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στους τομείς Έρευνας, Τεχνολογικής Ανάπτυξης και Καινοτομίας

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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

High Performance Topology Optimization Computing Platform

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ABSTRACT

One of the most challenging tasks in the construction industry nowadays, is to reduce the material demands and distribute, in the same time, the material among the structural system in the best possible way. Topology optimization is a design procedure that is increasingly used, to generate optimized forms of structures in several engineering fields. The current paper presents the Topology Optimization (TO) module of the High-Performance Optimization Computing Platform (HP-OCP) which focuses on civil engineering problems.

More specifically the SIMP method [1] is implemented and the topology optimization problem is solved by using both OC and MMA algorithms. The HP-OCP is a platform which evaluates several objective functions, such as the volume of the structure, the compliance etc. and can solve constrained or unconstrained structural optimization problems. The above libraries are developed in C#. The core of the platform is created in such way that it can be integrated with any CAE program that has OAPI. In the proposed work we used the structural analysis and design software SAP2000.

Lagaros et al. [2] presented a C# code that solves topology optimization problems, which are discretized with 3D solid elements, using SAP2000. One of the highlights of the proposed work is that the above module can be used for all kind of finite elements. Benchmark tests are presented with structures that are simulated by 2D plane-stress elements, 3D-solid elements and shell elements. Furthermore, it is independent of the type of the mesh, structured or unstructured, so both examples are presented. In addition, a tool in C# was developed in order to connect Rhino's plugin Grasshoppers with SAP2000. In that way more complicated geometries can be generated in the CAD program Rhino then the structural engineering problem can be formulated in SAP2000 and finally the above module can solve the topology optimization problem.

In the proposed work a powerful tool for both architects and civil engineers is introduced. The capabilities of the TO module of the HP-OCP are presented and several test cases are shown. The analysis and design of the structures are performed in SAP2000 software, in order to achieve a realistic result that could be a solution for a real-world structure.

Acknowledgement

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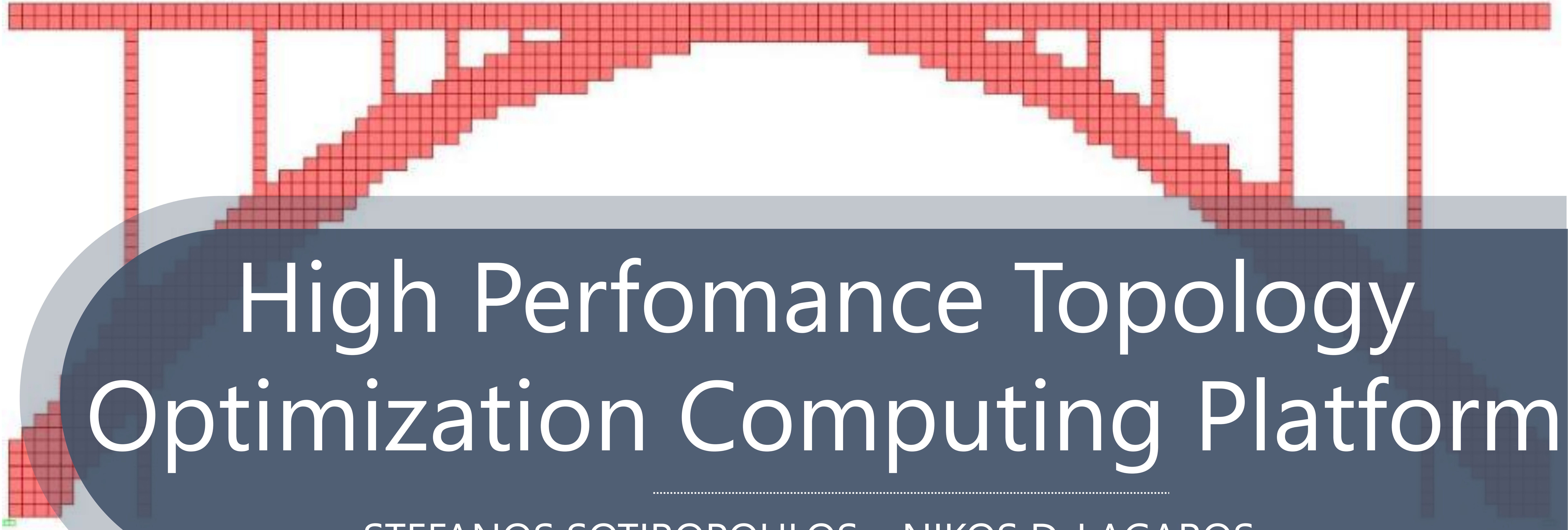
References

[1] M.P. Bendsoe, O. Sigmund, *Material interpolations in topology optimization, Arch. Appl. Mech. 69* 1999.

[2] N.D. Lagaros, N. Vasileiou, G. Kazakis, *A C# code for solving 3D topology optimization problems using SAP2000. Optimization and Engineering*, Springer, 2018.



High Perfomance Topology Optimization Computing Platform

STEFANOS SOTIROPOULOS – NIKOS D. LAGAROS

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Topology Optimization

Commercial software applications

- Most of commercial software are integrated into mechanical engineering oriented analysis and design software.
- Optistruct (Altair), Tosca (ABAQUS and MSC Nastran), ANSYS, SOLIDWORKS
- TO of HP-OCP is independent of the static analysis software
- Developed in C# language in .NET framework
- Integration via OAPI, XML data exchange format, etc. with commercial CAE
- SAP2000 is presented

Topology Optimization Formulation

Mathematical Formulation

- Initial mesh, loads, boundary condition
- Objective function: compliance
- Design variable: density of elements(x)
- Constraints: FEA, volume, limits of density
- Methods: SIMP, Level set, BESO
- Optimization Algorithm: OC, SLP, MMA

$$\min_{x} C(x) = F * U(x)$$

s.t.

