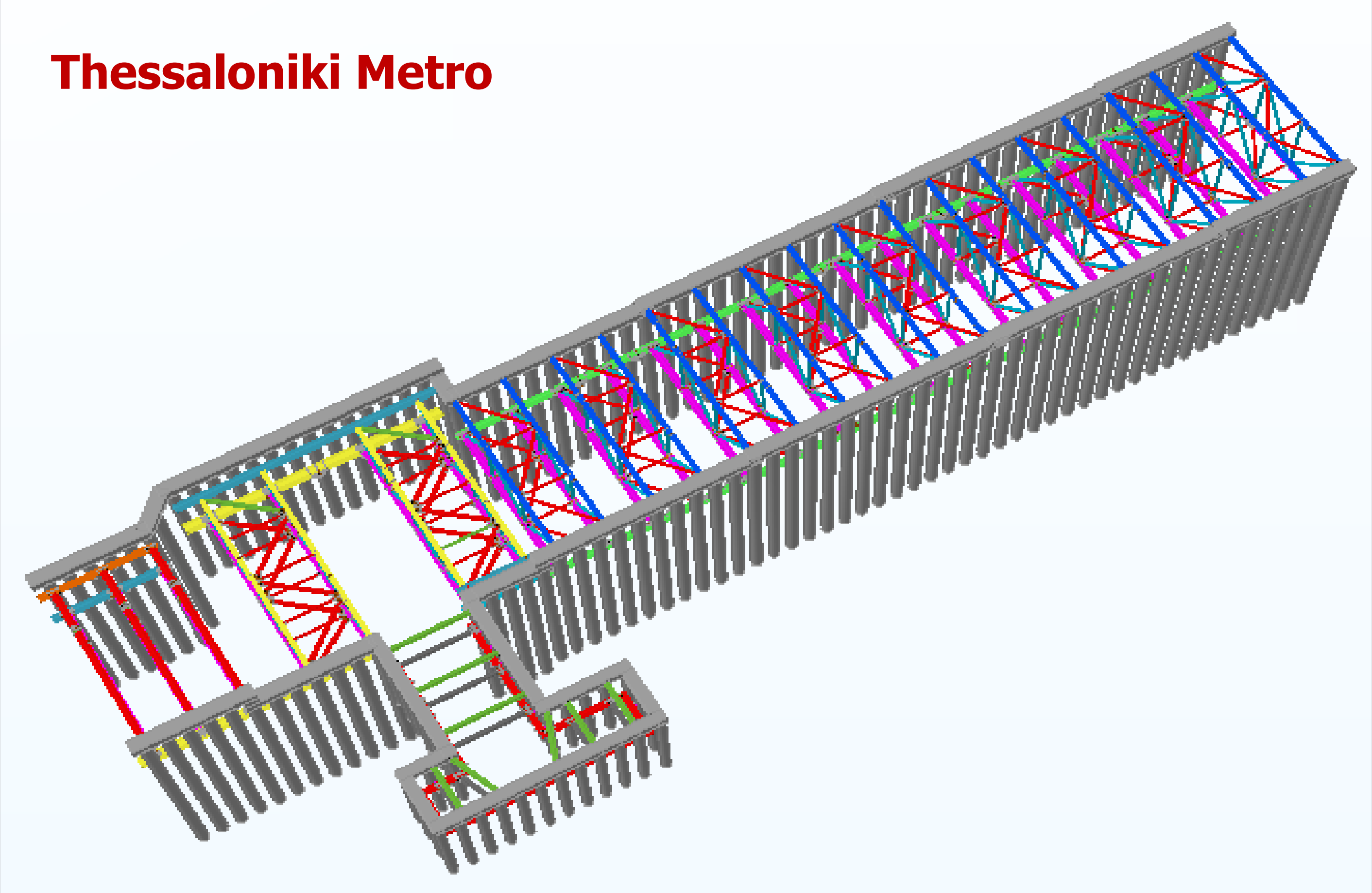


Buried pipelines for fuel transit

Publications

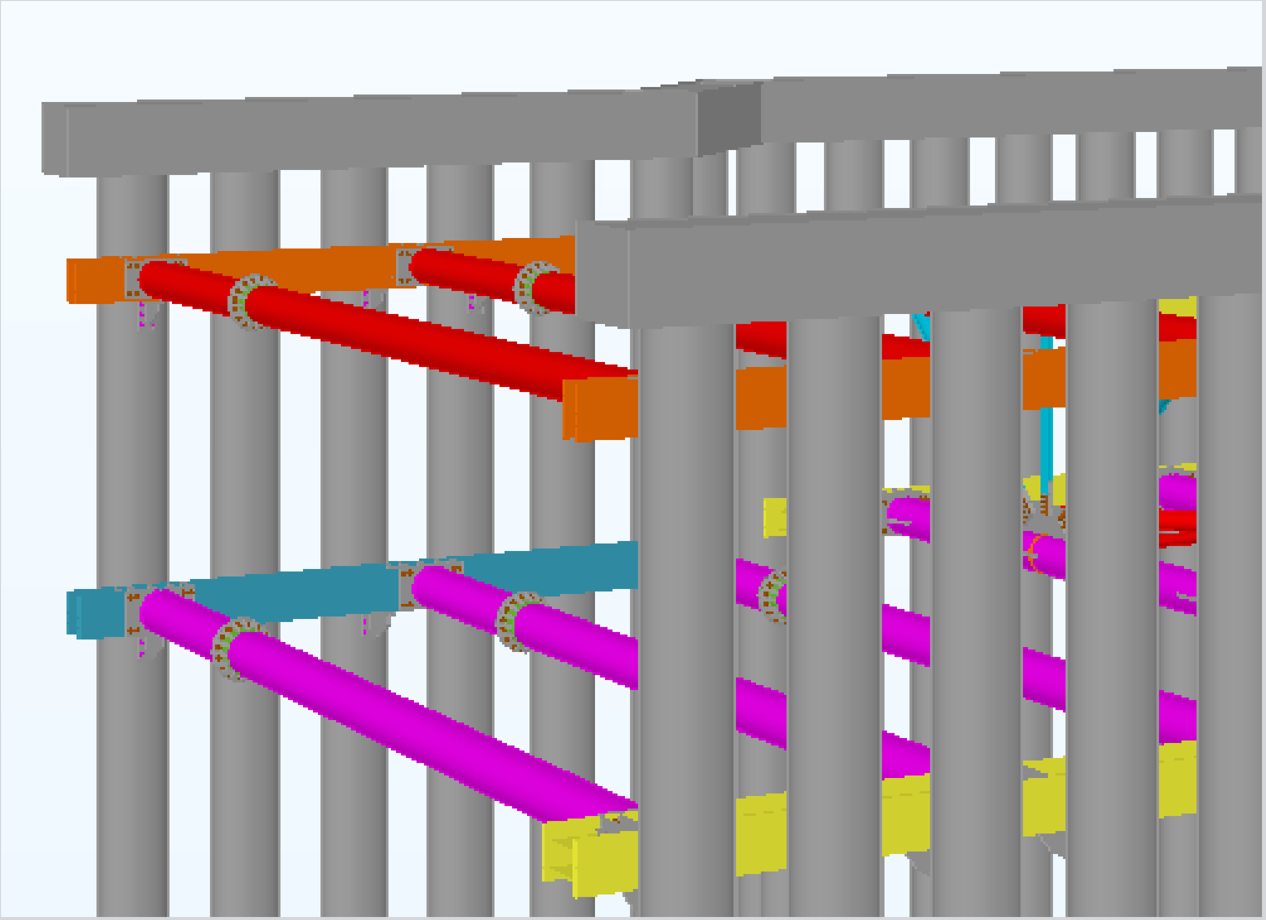
- Melissianos, V.E., Vamvatsikos, D. and Gantes, C.J., "Probabilistic Assessment of Flexible Joints in Mitigating the Consequences of Faulting on Buried Steel Pipelines", *Journal of Performance of Constructed Facilities (ASCE)*, submitted for publication.
- Melissianos, V.E., Lignos, X.A., Bachas, K.K. and Gantes, C.J., "Experimental Investigation of CHS Beams with Flexible Joints under Transverse Loading", *Journal of Constructional Steel Research*, accepted for publication.
- Melissianos, V.E., Vamvatsikos, D. and Gantes, C.J., "Performance Assessment of Buried Pipelines at Fault Crossings", *Earthquake Spectra*, accepted for publication.
- Melissianos, V.E., Korakitis, G.P., Gantes, C.J. and Bouckovalas, G.D., "Numerical Evaluation of the Effectiveness of Flexible Joints in Buried Pipelines Subjected to Strike-Slip Fault Rupture", *Soil Dynamics and Earthquake Engineering*, Vol. 90, pp. 395–410, Nov. 2016.
  http://dx.doi.org/10.1016/j.tws.2012.02.011
- Melissianos, V.E. and Gantes, C.J., "Buckling and Post-buckling Behavior of Beams with Internal Flexible Joints Resting on Elastic Foundation Modeling Buried Pipelines", Structures, Vol. 7, pp. 138–152, Aug. 2016.
  http://dx.doi.org/10.1016/j.istruc.2016.06.007
- Gantes, C.J. and Bouckovalas, G.D., "Seismic Verification of High Pressure Natural Gas Pipeline Komotini–Alexandropoulis–Kipi in Areas of Active Fault Crossings", *Structural Engineering International*, Vol. 23, Number 2, pp. 204–208, May 2013.
  http://dx.doi.org/10.2749/101686613X13439149157164
- Kouretzis, G.P., Bouckovalas, G.D. and Gantes, C.J., "Analytical Calculation of Blast-Induced Strains to Buried Pipelines", *International Journal of Impact Engineering*, Vol. 34, Issue 10, pp. 1683-1704, October 2007.
  http://dx.doi.org/10.1016/j.ijimpeng.2006.08.008
- Kouretzis, G.P., Bouckovalas, G.D. and Gantes, C.J., "3-D Shell Analysis of Cylindrical Underground Structures under Seismic Shear (S) Wave Action", *Soil Dynamics and Earthquake Engineering*, Vol. 26, Issue 10, pp. 909-921, October 2006.
  http://dx.doi.org/10.1016/j.soildyn.2006.02.002

Temporary support of deep excavations
Problem description



3D view

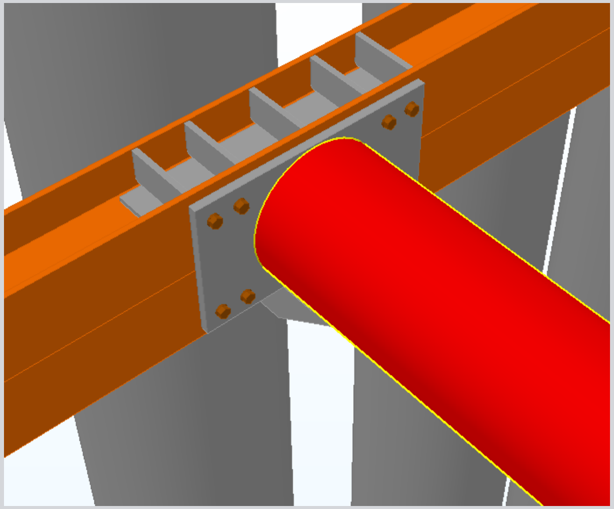
Temporary support of deep excavations
Problem description



