Computer Program for Frame Analysis and Design

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Abstract

Commercial software for structural analysis are proprietary (black box) and not user friendly for the learning process. Also, Finite Elements and Design courses are inadequately supported by teaching software. From previous research, an open source beam analysis software was developed using Java. By extending it to handle 2D Frame elements and introducing design to the Eurocodes this paper sought to create a lab facility (program) that can be used at the institutions of higher learning for self or remote study in a post Covid-19 future. Findings of the study indicate that the program's results were consistent with those of hand calculations and commercial software. The resulting program has a simple and straight forward graphical interface for input and output of results. Moreover, being open source allows for extension to other Finite Elements and design to the Eurocodes.

Keywords: Structural Analysis, Finite Elements, Eurocodes.

1 Introduction

Okoth (2011) developed an open source computer program for 2D and 3D truss analysis. Later on, Kisia (2018) continued the project introducing analysis of 2D beams. It was recommended to not only extend the software to analyse other structural elements but also carry out the corresponding designs according to standards.

The problem was that several companies have student version software that is of a lower version of their commercial software, to build learners' capacity in analysis and design. Unfortunately, these software programs are proprietary (black box). In addition, they are complicated thus not adequate as a teaching tool to aid the learning process.

Recognizing that Finite Elements and Design courses are inadequately supported by teaching software, this paper focused on extending the program of Kisia (2018) to analyze 2D Frames. In addition, the design of beams to Eurocode 2 was introduced.

The main objective was to create a software tool for self study at the institutions of higher learning in a post Covid 19 future. A tool that the student can use to compare their hand calculations and experiment with various examples in an era of limited contact with the instructor. The scope of the study was limited to analysis of two dimensional frames using Finite Element techniques and the design reinforced rectangular concrete cross sections for moment and shear.

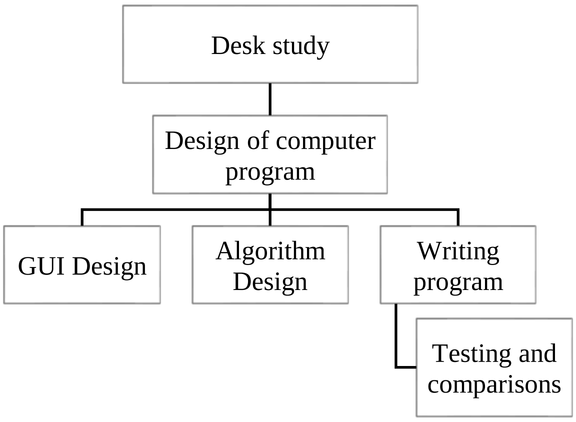

Figure 2.1: Summary of methodology

2 Materials and Methods

The following flow chart in figure 2.1 summarizes the methodology used to achieve the objectives of the project.

2.1 Desk study

2.1.1 Finite Elements

A desk study was done to obtain background information on Finite Elements. Energy methods in combination with basic concepts from mechanics of materials, (Chennakesava, 2008), were found to be simpler and therefore used to formulate element stiffness matrices. From the study, the stiffness matrix of a 2D Frame element, equation 2.1, was found to be a superposition of the stiffness matrix of a 2D bar (truss) element and that of a 2D beam element (Hibbeler, 2012).

$$\mathbf{K^e} = \begin{bmatrix} \frac{AE}{L} & 0 & 0 & -\frac{AE}{L} & 0 & 0 \\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & -\frac{12EI}{L^3} & \frac{6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{2EI}{L} \\ -\frac{AE}{L} & 0 & 0 & \frac{AE}{L} & 0 & 0 \\ 0 & -\frac{12EI}{L^3} & -\frac{6EI}{L^2} & 0 & \frac{12EI}{L^3} & -\frac{6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{4EI}{L} \end{bmatrix} \quad 2.1$$

Where $\boldsymbol{K^e}$ is the stiffness matrix, EI is the Flexural rigidity, AE is the axial rigidity, and L is the length of the element. Finite Element analysis is a formalized method and can be broken down into steps as illustrated in **Figure 2-1**: FEM steps**Error! Reference source not found.**. From the previous study (Osome, 2018) and (Okoth, 2011), the code to carry out the major steps (i.e. Assembly, partitioning and solution of linear systems of equations) was already developed and made available.

