Using Excel and VBA for Excel to Learn Numerical Methods

Shkelqim KUKA[1], Brunela KARAMANI[2]

[1]*Department of Mathematics, FIMIF, Polytechnic University, Tirana, Albania*
[2]*Department of Computer Science, FTI, Polytechnic University, Tirana, Albania*

Abstract

Spreadsheets, by virtue of being distributed with office suites, are available in most computers, and can be used efficiently in the solution of numerical methods. In this paper we present calculations for numerical methods, specifically, solution to equations, using one of the most popular spreadsheet software currently available, namely, *Microsoft Office's EXCEL*. Spreadsheet calculations can be performed by simply using formulas in the spreadsheet cells, or by creating programs (subroutine programs, or SUBs, and FUNCTION programs) using a programming language accessible through the spreadsheet interface. *EXCEL* uses exclusively a language called *Visual Basic for Applications* (*VBA*).
Microsoft Excel is a excellent tool for students to learn numerical methods. It makes easy to construct illustrative examples, to experiment with them, and to plot results in graphical forms. The paper outlines the reasons for choosing Visual Basic for Applications (VBA) for Excel. Certain topics of interest with regard to VBA for Excel are explored, and sample programs are included
Some illustrative examples are presented to demonstrate the use of Goal Seek and Solver features as a powerful tool for solving of some problems in hydro engineering.

Keywords: *Numerical Methods, Spreadsheets, Microsoft Excel, VBA, Engineering Education.*

INTRODUCTION

Programming languages such as Fortran, Basic, Pascal and C have been used extensively by scientists and engineers, but they are often difficult to program and to debug. Modern commonly-available software has gone a long way to overcoming such difficulties. Matlab, Maple, Mathematica, and MathCAD for example, are rather more user-friendly, as many operations have been modularized, such that the programmer can see rather more clearly what is going on. However, spreadsheet programs provide engineers and scientists with very powerful tools.

Spreadsheets are much more intuitive than using high-level languages, and one can easily learn to use a spreadsheet to a certain level.

1.1 Overview of Visual Basic and Spreadsheets

Spreadsheets are becoming increasingly popular in solving engineering related problems. Among the strong features of spreadsheets are their instinctive cell-based structure and easy to use capabilities[3; 4].

Spreadsheets are among the earliest software innovations that had a profound effect on the widespread use of personal computers. Spreadsheets made their first appearance for personal computers in 1979 in the form of VisiCalc, an application designed to help with accounting tasks [1; 2]. Since that time, the diversity of applications of the spreadsheet program is evidenced by its continual reappearance in scholarly journals. Underneath the structure and the interface is a host of powerful and versatile features that can be utilized in teaching from data entry and manipulation to a large number of functions, charts, and word processing capabilities. This is in addition to its visual basic for applications (VBA) powerful programming capabilities. Newer spreadsheet versions have also added many productivity features for Internet connectivity, workgroup sharing, powerful programmability options, and a number of add-in programs.

1.2. SPREADSHEET AS A POWERFUL TEACHING TOOL

Several powerful and infrequently used Excel features are available and can be used to develop practical and powerful models for teaching civil engineering concepts. These features include data lists, data menu options, data filtering, referencing and searching lists, basic spreadsheet functions such as "Vlookup", and pivot table reports. Sorting the data helps bring similar records together for visual inspection or other purposes such as preparing reports and charts. Using the "Data, Sort" menu option, the list's data can be arranged in an order that is chosen by sorting the records. Filtering the data is also a useful way to view a subset of the records that compose a list. To filter a list is to extract records from it, based on criteria set by the user. Referencing and searching the list is another important part of the data management process.

In addition to the features and functions of Excel, its programming capabilities, called visual basic for applications (VBA) are very powerful and can be used to solve complex civil engineering problems.

However there is a lot more to Excel than meets the eye of many engineers.

There are numerous functions for assisting in financial, date and time, math and trig, statistical, database, text, logical, information, and general engineering calculations. Its graphing facilities are impressive as is its data handling facilities. What are often overlooked are the modeling tools including optimization, sensitivity analysis, and scenario management. Features like data lists and Pivot table/charts provide enormous flexibility for summarizing and formatting data. Data can be imported and incorporated in the worksheets anywhere from legacy files to modern data bases. By adding input controls and data validation, worksheets can be designed to accept valid data for special uses from the design of amusement park fountains to sales engineering expense reports. Furthermore "add-ins" provide numerous facilities for statistical analysis, optimization, and database interfaces.
Because VBA is generally incorporated in software applications that exist on the Windows platform, numerous software applications contain it. Once you learn VBA for Excel you can use VBA to extend Access, Word, PowerPoint, Visio, Outlook, and numerous other software packages like AutoCad and Arena. VBA is actually a very simple language, but when used in the context of an object-based application like Excel becomes a powerful tool.