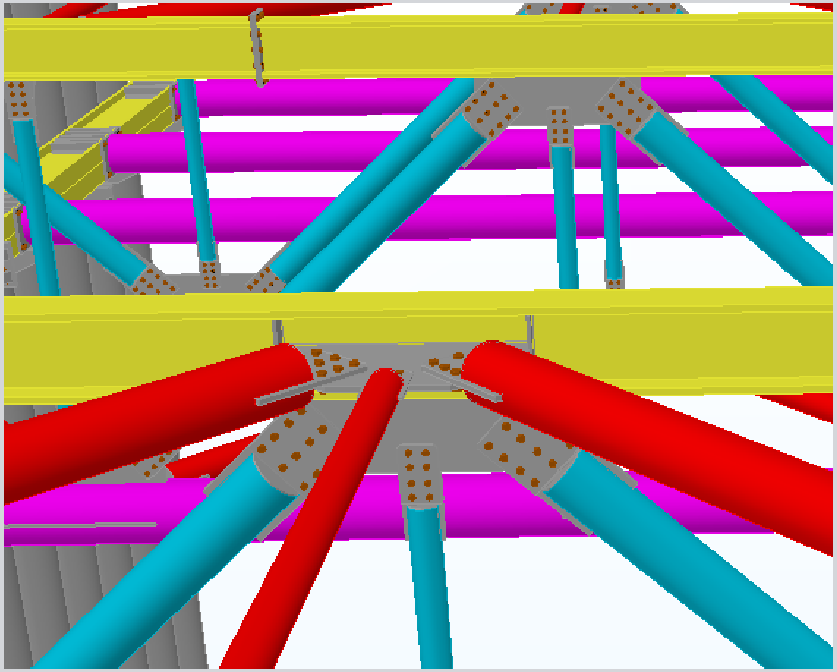
3D view detail

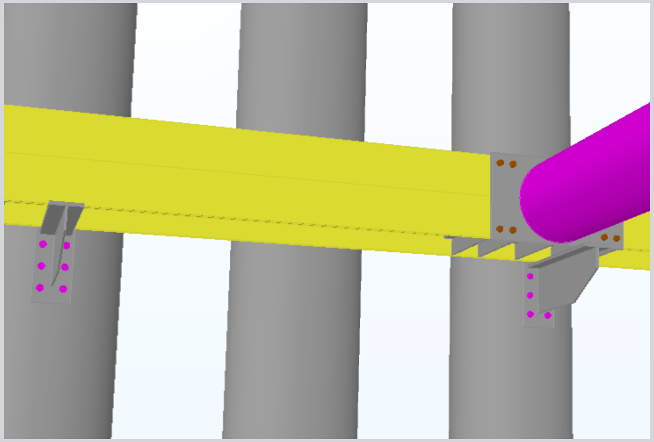
Temporary support of deep excavations

Problem description

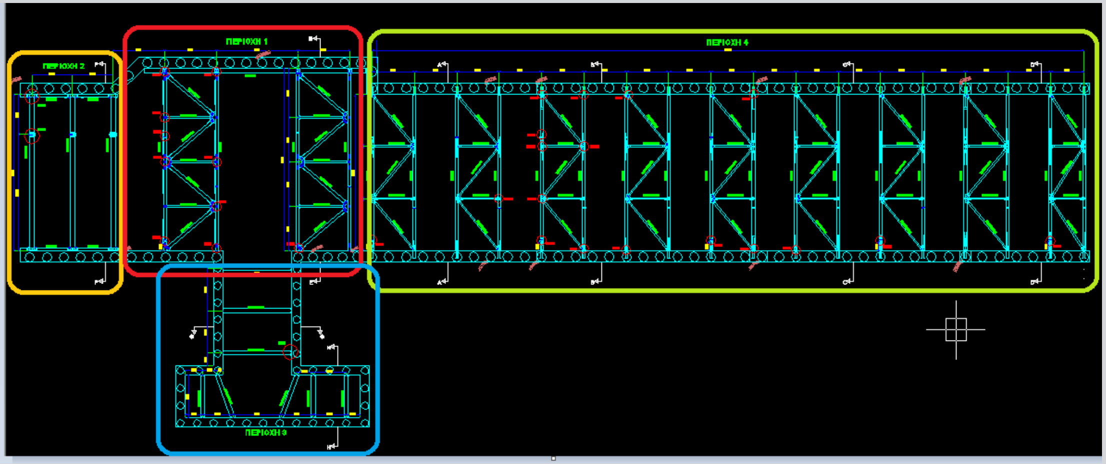


3D view details

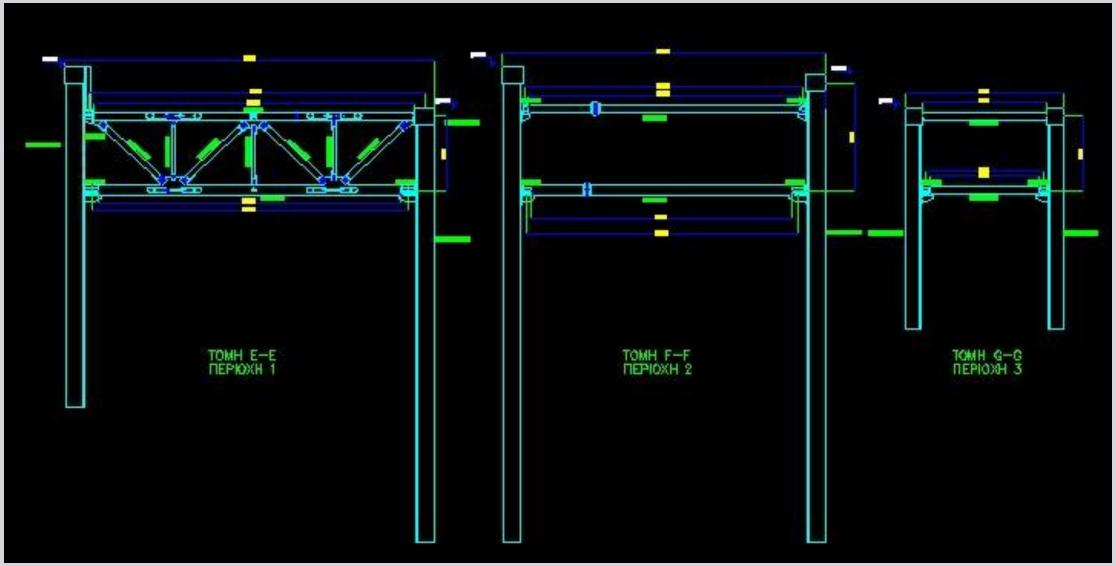




Temporary support of deep excavations
Problem description



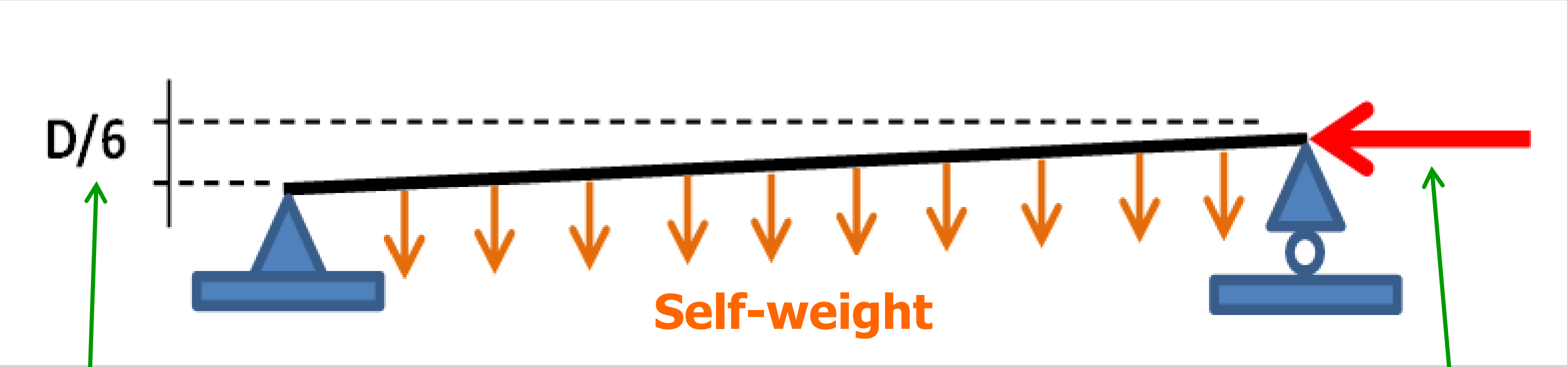
Plan view



Typical sections

Temporary support of deep excavations
Problem description

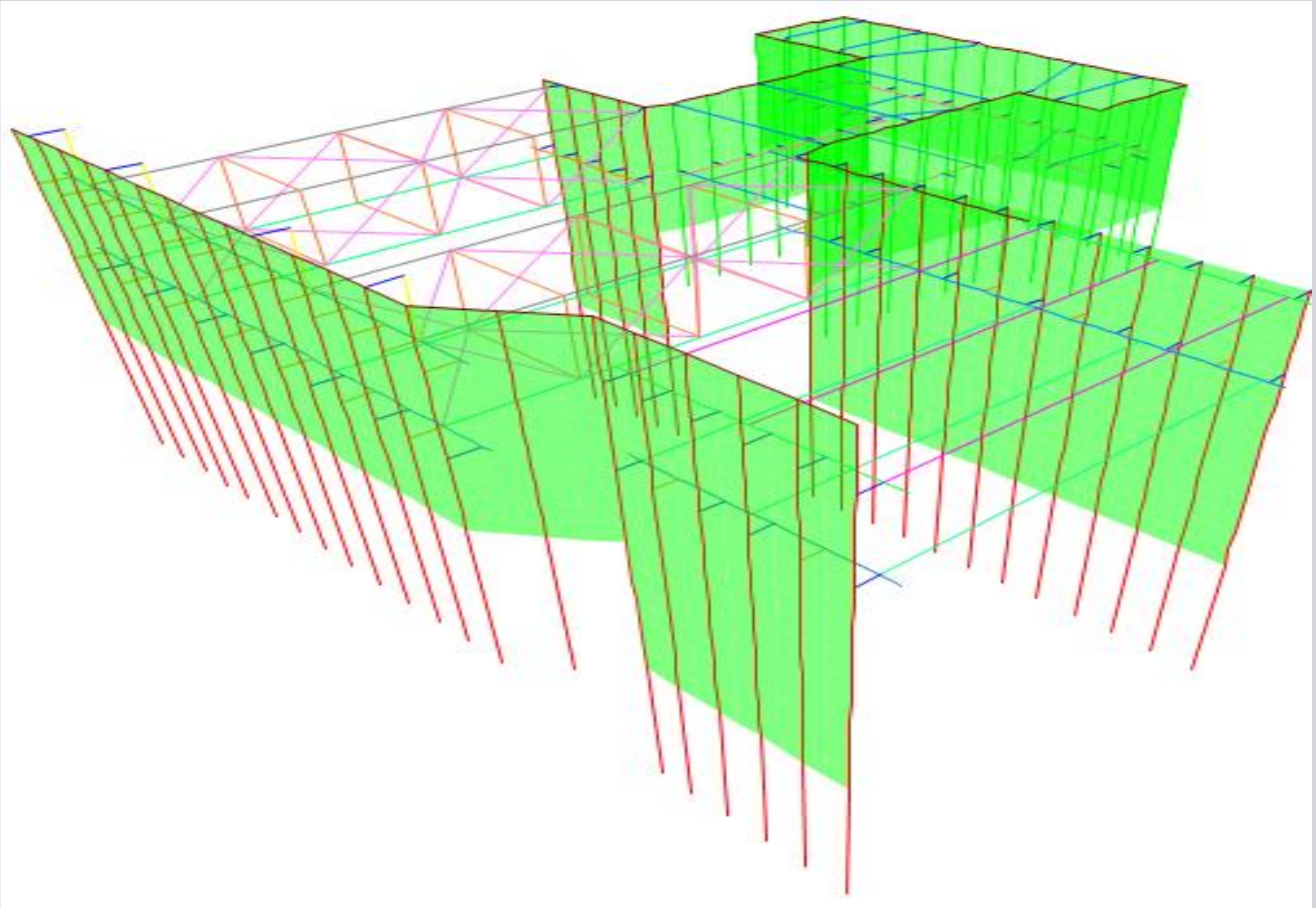
Motivation for nonlinear analysis



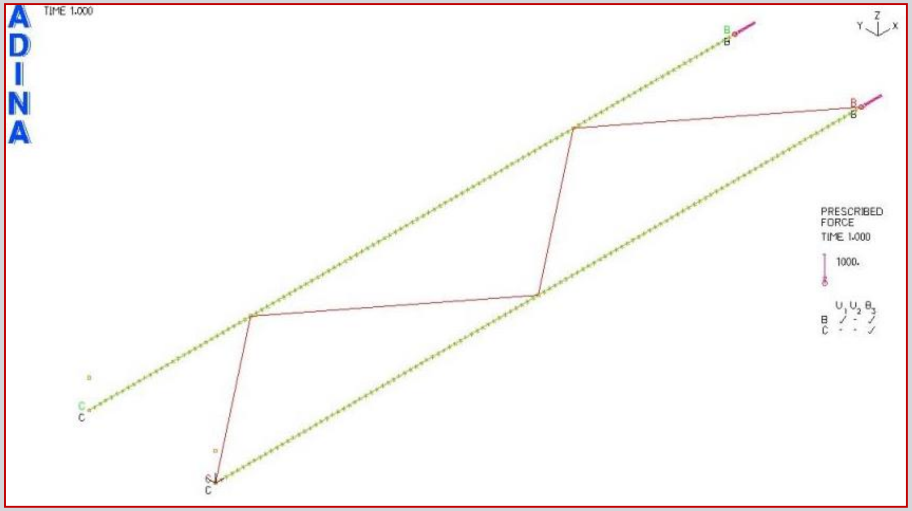
Vertical eccentricity
Between the two ends
due to constructional inaccuracies