$$F = K(x) * U$$

$$\sum_{e=1}^{N} x_e = \mathrm{V}$$

$$0 \leq x_e \leq 1$$

Topology Optimization Formulation

SIMP, OC, FILTER

- SIMP Formulation: $E(x) = x^p E_0$

- Partial Derivative of Compliance with respect to the design variable:

$$\frac{\partial C(x)}{\partial x_e} = -u_e(x)^T \frac{\partial k_e(x)}{\partial x_e} u_e(x)$$

- Modified expression:

$$k_e(x_e) = x_e^p * k_e^0 \Leftrightarrow k_e^0 = \frac{k_e(x_e)}{x_e^p}, \qquad \frac{\partial k_e(x_e)}{\partial x_e} = p * x_e^{p-1} * k_e^0 = p * x_e^{p-1} * \frac{k_e(x_e)}{x_e^p} = p * \frac{k_e(x_e)}{x_e},$$

$$\frac{\partial C(x)}{\partial x_e} = -u_e(x)^T * p * \frac{k_e(x)}{x_e} u_e(x) = -p \frac{F^T u_e(x)}{x_e} = -\frac{p * C_e}{x_e}$$

- In order to avoid checkerboard problem a filter is applied: $H_{ij} = R - dist(i,j)$

HP-TOCP Module

General Structure

- Preprocessing, Iterative procedure.
- Delegates functions to retrieve necessary info from SAP2000.
- These functions remain the same for all the commercial software.
- Simple features (ex. open, save, close program etc.)
- Specific features (ex. get FE name, add section & material property, etc.)
- Dll libraries perform computations.
- In each iteration there is interaction between HP-TOCP and the static program.

Preprocessing

Basic features

- Define the initial structure, boundaries and load condition in SAP2000 model.
- The first step of HP-TOCP is to collect all the geometrical information.
- Apply SIMP by defining a finite (k) number of material properties.
- The modified equation of the Young Modulus is : $E = E_{min} + (E_0 - E_{min}) * 1/k$
- Create (k) number of section properties, so everyone has a different material.
- Correspond densities to the right section property.
- Update function: $index = Convert.ToInt32\left(x^p * (k-1)\right)$

Preprocessing

Specific features

Filter

- Centroid of each element is computed
- Compute distances between each element and its neighbors
- Create a matrix with the convolution operator of each element

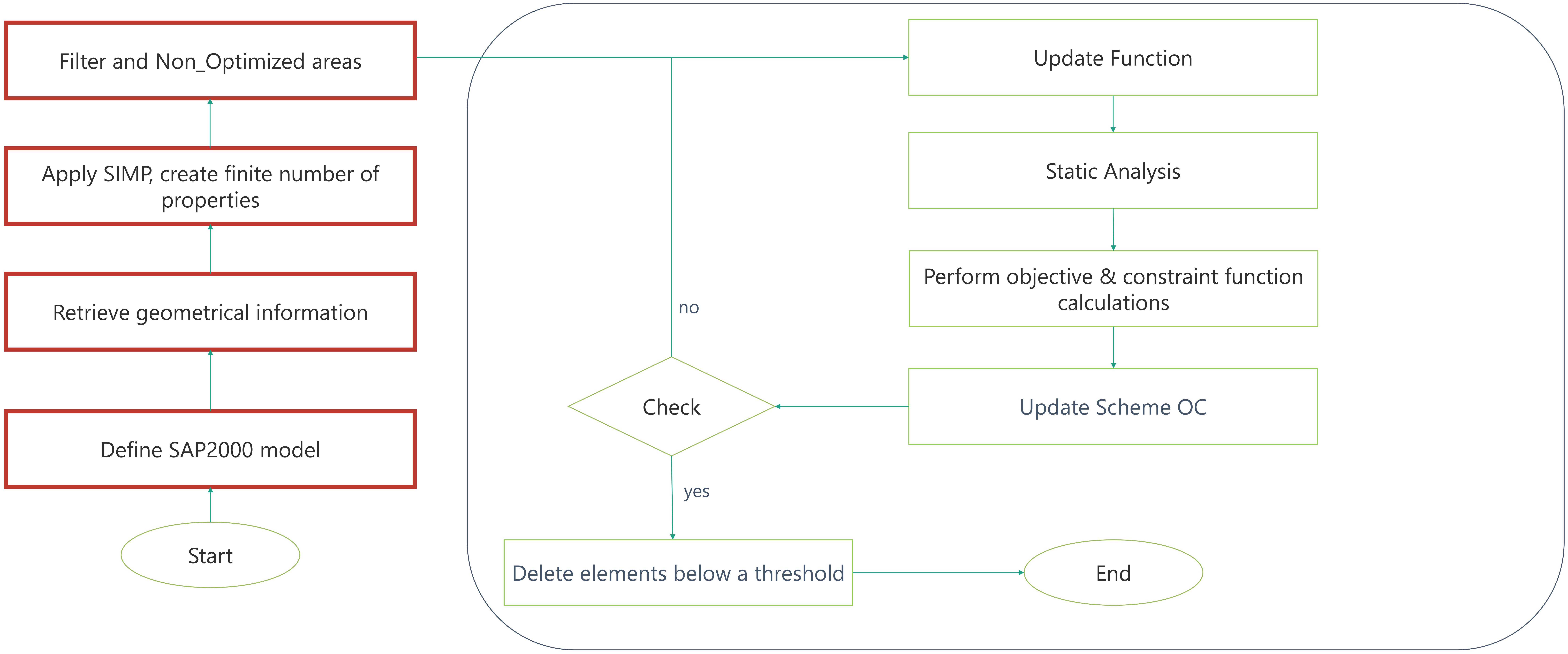
Optimized – Non optimized areas

- Define a Group of FE named “Non_Optimized” and assign the desired elements
- Define whether this area is void or full
- HP-TOCP recognize the areas and exclude them from the density update