USING SPREADSHEETS IN TEACHING Numerical Methods

The common spreadsheet is an excellent tool for students to learn numerical methods [6,7]. It makes it easy to construct illustrative examples, to experiment with them, and to plot results in graphical form. All students, in fact, no matter what their major, seem to appreciate the immediate display of results that spreadsheets allow.
In this paper we present calculations for numerical methods, specifically, solution to equations, using Microsoft Office's EXCEL .
Spreadsheet calculations can be performed by simply using formulas in the spreadsheet cells, or by creating programs (subroutine programs, or SUBs, and FUNCTION programs) using a programming language called Visual Basic for Applications (VBA), accessible through the spreadsheet interface.

Some of its effectiveness for numerical computations comes from a pair of modules, Goal Seek and Solver, which obviate the need for much programming and computations.

Goal Seek, Solver

Goal Seek, is easy to use, but it is limited – with it one can solve a single

equation, however complicated or however many spreadsheet cells are involved, whether the equation is linear or nonlinear.
Solver is much more powerful. It was originally designed for optimization problems, where one has to find values of a number of different parameters such that some quantity is minimized, usually the sum of errors of a number of equations. With this tool one can find such optimal solutions, or solutions of one or many equations, even if they are nonlinear. Solver is not automatically installed.
Some illustrative examples are then presented to demonstrate how spreadsheets can be used as a powerful tool for teaching of numerical methods.
The Solver function can replace traditional methods such as trial-and-error and chart method to solve various problems . Using the Solver function not only provides more accurate solution but also saves time and effort to solve the same or similar type of problems since spreadsheet developed for using Solver can be used repeatedly with different input data, constraints, changing cells (variables), and target cell (parameter).

Solving Non-linear Equation Using the Solver function in Microsoft Excel

Some of non-linear equations may be solved analytically, for example, a quadratic equation, but for many other non-linear equations the analytical solution may be very complex or not exist at all. Therefore, numerical methods, e.g., the Newton-Raphson method, are often used to find approximate roots or numerical solutions for those non-linear equations. Goal Seek is a very easy tool to solve equations but it has its limitations.
Solver is a useful tool for conducting a what-if analysis when we need to adjust the values in more than one cell and have multiple constraints for those values. Many problems in water resources engineering were used to solve by a trial-and-error method, and by using the Solver function, these problems can be solved very easily with high accuracy of results devoting minimum amount of time.

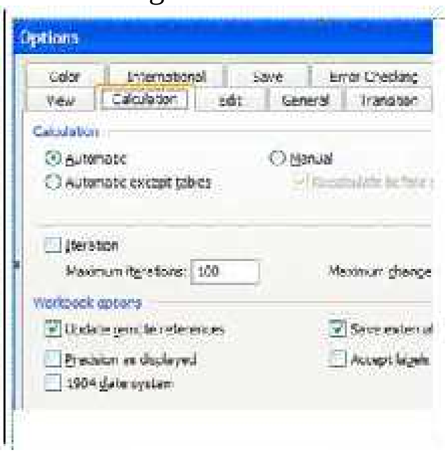
Circular References

A "circular reference" occurs when a Formula references, either directly or indirectly, the same cell where the Formula resides. Excel will "throw" (activate and display) an error message when a circular reference is encountered.

Intentional Circular References

Engineers will often encounter equations in which the unknown variable cannot be factored out to the left-hand-side of the equation, for example: {A5}: = Cos(A5/2). These are referred to as "implicit" equations . An implicit equation will result in a circular reference.

You can tell Excel to try to solve an implicit equation by checking the "Iteration" box on the "Calculation" tab of the "Options" dialog Instead of throwing an error message, Excel will use a trial-and-error method to try to find a value for the unknown variable that satisfies the equation. This "iterative" process will continue until either the "Maximum Iterations" has been exceeded, or until the "Maximum change" in the value of the variable is less than the stated value during an iteration.



(Figure 1.1).

The maximum iterations and the maximum change properties can be specified on the "Calculation" tab of the "Options" dialog (Figure 1.1).

Simultaneous Equations Example

The Iteration process can also be used to try to solve simple systems of linear simultaneous equations. For example suppose you wish to solve the following system for X and Y:

3X + 4Y = 8 (1.2)

3X + 8Y = 20

Rearrange the equations to isolate X on the left-hand-side of the first equation in the system and isolate Y on the left-hand-side of the second.

