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Study with topology optimization domains in two-dimensional algorithms

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Abstract. Topological optimization is a numerical analysis technique used in many applications such as additive manufacturing, casting, industry, plastic automotive and others. Educational algorithms have been developed, mostly two-dimensional configuration and with well-defined domains, which clearly describe the various possibilities of boundary conditions found in structures. The aim of this study is to evaluate the domains of topological optimization in some two-dimensional cases and contribute for the training and insertion of students in research activities. For the optimization of the topology, pre-established educational codes were used, such as sigmund's code, the finite element theory to define the meshes and generate the matrix with displacements and supports, through software such as MATLAB®. From the analysis of these domains, it was possible to verify that some educational algorithms do not work correctly as they should. The results of this study provided knowledge about the first optimization algorithms and the Evolution of their approaches to design the details of the numerical aspects of the code and its equations. Due to the facts mentioned it is concluded that it is important to know in detail the domains used in two-dimensional educational algorithms and to what extent each of the algorithms facilitates work with a specific boundary condition. In addition, the evaluation of two-dimensional algorithms and optimization of the approaches studied helped to consolidate and expand knowledge about technological development and software for analysis and simulations.

Keywords. *Topological optimization, Finite element analysis, technological development*

Introduction. The search for solutions for the growing need to reduce costs and improve quality requires the definition of an ideal product. This product must have a geometry that resists the imposed efforts, as a working condition, added to the need to be accessible, light and with the least possible complexity. Topology optimization (TO) is a technical that can be introduced to lightweight of structures (12). Finding the ideal model requires the evaluation of dozens or hundreds of different configurations until a profile is determined that meets the conditions mentioned. This process can be performed through specimens and tests; however, the cost to design, produce and test the different geometries, in addition to the time available for this entire cycle, makes the process impeding. The virtual execution of this process becomes the ideal option, with extremely reduced cost and time.

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With the topology optimization tool, it is possible to design durable and lightweight components for any application, making it an excellent path to follow when developing and updating products (11). To meet this concept of virtual evaluation, some elements of optimization are the key to the automated execution of this procedure. In topology optimization it is used when there is no previously established profile for the geometry, thus, the optimization process is performed based on a generic initial model. The use of topology optimization becomes a fundamental part of this concept of ideal model, since it defines the conceptual geometry that will later be physically tested.

Until the beginning of the 1960s there were no practical optimization studies, only simple problems were studied (beams, trusses), but from this, and with the advent of information and the FEM (Finite Element Method), techniques were employed for the design of weight reduction with stress restriction in truss structures in an analytical way. This was observed in (17), in which the structural optimization was broken when the title “Soil structure approach” developed by Dorn was introduced (10) which was based on topological optimization of structures.

In 2001, Sigmund (14) presents a paper with a topology optimization algorithm based on mathematical programming. The code is implemented using just 99 lines of MATLAB® input and includes optimization, mesh-independent filtering, and finite element code, which can be easily extended to include multiple load problems. Among one of Sigmund's 99-line code applications is Sofia Leão and Silvia Regina, but as the code was developed for 2D structures, they adapted the code developed for 2D structures and redid it for three-dimensional analysis, using the FEM - a numerical method that obtains approximate and discrete solutions. The main limitation found in this application was the capacity of the MATLAB® language in relation to obtaining solutions for algebraic systems with a large number of variables. Adapting to the C language, for example, could solve part of the problem and speed up program execution.

As a general objective, the initial proposal is to research references on topological optimization, in order to evaluate the domains in some cases (symmetrical MBBB, MBBB, lower load cantilever - BLC, automotive chassis and bridge) and subsequently create a computational model of library capable of optimizing with different cases, based on the educational algorithms previously available. In addition, as specific objectives, it appears that the project aims to benefit designers and the companies in which they work since, the quality of the project is directly related to the profits of the enterprise. If a project is well designed and detailed, it is possible to anticipate and solve problems that could arise during the execution phase. Thus, there is an increase in the control of materials and services, providing cost reduction due to obtaining results through optimization, reducing project costs, whether with engineering rework, re-manufacture of new molds, etc. For this, the following specific objectives are posed: Simulate the 2D topological optimization technique to identify empty spaces and solid elements, and develop models that can previously calculate whether the structure can handle without breaking, without cracks, without deformation. And at the same time saving material in places where the analyzed structure is less affected.

