Implementing Steel Design in Educational Software: The Linear Elements Structure Model Program

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Abstract. The Linear Elements Structure Model, or LESM for short, is a user-friendly, free-to-use, and open-source educational software for the structural analysis of models composed of linear elements. Aimed at aiding students, teachers, engineers, and architects to better understand the behavior of structures and improve their workflow, its intuitive and straightforward GUI (Graphical User Interface) allows a simple, yet effective approach to modeling, running calculations of linear-elastic static and dynamic effects, and visualizing the internal stresses and strains in two-dimensional and three-dimensional trusses and frames. This paper expands upon the capabilities of LESM by detailing the implementation of steel design for bidimensional frames in compliance with the Brazilian steel structure design code, NBR8800:2008, within the current version of the software, building upon previous efforts to enhance LESM's functionality, through object-oriented programming in the MATLAB environment. With the feature of steel design originally conceived as an extension for a previous version of the software, the LESM program has since been updated and reworked with easier and quicker user interaction, a more optimized source code, and the addition of new features. By comparing past and current versions of the software and examining the source code of the steel design extension, it was possible to successfully integrate the steel design feature into the latest iteration of LESM, broadening the program's scope of use, both for the academic and industrial sectors in the field of analysis and design.

Keywords: Steel Design; Educational Software; Linear Elements Structure Model.

1 Introduction

The Linear Elements Structure Model software, or LESM for short, is an educational software designed for the structural analysis of models composed of linear elements (i.e., straight bar elements) developed through object-oriented programming. With an open-source code available for community contributions written in the MATLAB script language and a modularized structure of scripts that offers easier understanding and manipulation of the code structure, the software provides not only simple, yet effective access to structural analysis to engineering students and professionals, but a better understanding of the structural analysis process.

As stated by Rangel and Martha [1], LESM allows for the calculation of static and dynamic linear-elastic effects as well as the visualization of stresses and deformations in trusses, frames, and grillages, with a friendly graphical user interface. Despite being a powerful tool for the analysis of structures composed of linear models, a feature intended to design structures regarding their stresses, buckling parameters, loads, and boundary conditions could greatly broaden the functionalities of the program and the appeal to the industry, as most of the software capable of returning profile sections and verifications require a paid license. The addition of a design feature would also be of great aid to students interested in working as structural designers, giving them a chance to better visualize the iterative process of choosing the best configuration of structures for an effective project design.

With that in mind, a plugin for the design of two-dimensional steel structures following the NBR 8800 guidelines [2] was developed and implemented in version 2.0 of the program, which expanded the range of possibilities offered by the software for both commercial and educational use. Currently, LESM is at version 3.0, with a more optimized source code and new features compared to previous versions. However, the plugin developed for the design of steel structures is no longer compatible with the program due to its code restructuring in its latest iteration, making the feature obsolete. This paper aims to describe the process of reimplementation of the two-dimensional steel structure design plugin in version 3.0 of LESM through the preparation of documentation and the incorporation of scripts previously written on the 2.0 iteration of the software, as well as the implementation of new features and improvements over the past version of the steel design plugin.

2 Materials and Methods

To integrate the steel design plugin into the current version of LESM, it was necessary to compare lines of code between different versions. To minimize human error and streamline the comparison process, a file and code comparison software was used to identify discrepancies between the MATLAB scripts in LESM versions 2.0 and 3.0. The modularization of Object-Oriented Programming proved especially effective in this approach, granting the possibility to select and edit each different module of the program associated with the plugin without having to work through the code scripts of other features that were not in the scope of this study. Having different files that refer to each feature and function in the LESM software also made it easier to identify sources of error and irregularities within the code implementation phase. Modularization also facilitated the documentation of script changes and reworks across different software versions, provided an effective method for identifying and incorporating updates from the steel design plugin's author, and simplified the integration of improvements.

For better information management and file-to-file change history, a repository was created on the GitHub development platform (available at https://github.com/allpitanga/LESM-Steel-Design) containing an unaltered instance of LESM 3.0 named "main," and another named "Steel-Design," where the updates written on the code files were continuously implemented. Having the possibility to revert changes that proved unstable to the program aided in identifying programming shortcomings and poor implementation of code scripts, as well as facilitated the process of comparing performance and metrics with the plugin's past iteration. During the implementation phase, the scripts were classified according to the modifications needed in their respective lines of code as follows:

Added Codes: Files of code that were not present in version 3.0 of LESM and version 2.0 originally but were written and included for the functionality of the steel design plugin.

Updated Codes: Files that had changes made to their script by the steel design plugin's author for design calculations and interactions with the steel design files present in version 2.0 of LESM.

Verified Codes: Files where the scripts in version 2.0 and version 3.0 have divergences, but no changes or additions were made by the steel design plugin's author.