Iterative Procedure

- Assign the right properties using the Update function
- Perform the Static Analysis
- Retrieve Analysis Results using delegates functions
- Compute Compliance, Derivative and volume
- Apply OC update scheme
- Threshold that indicates that a material doesn't exist
- Delete the equivalent elements

Flowchart


Filter and Non_Optimized areas
Apply SIMP, create finite number of properties
Retrieve geometrical information
Define SAP2000 model
Start
Update Function
Static Analysis
Perform objective & constraint function calculations
Update Scheme OC
Check
no
yes
Delete elements below a threshold
End

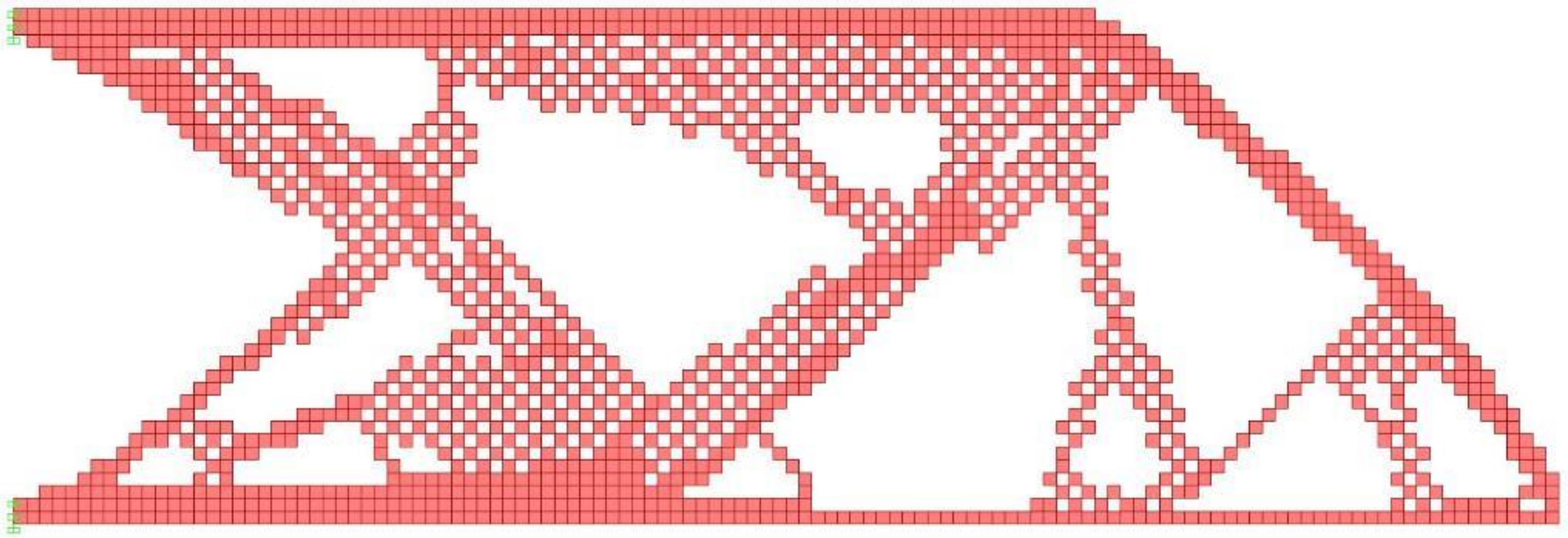
2D Test Cases

Cantilever beam problem

Initial domain

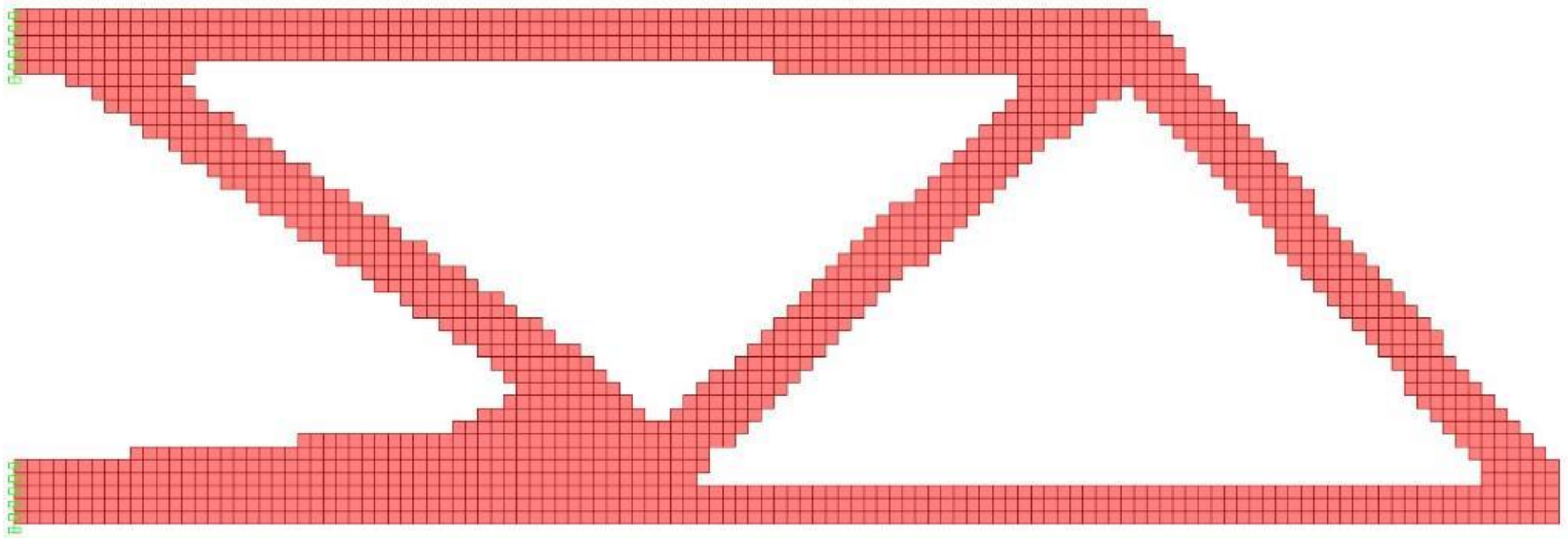
(a)