Methodology. Most researchers and authors emphasize the importance of research planning so that it is possible to obtain reliable and adequate information for their purposes. According to (19)

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"Once the research problem has been formulated in a way that is clear enough to specify the types of information needed, the researcher needs to create his research plan ... which varies according to the objective of the research". Fig. 1 shows how the planning of this research was carried out.

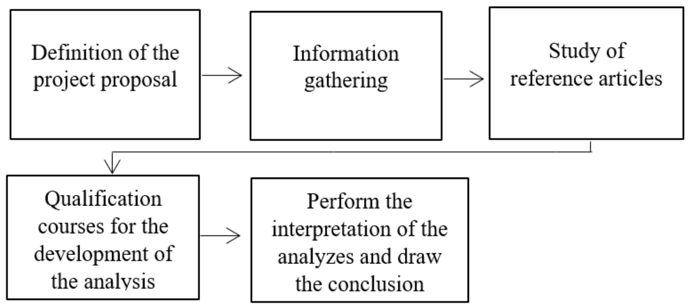

Figure 1. Schematic diagram of the search strategy.

Materials. The 2D TO algorithms were modified and implemented from codes developed by (14), (4) and (8). It was used the MATLAB®- Student Version R2017a, 64-bit model to work with the algorithms. A CPU Dell Inspiron processor based notebook Intel (R) Core (TM) i7-3630QM with 2.4 GHz CPU, with installed 12 GB RAM, with Windows 10 operating system, 64-bit version was used to synthesized TO with algorithm.

Methods. To achieve the proposed objectives, a case study should be carried out using MATLAB® and Scilab computer programs, and topology algorithms. The research methodology will be adopted based on the execution of bibliographic studies of existing references, such as the 99-line code of (14), and from these studies, adapt to studies related to the application of topological optimization in engineering projects. In preparing the work, a methodology structured by the sequence of steps graphically represented in Fig. 1 will be adopted.

Through the proposed data collection technique, a bibliographic search of references such as "Challis - A TO code of discrete level set written in Matlab.com" and "Sofia Leao e Almeida - Topology optimization of 2D and 3D structures will be carried out ", Focusing on the areas of Topological and Mechanical Optimization and on some factors that affect the quality of the optimal results, such as gray regions and "standard chessboard". After the bibliographical survey of the object of study, a selection is made in relation to the acquired information and the methods of structural optimization in order to delineate the boundaries that establish a research.

This documental part will be generated through the results of the computational programs MATLAB®, Scilab and OT algorithms. The possibility of observing the systematic of algorithms and the operation of computer programs generates a nature of giving criteria to the reader to be able to assess whether the use of Optimization is efficient to find new topologies. As methodological procedures, shown in Fig. 2, all data from computer programs and algorithms will be collected and will be analyzed and discussed. It is known that every procedure must be followed in stages so that other researchers can test the same conditions found in this work. Therefore, in the next chapter we will discuss such methodological procedures.

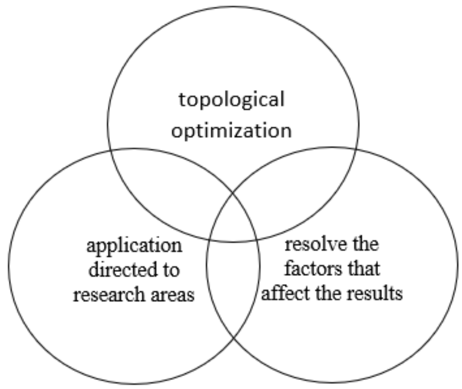

Figure 2. Methodological procedures.

Domain boundary condition. The domain of the project used was based on studying a small structure and that presents a fixed point of support and a load distributed in the superior part, Fig. 3. It is known that this domain refers to a structure of 5 cases, so the idea was to evaluate how these fixations and the distributed load, that in the case was used as unitary, could corroborate to create the profile of free form based on the topology optimization.