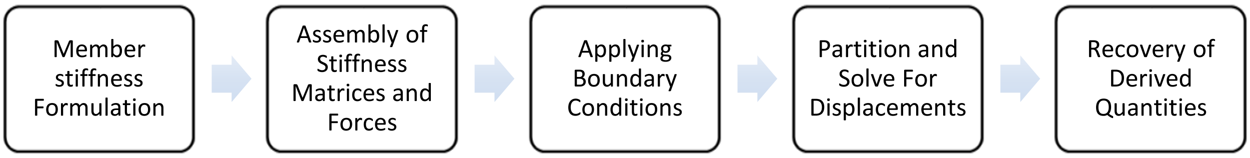

Figure 2-1: FEM steps

2.1.2 Design Codes

Structural design codes have been formulated to enable Engineers design structures for strength and stability using steel, concrete, timber and masonry (McKenzie, 2013). In Kenya the British standards have been use for a long time. However, the British standards are no longer supported. As a result, there is a transition to the Eurocodes with the adoption of the UK Annexes. The desk study was limited to reinforced concrete beams taking into account the design for bending and shear according to Eurocode 2 (Mosley, Bungey, & Hulse, 2012).

2.1.3 Programming

The Java programming language was initially chosen because it is open source. The language also follows the object oriented programming paradigm (Charatan & Kans, 2009). In order to have a three dimensional user interaction, jReality library was chosen for visualization purposes.

2.2 Design of computer program

The computer program was organized into key modules as shown in Figure 2-2.

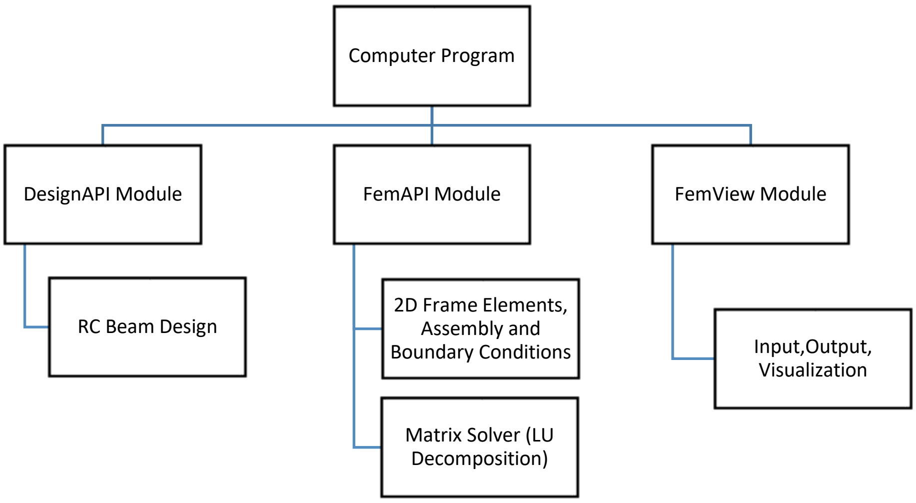

Figure 2-2: Summary of Computer Program

The design of the program consisted of two stages as follows:

a) Graphical User Interface (GUI) Design

A graphical user interface provides a means by which human beings interact with computers using widgets (i.e. windows, icons, graphics, text boxes, drop downs etc.). NetBeans provides tools for rapid user interface design by drag and drop. Graphical interfaces for input, output and visualization are all contained in the FemView Module. Visualization was achieved using jReality, a 3D scene graph library (Weissmann, Gunn, Peter, Hofmann, & Pinkall, 2009). Graphical tools were also developed to allow for automatic modeling of basic frame structures. The output of the program was presented in LaTeX form then rendered to show the steps of the computations. Bending moments, shear and displacements were superimposed on the modeled structure as part of the visualization.