Compression
due to earth pressures
and temperature differential

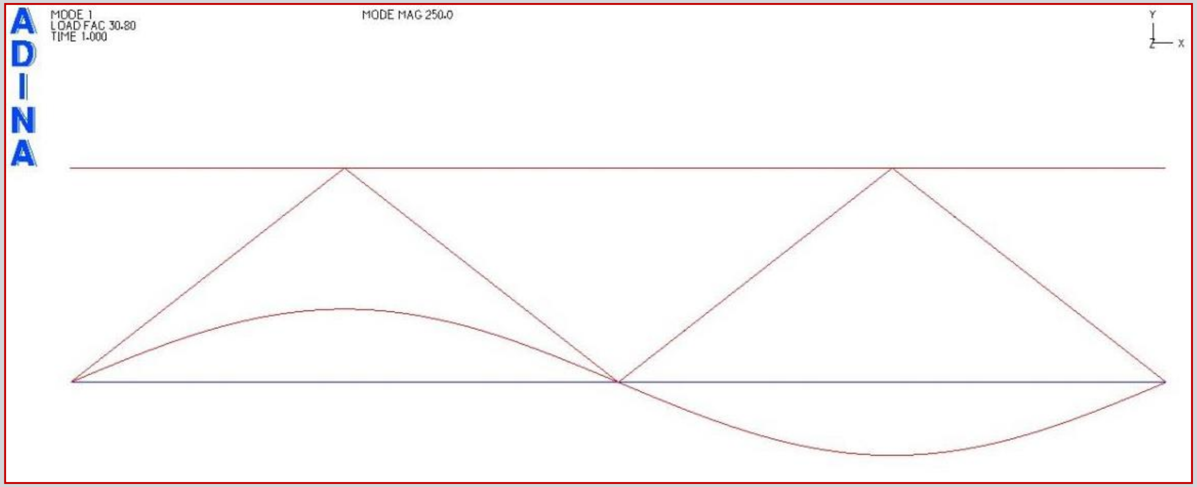
Linear analysis to obtain action effects



Temporary support of deep excavations
Numerical modeling

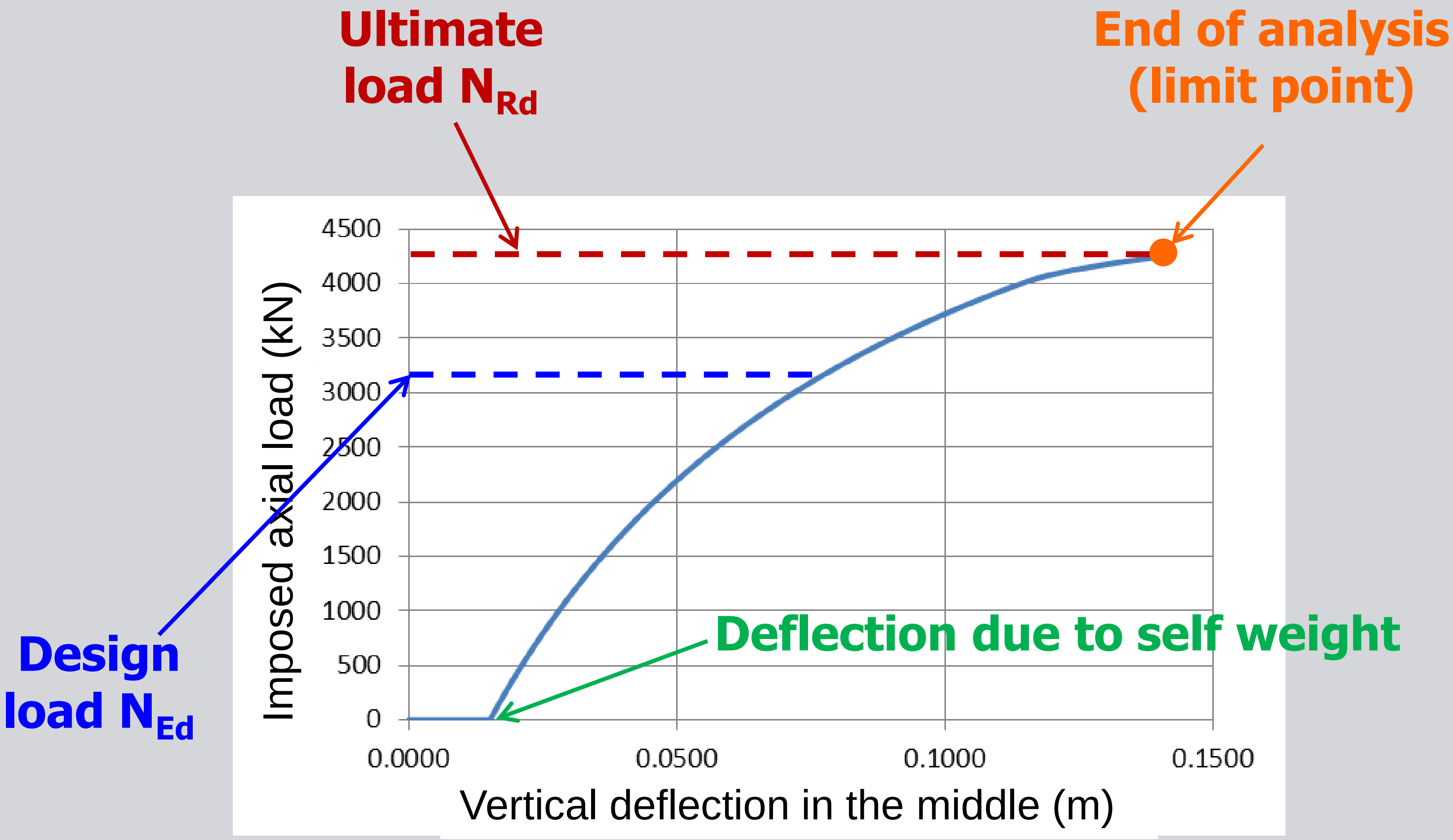


Linear Buckling Analysis (LBA) to obtain imperfection shapes and then Geometry and Material Imperfection Analysis (GMNIA) to obtain ultimate strength



Temporary support of deep excavations

Numerical results

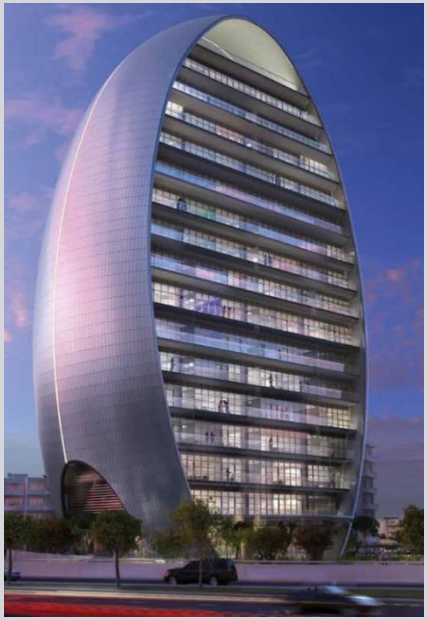


$$\text{Safety factor} = \frac{N_{Ed}}{N_{Rd}}$$

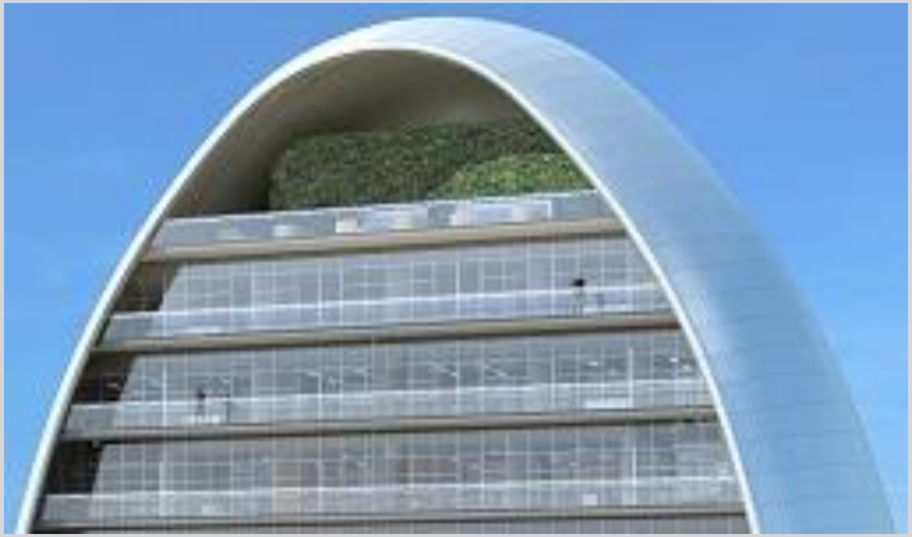
Temporary support of deep excavations
Construction

