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Spreadsheet Solution of Basic Axial Force Problems of Strength of Materials

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Abstract

In this work, we present a spreadsheet developed for some particular problems of Strength of Materials. This paper is focused on the study of axial force systems, some statically determinate, such as trusses, and some statically indeterminate, such as a load-carrying rigid member supported by a pinned connection and by two axial bars. Starting with simple calculations for a particular problem, students develop the spreadsheet with more advanced calculations. The examples have been modelled on Microsoft Excel software. The aim is that, at the end of the course, students have developed a collection of such spreadsheets. This methodology contributes to enhancing the motivation in the study of the subject, which is the main learning objective.

KEYWORDS: spreadsheets, strength of materials, axial force systems

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Abstract

In this work, we present a spreadsheet developed for some particular problems of Strength of Materials. This paper is focused on the study of axial force systems, some statically determinate, such as trusses, and some statically indeterminate, such as a load-carrying rigid member supported by a pinned connection and by two axial bars. Starting with simple calculations for a particular problem, students develop the spreadsheet with more advanced calculations. The examples have been modelled on Microsoft Excel software. The aim is that, at the end of the course, students have developed a collection of such spreadsheets. This methodology contributes to enhancing the motivation in the study of the subject, which is the main learning objective.

Keywords: spreadsheets, strength of materials, axial force systems.

1. Introduction

In our laboratory of strength of materials we have developed a way to teach mechanics of solids using computers and experiments that we have designed (Figure 1). These laboratory activities are used to show the connections between theoretical ideas and real life problems.

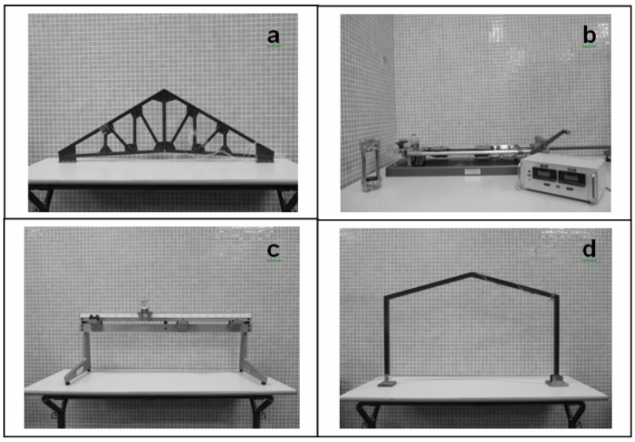


Figure 1. a) Truss, b) Tensometer, c) A system to study deflections in beams, d) Frame.

When learning structural engineering, students are very quickly faced with problems for which the mathematical analysis is beyond “pencil and paper”. It is essential to use a computing environment.

Very often students are thrown straight into using sophisticated computing systems, such as those based on the finite element method, and while they may well obtain results, the underlying principles are not entirely clear. The spreadsheet, however, offers a computing environment in which students can set up the mathematical relationships for quite sophisticated systems in a similar way in which they would do it by hand. There are some books that use spreadsheets to explain and to solve different problems about mechanics [1].

Sometimes, students become overwhelmed because of the great amount of theoretical concepts that they have to study in their subjects. For this reason we have designed several experimental set-ups in the laboratory to enhance active learning [2]. The design of the experiments is based on the idea that the learning is best assimilated when it is linked to previous experience (“scaffolding” learning), as Linn explains [3].

Steiff and Dollar say that we cannot expect students to learn engineering subjects (Statics, Dynamics, Strength of Materials, etc.) in an abstract way [4]. Our experimental set-ups aim to enable students to be able to understand the theoretical concepts that are explained in class. One of the most effective ways of capturing the interest of the students is showing the connection between theoretical concepts and real life situations, by means of the designed experimental set-ups.

The combination of experimental procedures with the use of the computer as a tool to solve problems has so far proved a good way to improve the motivation of students in the subject, in our view. With this idea of the teaching-learning process, we present a schematic that shows the way to work in our laboratory (Figure 2) [5].

