The Development of Engineering Mechanics Software as a Self-study Tool of Structural Design

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Abstract. The main purpose of this research is to get design parameters that can be used as a basis for consideration for the design of the final construction. This is a development research where the product that will be produced is a software. The developed software using Borland Delphi XE 3. The data will be analysed in the form of data nodal displacement, reactions, and styles in, in the form of different relative to the reference software. The data obtained during testing processed and presented in the form of tables and graphs. As comparison to verify the data issued, used MS Excel and commercial program. Based on the results of the research can be deduced that: (1) Program designed still has relative error 0%. This indicates that the program is designed to have the level of thoroughness is good enough, (2) The program can be started with a simple input and can run well without any obstacles, (3) Program is still limited to the delivery of the result is numeric, not display the results in the form of graphics, (4) Input data entered is also still in the form of numbers, not be graphics.

Keywords: structural analysis, mechanics, Borland Delphi

1. Introduction

The purpose of structures, other than aircraft, ships and floating structures, is to transfer applied loads to the ground. The structures themselves may be constructed specifically to carry load (for example, floor or bridges) or their main purpose may be to give protection from the weather (for instance, walls or roofs). Even in this case, there are loads (such as self-weight of the roofs and also wind forces acting on them) that need to be transferred to the ground.

Before a structure can be designed in a rational manner, it is essential to establish the loads on various parts of the structure. These loads will determine the stresses and their resultants (internal forces) at a given section of a structural element. These stresses or internal forces have to be within desired limits in order to ensure safety and to avoid excessive deformations. To determine the stresses (forces/unit area), the geometrical and material properties must be known. These properties influence the self-weight of the structure, which may be more or less than originally assumed. Hence, iteration in analysis may be required during the design process [1].

The usual procedure is to idealize the structure by one-, two-, or three-dimensional elements. The lower number of dimensions considered, the simpler the analysis. Thus, beams and columns, as well as members of trusses and frames, are considered as one-dimensional; in other words, they are represented by straight lines. The same applies to strips of plates and slabs. One-dimensional analysis can also be used for some curvilinear structures, such as arches or cables, and also certain shells. Once
the analysis has been completed, members and their connections are designed: the designer must be fully conscious of the difference between the idealized structure and the actual outcome of construction. [1]

Complex engineering structures have been successfully built for a long time, even without the use of any computer-based design and simulation tools. However, computer-based design and analysis is becoming more and more important in all high-technology areas. This computational focus enables engineering companies to realize significant cost reductions in the design and development process due to the reduced need for physical models and real experiments. A significant contribution to the success of this approach is based on the development of powerful computer hardware and software in the last few decades. As a recent example, the design of commercial aircrafts reflects this trend [2].

However, solely focusing on commercial packages and complex structures involves many dangers for the finite element beginner. Without the knowledge of the underlying theory, a generation of an appropriate and accurate computational model (e.g. element type, mesh size, and refinement) might be difficult. Furthermore, to rely on displayed colours or values might be misleading if, for example, the difference between nodal and integration point results is not known. Thus, a serious introduction to the finite element method must incorporate the corresponding theory and must enable the user to judge the quality of the obtained results [3].

![Figure 1. Structure idealization for analysis purposes [1]](image)

Structural analysis is just one component of the design process. Analysis of a structure does not occur until after numerous design decisions have been made, many of them based on the economics of the particular structural problem. Practicing structural engineers know that good structural design depends on numerous other factors or types of knowledge apart from mathematical structural analysis. Hence successful structural design requires an engineer to possess theoretical, practical and experiential knowledge as well as skills such as innovation, translating concepts into details, and the ability to create designs which can be built easily and cheaply [4].
The fundamental idea of the finite element method is the replacement of continuous functions by piecewise approximations, usually polynomials. Although the finite element method itself is relatively new, its development and success expanding with the arrival and rapid growth of the digital computer, the idea of piecewise approximation is far from new. Indeed, the early geometers used ‘finite elements’ to determine an approximate value of \( \pi \). They did this by bounding a quadrant of a circle with inscribed and circumscribed polygons, the straight-line segments being the finite element approximations to an arc of the circle. In this way, they were able to obtain extremely accurate estimates. Upper and lower bounds were obtained, and by taking an increasing number of elements, monotonic convergence to the exact solution would be expected. These phenomena are also possible in modern applications of the finite element method. One remark regarding ancient finite elements: Archimedes used these ideas to determine areas of plane figures and volumes of solids, although of course he did not have a precise concept of a limiting procedure. Indeed, it was only this fact which prevented him from discovering the integral calculus some two thousand years before Newton and Leibniz. The interesting point here is that whilst many problems of applied mathematics are posed in terms of differential equations, the finite element solution of such equations uses ideas which are in fact much older than those used to set up the equations initially. The engineers had put the finite element method on the map as a practical technique for solving their elasticity problems, and although a rigorous mathematical basis had not been developed, the next few years saw an expansion of the method to solve a large variety of structural problems [5].