Cladding of Oval Tower in Limassol
Architectural concept

The building …

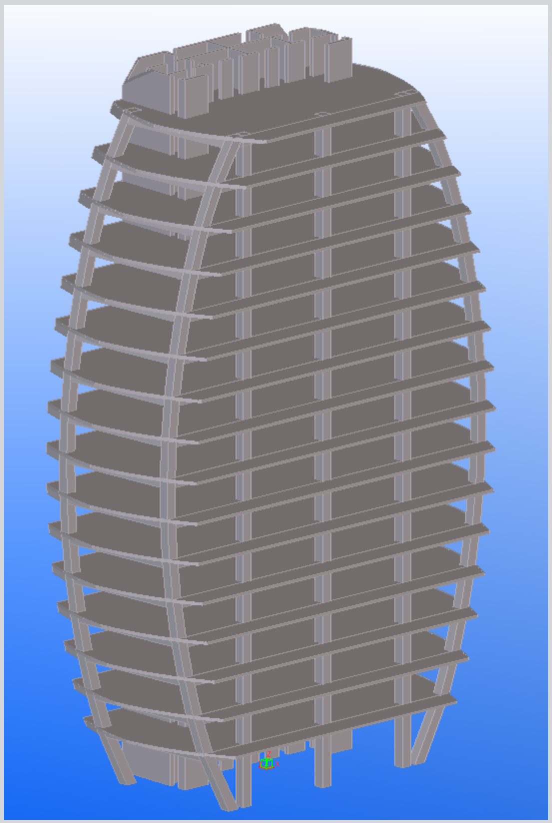


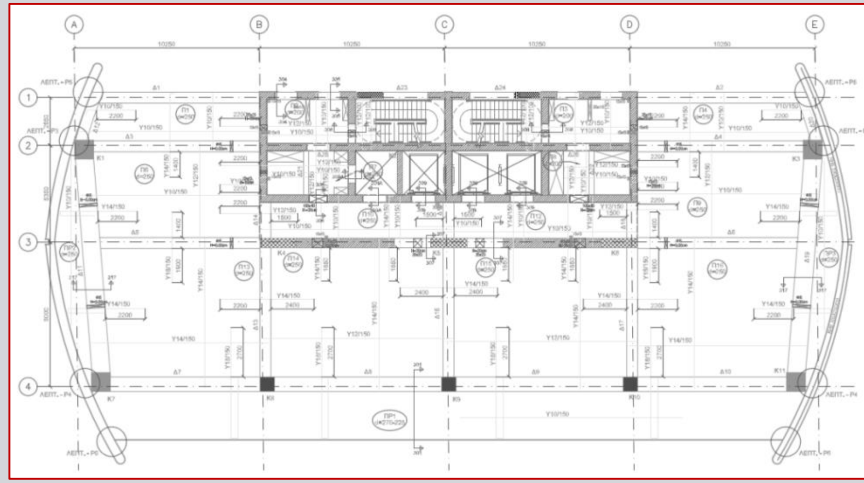
… and features that are relevant to the steel structures supporting the cladding

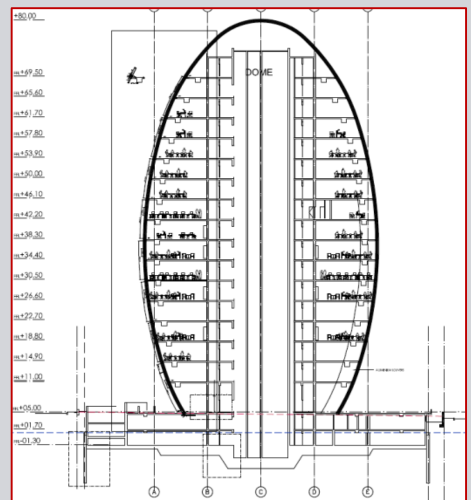


Cladding of Oval Tower in Limassol
Main structural system

Structural system of the building



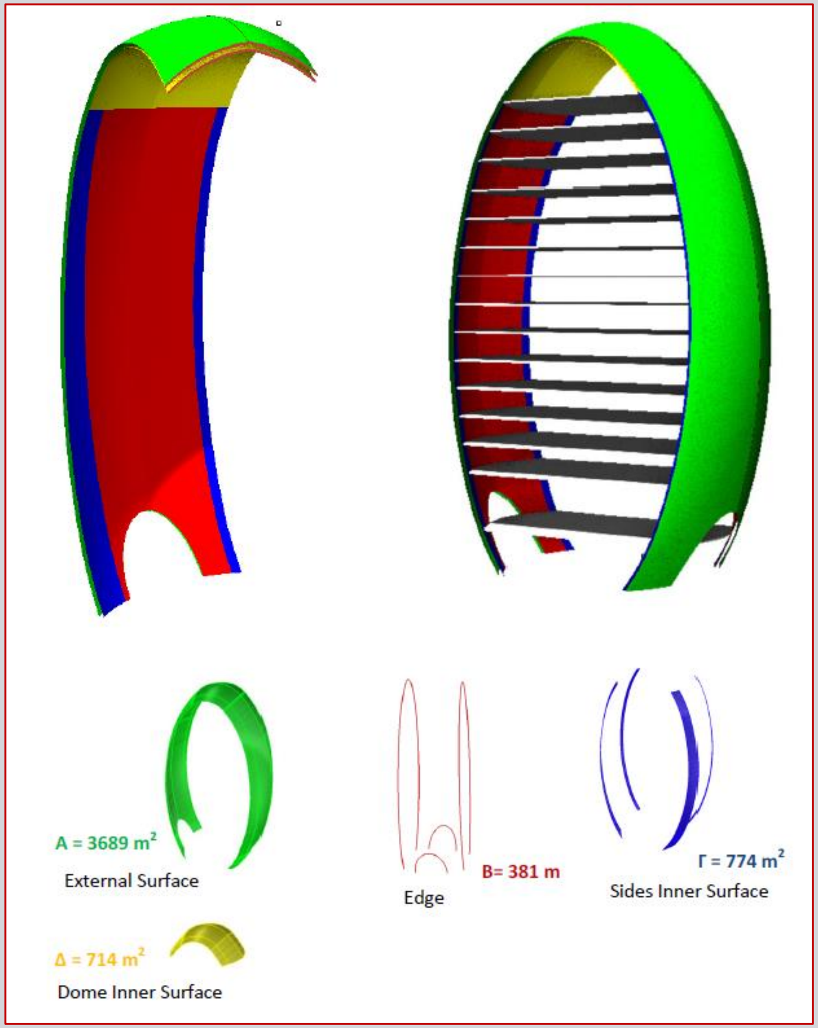




Cladding of Oval Tower in Limassol

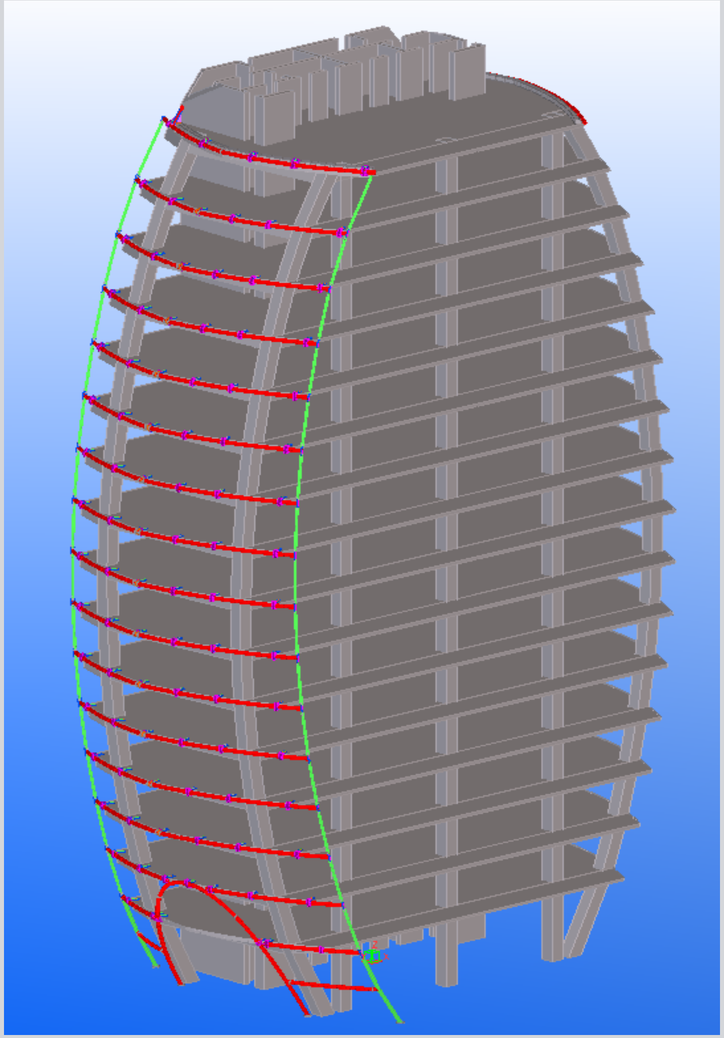
Cladding

Cladding areas



Cladding of Oval Tower in Limassol

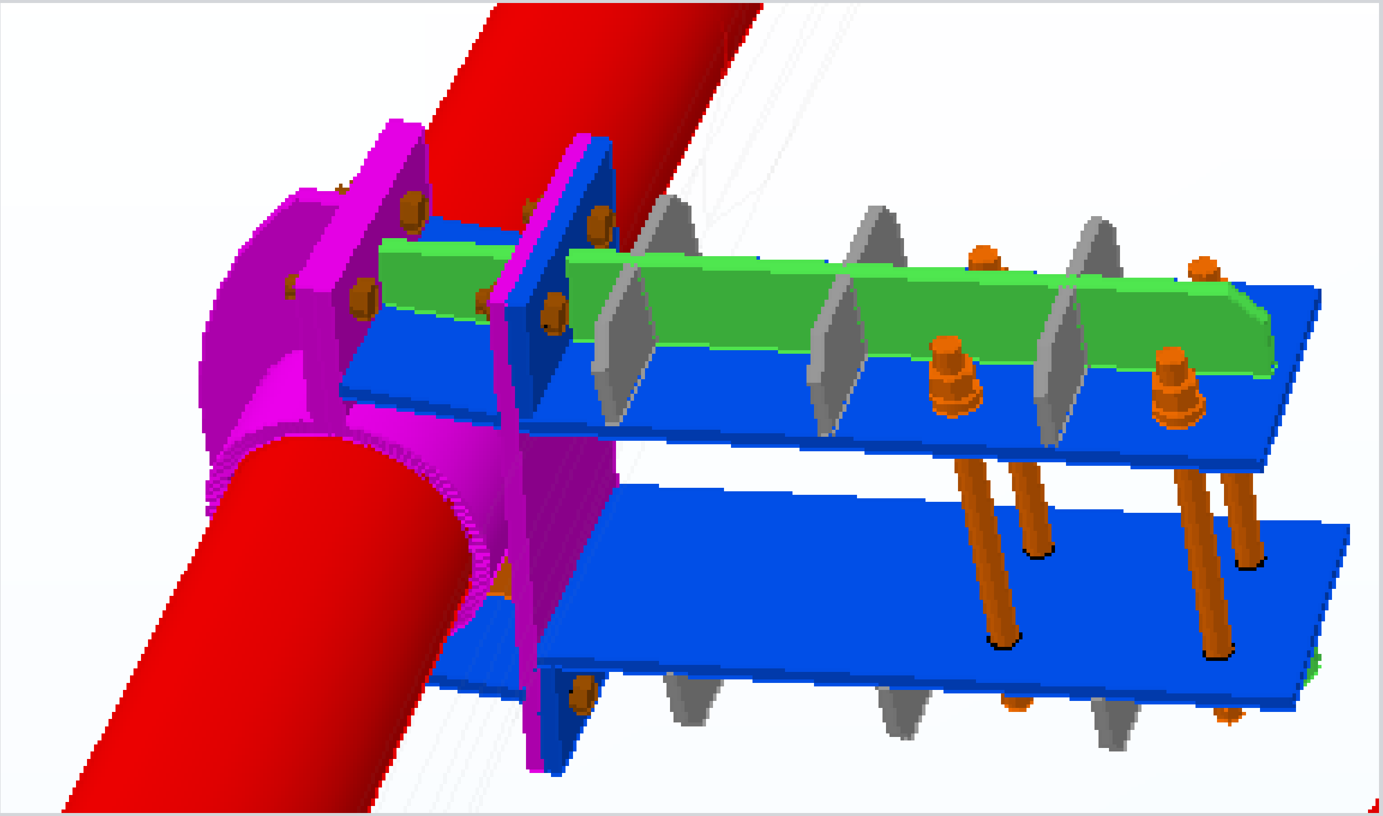
Structural steel components supporting cladding (dome area excluded)