It is important to note that initially, the verified codes were not changed, as the code scripts pertained to internal program routines and features that were reworked during the LESM software update. However, it was important to document the files and functions of these scripts as the codes of the steel design plugin that interacted with files that suffered changes between the two iterations of the LESM software had the risk of no longer working as intended or not running at all. The proper documentation of the changes made between the different versions of the analyzed files, as well as relevant comments regarding their divergences between the two versions of the LESM software, proved necessary for the implementation and improvement of the steel design plugin.

3 Results

The implementation of the steel design plugin features in the current iteration of LESM was a success, as exemplified by Fig. 1, which illustrates in red highlight the modified GUI (Graphical User Interface) window for the creation of a new load case, previously presented in the steel design plugin and now featured on LESM 3.0. In the screenshot, newly added toolbar buttons related to the steel design functionalities are also highlighted and incorporated into the current version of the software.

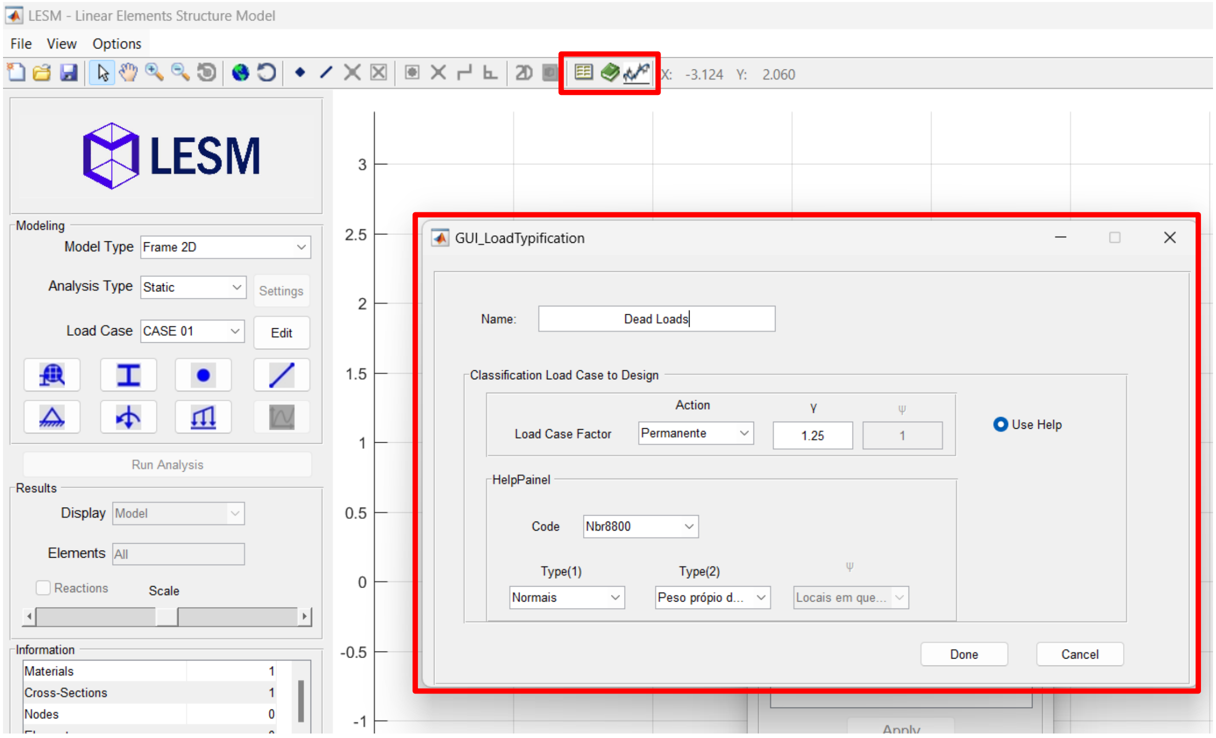

Figure 1. Graphical User Interface for New Load Case creation on LESM 3.0 and toolbar highlights: authors

The added codes, most previously located on the root folder of LESM 2.0, were redirected to a corresponding folder on LESM 3.0 according to their function on the program, as a better-organized code helps with the understanding of each script's functionality and aids the future implementation of features, especially in Object-Oriented Programming. To that end, code scripts such as W_beam.m and Steel.m, both related to the calculations and beam parameters, were directed to the analysis folder of LESM 3.0. For files related to the design calculation report generated by the plugin, such as Designreport.m and Standards.m, a folder named "report" was created in the LESM 3.0 root directory.