X = (8 – 4 * Y) / 3

Y = (20 – 3 * X) / 8

Turn on the Automatic calculation and the Iteration options. Let cell A2 represent X and cell A3 represent Y. Then:

{A2}: = (8 – 4 * A3) / 3

{A3}: = (20 – 3 * A2) / 8

The result of the iteration process is: X = -1.33268 and Y = 2.999756 compared to the exact solution of -3/4 and 3

Non-Linear Equation Example with Goal Seek

The Excel "Goal Seek" feature is a useful tool for finding the value of a single variable in a non-linear equation. Single-cell goal seeking (also known as "back solving") represents a rather simple concept. It does the trial-and-error for you that you could have done yourself; it just does it faster and more accurately. Goal seeking determines what value in an input cell produces the desired result in a Formula cell.

In this example we will use Goal Seek to solve Equation 1.3. This is a much more straight forward process than using circular referencing.

Our objective is to find a value for θ that will satisfy Equation 1.3 when t = 30 days.

$$\pi t - 50\theta + 25\sin(\theta) = 0 \quad (1.3)$$

1. Establish B3 as the "Variable" cell and enter an initial guess of 1 for θ.

2. Establish B5 as the "Result" cell and enter the Formula:

   {B5}: = PI()*30 - 50 * B3 + 25 * SIN(B3)

3. Process *Tools* -> *Goal Seek* to display the Goal Seek dialog, and enter the information shown in Figure 1.2.

Click *OK*.

The Result cell is about -2.8E-5 (close to the target 0). The solution is 2.67 appearing in the Variable cell (B3).

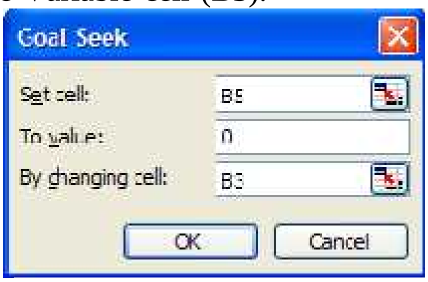


Figure 1.2. Goal Seek dialog

Designing A Steel Tank,

Example with Solver

Problem Statement

A sedimentation tank is circular in plan with vertical sides above the ground and a conical hopper below the ground as shown in Figure 1.3. The slope of the conical part is 3 vertical to 4 horizontal. Determine the dimensions to hold a volume of 4070 cubic meters for a minimum cost which, in this case, will be a tank with a minimum total area of bottom and sides.

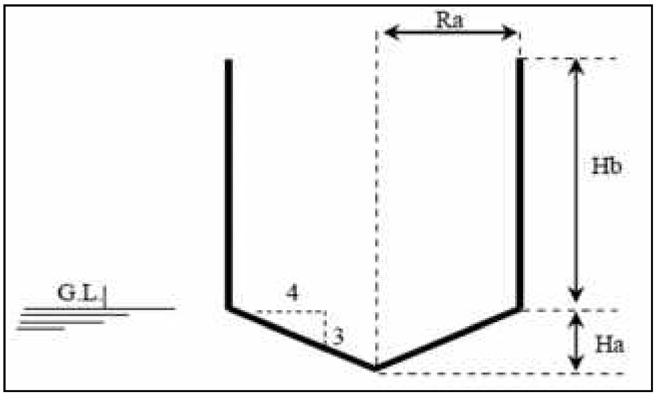


Figure 1.3. Steel sedimentation tank

Parameterization

Ra: Radius of the cylinder and base of the cone (m)
Ha: Height of cone (m)
Hb: Height of cylinder (m)
Aa: Surface area of cone (m^2) $Aa = \text{®} * Ra * \sqrt{Ra^2 + Ha^2}$
Ab: Surface area of cylinder (m2) $Ab = 2\text{®}\, RaHb$
Va: Volume of cone (m^3) $Va = \text{®}\, Ra^2 \frac{Ha}{3}$
Vb: Volume of cylinder (m^3) $Vb = \text{®}\, Ra^2 Hb$
Vt: Total volume (m3) $Vt = Va + Vb$
Za: Slope of cone sides (vertical/horizontal) $Za = \frac{Ha}{Ra}$

Objective Function

Your goal (objective) is to minimize
the total surface area of the tank:
Minimize: At

Decision Variables

The decision variables are the parameters that you will need to design the tank (i.e. the dimensions). They are: Ra, Ha, and Hb.