2. Methods

A computer program was developed using Borland Delphi XE 3. Three different computer packages were developed to analyse truss, beam and frame structures. The flowchart of each structures was adopted from Logan [6], and given as follow:

![Flowchart](image)

**Figure 2.** Basic flowchart for software development
3. Result and Discussion

In order to test developed computer packages, the computer package was used to analyse several structural analysis problems. The result from the computer package then compared with other method, i.e. with spreadsheet and commercial structural analysis program. The displacements, internal forces and reactions are used as references. For each considered structures (truss, beam and frame) the result is given as follow.

a. Truss

**Table 1. Relative difference of truss internal forces**

| Element | Developed program | Spreadsheet | Commercial software |
|---------|-------------------|-------------|---------------------|
| 1       | 41.667            | 41.667      | 41.642              |
| 2       | -41.667           | -41.667     | -41.578             |
| 3       | 25                | 25          | 24.947              |
| Average relative difference | 0%            | 0%          |                     |

**Table 2. Relative difference of truss nodal displacement**

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1x    | 0.000             | 0.000       | 0.000               |
| 1y    | 0.000             | 0.000       | 0.000               |
| 2x    | 0.000             | 0.000       | 0.000               |
| 2y    | 0.000             | 0.000       | 0.000               |
| 3x    | 0.000             | 0.000       | 0.000               |
| 3y    | 0.000             | 0.000       | 0.000               |
| Average relative difference | 0%            | 0%          |                     |

**Table 3. Relative difference of truss joint reactions**

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1x    | -50.000           | -50.000     | -50.000             |
| 1y    | -33.333           | -33.333     | -33.333             |
| 2x    | 50.000            | 50.000      | 50.000              |
| 2y    | 0.000             | 0.000       | 0.000               |
| 3x    | 0.000             | 0.000       | 0.000               |
| 3y    | 33.333            | 33.333      | 33.333              |
| Average relative difference | 0%            | 0%          |                     |
b. Beam

Table 4. Relative difference of beam joint displacement

| Joint | Rotation | Translation |
|-------|----------|-------------|
|       | Developed program | Spreadsheet | Commercial software | Developed program | Spreadsheet | Commercial software |
| 1     | -0.0000398 | -0.0000397 | 0.0000400 | 0.000 | 0.000 | 0.000 |
| 2     | 0.000154  | 0.000154   | -0.000160 | 0.000 | 0.000 | 0.000 |
| 3     | 0.000      | 0.000      | 0.000     | 0.000 | 0.000 | 0.000 |

Average relative difference 0% 1% 0% 0% 0% 0%

Table 5. Relative difference of beam joint reactions

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|----------------------|
| f1y   | 1.144             | 1.144       | 1.147                |
| m1    | 0.000             | 0.000       | 0.000                |
| t1y   | 1.236             | 1.236       | 1.222                |
| m2    | 0.000             | 0.000       | 0.000                |
| t3y   | -0.379            | -0.379      | -0.369               |
| m3    | 0.000             | 0.000       | 0.000                |

Average relative difference 0% 5%

Table 6. Relative difference of beam internal forces

| Element | Joint Number | Shear Force | Bending Moment |
|---------|--------------|-------------|----------------|
|         |              | Developed program | Spreadsheet | Commercial software | Developed program | Spreadsheet | Commercial software |
| 1       | 1            | 1.144       | 1.144         | -1.147      | 0.000 | 0.000 | 0.000 |
| 2       | 2            | 0.856       | 0.856         | 0.853       | -1.138 | -1.138 | -1.119 |
| 3       | 3            | 0.379       | 0.379         | -0.369      | 1.138 | 1.138 | -1.119 |
| 4       | 4            | -0.379      | -0.379        | -0.369      | 0.569 | 0.569 | 0.540 |