No filter



(b)

Filter



(c)

$Mesh = 120x40$
$Volfrac = 0{,}3$
$PropNum = 500$
$D_{lim} = 0{,}4$
$R = 3$

D_{lim} = Limit density for deleting area elements

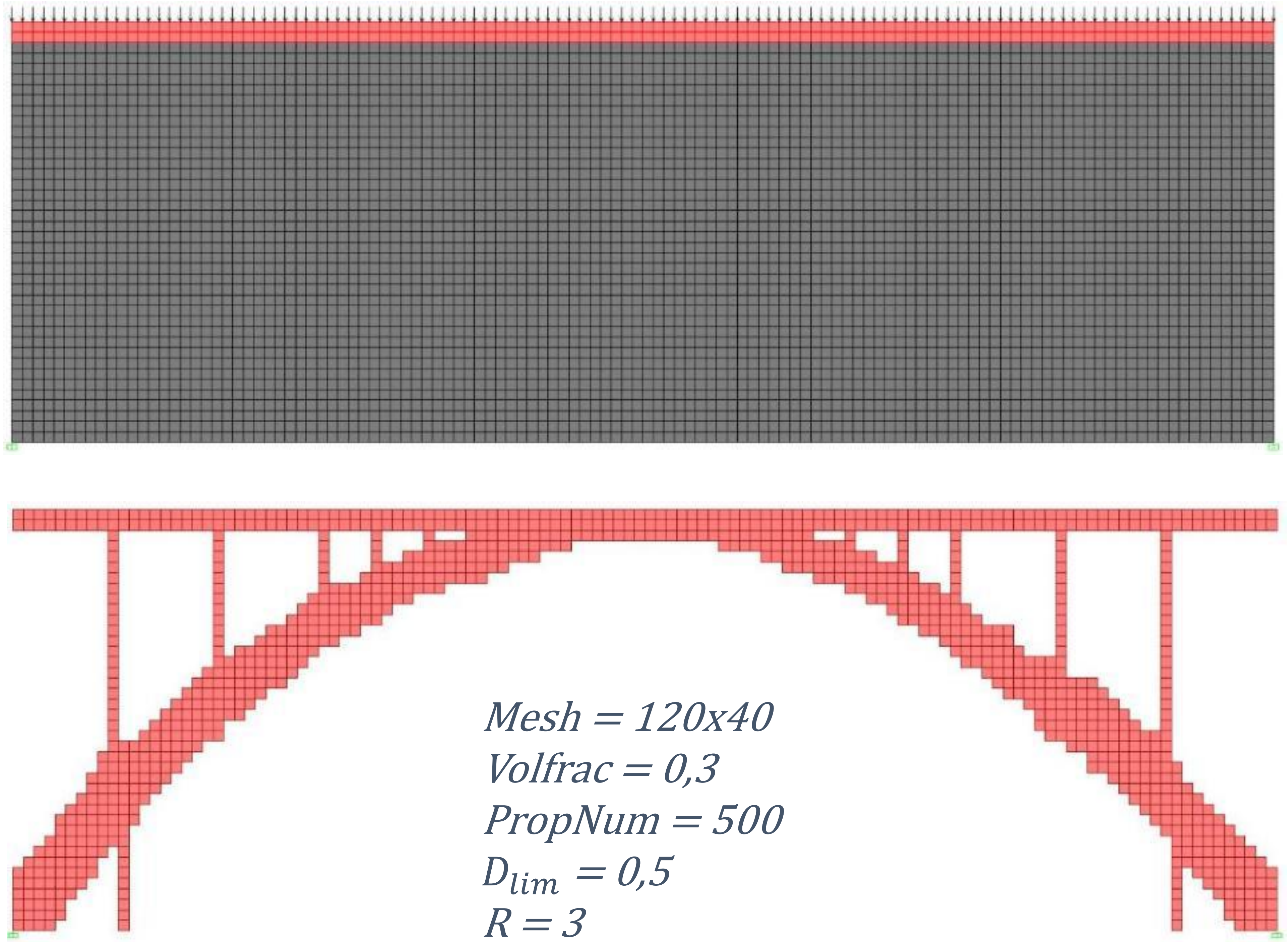
$PropNum$ = Section and material properties number