Dependent Variables

These are variables that are used to define the constraints. They are also used in a supporting role for calculating the objective function.

Coefficients

Coefficients are numbers that you can change to modify the design: Vdesign , Zdesign

Constraints

Constraints are limitations on the decision variables. In our case they require that the volume be at least equal to Vdesign and that the slope of the cone sides be equal to Zdesign. Mathematically:

Vt >= Vdesign
Za = Zdesign

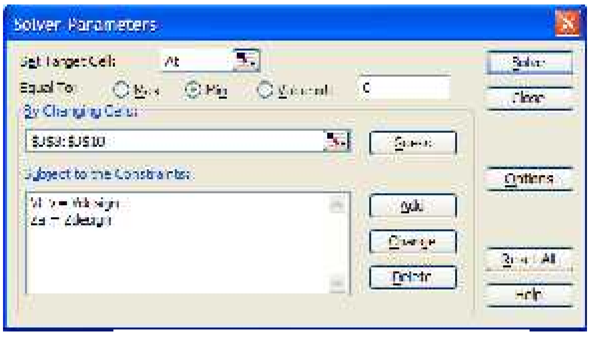


Figure 1.4. Solver parameters

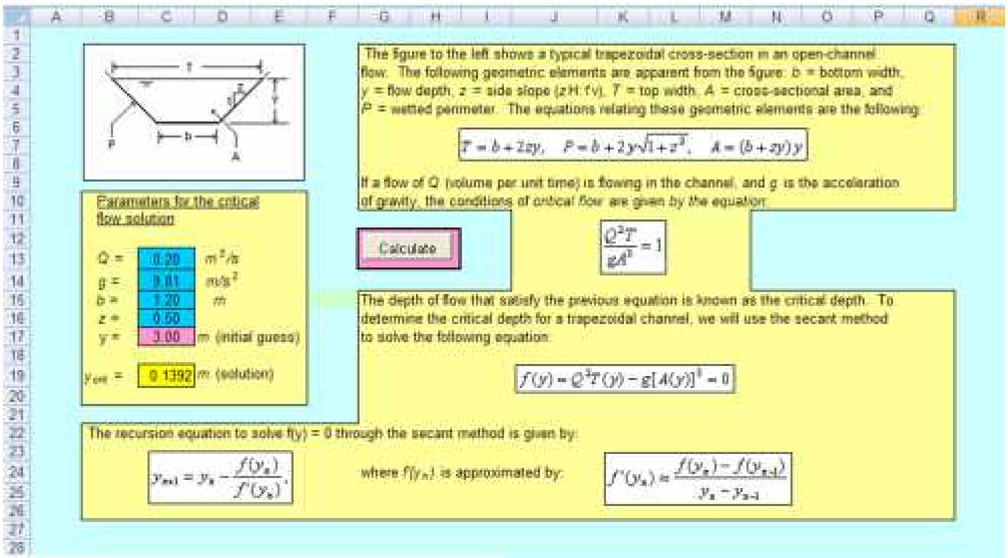
Implementation

The implementation is shown in Figures 1.4 – 1.5.

	A	D	C	D
1	Steel Tank			
2				
3				
4	Objective Function			
5	At =	=Aa+Ab	Total surface area (m²)	At = Aa + Ab
6				
7	Decision Variables			
8	Ra =	11.3905220390024	Radius of cylinder and base of cone (m)	
9	Ha =	8.99889194241139	Height of cone (m)	
10	Hb =	5.99926031053397	Height of cylinder (m)	
11				
12	Dependent Variables			
13	Aa	=PI()*Ra*SQRT(Ra^2+Ha^2)	Surface area of cone (m²)	Aa = π*Ra*Sqrt(Ra² + Ha²)
14	Ab =	= 2*PI()*Ra*Hb	Surface area of cylinder (m²)	Ab = 2*π*Ra*Hb
15	Va =	=PI()*Ra^2*Ha/3	Volume of cone (m³)	Va = π* Ra²*Ha/3
16	Vb =	=PI()*Ra^2*Hb	Volume of cylinder (m³)	Vb = π*Ra²*Hb
17	Vt =	=Va+Vb	Total Volume (m³)	
18	Za =	= Ha/Ra	Slope of cone sides (m vertical/m horizontal)	
19				
20	Coefficients			
21	Vdesign	4070	Design Volume (m³)	
22	Zdesign	0.75	Design slope of cone sides (m vertical/m horizontal)	
23				

Figure 1.5. Solution for the steel tank design shown in Formula Mode

Critical depth for a trapezoidal channel, Example with Secant Method
In this example we will find critical depth for a trapezoidal channel using the secant method (see Figure 1.6)