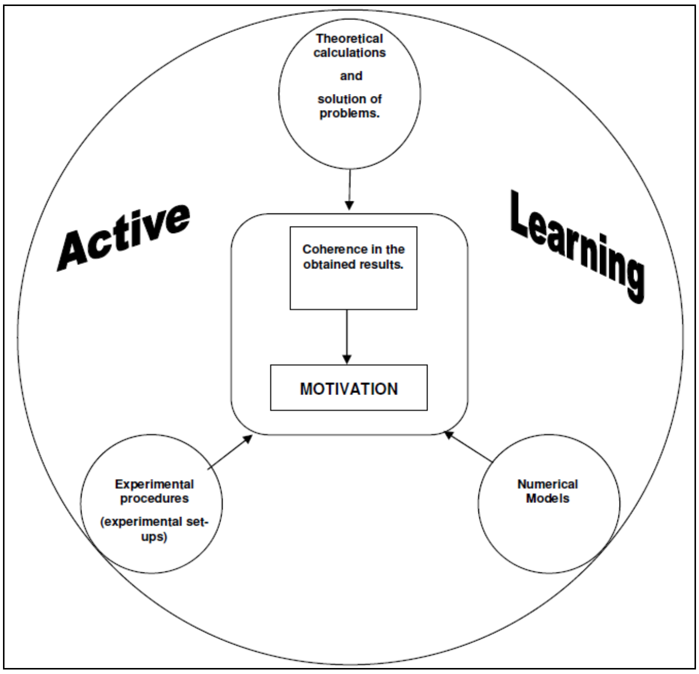


Figure 2. The active learning diagram applied to our laboratory.

The diagram shows that the active learning that we propose aims to relate the theoretical concepts, the experimental procedures and the computational methods to improve the motivation of the students by means of the coherence in the obtained results. Figure 3 shows the part of the diagram in which the application of the spreadsheets take an important role in the motivation of students [6].

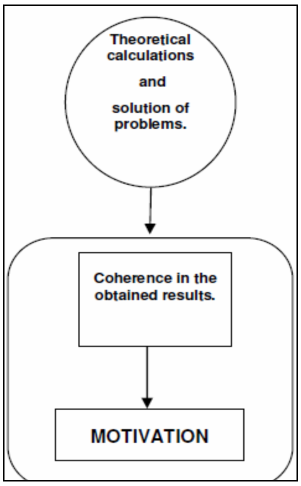


Figure 3. The use of the computer is related with the motivation.

With this methodology, it is intended to change the classical way of teaching the concepts and the procedures in mechanics [7].

Spreadsheet programs are very useful tools in teaching in all fields of engineering. One of the main advantages is that students can interfere with the program. The use of these spreadsheets suits well with the subject of Mechanical Systems, that is studied in the Design Engineering Degree.

2. Basic problems of strength of materials: axial force systems

We have developed some applications to study some particular problems of strength of materials [8]. In this work we present three typical problems to study axial forces in structural members.

Figures 4, 5 and 6 show the particular problems to study.

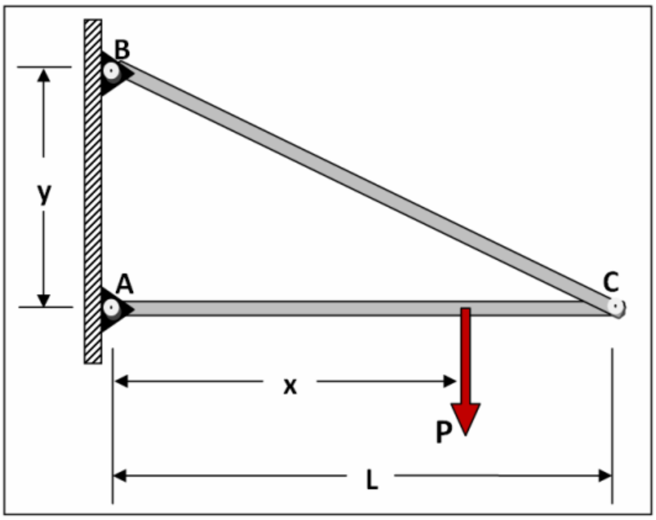


Figure 4. Beam and strut.