R = Radius Filter

2D Test Cases

Non optimized – Multiple loads

Bridge test case

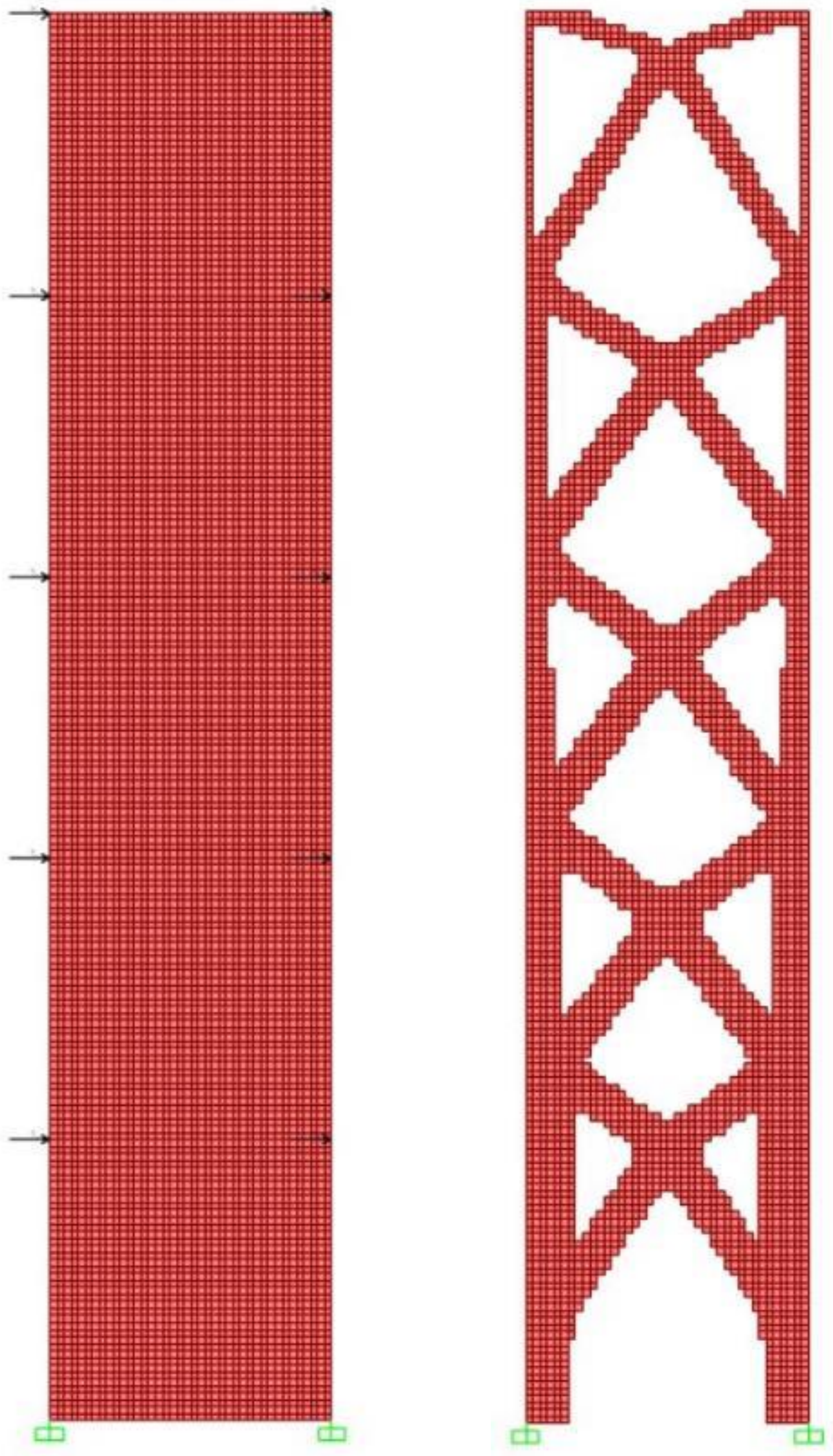


$Mesh = 120x40$
$Volfrac = 0{,}3$
$PropNum = 500$
$D_{lim} = 0{,}5$
$R = 3$

(b)

MRF test case

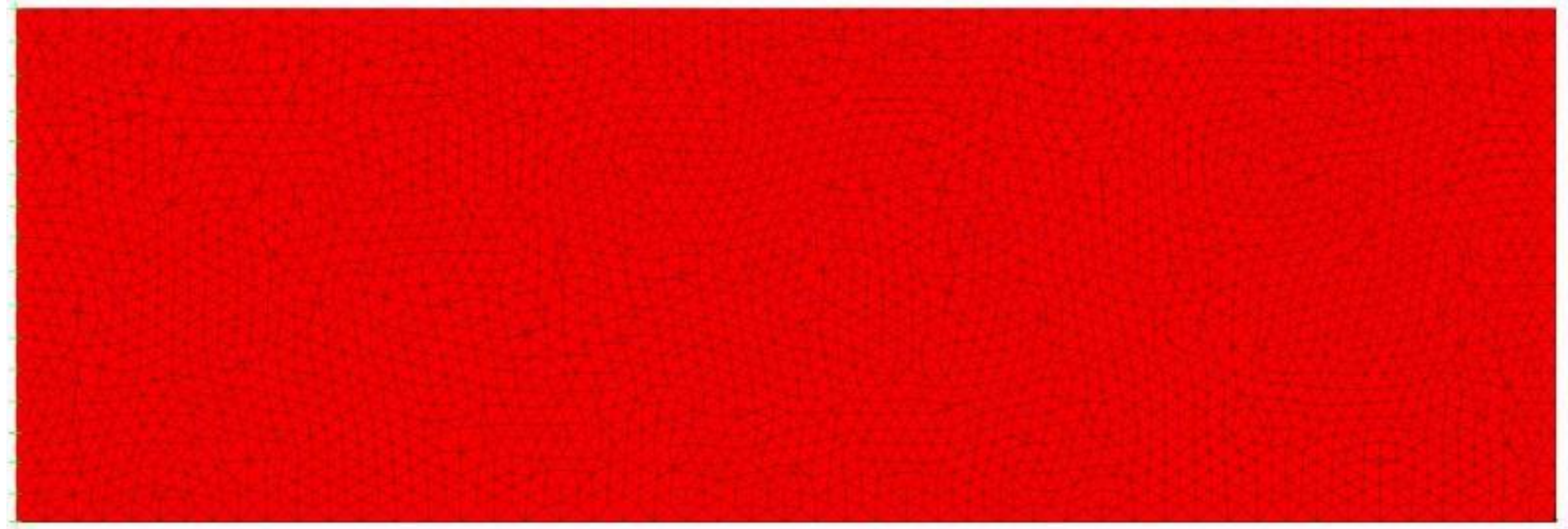
$Mesh = 40x200$
$Volfrac = 0{,}3$
$PropNum = 500$
$D_{lim} = 0{,}2$
$R = 3$