Private Sub cmdCalculate_Click()

```
Dim Q As Single, g As Single
Dim b As Single, z As Single
Dim y As Single, T As Single
Dim P As Single, A As Single
Dim f As Single, fp As Single
nmax = 100: epsilon = 0.001
Q = Range("C13")
g = Range("C14")
b = Range("C15")
z = Range("C16")
y1 = Range("C17")
y2 = y1 + 0.1
k = 1
Do While k < nmax
  T1 = b + 2 * z * y1
  A1 = (b + z * y1) * y1
  f1 = Q ^ 2 * T1 - g * A1 ^ 3
  y2 = y1 + 0.1
  T2 = b + 2 * z * y2
  A2 = (b + z * y2) * y2
  f2 = Q ^ 2 * T2 - g * A2 ^ 3
  fp = (f2 - f1) / (y2 - y1)
  yn = y1 - f1 / fp
  Tn = b + 2 * z * yn
  An = (b + z * yn) * yn
  fn = Q ^ 2 * Tn - g * An ^ 3
 If Abs(fn) < epsilon Then
    MsgBox "solution: y = " + Str(yn)
    Range("C19") = yn
    Exit Do
  End If
  y2 = y1
  y1 = yn
  k = k + 1
Loop
  If k >= nmax Then
  MsgBox "No convergence after " +
Str(nmax) + " iterations"
End If
nmax = 100
epsilon = 0.001
End Sub
```

SUMMARY AND CONCLUSION

Spreadsheet calculations can be performed by simply using formulas in the spreadsheet cells, or by creating programs (subroutine programs, or SUBs, and FUNCTION programs) using a programming language accessible through the spreadsheet interface.
Microsoft Excel has a Solver function that can be used to solve non-linear equations for various combinations of input data desired.
This paper has described and demonstrated how effective the Solver function can be used to solve various hydraulics and hydrology problems,
The Solver function is an effective tool to solve one or multiple unknown parameters as long as unknown parameters can be presented as one or several linear or non-linear equations or formulas. Various constraints can be used with Solver function which greatly increases the power of the Solver function. The Solver function can be utilized to replace traditional methods
such as trial-and-error method and chart method to solve various problems in the water resource engineering area.
It not only provides more accurate solution but also saves time and efforts to solve the same or similar type of problems since spreadsheet developed with using the Solver can be utilized repeatedly with different input data, constraints, changing cells (variables), and target cell (parameter). Development of Excel spreadsheets using the Solver function can help students, graduates, and professionals to get in-depth understanding of basic principles in hydraulics and hydrology.
Among the advantages spreadsheets offer are ease of programming (including relative references that are often ideally suited to numerical methods, and automatic renaming as rows and columns are introduced and removed), and immediate recalculation upon changes to any number.
Of course, numerical methods are about more than looking for numerical patterns and coincidences. Students who have engaged the material by translating mathematical notation into spreadsheet or program code and doing numerical experiments still have a lot to learn about numerical methods, many of them not at all suited to spreadsheet implementation.
Microsoft Excel is a excellent tool for students to learn numerical methods. It makes easy to construct illustrative examples, to experiment with them, and to plot results in graphical forms. By using spreadsheet we are developing students' skills with a standard tool of today's business world. The ability to do 'what if' analysis, to make tables, graphs and charts to show the analysis of the results, and in addition the ability to implement numerical methods , all gives students a competitive advantage when job hunting.

REFERENCES

[1] Baker, J. and Sugden, S., 2003. Spreadsheets in education– the first 25 years. *SIE journal*, 1(1), 18-43.
[2] Zaneldin, E., and Ashur, S., 2008. Using Spreadsheets as a Tool in Teaching Construction Management Concepts and Applications. *The 2008 American Society of Engineering Education (ASEE) Annual Conference*. June 22-25, 2008, Pittsburgh, PA, USA.
[3] Hegazy, T. and Ersahin, T., 2001. Simplified spreadsheet solutions. I: Subcontractor information system. *Journal of Construction Engineering and Management*. ASCE, 127(6), 461–468.
[4] Hegazy, T., and Ersahin, T., 2001. Simplified spreadsheet solutions. II: Overall schedule optimization. *Journal of Construction Engineering and Management*. ASCE, 127(6), 469–475
[5] Numerical Methods for Engineers, Fifth Edition, Steven C. Chapra, Raymond P. Canale, McGraw HILL, 2006
[6] Introduction to VBA for Excel, Second Edition, Steven C. Chapra, Prentice Hall, 2010