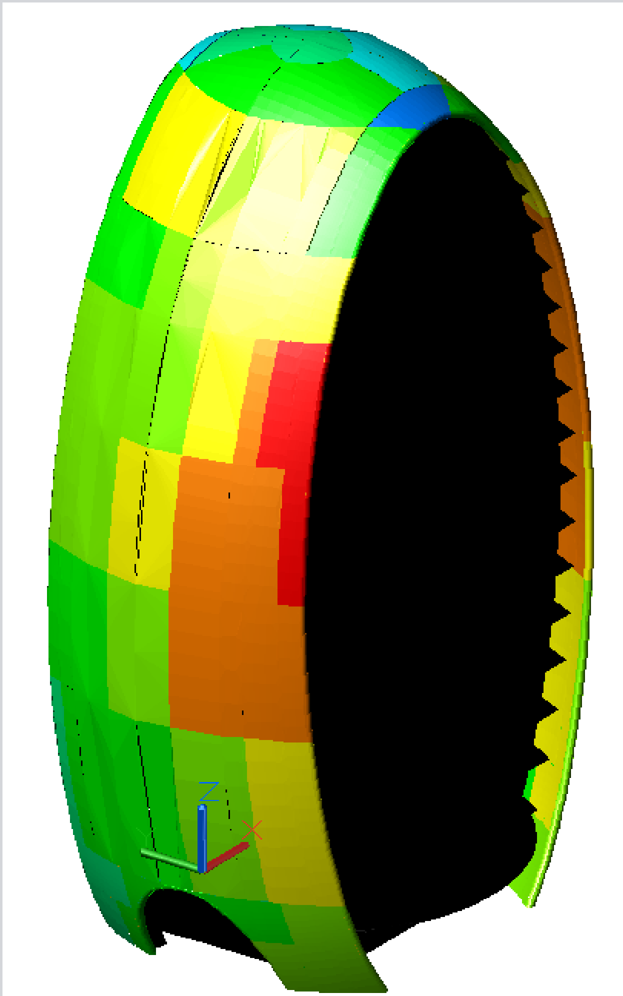
Cladding of Oval Tower in Limassol

Typical anchorage on slab

Contact nonlinearities



Cladding of Oval Tower in Limassol



Wind tunnel study conducted by BMT Fluid Mechanics Ltd

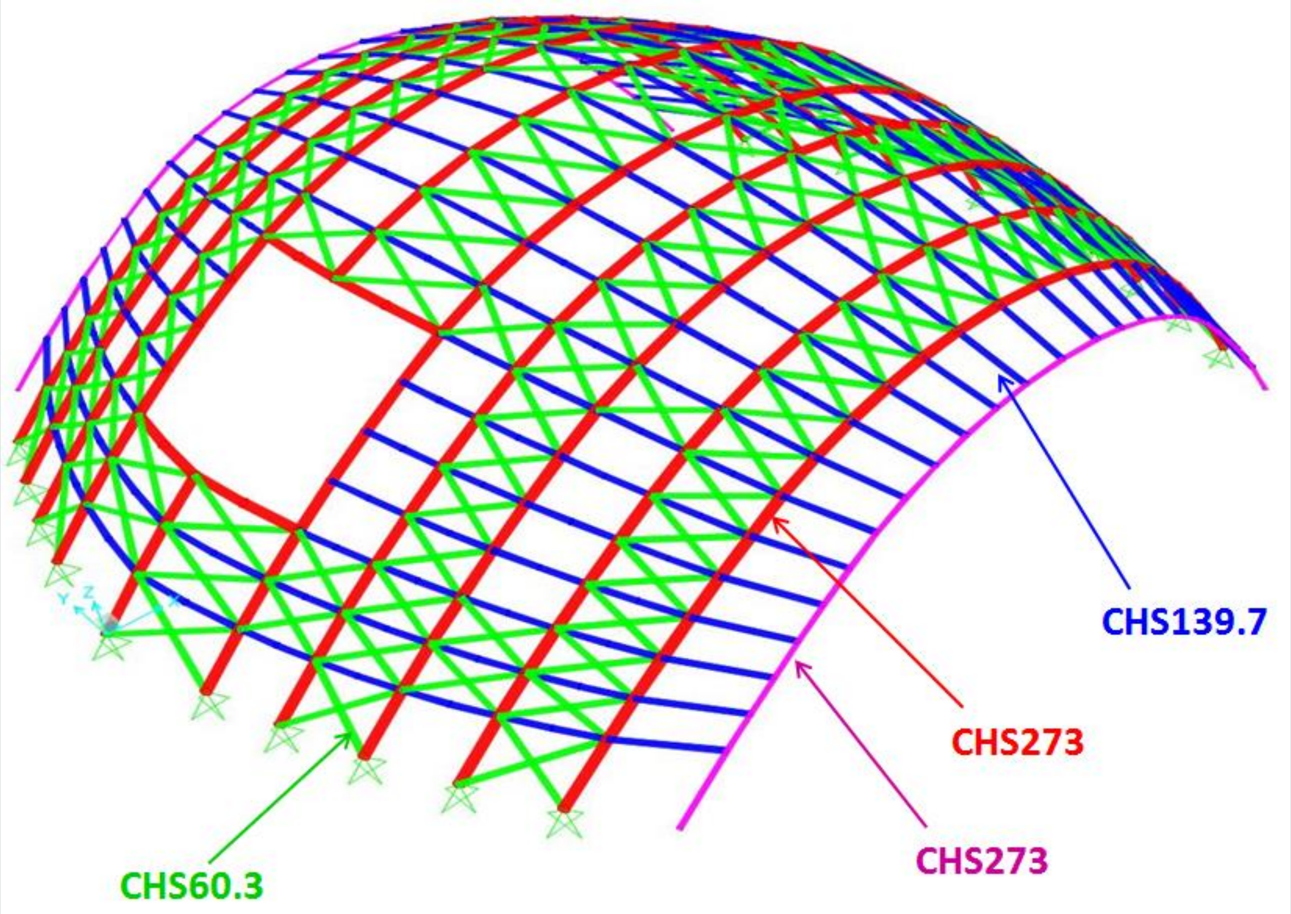
0	white
0_5_KPA	150
0_75_KPA	cyan
1_0_KPA	110
1_25_KPA	green
1_5_KPA	70
1_75_KPA	yellow
2_0_KPA	30
2_25_KPA	red
NO_CO...	white

Cladding of Oval Tower in Limassol

N.T.U.A.