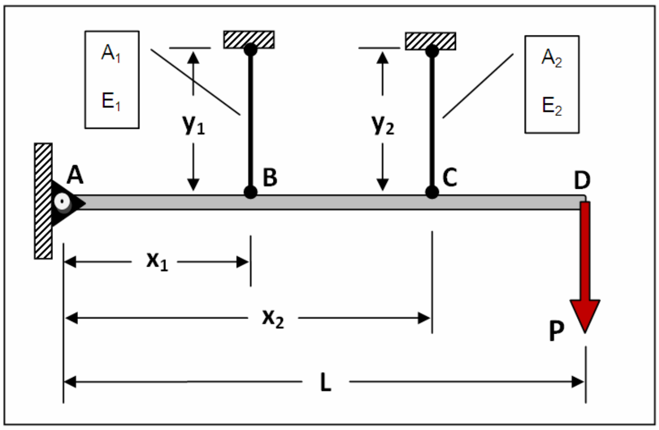


Figure 5. Rigid member and two bars.

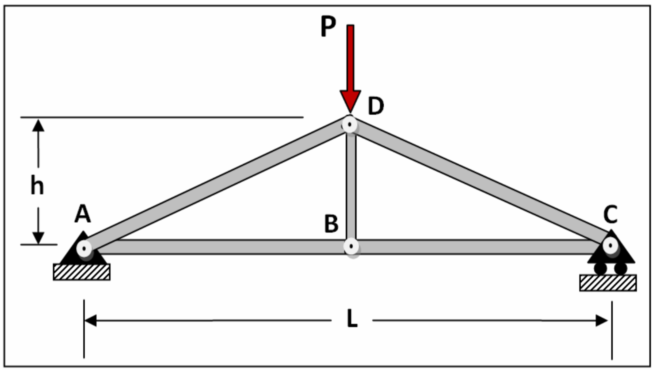


Figure 6. Statically determinate truss.

2.1. Static analysis

Consider the example proposed in Figure 4. The aim is to calculate the force that acts on the strut BC. One way to solve this problem is to study the equilibrium of the body by means of a free-body diagram. Figure 7 shows the free-body diagram of the beam AC.

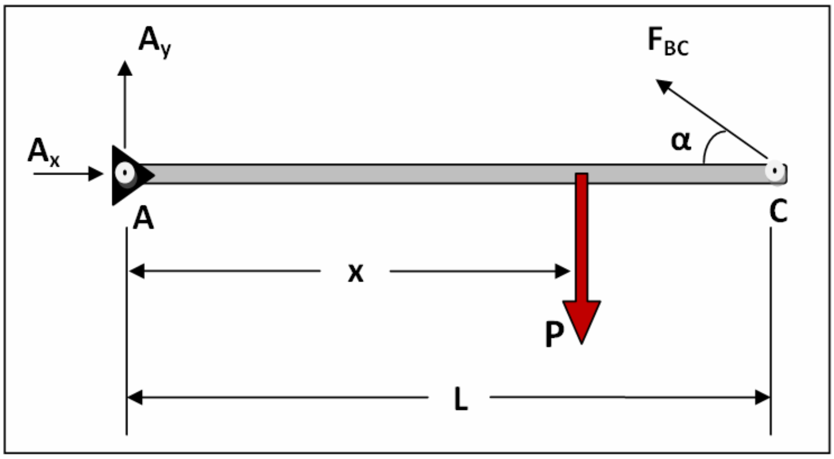
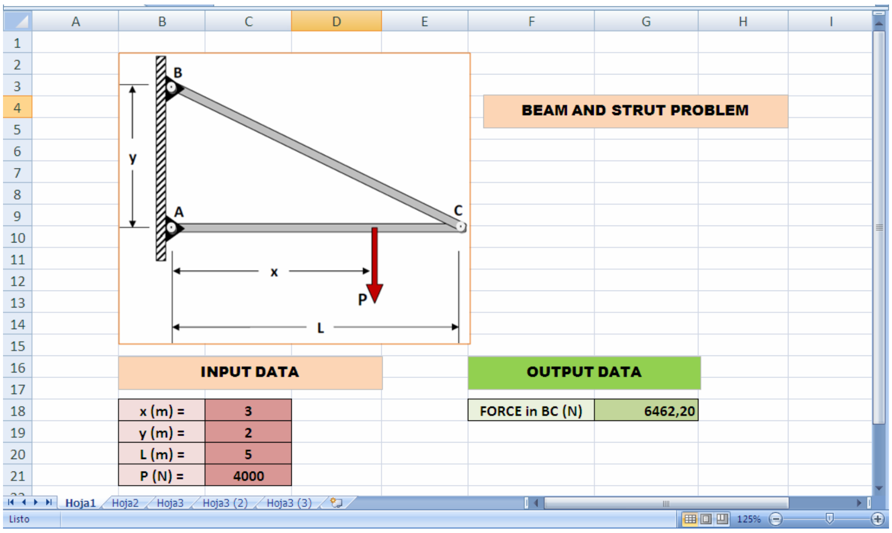


Figure 7. Free-body diagram of the beam AC.