The implementation of the steel design plugin also needed to accommodate the option of using different materials and steel profiles in LESM, which was not accounted for on the LESM 2.0 version of the addon. In its original iteration, as described in Assunção's work [3], the software only supported the analysis of W-shaped sections in accordance with NBR:8800. A significant enhancement in the implemented version of the steel design plugin is the introduction of a wider variety of beam shapes. The updated software now includes beam types such as welded W beams, double W beams, welded and hot-rolled double L beams, welded circular tubes, and both hot-rolled and welded WT beams. This expanded selection offers users a greater variety of structural configurations and design possibilities, adhering to either GERDAU Açominas catalogs, commonly used in the Brazilian civil engineering industry, or the ASCII American code [4]. Additionally, users have the option to define custom section sizes for the supported shapes.

To accommodate the possibility of having different materials, a new abstract class, following the Object-Oriented Programming structure suggested by Martha [5] was introduced for generic materials, with subclasses containing different kinds of materials commonly used in design projects. With that addition, every parameter that was common to the different types of materials (such as steel or concrete) was allocated in the abstract material class, and their individual values (concrete, steel, timber, for instance) were set to different subclasses according to the material type and parameters such as stiffness and strength. Another area of improvement was in how the plugin handles groups and spans.

On the LESM 2.0 iteration of the steel design plugin, groups were used as means of defining continuous beams with more than two nodes, such as beans with point loads along the span for instance. When incorporated into version 3.0 of LESM, groups now handle beams and columns with the same steel profile for designing purposes, which is a common practice in the design of steel structures, and the previous purpose of groups was applied to functions referred to as column spans and beams.

Regarding shear stresses, the plugin originally did not consider stiffeners, adopting a default value of the k_v parameter used for the calculation of shear effects. During the implementation process, the possibility for users to input a different value of k_v was implemented. Additionally, a geometric nonlinear analysis module is currently being developed by the same research group that contributes to LESM, building upon previous works of Rodrigues, Burgos, and Martha [6] [7] [8], and is planned to be included as a feature in future releases of the software. This functionality, expected to be included in future releases of the software, will effectively account for nonlinear effects in structures that may be significantly influenced by them.

Another significant addition to the design routine of the plugin was the verification of the serviceability of the structural members, incorporating the maximum allowable displacement as specified by the Brazilian code. Finally, during the implementation phase, several calculation routines were revised and optimized to reduce errors and enhance the plugin's overall effectiveness.

4 Conclusions

The implementation of the steel design plugin in the current iteration of LESM significantly broadens the software's scope and enhances its usability and effectiveness. While many design software solutions require paid licenses and do not disclose their source codes, LESM stands out as a valuable tool for both engineering students and professionals. Its ability to inspect calculation routines and the design report generated by the program offers an effective way for users to learn and analyze the design parameters, which facilitates the fine-tuning of project choices by the designer. Further development is encouraged for the software, including the addition of non-symmetric steel section shapes, automation of the Cb parameter calculation (currently a user input), and the incorporation of cold-formed steel sections in accordance with the Brazilian code NBR:14762.

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References

[1] RANGEL, R. L.; MARTHA, L. F. *LESM – An object-oriented MATLAB program for structural analysis of linear element*. Wiley Periodicals, Inc., 2019
[2] ASSOCIACAO BRASILEIRA DE NORMAS TECNICAS. *NBR8800:Projeto de estruturas de aço e de estruturas mistas de aço e concreto de edifícios*, 2008.
[3] ASSUNÇÃO, R. *Uma estrutura de classes orientada a objetos para verificação de projeto de perfis metálicos em MATLAB*. Master Thesis — Pontifical Catholic University of Rio de Janeiro, 2021.
[4] ALMEIDA, T. *Dimensionamento de Barras de Aço em MATLAB*. Bachelor Thesis — Pontifical Catholic University of Rio de Janeiro, 2019.
[5] MARTHA, L. *Análise matricial de estruturas com orientação a objetos*. – 1. Ed. - Elsevier: PUC-Rio, 2018.

[6] RODRIGUES, M.A.C.; BURGOS, R.B.; MARTHA, L.F. *A Unified Approach to the Timoshenko 3D Beam-Column Element Tangent Stiffness Matrix Considering Higher-Order Terms in the Strain Tensor and Large Rotations* - International Journal of Solids and Structures, Vols. 221-222, 2021.
[7] RODRIGUES, M.A.C.; BURGOS, R.B.; MARTHA, L.F., *Complete Tangent Stiffness Matrix Considering Higher-Order Terms in the Strain Tensor and Large Rotations for a Euler Bernoulli - Timoshenko Space Beam-Column Element* - MethodsX, Vol. 8, 2021.
[8] BURGOS, R.B.; MARTHA, L.F. *Geometric Nonlinear Analysis using the Two-cycle Method in Ftool* - Proceedings of CILAMCE-2024: the joint XLV Ibero-Latin-American Congress on Computational Methods in Engineering, ABMEC, 2024.