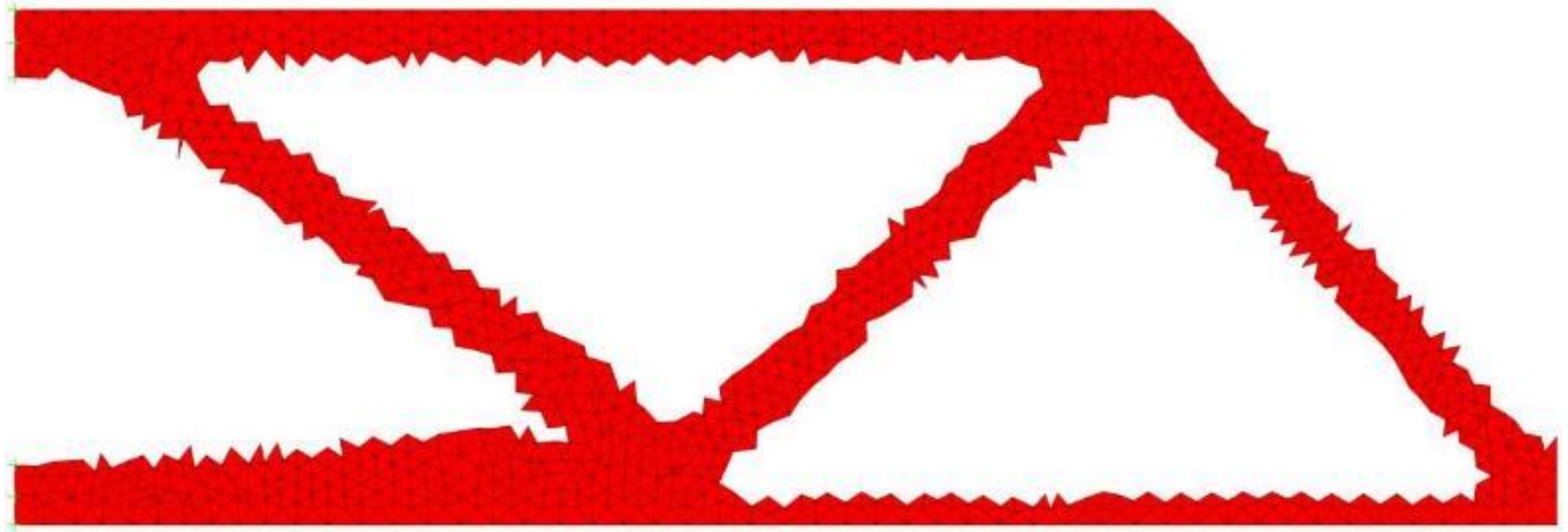
(b)

Unstructured mesh & Plate case

Cantilever beam

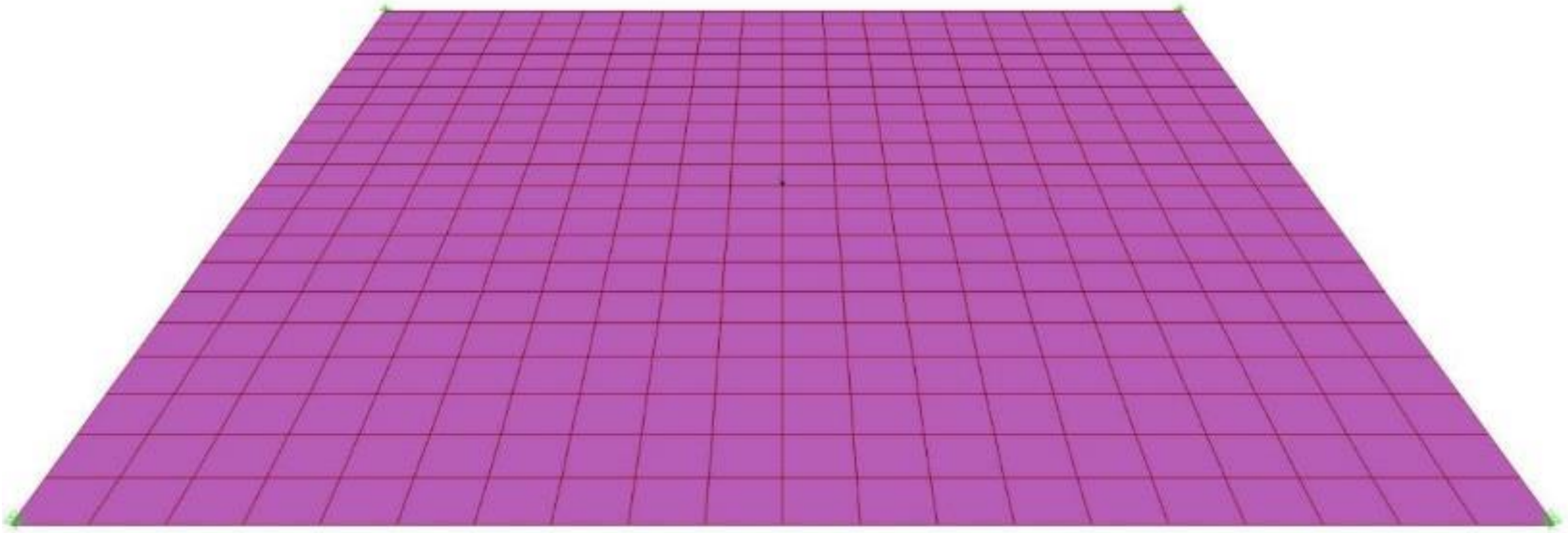


Unstructured mesh: 5000 elements
Volfrac = 0,3
PropNum = 500
$D_{lim} = 0,5$
$R = 3$