The next step is to calculate the force F_{BC} that acts on the strut BC. Considering the condition of equilibrium, the sum of the moments of all external forces about point A is (equation 1):

$$(F_{BC}\cdot sin(\alpha))\cdot L = P\cdot x \qquad (1)$$

Resolving this equation, the force F_{BC} is determined. Figure 8 shows the initial spreadsheet developed for this problem.



BEAM AND STRUT PROBLEM

INPUT DATA

x (m) =	3
y (m) =	2
L (m) =	5
P (N) =	4000

OUTPUT DATA

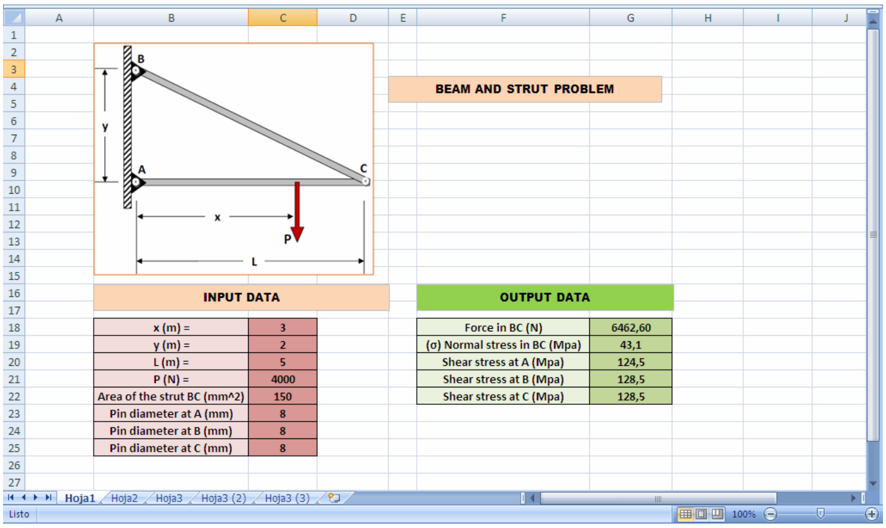
FORCE in BC (N)	6462,20

Figure 8. Initial spreadsheet for the beam and strut problem.

With a simple spreadsheet like this, we encourage students to solve the problem and to develop the spreadsheet completing it with advanced calculations.

2.2. Advanced calculations

Starting with the explained problem, students develop another spreadsheet that is shown in Figure 9.



BEAM AND STRUT PROBLEM

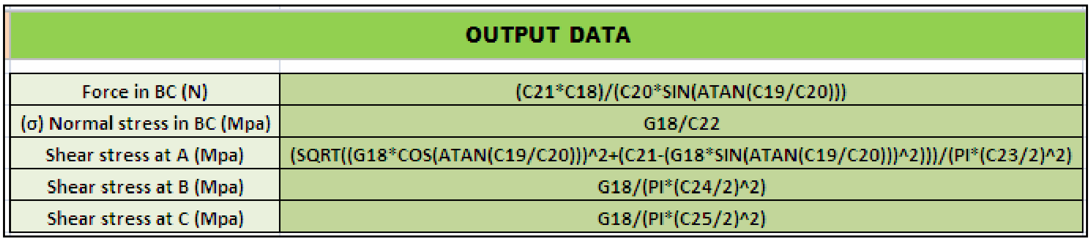
INPUT DATA	
x (m) =	3
y (m) =	2
L (m) =	5
P (N) =	4000
Area of the strut BC (mm^2)	150
Pin diameter at A (mm)	8
Pin diameter at B (mm)	8
Pin diameter at C (mm)	8

OUTPUT DATA	
Force in BC (N)	6462,60
(σ) Normal stress in BC (Mpa)	43,1
Shear stress at A (Mpa)	124,5
Shear stress at B (Mpa)	128,5
Shear stress at C (Mpa)	128,5

Figure 9. Spreadsheet developed by one of the students.