b) Algorithm Design

An algorithm is a set of instructions to perform a specific task. A crucial algorithm in Finite Elements is that for solving a set of linear equation. Crout's algorithm, (Teukolsky, Vetterling, & Flannery, 1992), for solving linear systems of equations was chosen. During reinforced concrete beam design, after determining the required area of steel, an algorithm was developed to automatically determine the diameter and number of bars to be provided. Another algorithm was also developed for modeling rebar in 3D space.

2.3 Writing of the Program

NetBeans IDE (Integrated Development Environment) was chosen for writing the program with Java as the programming language. The IDE provides tools that make writing programs simpler for example debugging, compiling, code completion etc.

2.4 Testing and debugging

Testing and debugging is an essential process to validate the program. The tests consisted of comparisons with hand calculated examples together with commercial software. In the process of testing, debugging was done to remove errors that were identified. Testing and debugging is a continuous process which will lead to future updated of the program. An advantage of being open source is that any person who understands programming can make changes to the program and update it.

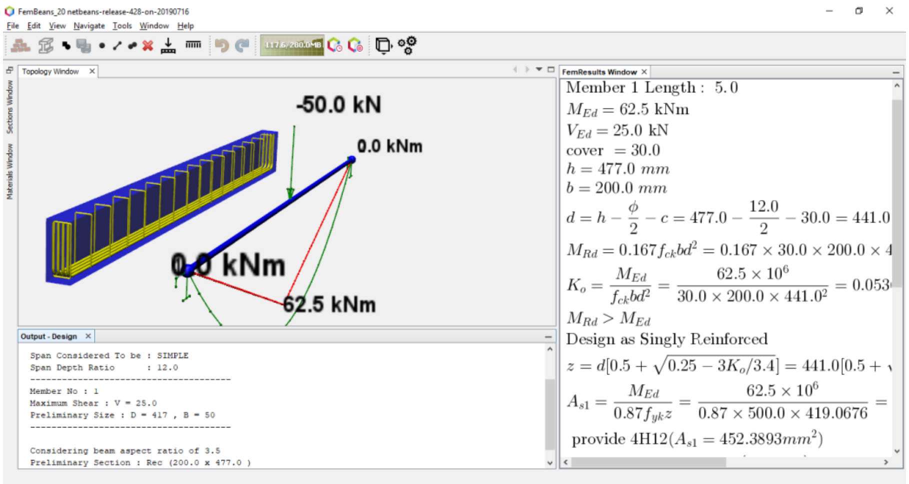

Figure 2-3: Graphical Interface for design of simply supported beam

3 Results

Figure 2-3**Error! Reference source not found.** shows the resulting graphical user interface for the design of a simply supported beam to Eurocode 2. The results for an example of a 2D frame analysis are shown in **Figure 3-2** and **Figure 3-3** for moment and shear respectively. The comparisons were made against the results from Autodesk Robot Structural Analysis software. It was also observed that the program obtained the same values with those of hand calculations.

