Educational interactive graphics tool for teaching the Cross process

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Abstract. The program demonstrates to students in the Structural Analysis discipline of the Civil Engineering course how the Cross Process (Moment Distribution Method) works for continuous beams, visually showing the physical interpretation of the method associated with the calculations in the same way as they are done in calculation memory. In addition to the calculations, the program shows the structural model with the loads (uniformly distributed forces across each span), its deformation, and its bending moment diagram. The program, with open-source code, was implemented in Java, based on the Object-Oriented Programming paradigm. The program for calculating continuous beams using the Cross Process has four canvases. It is on these canvases that the structural models, their diagrams, and their results will be drawn. The user can interact using the mouse to model the continuous beam, create new internal supports, remove internal supports, modify the dimensions of the spans, or modify the load values. The student can track the results by following the incremental analysis of the method step by step. Furthermore, the student can interfere in the iterative solution process by forcing the bending moment balance of any internal node in any order. All these procedures help the student to understand the analysis process. Well-documented source code is also an essential component for learning the method.

Keywords: analysis of continuous beams; Cross process; interactive educational software.

1 Introduction

The Cross Process (or Moment Distribution Method) is a relatively simple method for calculating bending moments in continuous beams, flat frames, grids, and space frames. This method only applies to structures without external dislocations (of the translational type); that is, it only applies to structures with inextensible bars and those with rotational dislocations. Despite this limitation, the method created by Hardy Cross in the 1930s [1] is still used to calculate structures. The Moment Distribution Method also has an academic objective, as it serves as an introduction to the Displacement Method, the method currently most used for analyzing structures formed by beams and columns.

The Cross Process is an old method for analyzing structures that only made sense to be used when computers did not exist. It only applies to structural models with solely node rotation degrees of freedom. Despite this, the process is interesting from an educational point of view as it demonstrates the behavior of structures in which structural elements with higher stiffness absorb more internal forces. Furthermore, the process is an interesting example of an iterative relaxation method. For these reasons, the technique is still taught in some civil engineering courses. Educational material about the Cross Process is found with the following designations: Moment Distribution Method – White, Gergely, and Sexsmith [2], Udoeyo [3], Hafeez [4] –, 2-cycle Moment Distribution Method, Leong [5], and Kanis Method of Rotation Distribution, Rizwan [6].

This article describes a graphical tool called e-Cross for teaching the Cross Process. This program aims to demonstrate to users, undergraduate students in Civil Engineering, how the Cross Process works in the case of continuous beams. The program's execution highlights the physical interpretation of the Moment Distribution Method, showing how the deformed configuration of the beam and the diagram and bending moments vary during the iterative solution of the method. The program also shows the calculations in the same way they are done in a manual solution, making an association with the physical interpretation.

The main advantages of the e-Cross program come from the programming language used: Java. This language was chosen because it allows the program to be executed online via the Internet or offline after downloading the program and the JRE (Java Runtime Environment). The program can be obtained via the URL: http://www.tecgraf.puc-rio.br/etools/cross. Another advantage of the Java language is that it is based on the object-oriented programming paradigm, allowing code to be reused naturally. The source code of e-Cross is open, and it is available on its website.

The e-Cross program is an educational tool used during Structural Analysis classes in any Civil Engineering course when teaching the Cross Process. Students can also access the program from their homes, making learning the method much more accessible. Easy access also makes it possible to use the program to calculate continuous beams, which is always helpful for structural design.

The development of this educational tool was motivated by the excellent textbook authored by Richard White, Peter Gergely, and Robert Sexsmith [2] of Cornell University. The book explains the Moment Distribution Method with the help of a physical experiment shown in Fig. 1 (copied from the book). The e-Cross program can be seen as a virtual version of this experiment.