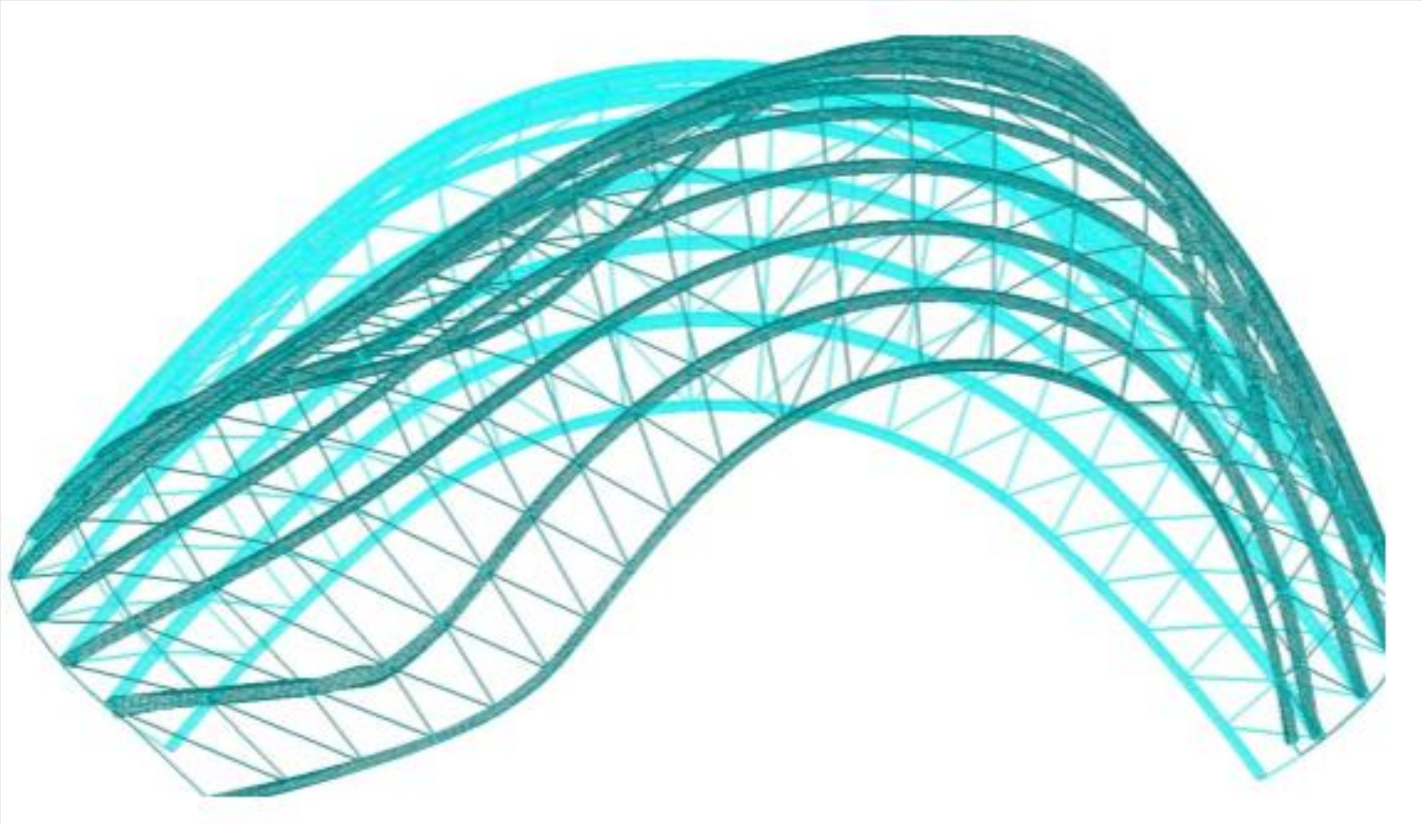
INSTITUTE OF STEEL STRUCTURES

3-D view of dome structure



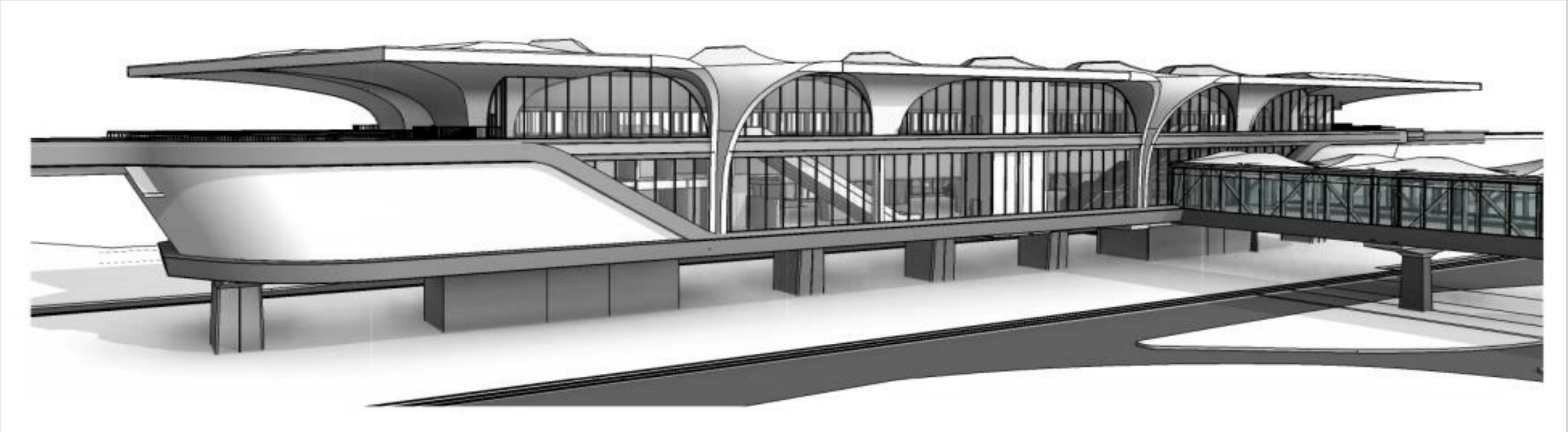
Cladding of Oval Tower in Limassol

Deformed shape from nonlinear buckling analysis



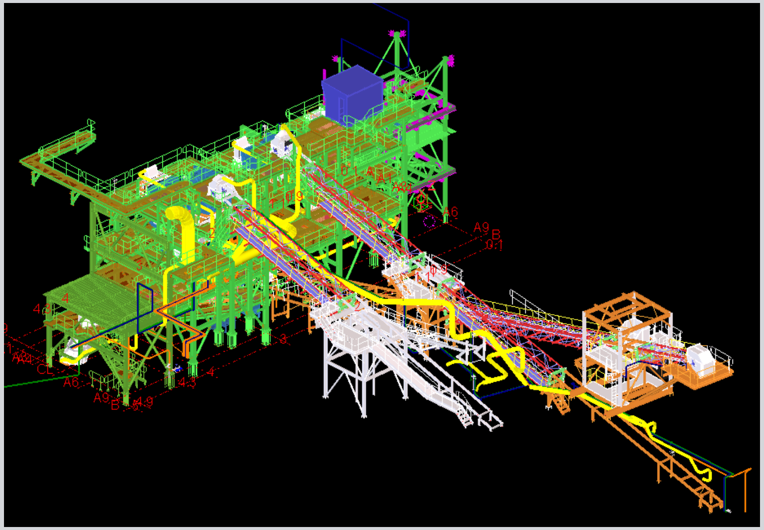
Cladding of Oval Tower in Limassol

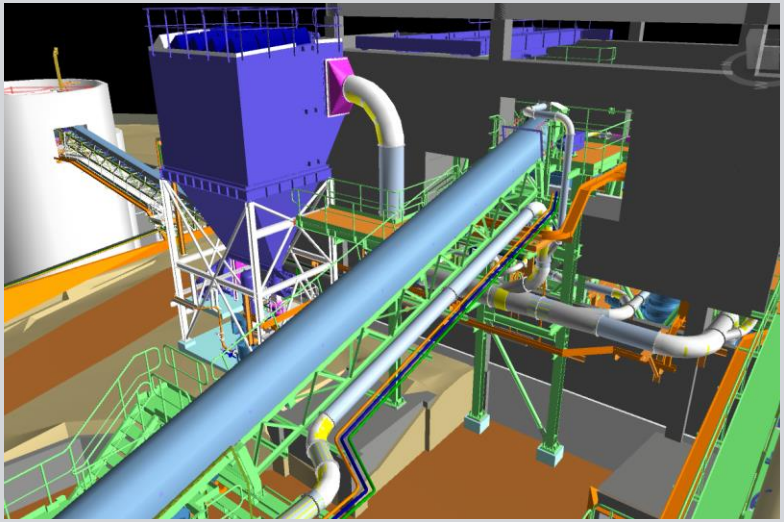
Doha Red Line South Elevated & at Grade Metro Stations

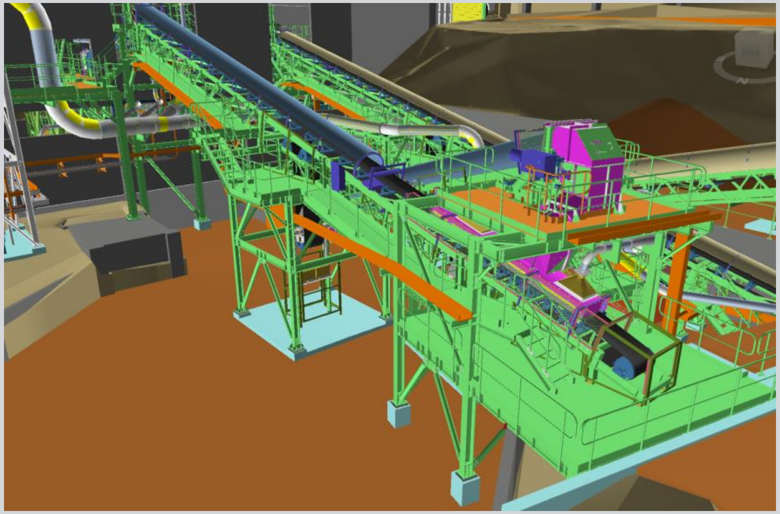


Inspiration for research on structural design recommendations for free-form structures

Structural design of industrial facilities







**Hellas Gold Facilities
in Olympiada, Chalkidiki
Crusher building + Conveyors**

Several restrictions to accommodate MEP passages lead to unconventional structural solutions

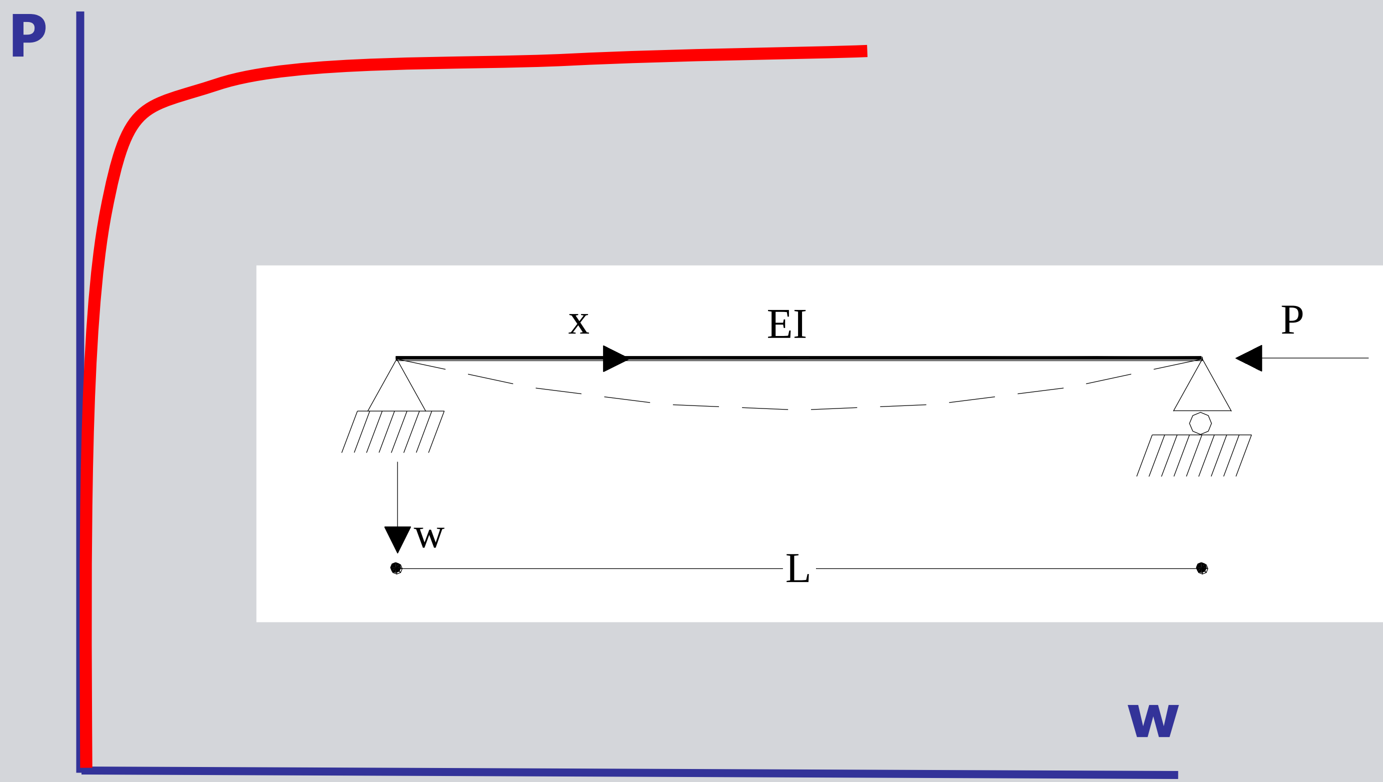
Structural steel design education at NTUA

The example of compression members

Physical problem

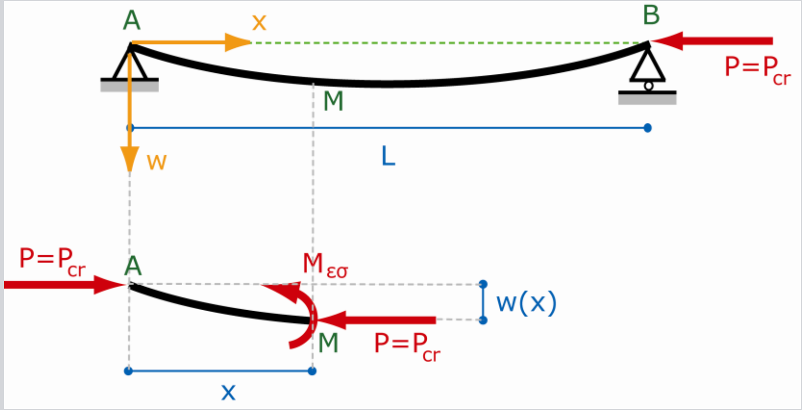
Structural steel design education at NTUA

Structural function



Structural steel design education at NTUA

Structural mechanics



$$EIw'' + Pw = 0\,, \quad k^2 = P/EI$$

$$w'' + k^2 w = 0 \Rightarrow w = A\sin kx + B\cos kx$$

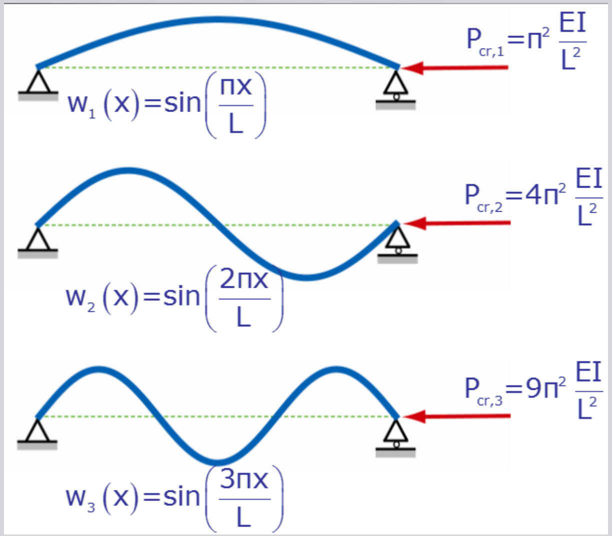
$$w(0) = 0 \Rightarrow A\sin k0 + B\cos k0 = 0 \Rightarrow B = 0$$

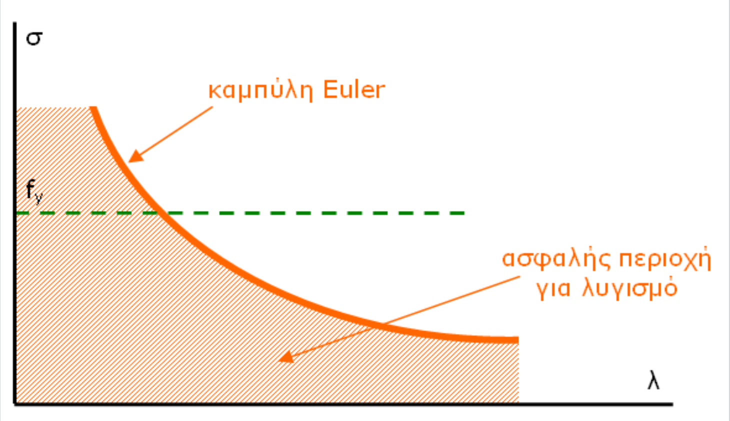
$$w(L) = 0 \Rightarrow A\sin kL = 0$$

$$\sin kL = 0 \Rightarrow kL = n\pi \Rightarrow k = \frac{n\pi}{L},\ n = 1,2,3,\ldots$$

$$k^2 = \frac{P}{EI} = \frac{n^2\pi^2}{L^2} \Rightarrow P_{cr,n} = \frac{n^2\pi^2 EI}{L^2}$$

$$\boxed{P_{cr} = \pi^2 EI/L^2}$$

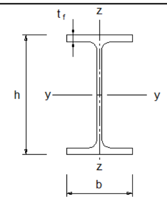
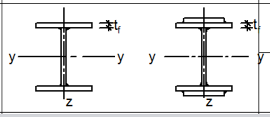