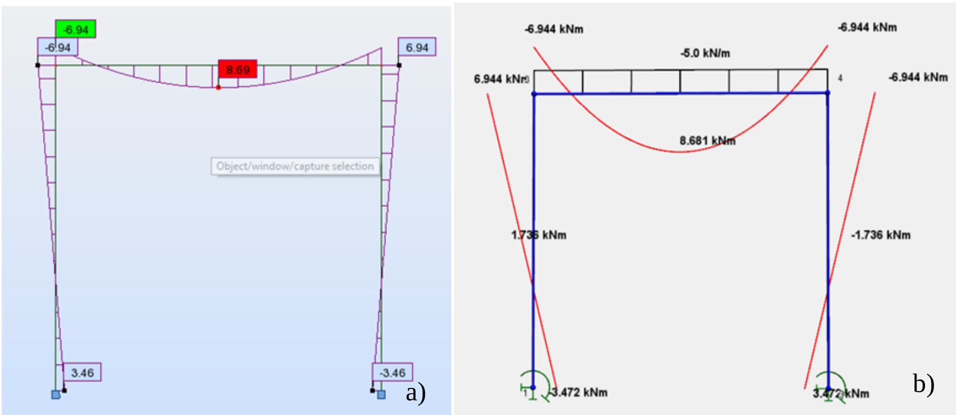

Figure 3-1: Results for Bending Moments a) using Autodesk Robot Structural Analysis b) using the program

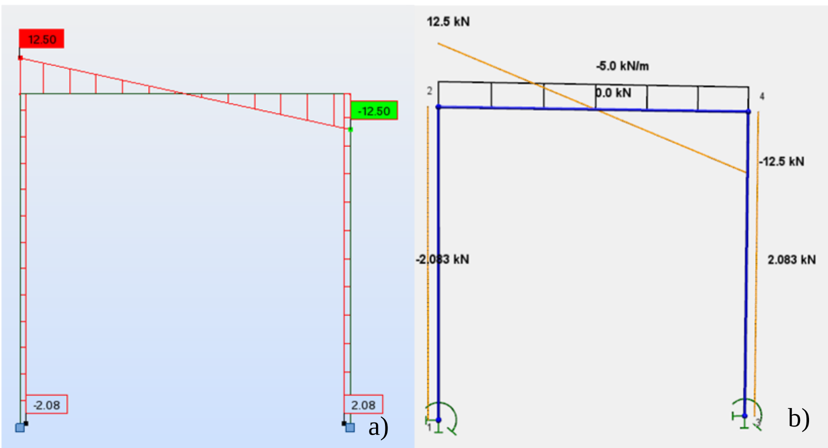

Figure 3-2: Results for Shear a) using Autodesk Robot Structural Analysis b) using the program

For design to Eurocode 2 comparisons were made with only those of hand calculations for simply supported beams. An example is summarized in **Table 1** for a beam of Beam width, b = 275mm and effective depth, d = 450mm.

Table 1: Comparison of Design by Hand calculations

	Hand calculation	**Design Module**	**Percentage difference**
K_o	0.124	0.124	0.000
z	393.7279	393.7018	0.007
$A_{s1,req}$	1008.3398	1008.4066	0.007
$A_{s1,prov}$	1257	1257	0.000
No. of bars	4T20	4T20	
$V_{Rd.max2}$	501.1875	501.1875	0.000
$V_{Rd.max1}$	345.2625	345.2625	0.000
$(A\_sw/s)_{min}$	0.22	0.22	0.000
$(A\_sw/s)_{req}$	0.195	0.195	0.000
$(A\_sw/s)_{prov}$	0.335	0.3351	0.03
s_v	T8 @ 300	T8 @ 300	

4 Discussions

The results yielded by the program were accurate and consistent with only discrepancies of 0.3 percent for the bending moments and reactions at the supports and 0.1 percent for the shear. The bending moment and shear force diagrams were also similar, throughout the frame. One discrepancy was observed on the shear force diagram where they had same values but different signs; this is due to the sign convention differences. It was also observed that the design of the beam cross section to Eurocode 2 was consistent with that of hand calculations.

5 Conclusions

It is evident that the results yielded are accurate and consistent with negligible margin of error thereby making the program an effective learning tool. The unique feature of the program is the way it enables the user to track the computational process that was used to arrive at the solution. The graphical user interface (GUI) has been fashioned in a trainer-student friendly manner that allows easier interaction of the program. An auto-generation component in the analysis program was necessary to minimize the input and element declaration phase for frames. The program can therefore be used as a tool for self study by students. Since the source code is available, the program can be further extended to cover other structural elements and design of steel and timber to Eurocodes.

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