Table 1 shows the boxes developed for the output data.

TABLE 1. BOXES FOR OUTPUT DATA



OUTPUT DATA	
Force in BC (N)	(C21*C18)/(C20*SIN(ATAN(C19/C20)))
(σ) Normal stress in BC (Mpa)	G18/C22
Shear stress at A (Mpa)	(SQRT((G18*COS(ATAN(C19/C20)))^2+(C21-(G18*SIN(ATAN(C19/C20)))^2))/(PI*(C23/2)^2)
Shear stress at B (Mpa)	G18/(PI*(C24/2)^2)
Shear stress at C (Mpa)	G18/(PI*(C25/2)^2)

So, students have to study the particular problem in a more detailed way in order to develop a new spreadsheet with a more detailed solution. In this case, starting with the geometry of the mechanical system of the Figure 4, the output data is the force that acts on the strut BC. Students have improved the spreadsheet with new input data to obtain other results that give additional information for the system.

In solving the problem, they have to understand the procedure to develop the equations that are used in the spreadsheet program. The newly applied equations are explained below.

In order to determine the normal and shear stresses, it is necessary to analyse the condition of equilibrium in X and Y directions (equations 2 and 3 from Figure 7):

$$A_x = F_{BC} \cdot cos(\alpha) \tag{2}$$

$$A_y = P - (F_{BC} \cdot sin(\alpha)) \tag{3}$$

Then, to calculate the normal stress in the strut BC (equation 4):

$$\sigma_{BC} = F_{BC} / A_{BC} \tag{4}$$

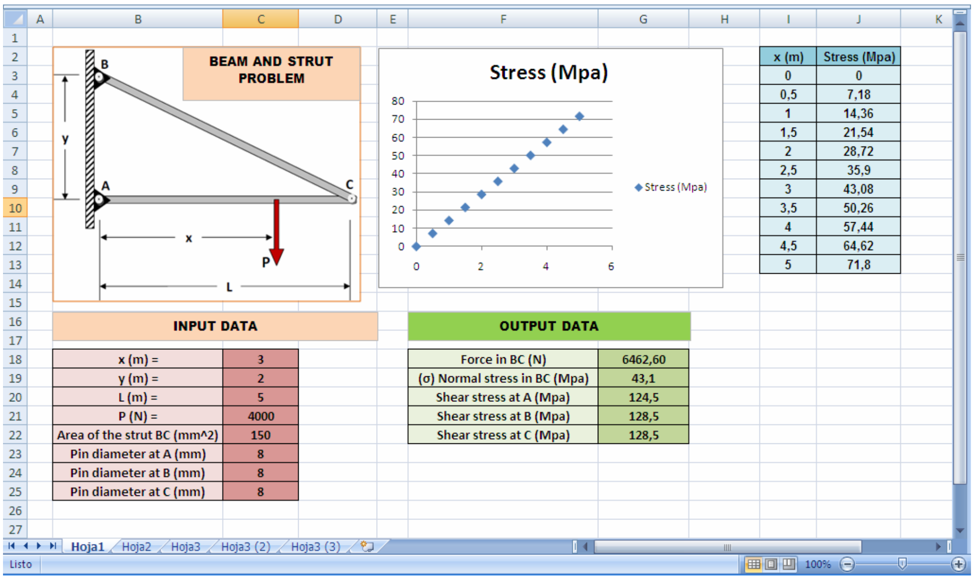
F_{BC} is the force in the strut BC and A_{BC} is the cross-sectional area of the strut BC.

And finally, to calculate the shear stress (τ) in one particular connection (equation 5):

$$\tau = (F_{connection}) / (A_{pin}) \tag{5}$$

$F_{connection}$ is the resultant force in the connection and A_{pin} is the cross-sectional area of the pin.