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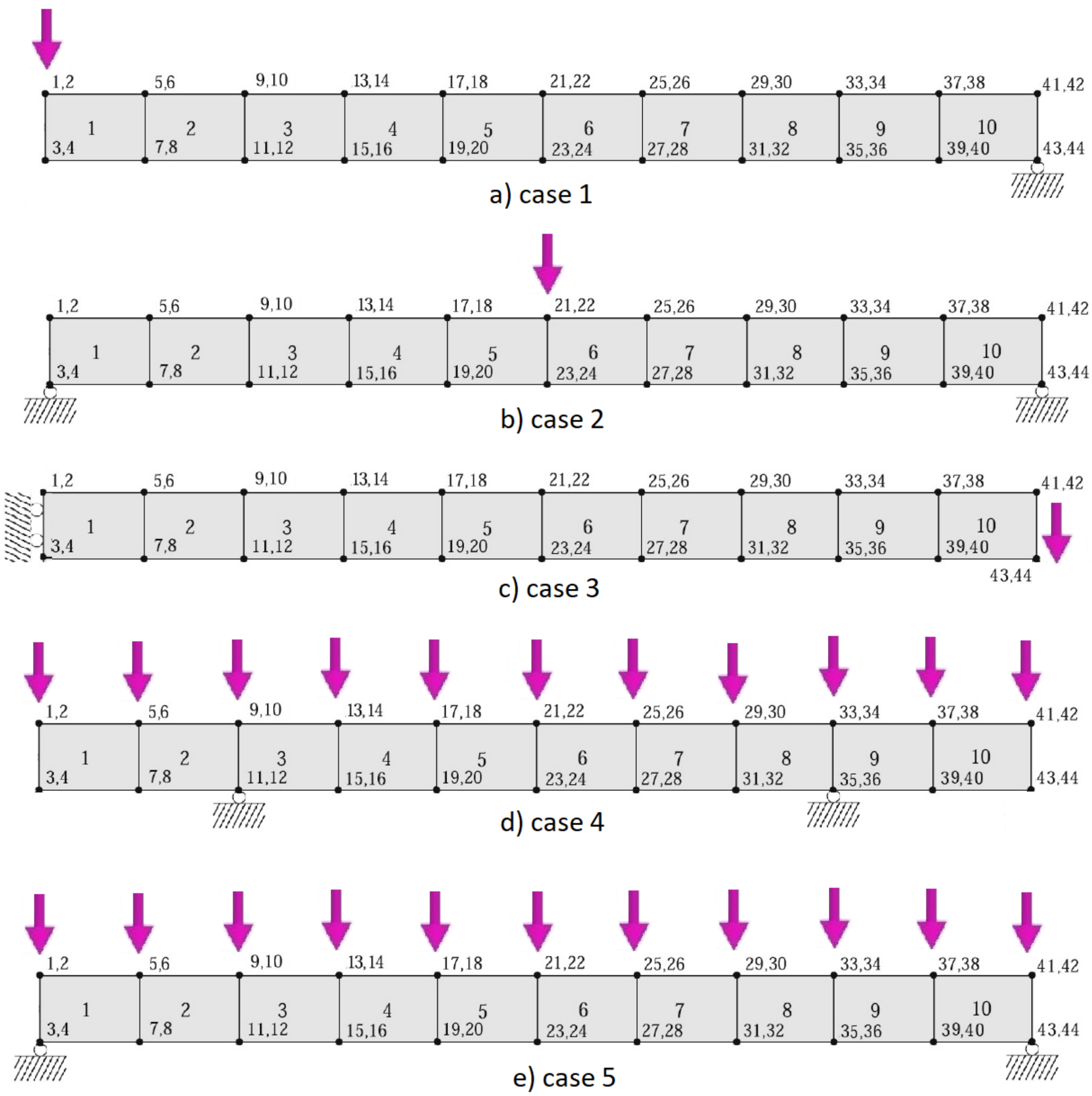

Figure 3. Types of applications domains a) MBBB symmetric b) MBBB c) Bottom-Load Cantilever (BLC) d) Automotive chassis e) Bridge

It is observed that the length of the original domain had nelx = 10 and nely = 1 that for this structure had a square mesh size in accordance Tab. 1. In Tab. 2 it is observed the parameters that can be utilized in theses structures.