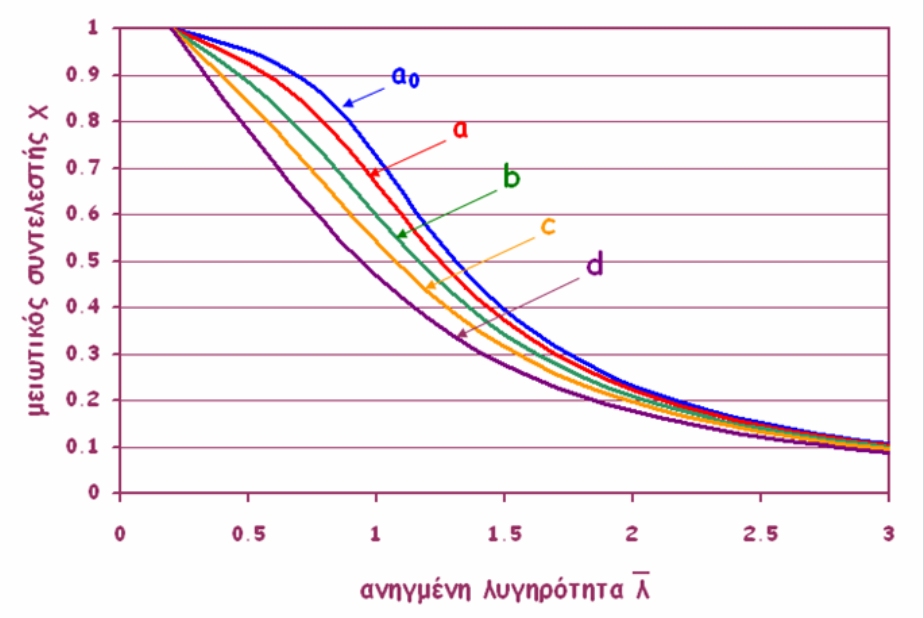


Structural steel design education at NTUA

Code provisions

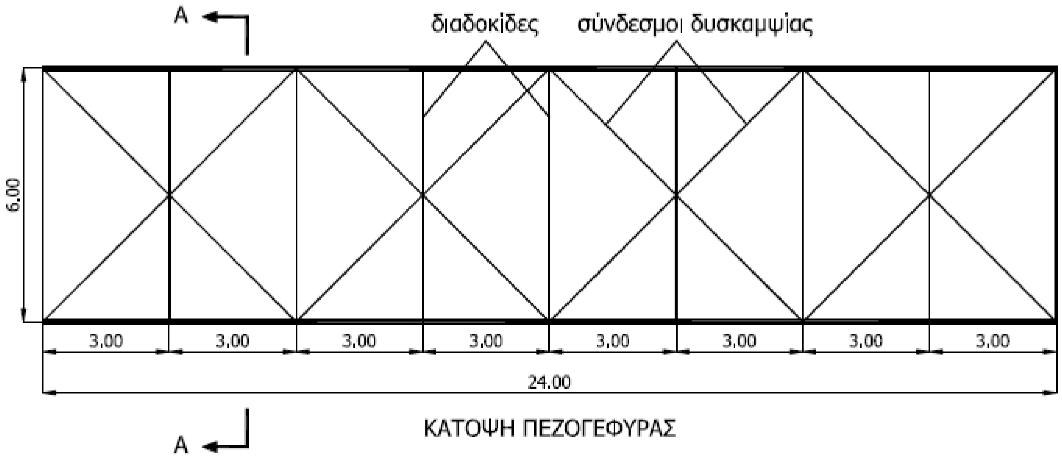
$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}$$

Διατομή		Όρια		Λυγισμός περί τον άξονα	Καμπύλη λυγισμού S 235 S 275 S 355 S 420	Καμπύλη λυγισμού S 460
Ελατές διατομές		h/b > 1,2	$t_f \le 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm < $t_f \le$ 100	y – y z – z	b c	a a
		h/b ≤ 1,2	$t_f \le 100$ mm	y – y z – z	b c	a a
			t_f > 100 mm	y – y z – z	d d	c c
Συγκολλητές I-διατομές		$t_f \le 40$ mm		y – y z – z	b c	b c
		t_f > 40 mm		y – y z – z	c d	c d



Numerical examples

Δίνεται ποιότητα χάλυβα S355 και κοχλίες ποιότητας 8.8. Το σπείρωμα των κοχλιών βρίσκεται εκτός του επιπέδου διατμήσεως. Το βάρος επίστρωσης επί της πλάκας σκυροδέματος αμελείται.



