## Educational Tool for the Analysis of Structures with Geometric Nonlinearity

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This article presents in detail the development and use of a graphical tool to analyze framed structure models with the consideration of large displacements, rotations, and deformations in the elastic regime of the material. The main objective in the development of this application is the focus on the educational aspect about the behavior of reticulated structures with geometric nonlinearity, and this article seeks to demonstrate, through a series of validation examples, the performance and results of the developed system.

This tool is being implemented from the FTOOL (Two-dimensional Frame Analysis Tool Program) program [1]. The FTOOL was conceived in 1991, from a research project of the Tecgraf Institute of Technical-Scientific Software Development of PUC-Rio (Tecgraf/PUC-Rio). Over the last years FTOOL have demonstrated to be a valuable tool for structural engineering teaching, being used on structural analyses, concrete and steel design courses on various civil engineering programs of universities all over the world. It consists of a structural analysis program possessing, in a single platform, all the necessary tools for an efficient model pre and post processing and a fast solving strategy. The implemented graphical user interface is an efficient and user-friendly environment built using the IUP (Portable User Interface) system [2]. FTOOL uses an internal solver, FRAMOOP, which is a simplified version of the FEMOOP (Finite Element Method – Object Oriented Program) system [3] adequate for the analysis of framed structure models.

The IUP system is a multi-platform toolkit for building graphical user interfaces that offers a simple API in different programming languages and allows a program source code to be compiled in different systems without any modification. Its main advantage is the high performance, due to the fact that it uses native interface elements.

The FRAMOOP system is written in the C programming language and adopts a programming philosophy similar to the Object Oriented Programming (OOP) paradigm, and is responsible for the process of analyzing plane and space reticulated structures.

To provide a way for students to analyze the geometrical nonlinear behavior of the structures, some numerical algorithms will be available to solve the nonlinear system of equilibrium equations and follow the equilibrium path. These algorithms include the standard Newton-Raphson, Two-Cycles, and Generalized Displacement Control [4] schemes, all of them implemented following the updated Lagrangian formulation. The tangent stiffness matrices corresponding to the aforementioned formulation are included in the FRAMOOP code for Euler-Bernoulli and Timoshenko beam elements. These matrices were formulated considering the second-order nonlinear terms of the Green-Lagrange strain tensor [5].

The possibility of performing a nonlinear analysis through different iterative-incremental methods is necessary to allow users to follow the post-critical equilibrium trajectory and to evaluate the snap-through and snap-back phenomena, characteristic of this type of analysis, since different responses can be obtained by the use of each method, including inappropriate responses if a convenient method for the model is not used. Load versus displacement graphs will be displayed to express the nonlinear behavior of the structure along the incremental steps of the method in question until it reaches the desired load stage by the user.

Thereby, this tool is not intended to teach the implementation or the theory behind an analysis with geometric non-linearity, but rather to develop understanding of structure behavior with second order effects. The possibility for students to test different models with different solution algorithms and to evaluate the equilibrium path and critical points is important to give them a sensitivity on how the structure behaves.

## References

[1] L.F. Martha, *FTOOL: A Structural Analysis Educational Interactive Tool*, Proceedings of the Workshop in Multimedia Computer Techniques in Engineering Education, Technical University of Graz, Austria, 51-65, 1999.

[2] C.H. Levy, L.H. Figueiredo, M. Gattass, C. Lucena, D. Cowan, *IUP/LED: A Portable User Interface Development Tool*, Software: Practice & Experience, 1995.

[3] L.F. Martha, E. Parente Jr., *An Object-Oriented Framework for Finite Element Programming*,
Proceedings of the Fifth World Congress on Computational Mechanics, IACM, Vienna, Austria, 2002.
[4] S.E. Leon, G.H. Paulino, A. Pereira, I.F.M. Menezes, E.N. Lages, *A unified library of nonlinear solution schemes*, Appl Mech Rev, Article 040803, Vol. 64, No. 4, 2011.

[5] M.A.C. Rodrigues, R.B. Burgos, L.F. Martha, A Unified Approach for Timoshenko Geometric Stiff-ness Matrix Considering Large Rotation and Large Dis-placements Gradients, to be submitted to Latin America Journal of Solids and Structures