Table 1. Description of input parameters and SIMP (3-7) and LS (1;2;9;13;15;16;18) characteristics

Variables	Description	Input
Nelx	No. elements in horizontal direction	60
Nely	No. elements in vertical direction	30
volReq	Solid frac. Of. Vol.	0.7
penal	Penalty p	3
rmin	Min. radius filter	1.5

Table 2. Parameters input description to algorithm;

Variables	Description	Input	Unit.
Unit.	mm, Newton, second	mm	-
E	Modulus of elasticity	210,0	MPa
nu	Coefficient of poison	0.3	Adm.
rho	Specific gravity material	7.7e-006	g/cm3
Yield	Flow limit	455	MPa
mesh	tetrahedral	14	mm
N	No of elem. In the mesh	10	Adm.
frac	Volume fraction	70	%

Proposed changes to the code. In accordance with Tab.1 and Tab. 2 and Fig. 3, Eq. 1 represents the input function of the SIMP algorithm in all cases.

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topopt(nelx, nely, volfrac, penal, rmin) (1)

The distributed loading that is desired in this beam is known in [N/m] but it must be transformed into nodal load [N], since the charge is applied to the DOFs (degree of freedom of each element). In order to distribute the values of the loads in each element node considering the direction x, which is the direction we are adopting for the loads, we just divide the value of –Ftotal/ nelx+1, in this way it was ensured that the force is equally distributed in each node. Therefore, to define the applied loads on the elements in the upper line we consider an example according to Fig. 4, where we have 10 elements arranged side by side, so nelx = 10 and nely = 1.

As seen in Fig. 4, there are 2 DOFs for each node, one representing horizontal displacement and the other.

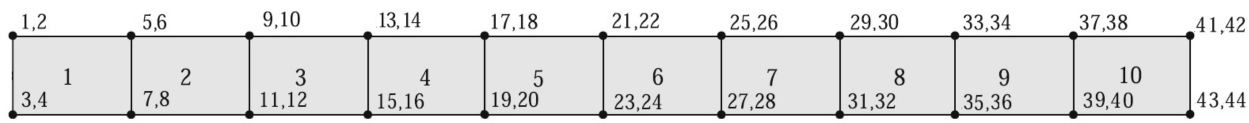

Figure 4. Example for to define distribute loads domain node

The equations demonster all codes in all cases (1, 2, 3, 4 and 5) that was configured in algorithm.

% define loads and suports (MBBB symmetric divided, force on upper left side) CASE 1

%F(2,1) = -1;

%fixeddofs = union([1:2:2(nely+1)],[2*(nelx+1)*(nely+1)]);*

%alldofs = [1:2(nely+1)*(nelx+1)];*

%freedofs = setdiff(alldofs,fixeddofs);

%define loads and suports (MBBB symmetric, vertical force at top center) CASE 2

%F(2(nely+1)*nelx/2+2,1) = -1;*

%fixeddofs = [2(nely+1)-1,2*(nely+1),2*(nely+1)*(nelx+1)];*

%alldofs = [1:2(nely+1)*(nelx+1)];*

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```
%freedofs    = setdiff(alldofs,fixeddofs);


% define loads and suports (CANTILEVER top(10,1,0.7,3.0,1.5)CASE 3
%F(2*(nelx+1)*(nely+1),2) = -1;
%fixeddofs = [1:2*(nely+1)];
%alldofs     = [1:2*(nely+1)*(nelx+1)];
%freedofs    = setdiff(alldofs,fixeddofs);


% Define loads and supports – Bridge with nsup CASE 4:
F(2*(round(nelx/2)+1)*(nely+1),1) = -1;
fixeddofs = [2*(nely+1)-1:2*(nely+1),2*(nelx+1)*(nely+1)-
1:2*(nelx+1)*(nely+1)];
alldofs = [1:2*(nely+1)*(nelx+1)];
freedofs = setdiff(alldofs,fixeddofs);