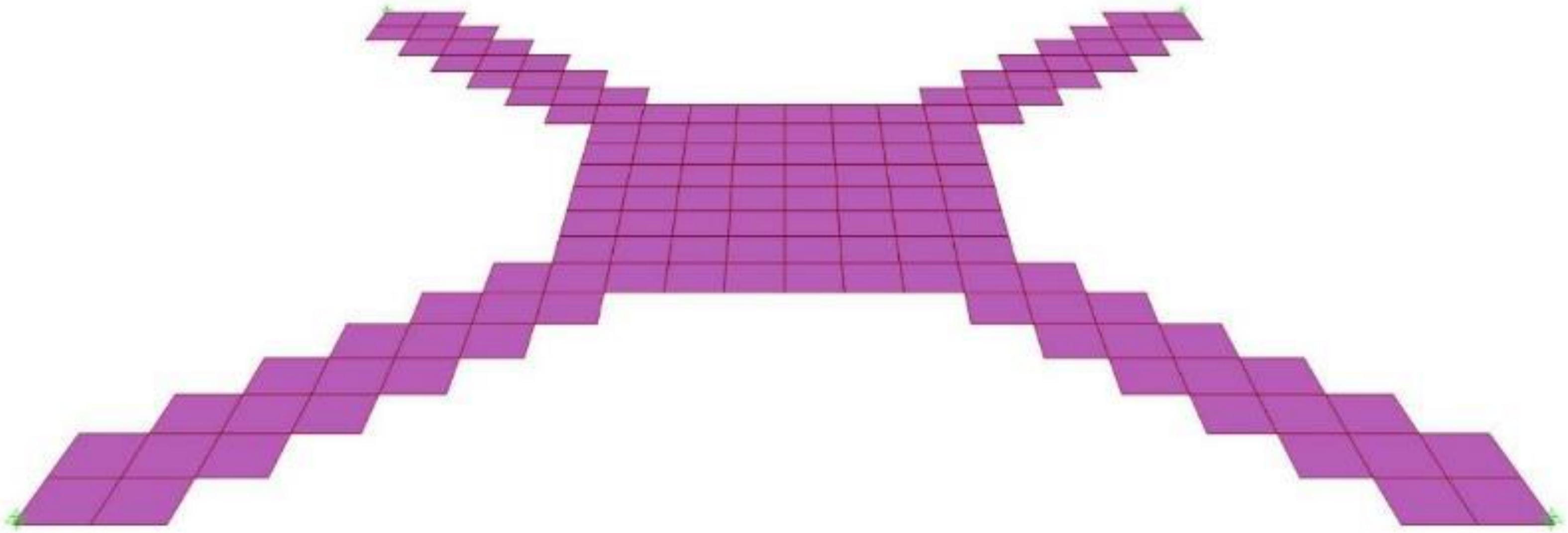


(a)

Simple plate



Mesh = 20x20
Volfrac = 0,3
PropNum = 500
$D_{lim} = 0,4$
$R = 3$



(b)

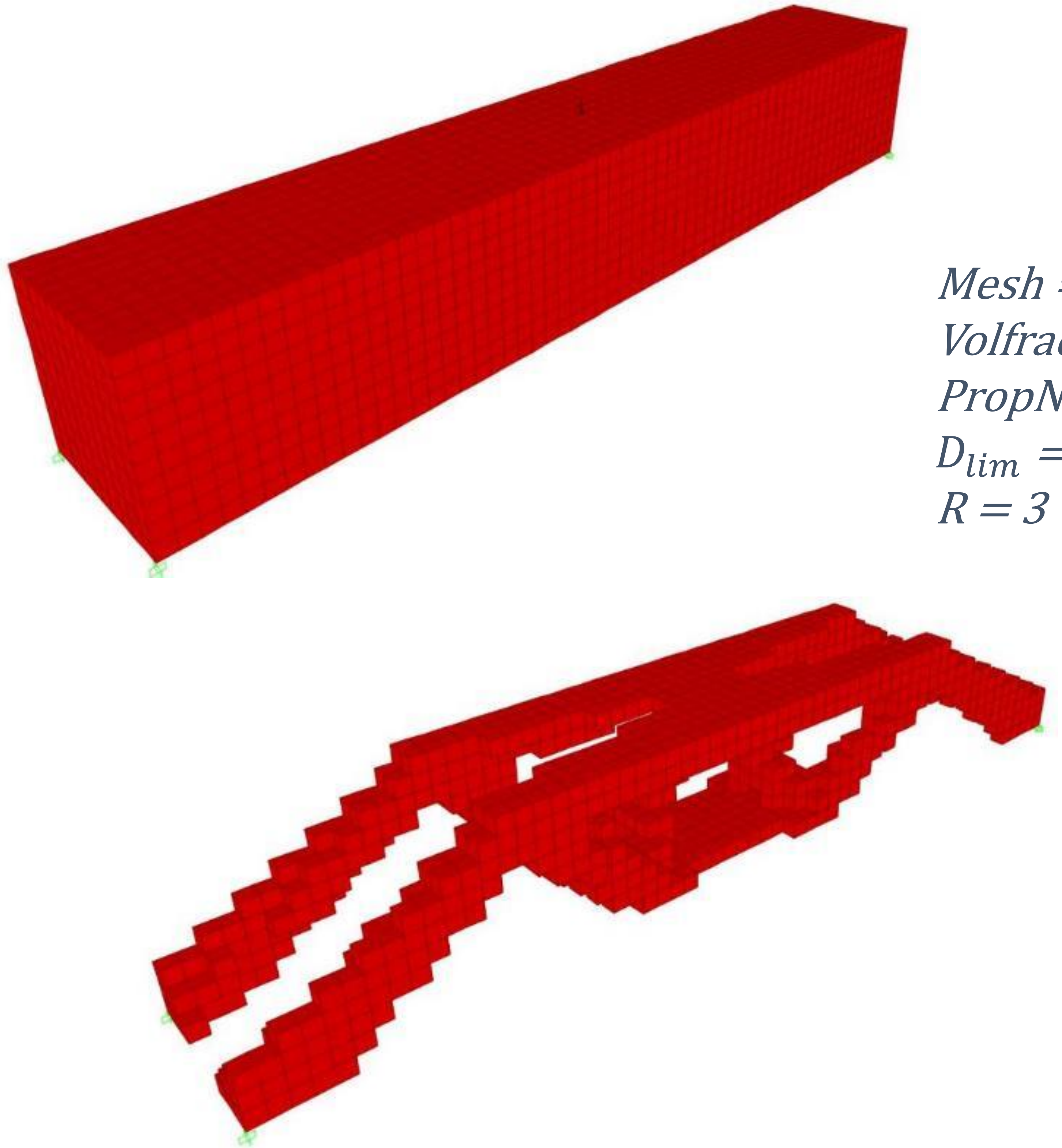
3D test cases

3D Wheel

$Mesh = 40x40x20$
$Volfrac = 0,2$
$PropNum = 500$
$D_{lim} = 0,4$
$R = 3$

(a)