For example, students can study now the variation of the normal stress in the strut BC, with the variation of the position of the load P. Figure 10 shows the new spreadsheet.



x (m)	Stress (Mpa)
0	0
0,5	7,18
1	14,36
1,5	21,54
2	28,72
2,5	35,9
3	43,08
3,5	50,26
4	57,44
4,5	64,62
5	71,8

INPUT DATA

x (m) =	3
y (m) =	2
L (m) =	5
P (N) =	4000
Area of the strut BC (mm^2)	150
Pin diameter at A (mm)	8
Pin diameter at B (mm)	8
Pin diameter at C (mm)	8

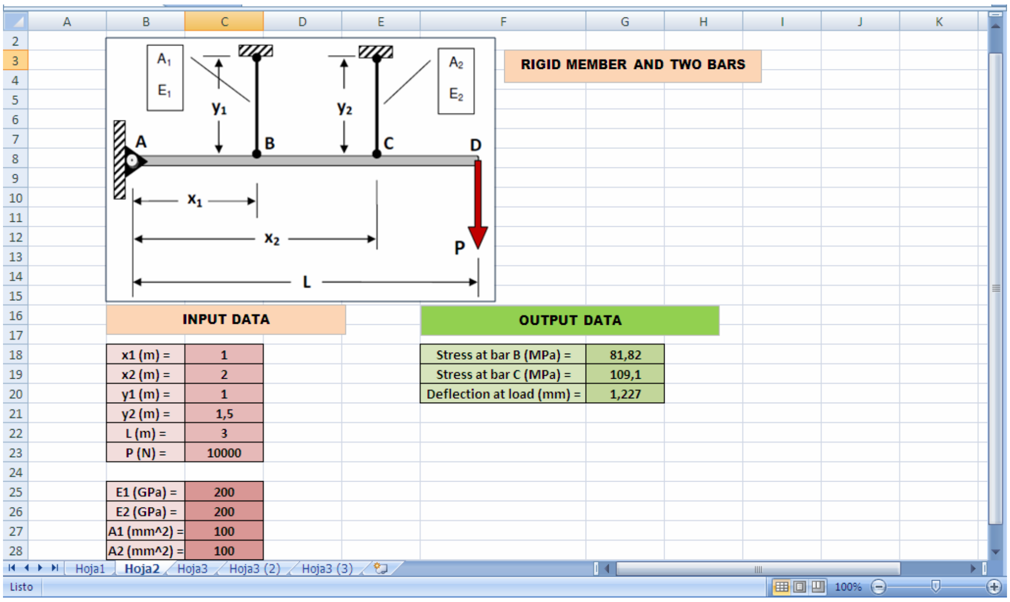
OUTPUT DATA

Force in BC (N)	6462,60
(σ) Normal stress in BC (Mpa)	43,1
Shear stress at A (Mpa)	124,5
Shear stress at B (Mpa)	128,5
Shear stress at C (Mpa)	128,5

Figure 10. Advanced study of the problem.

Following this example, problems proposed in Figures 5 and 6 can be solved in a similar way. Figures 11 and 12 show the other spreadsheets developed by students in these particular cases.

Figure 11 shows an indeterminate axial structure. This problem involves a load-carrying rigid member supported by a pinned connection at point A and by two axial bars attached to the member. Since there are more unknowns than equilibrium equations, this type of problem is termed statically indeterminate. The unknowns are the two axial forces in the two bars and the two external reactions at the pinned connections. So an additional equation must be developed, that is called a compatibility equation. This equation is based on the configuration and deformation of the structure.