% Define loads and supports – Bridge without CASO 5:
F(2*(round(nelx/2)+1)*(nely+1),1) = -1;
fixeddofs = [2*(nely+1)+7:2*(nely+1)*3,2*(nelx+1)*(nely+1)-
9:2*(nelx+1)*(nely+1)-8];
alldofs = [1:2*(nely+1)*(nelx+1)];
freedofs = setdiff(alldofs,fixeddofs);
```

Results and Discussion. It is possible to see in Fig. 5 all cases in accordance with Tab. 2. It is possible to identify the regions of de number between 0-1, that in 0 this regions can be cut or

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excludes od domains, but in regions of the number 1 are the locations in domain that the material have that to exist in all boundary conditions.

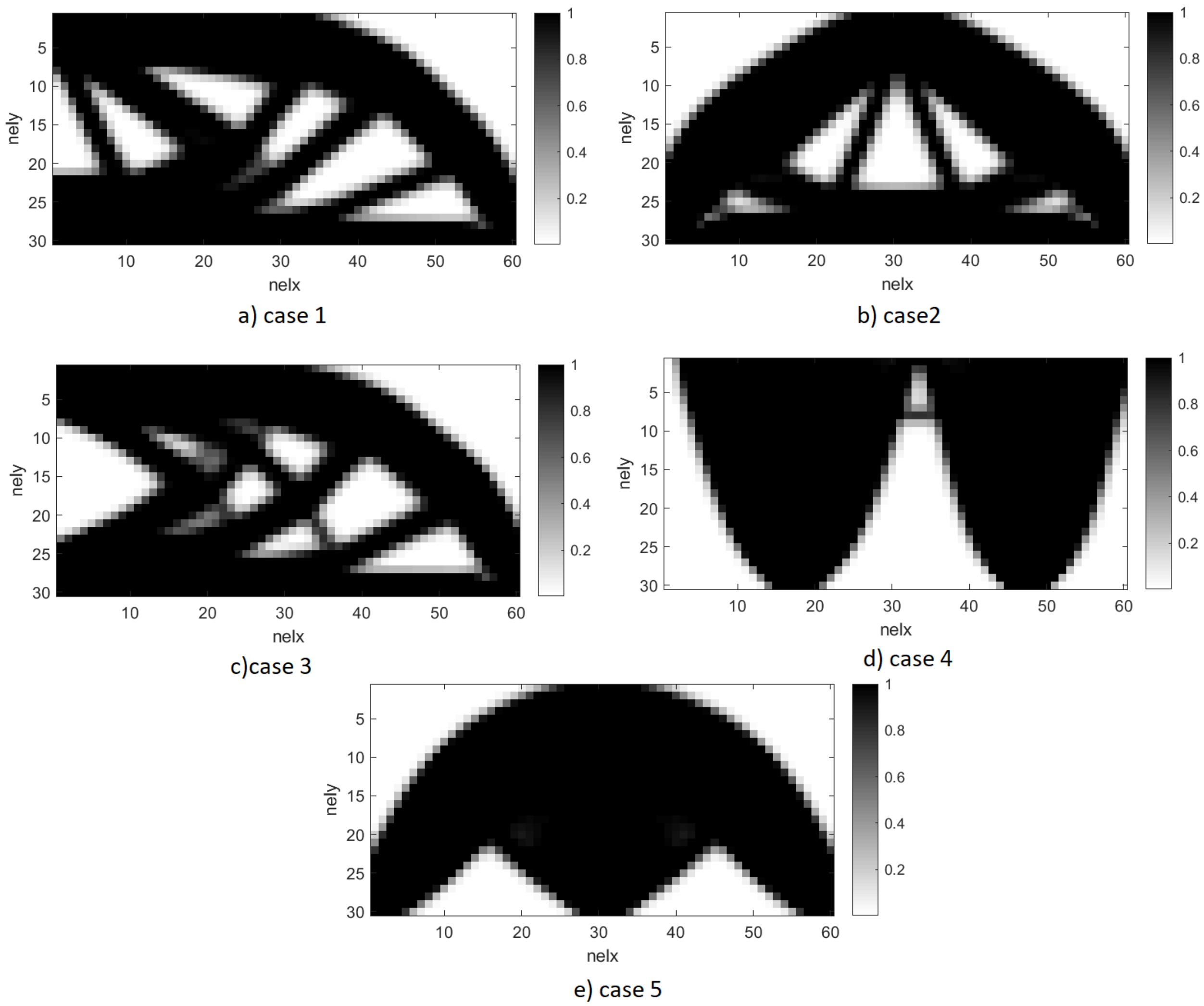

Figure 5. Types of TO applications domains a) MBBB symmetric b) MBBB c) Bottom-Load Cantilever (BLC) d) Automotive chassis e) Bridge

In Fig. 6 it is possible to see the numbers of Compliance (N.mm). It is possible also to see time of cicles in process of optimization.

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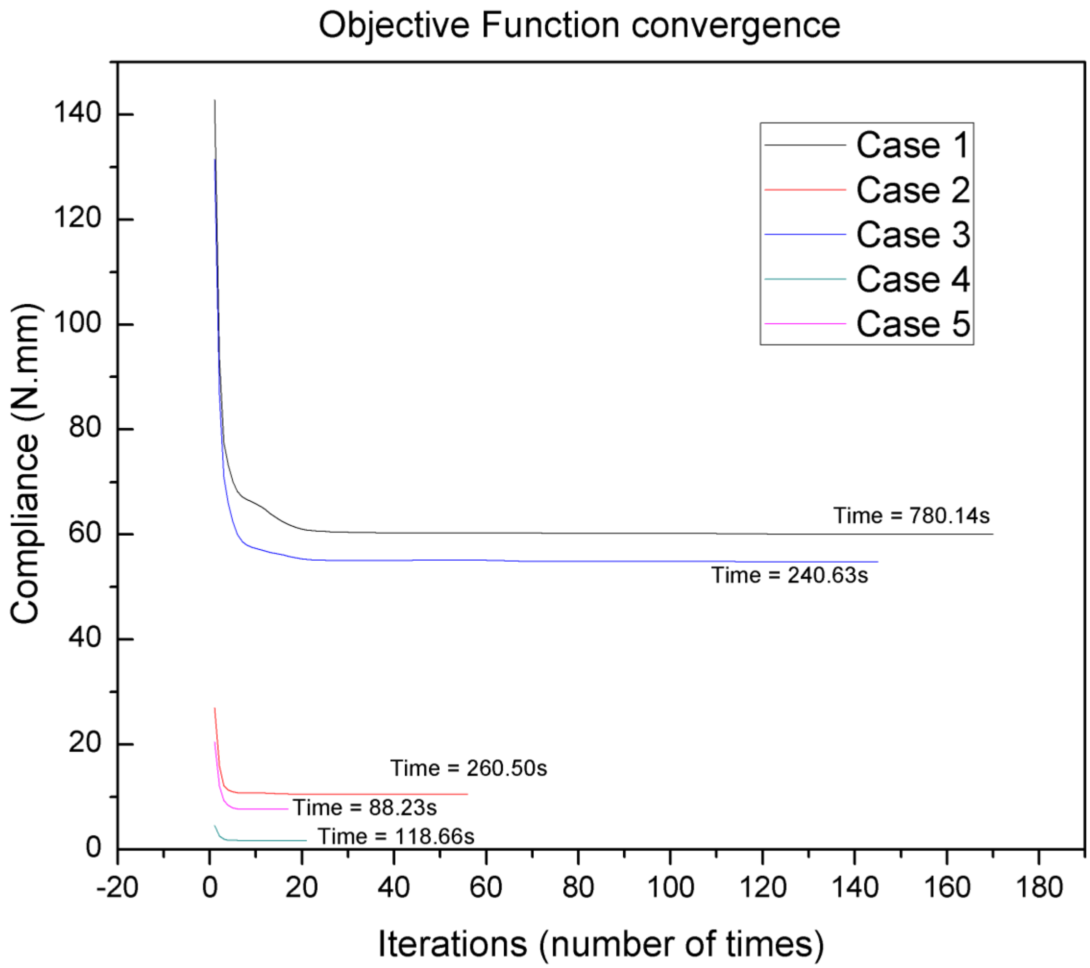

Figure 6. Graph objective function convergence: All cases.

Conclusion. It can be observed that for this domains occurs differents energy of compliance between case 1 and case 3 and others cases, because case 1-3 has force applied away from the support.

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References.

(1) Allaire G, Jouve F, Toader AM (2002) Une méthode de lignes de niveaux pour l'optimisation de forme, Comptes Rendus Math., 334-12 1125–1130