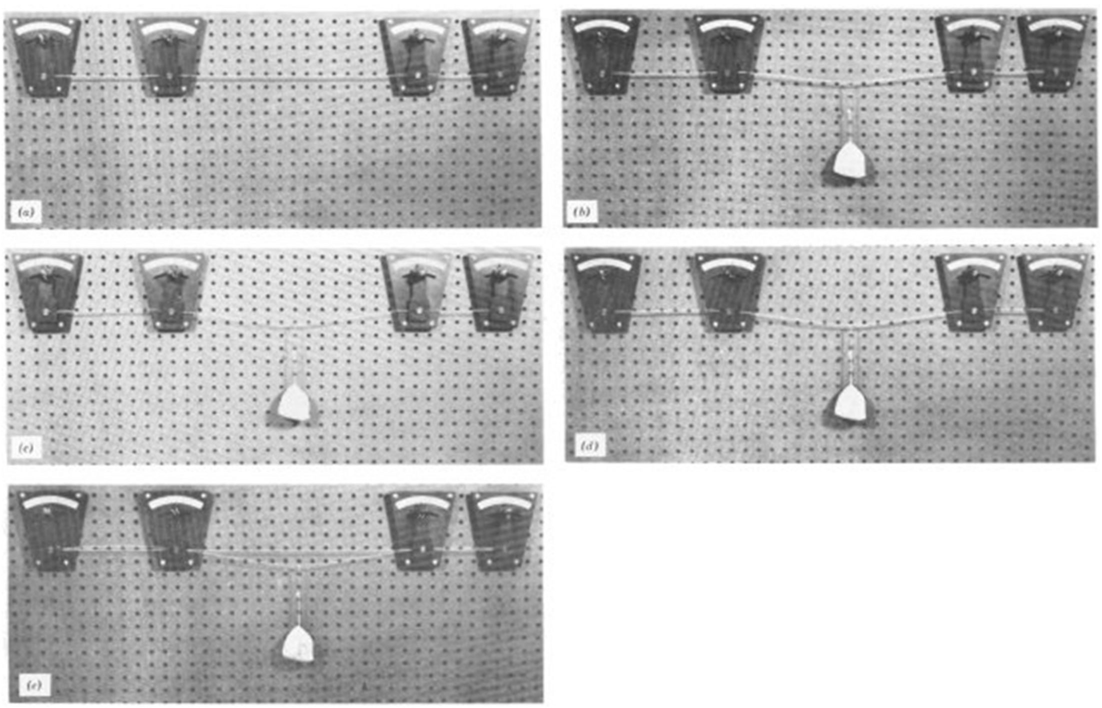

Figure 1. Physical experiment to simulate the Cross Process
(from White, Gergely, and Sexsmith [2])

2 The program

The graphical interface of the e-Cross program, shown in Fig. 2, has a drop-down menu at the top, a toolbar, a message line, and four large windows called screens. (comparison with the white canvases used by painters to make their paintings). It is on these canvases that the structural models, their diagrams, and their results will be "painted."