MBB beam



$Mesh = 120x40$
$Volfrac = 0,3$
$PropNum = 500$
$D_{lim} = 0,5$
$R = 3$

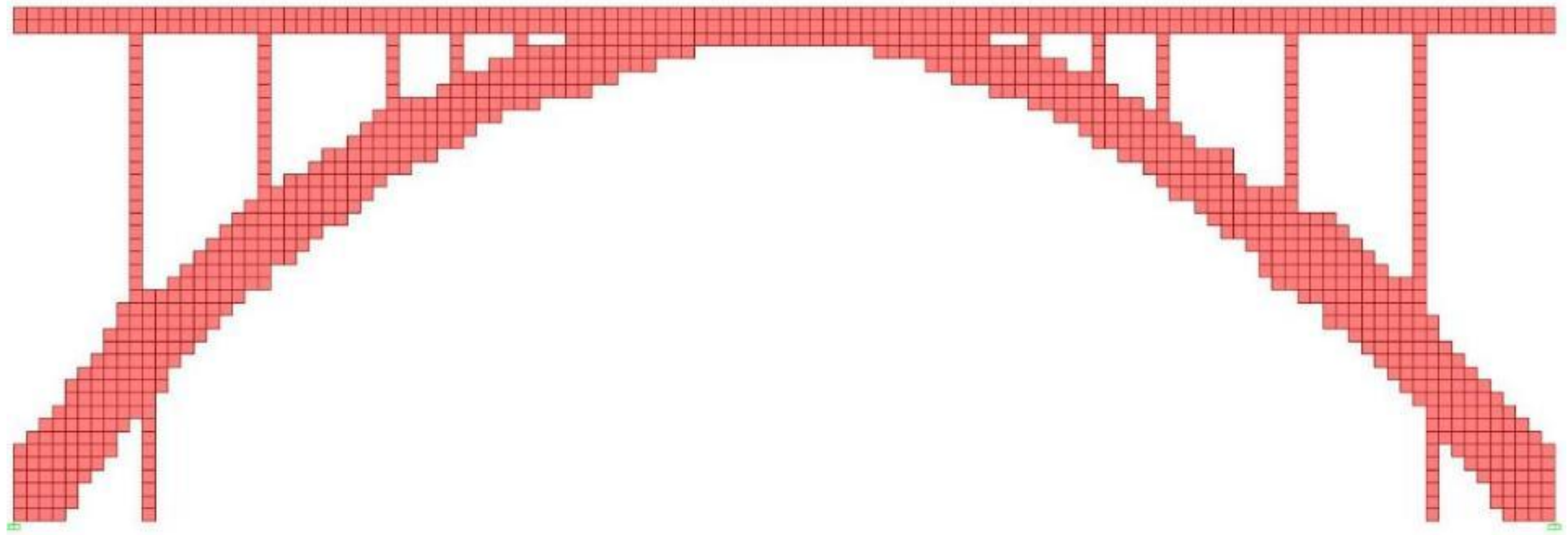
(b)

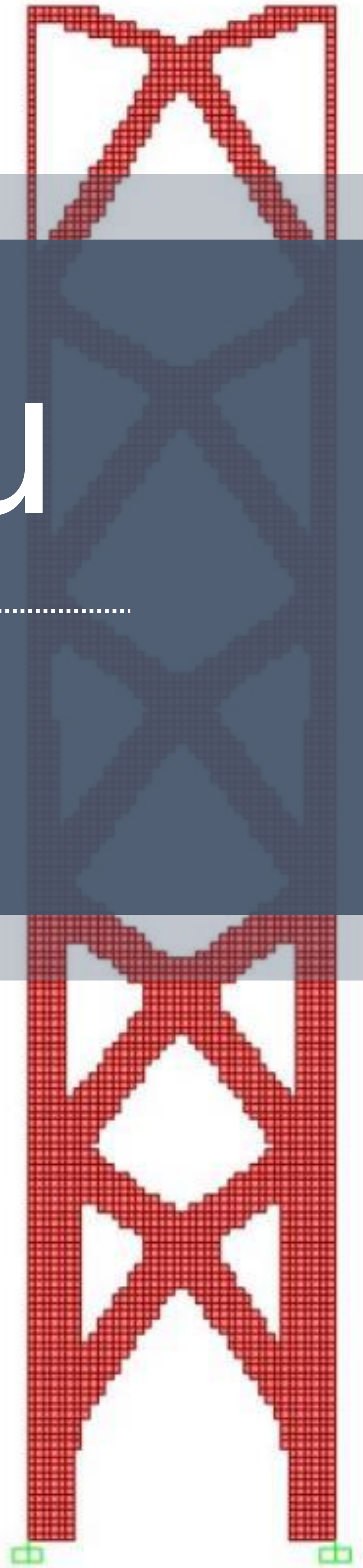
Conclusion

- HP –TOCP independent of the static software
- Integration with SAP2000
- SIMP method, OC algorithm
- Special features (Filter, Non_optimized areas and multiple load cases)
- Independent of the mesh and finite element type
- 2D structured and unstructured test cases
- Plate and 3D problems

Thank You

Questions?





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Σχόλια - Προβλήματα - Παρατηρήσεις

Δεν υπήρχαν παρατηρήσεις

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