RIGID MEMBER AND TWO BARS

INPUT DATA

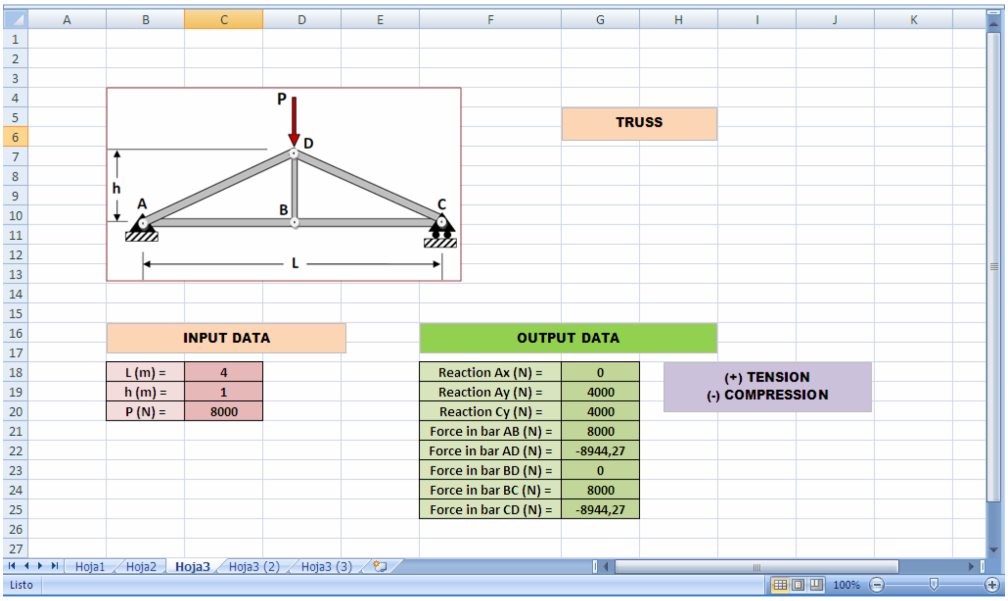
x1 (m) =	1
x2 (m) =	2
y1 (m) =	1
y2 (m) =	1,5
L (m) =	3
P (N) =	10000
E1 (GPa) =	200
E2 (GPa) =	200
A1 (mm^2) =	100
A2 (mm^2) =	100

OUTPUT DATA

Stress at bar B (MPa) =	81,82
Stress at bar C (MPa) =	109,1
Deflection at load (mm) =	1,227

Figure 11. Spreadsheet for a "Rigid member and two bars" problem.

Finally, the problem described in Figure 12 is a statically determinate truss. Since each member in the truss is a two-force member, connected only at the ends, the analysis of the internal member forces is possible through statics.



TRUSS

INPUT DATA

L (m) =	4
h (m) =	1
P (N) =	8000

OUTPUT DATA

Reaction Ax (N) =	0
Reaction Ay (N) =	4000
Reaction Cy (N) =	4000
Force in bar AB (N) =	8000
Force in bar AD (N) =	-8944,27
Force in bar BD (N) =	0
Force in bar BC (N) =	8000
Force in bar CD (N) =	-8944,27

(+) TENSION
(-) COMPRESSION

Figure 12. Spreadsheet to solve a particular truss.

3. A more advanced application: suspension-bridge cables

At the end of the course, students have developed several spreadsheets related to the different chapters of the subject. Figure 13 shows a more advanced application of an axial force system applied to suspension-bridge cables.

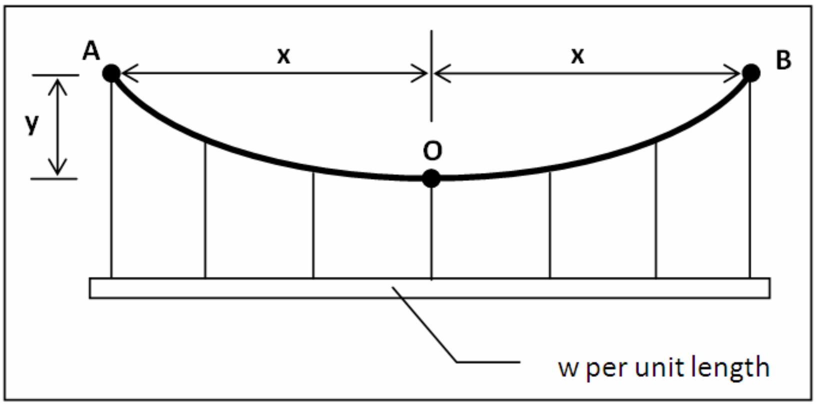


Figure 13. Suspension-bridge cable.

Figure 14 shows the free-body diagram to study the equilibrium of the left-hand part of the cable.