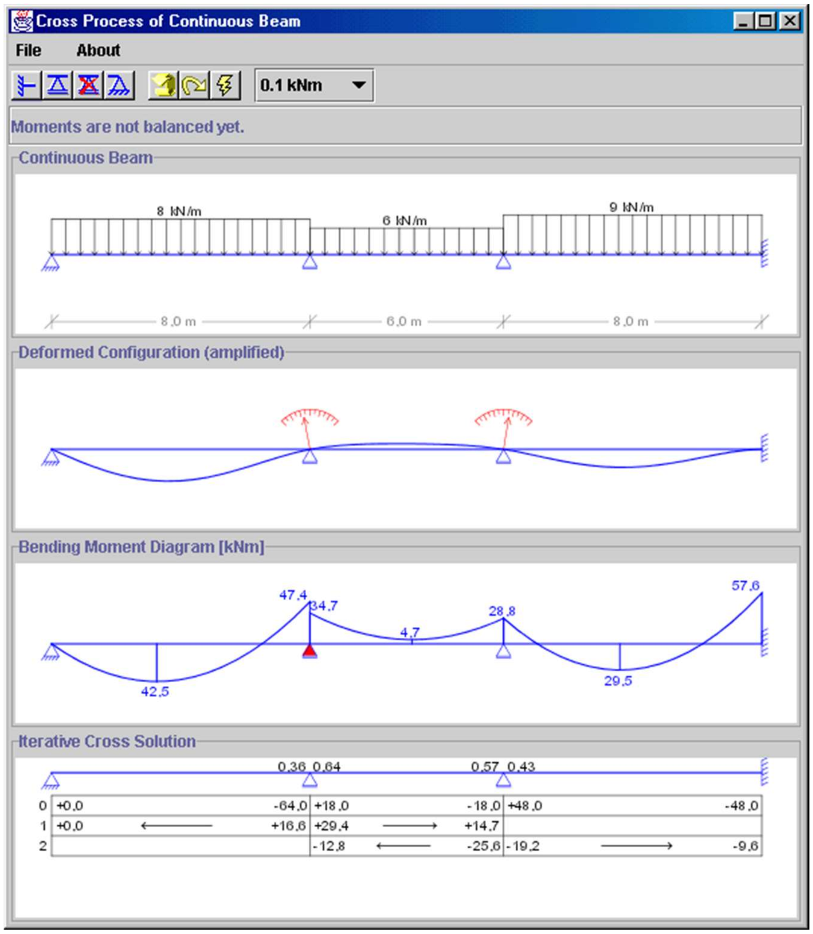

Figure 2. Graphical interface of the e-Cross program

2.1 File menu and control bar

The File menu at the top of the graphical interface contains options to open a file from a structure, save the current structure, or end the program execution (Fig. 3). It should be noted that there are no options to save or open a file in the online version of the program (via the Internet browser). This feature only appears in the offline version. The structure model is saved in a file in standard text format. The ".crs" extension is adopted as the standard for program files.

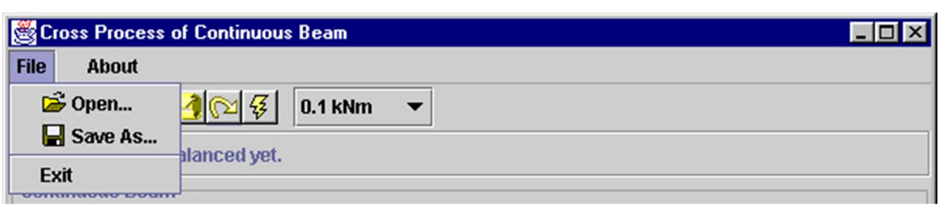

Figure 3. File menu with options for opening and saving models to files

The control bar, shown in Fig. 4, contains commands for modeling the continuous beam and controlling the simulation. The four buttons in the first group allow editing and modification of the structure. The first and fourth buttons change the types of the initial and end supports from simple to embedded or vice versa. The second and third buttons allow the inclusion and removal of internal supports, respectively.

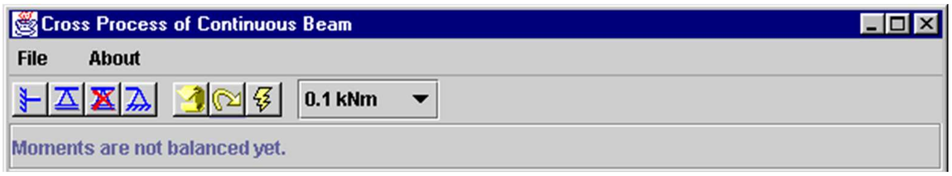

Figure 4. Control bar and message area

The three buttons of the second group of the control bar control the Cross Process iterative simulation. The first button in the group returns the process to the beginning, corresponding to the perfect engagement of all internal nodes. The second button in the group allows the process to be carried out step by step: the next node to be balanced is the one with the highest modulus value for the unbalance of bending moments. The third button in the group triggers the automatic resolution of the process until final convergence. The control bar also has an option to specify the numerical precision. This option is done by modifying the number of decimal places for bending moments.