ΚΑΤΟΨΗ ΠΕΖΟΓΕΦΥΡΑΣ

ΦΟΡΤΙΑ

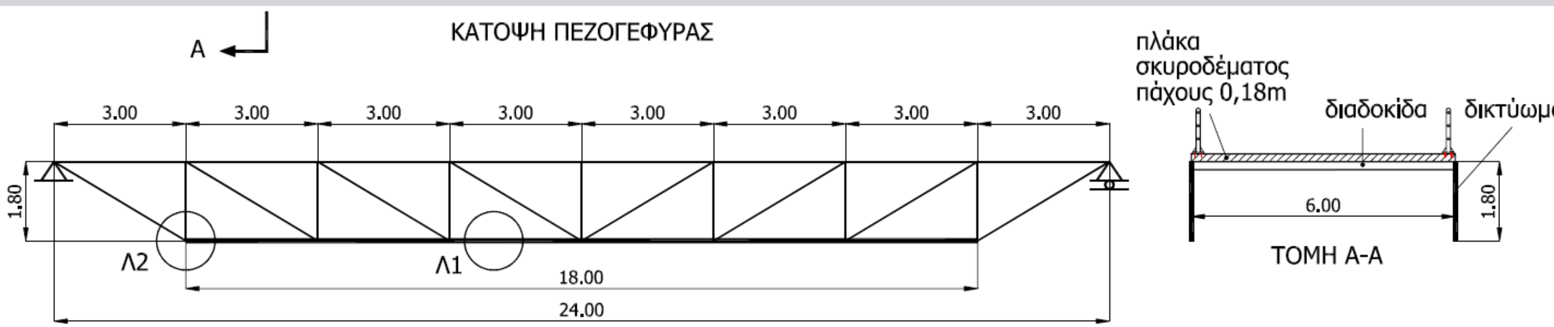
Ι.Β. μεταλλικής κατασκευής 1,8kN/m^2

Ι.Β. σκυροδέματος 25kN/m^3

κινητό 5kN/m^2

το βάρος επίστρωσης αμελείται

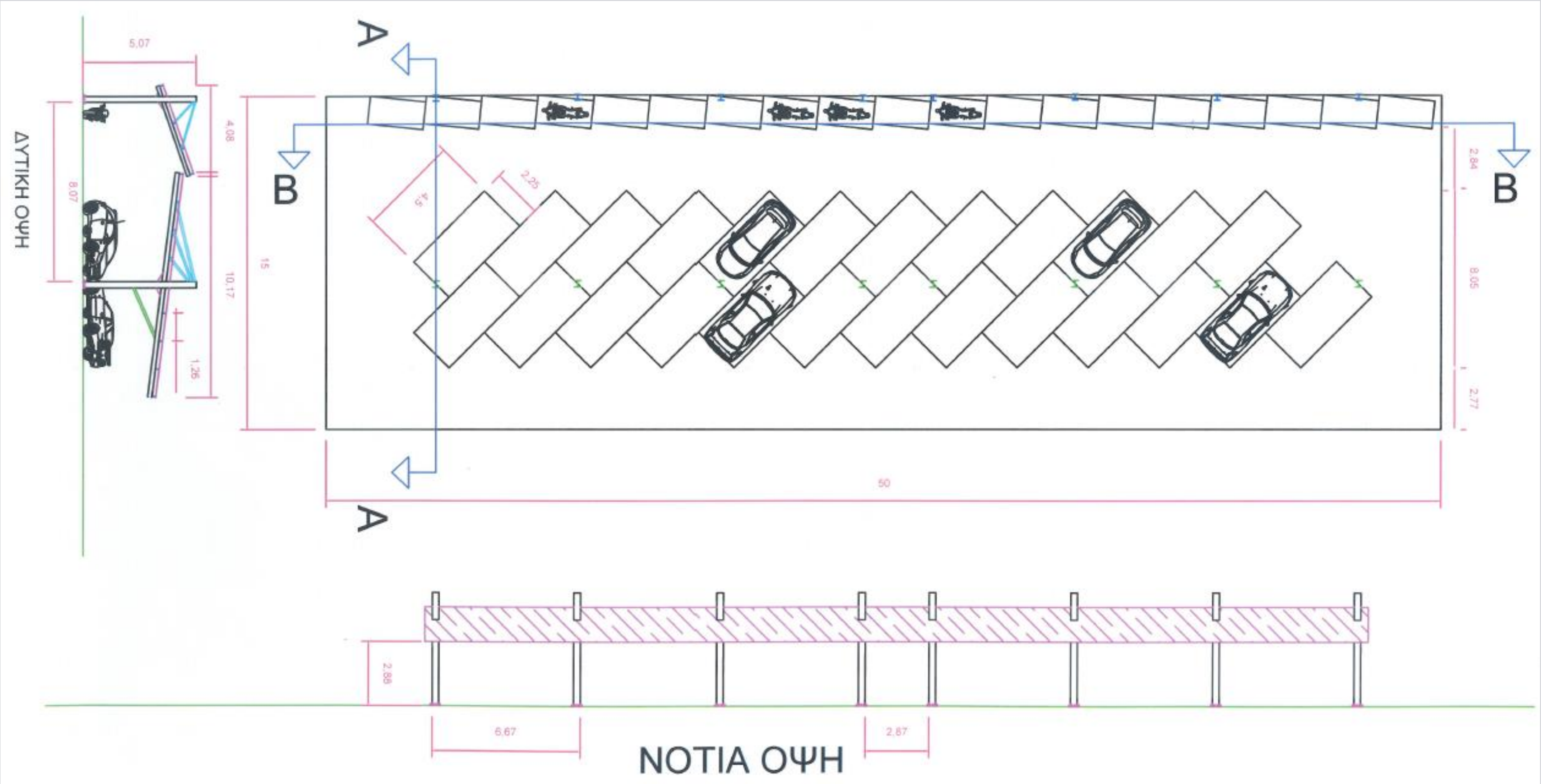
πλάκα



ΟΨΗ ΔΙΚΤΥΩΜΑΤΟΣ ΠΕΖΟΓΕΦΥΡΑΣ

Structural steel design education at NTUA

Design project



Structural steel design education at NTUA

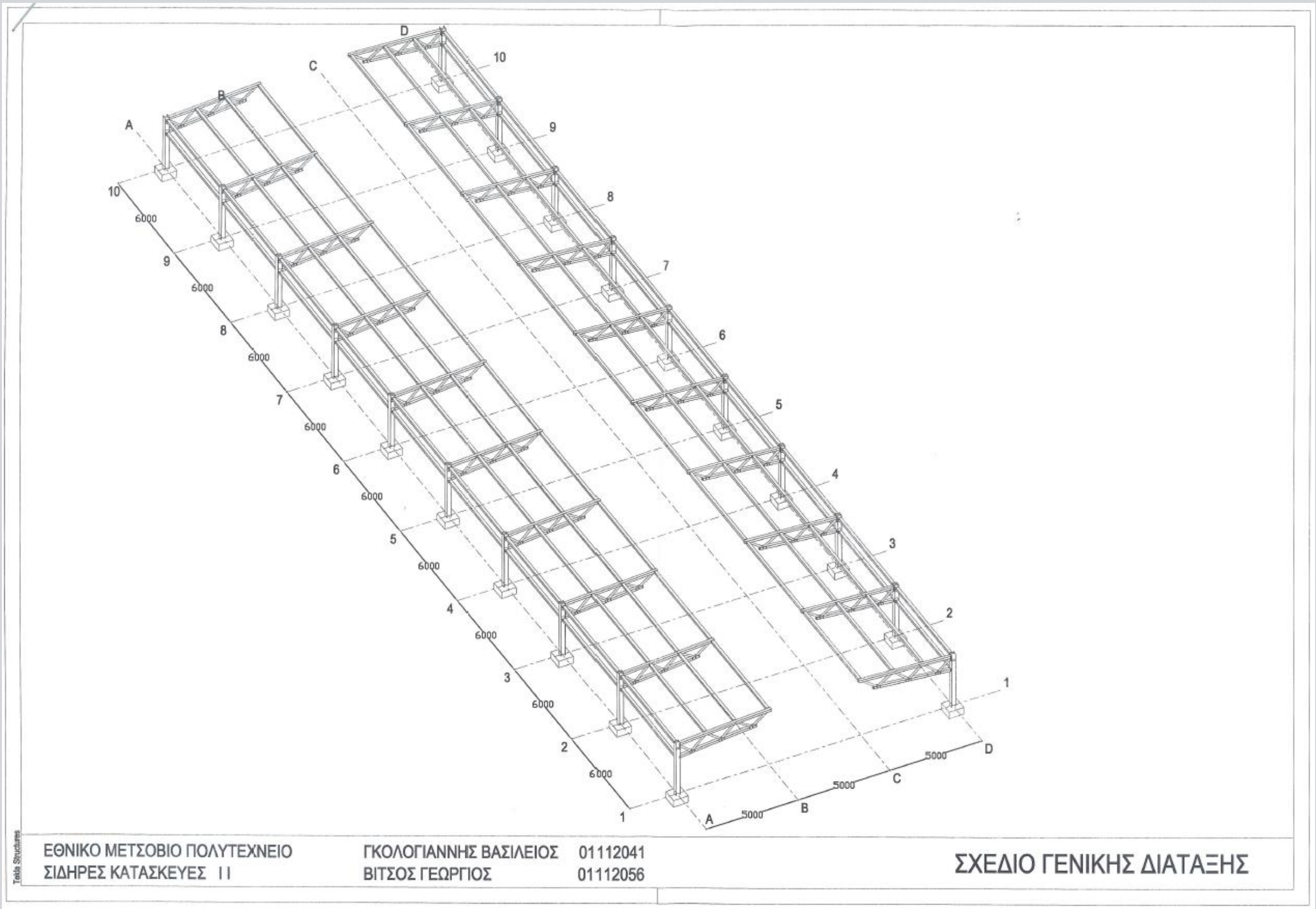
Design project

Structural steel design education at NTUA

Design project

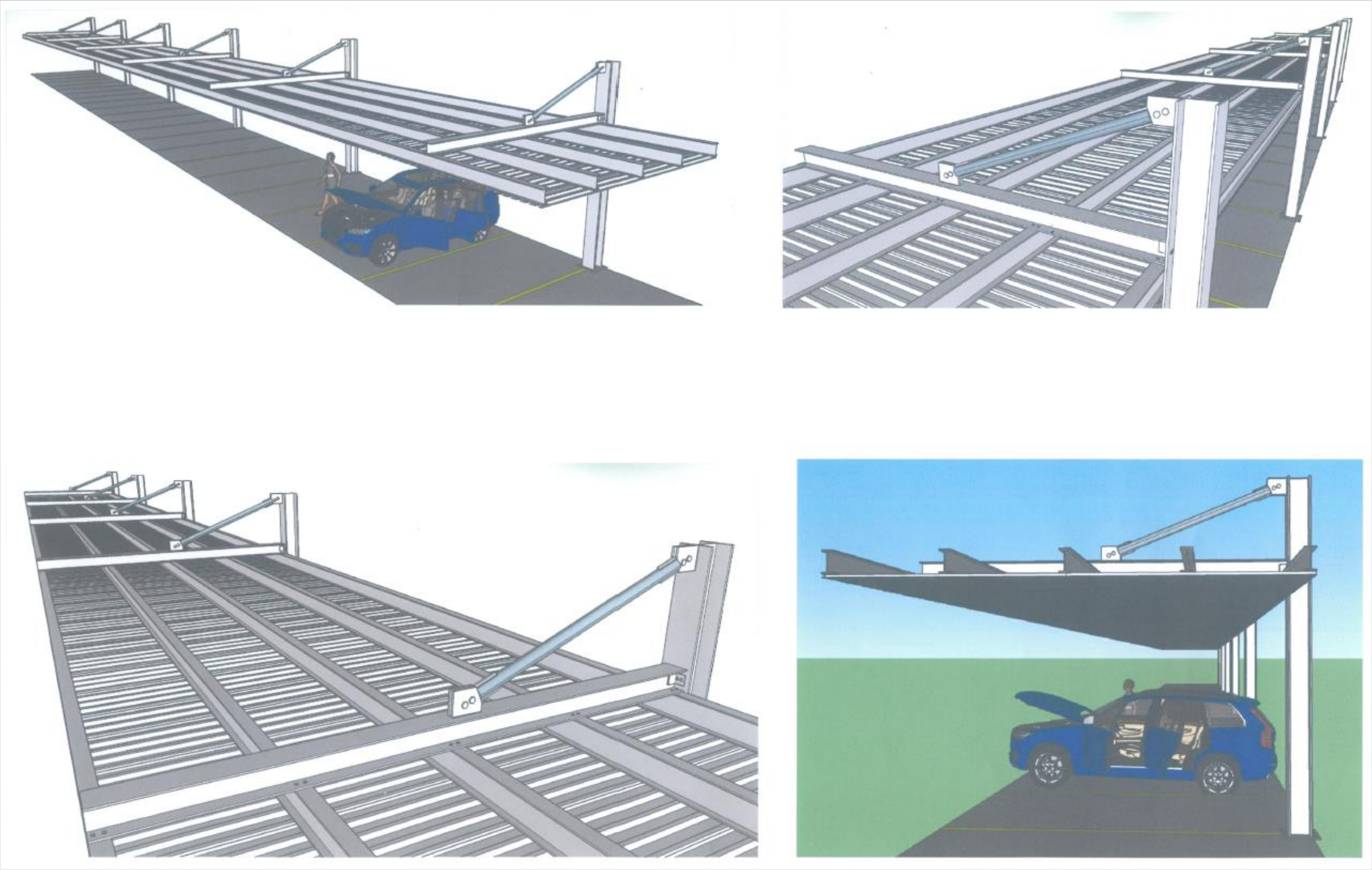
Structural steel design education at NTUA

Design project



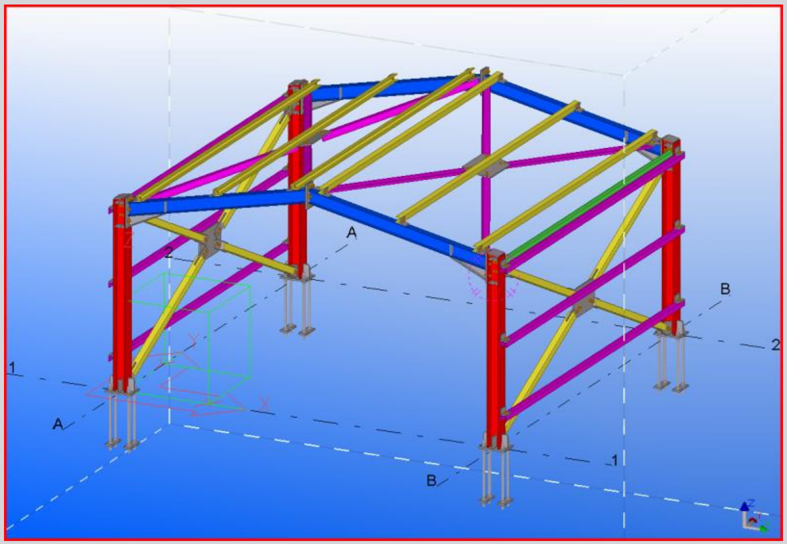
Structural steel design education at NTUA

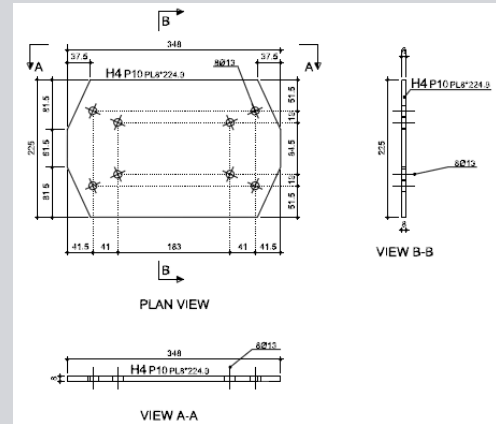
Design project

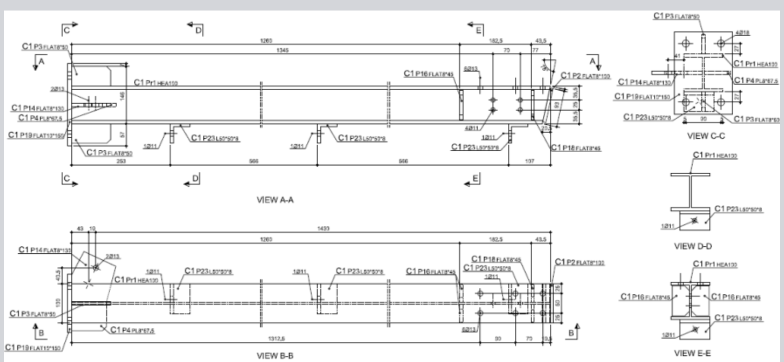


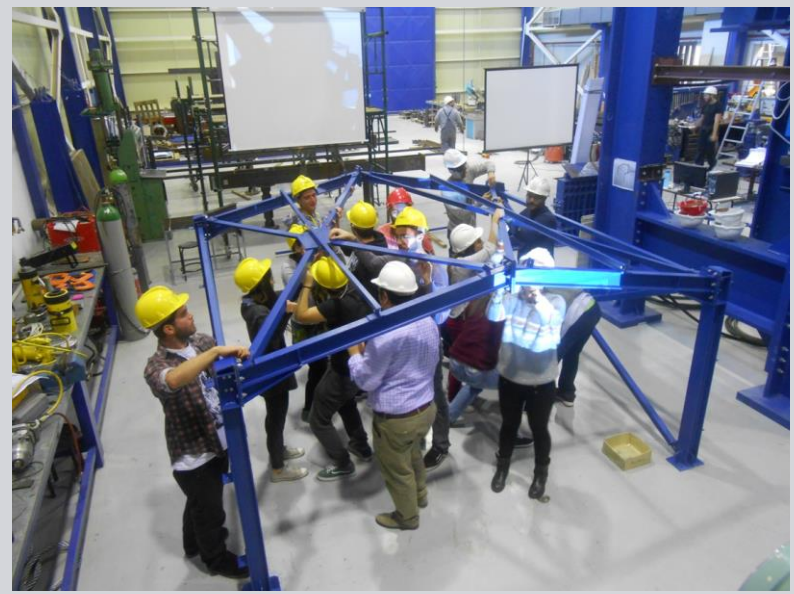
Structural steel design education at NTUA

Laboratory exercises









Final remarks

- Structural design is a mixture of art, science and technology.
- The interaction between structural design education, research and practice is mutually beneficial for all these three aspects.