(2) Allaire G, Jouve F, Toader AM (2004) Structural optimization using sensitivity analysis and a level-set method, 194-1 https://doi.org/10.1016/j.jcp.2003.09.032
(3) Alphen JMJ (2017) Structural Optmization for 3D concrete printing, Eindhoven University of technolog. Thesis
(4) Andreassen E, Clausen A, Schevenels M, Lazarov B S, Sigmund O (2011) Efficient topology optimization in MATLAB using 88 lines of code. Struct Multid Optim 43:1–16. https://doi.org/10.1007/s00158-010-0594-7
(5) Bendsøe MP, Kikuchi N (1988) Generating optimal topologies in structural design using a homogenization method. Comput Meth Appl Mech Eng 71:197–224. https://doi.org/10.1016/0045-7825(88)90086-2
(6) Bendsøe MP (1989) Optimal shape design as a material distribution problem. Struct Optim 1:193–202. https://doi.org/10.1007/BF01650949
(7) Bendsøe MP, Sigmund O. (2003) Topology Optimization: Theory, Methods, and Applications. Springer-Verlag Berlin Heidelberg GmbH
(8) Challis V J (2010) A discrete level-set topology optimization code written in Matlab. Struct Multid Optim 41:453–464. https://doi.org/10.1007/s00158-009-0430-0
(9) Dijk NPV, Maute K, Langelaar M, Keulen FV (2013) Level-set methods for structural topology optimization: A review, Struct. Multidiscip. Optim., 48- 3 437–472. https://doi.org/10.1007/s00158-013-0912-y
(10) Dorn, W. S. Automatic design of optimal structures. Journal de mecanique, v. 3, p. 25–52, 1964.
(11) Lima CR (2002) Projeto De Mecanismos Flexíveis Usando O método de Otimização Topológica. Dissertation, University of Sao Paulo 1-167