Below the control bar is an area for messages to the user (Fig. 4). The messages direct the program's execution, such as the message "Moments are not balanced yet," which indicates that the process has not yet converged; there are still bending moments to be balanced. When the iterative solution of a structure converges, the program notifies the user through the message "Cross solution performed."

2.2 Modeling canvas

The first large white area of the program's graphical interface, or the first canvas, is used to show the structural model and the loads (only a uniformly distributed load is considered per span). This canvas (Fig. 5) also allows for the manipulation of the structure. This means that the user can add or remove internal supports (after activating the corresponding option on the control bar), move supports horizontally, change the dimensions of the spans, or vary the load value in each span.

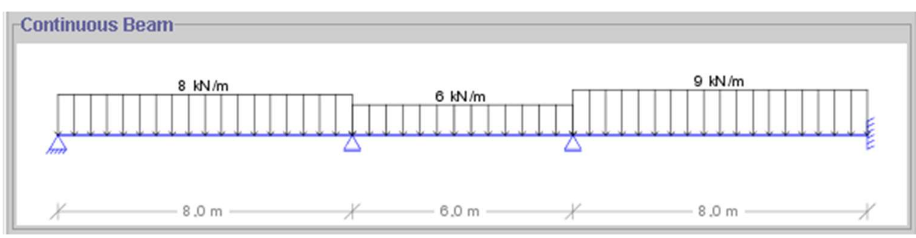

Figure 5. Continuous beam modeling canvas

The modeling process is done by direct manipulation by the user, who changes the structure very intuitively, always using the mouse. For example, to move a support, click the mouse on the desired support and drag it to its new position. The lengths of the spans adjacent to the node (drawn on the modeling canvas) change as the support is dragged. A similar procedure is used to change the loading of a span: the load is dragged in the vertical direction, modifying its value and size in the drawing. This procedure makes it very simple to create new structures and change them. This ease and speed of modeling are vital points in the educational process intended by the program: the student has the opportunity to test several alternatives, and the program shows the iterative steps that occur during the solution of the cross process.

2.3 Deformed configuration canvas

The other canvases show the structure's response in three different ways, literally “explaining” how the Cross Process works. The second canvas shows the deformed configuration of the structure (Fig. 6). The program shows changes in the deformation of the continuous beam throughout the process.

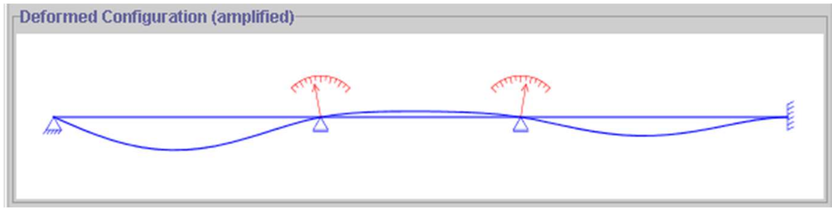

Figure 6. Continuous beam deformed configuration canvas

There are potentiometers at each internal node of the structure that represent the rotation of the beam at these nodes. This rotation comes from the Cross Process itself, which is generally a matter of stopping the rotation of all nodes and only releasing the rotation of the node to be balanced at each step. When rotation of a node is allowed, it balances itself through portions of equilibrating bending moments in the adjacent bars. Due to the node's rotation and balance, the bars adjacent to it deform, and their bending moments change. New unbalanced bending moments are "transmitted" to adjacent nodes. The process converges because the increments of rotation and the transmitted bending moments decrease with each step.

2.4 Moment diagram canvas

The third canvas presents the bending moments diagram (Fig. 7). This canvas is of great importance for understanding the Cross Process. This diagram will allow the visualization of unbalanced moments at each process stage. These are easily noticed by looking at the nodes and visualizing a discontinuity in the bending moment diagram.