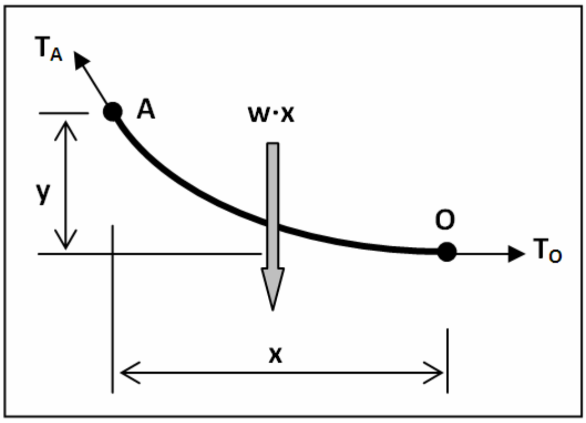


Figure 14. Free-body diagram.

It is considered that *w* is the weight per unit length, so the force *w·x* is acting through the mid-point of *x*. Taking moments about A, the equation 6 is obtained:

$$T_o \cdot y = (w \cdot x^2) / 2 \qquad (6)$$

This is the equation for a parabola (equation 7):

$$y = (w \cdot x^2) / (2 \cdot T_o) \qquad (7)$$

In order to determine the force acting in A, Figure 15 shows the triangle of forces.

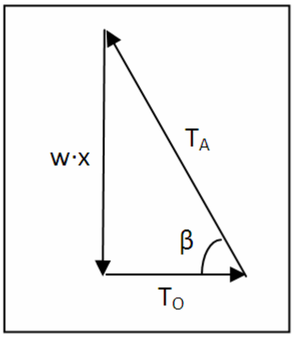
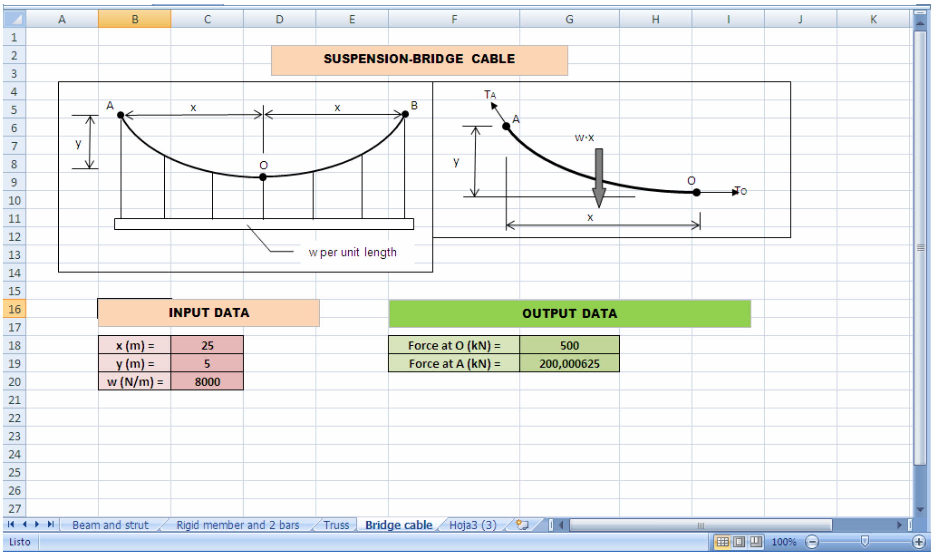


Figure 15. Triangle of forces.

Figure 16 is the spreadsheet used to determine the maximum force in point A in this system.



SUSPENSION-BRIDGE CABLE

INPUT DATA

x (m) = 25
y (m) = 5
w (N/m) = 8000

OUTPUT DATA

Force at O (kN) = 500
Force at A (kN) = 200,000625

Figure 16. Spreadsheet to determine the forces in a suspension-bridge cable.

4. Conclusions

The approach given has been our first step using spreadsheets in teaching the concepts and the procedures of mechanics of materials in the Design Engineering Degree.

Students can create a tool, that is very easy to use, in order to study this subject. Moreover, they enjoy learning strength of materials in this way. It is observed a reinforcement of student understanding of concepts and procedures of strength of materials take place, concommitant with this approach. Employment of this methodology in the laboratory includes work in experiments, in theory and in computation.

In this work, three particular applications of mechanics of materials have been presented. More spreadsheets utilising this methodology are currently being developed related to the study of shear stresses in bolted connections, torsion in shafts, bending in beams and buckling in columns.

The aim is that, at the end of the course, students have developed a collection of such spreadsheets. This methodology contributes to enhancing the motivation in the study, which is the main learning objective.

References

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