(12) Liu K, Tovar A (2014) An efficient 3D topology optimization code written in Matlab. Struct Multid Optim 50:1175–1196. https://doi.org/10.1007/s00158-014-1107-x
(13) Osher SJ (1988) Fronts Propagating with Curvature Dependent Speed, Comput. Phys., 79- 1 1–5
(14) Sigmund O (2001) A 99 line topology optimization code written in matlab. Struct Multid Optim 21:120–127. https://doi.org/10.1007/s001580050176
(15) Suresh K (2010) A 199-line Matlab code for Pareto661 optimal tracing in topology optimization. Stru Multid Opti 662 42:665–679. https://doi.org/10.1007/s00158-010-0534
(16) Suresh K, Takalloozadeh M. (2013) Stress-constrained topology optimization: A topological level-set approach, Struct. Multidiscip. Optim., 48-2 295–309. https://doi.org/10.1007/s00158-013-0899-4
(17) Victoria, M.; Martí, P.; Querín, O. M. Topology design of two-dimensional continuum structures using isolines. Computers and Structures, v. 87, n. 1–2, p. 101 – 109, 2009. ISSN 0045-7949. Disponível em: <http://doi.org/10.1016/j.compstruc.2008.08. 001>

TAS Journal, vol. 5, n. 4, p.165-176
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DECEMBER 2021
paulohlf@yahoo.com.br

(18) Wang M, Wang X, Guo D (2003) A level set method for structural topology optimization, Comput. Methods Appl. Mech. Eng., 192 227–246 https://doi.org/10.1016/S0045-7825(02)00559-5
(19) Selltiz, C.; Jahoda, M.; Deutsch, M.; Cook, S. W. Métodos de pesquisas nas relações sociais. São Paulo: E.P.U., 1974, 687 p.

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