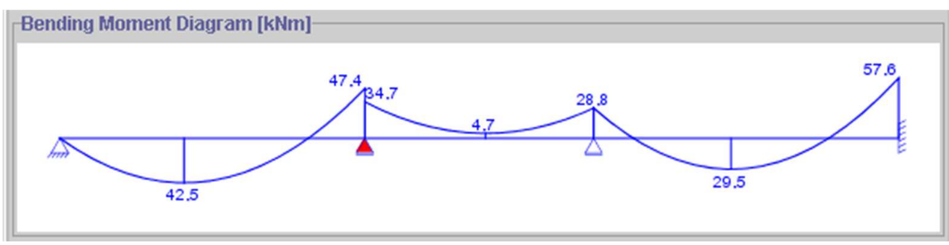

Figure 7. Canvas of the continuous beam bending moment diagram

An interesting feature of this canvas is that the supports are painted red when the node is unbalanced. This feature makes it easier to perceive unbalanced nodes, especially when the imbalance of bending moments is small. These red supports have an essential function: they will serve as a user interface for the simulation. When the user clicks on a painted support, a step will occur in the process, and this node will be balanced.

This possibility for the user to choose which node will be balanced is one of the keys to learning. The explanation is straightforward because if the most unbalanced node is clicked at each step, the number of interactions will be minimal. Convergence will be faster. The possibility of choosing the node to be balanced allows the student to learn the behavior of the Cross Process.

2.5 Canvas of the Cross Process iterative solution

The fourth canvas shows the results of each step of the Cross Process (Fig. 8). These results are usually presented when manually calculating a continuous beam with the Cross Process. That is, the results have a table format. Students can easily read this answer table, as it has a format identical to the one they make in their notebooks. The results consist of the balancing moments and the transmitted moments to adjacent nodes.

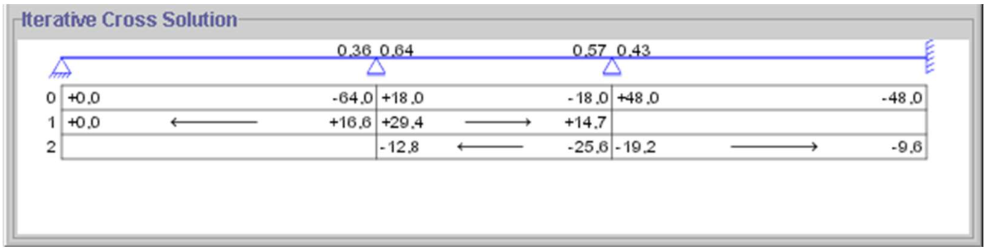

Figure 8. Canvas of the iterative solution of the continuous beam Cross Process

The results table, which has more lines than the canvas can show, can move up or down on the screen simply by clicking and dragging it with the mouse.

3 Conclusions

The e-Cross program has been successfully used in the Structural Analysis II discipline of the Civil Engineering course at PUC-Rio for over two decades. However, this experience was not published before this article.

Although, with the increasing use of computer programs for analyzing structures, the Cross Process has fallen into disuse in structural design, the Cross Process has an intuitive appeal. It demonstrates an essential concept in the behavior of structures: more rigid structural elements “attract” more internal forces to themselves than less rigid elements. Using the program facilitates understanding this concept and reduces the workload for teaching the Cross Process, allowing other, more modern methods to be presented.

It is worth mentioning that one interesting assignment proposed to the students consists of writing a report explaining the Cross Process methodology based on the program's use.

The software requires the installation of JRE - Java Runtime Environment. This is available at the following URL address: https://www.java.com/download/manual.jsp. The online (applet) version requires the installation of CheerpJ Applet Runner (https://cheerpj.com/cheerpj-applet-runner) in the browser.

Acknowledgements. This work has been supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) [Finance Code 001], the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) [Grant 308884/2021-3], and FAPERJ [process number E-26/201.224/2022].

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