Average relative difference 0% 3% 0% 0% 5%

c. Frame

Table 7. Relative difference of frame x-dir joint displacement

| Joint | x-dir translation |
|-------|-------------------|
|       | Developed program | Spreadsheet | Commercial software |
| 1     | 0.0000000         | 0.0000000   | 0.0000000 |
| 2     | -0.000824         | -0.000824   | -0.000824 |
| 3     | 0.0000000         | 0.0000000   | 0.0000000 |

Average relative difference 0% 0%
Table 8. Relative difference of frame y-dir joint displacement

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1     | 0.000000          | 0.000000    | 0.000000            |
| 2     | 0.000152          | 0.000152    | 0.000152            |
| 3     | 0.000000          | 0.000000    | 0.000000            |

Average relative difference: 0% 0%

Table 9. Relative difference of frame joint rotation

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1     | 0.000000          | 0.000000    | 0.000000            |
| 2     | 0.000047          | 0.000047    | 0.000047            |
| 3     | 0.000000          | 0.000000    | 0.000000            |

Average relative difference: 0% 0%

Table 10. Relative difference of frame joint reactions at x-dir

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1     | 4.058189          | 4.058189    | 4.058189            |
| 2     | 0.000000          | 0.000000    | 0.000000            |
| 3     | -0.058189         | -0.058189   | -0.058189           |

Average relative difference: 0% 0%

Table 11. Relative difference of frame joint reaction at y-dir

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1     | 3.184118          | 3.184118    | 3.184118            |
| 2     | 0.000000          | 0.000000    | 0.000000            |
| 3     | -3.184118         | -3.184118   | -3.184118           |

Average relative difference: 0% 0%
Table 12. Relative difference of frame joint moment

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1     | 18.212752         | 18.212752   | 18.212752           |
| 2     | 0.000000          | 0.000000    | 0.000000            |
| 3     | 5.434248          | 5.434248    | 5.434248            |

Average relative difference 0% 0%

Table 13. Relative difference of frame internal forces (axial force)

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1-2   | 5.157022          | 5.157022    | 5.157022            |
| 2-1   | -5.157022         | -5.157022   | -5.157022           |
| 2-3   | -3.184118         | -3.184118   | -3.184118           |
| 3-2   | 3.184118          | 3.184118    | 3.184118            |

Average relative difference 0% 0%

Table 14. Relative difference of frame internal forces (shear force)

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1-2   | 0.112381          | 0.112381    | 0.112381            |
| 2-1   | -0.112381         | -0.112381   | -0.112381           |
| 2-3   | 0.058189          | 0.058189    | 0.058189            |
| 3-2   | -0.058189         | -0.058189   | -0.058189           |

Average relative difference 0% 0%

Table 15. Relative difference of frame internal forces (bending moment)

| Joint | Developed program | Spreadsheet | Commercial software |
|-------|-------------------|-------------|---------------------|
| 1-2   | 18.21275          | 18.21275    | 18.21275            |
| 2-1   | 37.9775           | 37.9775     | 37.9775             |
| 2-3   | 12.0225           | 12.0225     | 12.0225             |
| 3-2   | 5.434248          | 5.434248    | 5.434248            |

Average relative difference 0% 0%

According to the average of relative difference of each subject (displacement, reaction and internal forces) it can be shown that the relative difference of each subject ranged from 0% to 5%. It
can be said that the result only has 5% of mistaken data, and we can consider 95% of the data can be trusted and the data have high level of accuracy. This 5% error is mainly came from number format of each developed program, spreadsheet and commercial software, which can’t be avoided and for the self-developed-program this 5% error is considered acceptable.

Even though this program is far from commercial software, which input still a numeric not a graphic as well as the output, but it can run the analysis smoothly without having errors. Further works need to be done to have this program having graphical interface, both on input and output.

4. Conclusion
From the discussion, we can take conclusion as follow: (1) the developed program have relative difference of result ranged from 0% to 5%. This indicate that the developed program has a good level of accuracy, (2) the developed program can be run with simple input and running without any particular error.

5. References
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