

Application of Excel spreadsheet in engineering education

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Abstract— Excel spreadsheet not only provides useful opportunities to solve various computational engineering problems but also can help improving the curriculum of engineering courses. In this paper, first the reasons of popularity of spreadsheets among other numerical softwares along with their unique facilities are introduced. Afterwards, a literature review on the application of spreadsheets such as Excel in different engineering fields was presented. Furthermore, two new application of Excel in civil engineering were recommended. Finally, it is highly suggested that instructors encourage educators to utilize spreadsheets such as Excel in their educational tasks since it provides a better understanding of exact problem solving procedure in comparison to other softwares, especially the commercial ones.

I. INTRODUCTION

In general, most of engineering problems can fit into one of these two categorizes: 1) Analysis or 2) Design and optimization. The former problems are kind of straight forward problems most of the time in which several governing equations have to be satisfied. Since the latter problems can be just turned into the former ones by considering initial guesses, the latter requires several trial-and-errors. Therefore, regardless of the type of a problem which a student in any engineering field is encountered, usually a tedious process is followed which may consist of several items: 1) building a model, 2) solving involving equations, 3) numerical computations, 4) checking some essential criteria, 5) finding the solution for other probable conditions, 6) regression/curve fitting and other possible items.

As far as educational purpose plays the key role, conducting the aforementioned items in the problem solving procedure becomes cumbersome if the student has to handle the problem in hand. The more complex the problem is, the more inevitable the need for using a computer-aided solver becomes. Although various commercial softwares have been presented to take care of different engineering problems in practice, they were not the appropriate enough for students

since: 1) These softwares are always designed to solve specific type of problems, 2) The users were not be able to see the real procedure which operates at the background of most of these softwares, 3) The cost of purchasing these softwares sometimes become unaffordable for students, 4) These softwares did not provide the students with actual fulfillment of educational purposes, and 5) These programs diminish the innovation-oriented minds of students in the progress of learning. Therefore, the usage of these kinds of softwares not only is practical but also do not fulfill educational purposes.

On the other hand, spreadsheets such as Excel provide a suitable platform to handle many engineering problems. Spreadsheets are a scientific tool which eliminates the tedious and repetitive computational tasks that may be performed manually [1]. It becomes increasingly popular in engineering education because of their instinctive cell-based structure and simply applied capabilities. For instance, Excel facilitates the user with numerous number of cells which deliberately can be linked and cooperated together. These cells along with built-in robust coding environment, i.e., Visual basic Application or VBA, can be desirably customized to implement the models required for solving problems. Getting involved to implement the problem into Excel helps the students discover the exact procedure working behind the solver programs. Moreover, the cells can be interpreted as the indices of a matrix and consequently matrix-based codes can be utilized. In addition, the add-in solver along with the capability of interacting cells can be programed to solve the governing equations in engineering problems. Furthermore, the computational part of solving a problem with numerous built-in functions is handed to a computer which encourages educators to utilize it. The substantial capability of solving the problem for other probable scenarios or different values brings about encouraging experiments for students. Graphical features of Excel also permit plotting various plots which can be considered as bless for educational purposes.

A survey of alumni from The University of Alabama's Department of Mechanical Engineering regarding software tools revealed that 100% of the respondents used Microsoft Excel regularly on their jobs; while a low percentage used standard packages such as ANSYS or MATLAB, and that

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none used software tools which had been bundled with textbooks [2]. The astonishing properties of Excel should be appreciated first by instructors, who carry the burden of not only teaching but also encouraging students. It seems that if an instructor solves a typical engineering problem in Excel in his/her lectures once in a while, it will grab the attention of students towards the powerful potential of this program. Additionally, asking students to conduct their assignments and projects in Excel will literally provide them to bring more innovation ideas in the problem solving procedure. Fortunately, when a problem is implemented in the Excel environment, it can be infinitely utilized. These files also can become a template file for solving the corresponding problem. Finally, it should be noted that although Excel has been applied in many engineering problems, it can be more than ever utilized for problem solving by not only researchers but also by students as well.

In this paper, the application of Excel as a powerful tool in educational engineering schools is being suggested. A short review on appraisal of Excel in several engineering field is presented to introduce its widespread potential to be utilized in more engineering problems. Moreover, several new application of Excel is presented in civil engineering fields. Since it has already been successfully utilized in various engineering problems, it is suggested not only to be introduced as an efficient problem solver in instructor lectures, but also to be used in student projects in various engineering courses.

II. LITERATURE REVIEW ON APPLICATION OF EXCEL SPREADSHEET IN DIFFERENT BRANCH OF ENGINEERING

The spreadsheets were extensively applied for teaching undergraduate engineering students in mechanical, electrical engineering, and mathematics regardless of their field of expertise. Clements [3] assessed spreadsheets as a tool for teaching elementary numerical analysis. Doak et al. [4] utilized animated spreadsheets as a teaching resource. Kharab and Kharab [5] investigated spreadsheets programs for the numerical solution of hyperbolic partial differential equations. Svoboda [6] utilized spreadsheets in electrical engineering specifically to predict and minimize the loading errors, the availability of standard resistor values, and resistor tolerances. Boye, Williams and Soukup [7] used spreadsheets to improve the problem-solving skills of educators. Aliane [8] reports the development of a control system teaching package using the Excel spreadsheet program. Evans [9] describes simulation techniques using the Excel spreadsheet program. Pecherska and Merkurjev [10] describe a spreadsheet-based approach to teaching simulation, where the objective is to introduce spreadsheets as a powerful simulation tool for educational purposes. Cooper [11] reports how data analysis and simulation can be carried out using the Excel spreadsheet program. Baker and Sugden [12] reviewed the application of spreadsheets in education 25 years after their first appearance for personal

computers. Similar studies were also conducted in conditional looping [13], partial differential equations [14], numerical methods [15], micros and macros [16, 17], matrix manipulation [18], integer and linear programming [19, 20], engineering product cost determination [21], and etc. The specific application of spreadsheet in different engineering fields is as follows:

A. Mechanical engineering

Schumack [22] investigated teaching heat transfer by using automotive-related case studies with a spreadsheet analysis package. Antar and Mokheimer [23] introduced different approaches to apply spreadsheet programs in heat conduction analysis. Tai [24] formulated the finite-element equations into a part of an optimization problem by considering the unknowns as decision variables and equations as equality constraints in spreadsheets. Woodbury et al. [2] reports on a proof-of-concept project to implement sustained emphasis on Microsoft Excel in the thermal mechanical curriculum at The University of Alabama. Specific add-in modules for use in thermodynamic analysis and heat transfer analysis have been developed and are continually being refined.

B. Electrical engineering

Yamani and Kharab [25] utilized spreadsheet program assisted electromagnetic education. Bissell and Chapman [26] applied spreadsheets in telecommunication, signal processing, and control engineering. Stanton, Drozdowski and Duncan [27] assessed the power of PC-based spreadsheet programs to aid educator's understanding and cognitive development. El-Hajj and Kabalan [28] presented pictorial simulation of the mathematical performance of an integrator. El-Hajj, Kabalan and Mahmoud [29] described a spreadsheet toolbox for simulating digital networks. Shapiro [30] illustrated how a spreadsheet could be used on a personal computer. Bissell [31] investigated the powerful features of spreadsheet including its graph-plotting ability. Diab [32] suggested spreadsheets for the performance analysis of cache-based multiprocessors for general-purpose computing. Ibrahim [33] describes how spreadsheet programs such as the Microsoft Excel can be utilized for the simulation of mathematical equations and also digital logic circuits thought to undergraduate students.

C. Chemical Engineering

Edgar [34] recommends a significant perspective to spreadsheet appraisal in chemical engineering. Rives and Lacks [35] studied the subject of teaching process control with a numerical method using spreadsheets. Chemical process simulation using the Excel program is described by Henao and Velasquez [36]. Ferreira, Lima and Salcedo [37] solved three nonlinear and one linear problems using Excel solver including: 1) the recovery of benzene from a gaseous emission, 2) the design of a chemical reactor network, 3) the solution of material balances in the production of vinyl

chloride from ethylene, and 4) the dephenolization of aqueous wastes. Sakuma and Matsui [38] studied the effectiveness of Microsoft Excel in engineering education by solving five examples including: 1) Understanding of sampling theorem, 2) Simulation of adaptive algorithm, 3) Speed control simulation of a DC motor, 4) System pole assignment, and 5) Acceleration animation of a pendulum. Bengtson [39] posted several commercial spreadsheets for engineering calculations on line including: 1) Nitrification-denitrification activated sludge process, 2) Gas compressibility factor calculation, 3) Moving bed biological reactor wastewater treatment design, 4) Flow through non circular ducts, 5) Hydraulic grade line and energy line, 6) Trilateration surveying data processing, 7) Turbulent and laminar flow in pipes, 8) Nature gas pipeline flow calculation, 9) Choked air flow calculation, and 10) Hydraulic Design of Storm Sewers with Excel.

D. Civil Engineering

Excel has been widely utilized in different branches of civil engineering because of its easy accessibility and the user's ability to solve complex systems without much prior knowledge of the software [40]. Huddleston [41] utilized Excel in branching pipe flow networking piping system analysis. Since the December 2001 issue of the *Journal of Hydraulic Engineering* was devoted to the topic of teaching hydraulic design, several studies were conducted on the application of Excel in engineering hydraulics in that year. Hegazy and Ersahin [42] utilized Excel and VBA to develop an information system for subcontractors and small/medium-sized contractors. Weiss and Gulliver [43] displayed the use of Excel for analyzing hydraulic design projects. Jewell [44] had shown the utility of equation solver in teaching hydraulic design to undergraduate students. Thiriez [45] developed several spreadsheets as educational tools for students. One example is to use the drawing capabilities of Excel to represent decision trees and where window switching and macros allow the educator to animate his presentation. Another example presented by Thiriez [45] is the use of Excel in dynamic programming, deterministic or stochastic, where Excel functions facilitate the development of specialized models. Huddleston, Alarcon and Chen [46] examined the use of Excel in analyzing water distribution networks. Ickert and Huston [47] developed a spreadsheet that can be used to analyze multiple solutions for engineering problems efficiently and accurately, and to produce graphs that convey the solution to the end users. Kaarahan and Ayvaz [48] applied spreadsheets for Time-dependent groundwater modeling. Rivvas, Gomez-Acebo and Ramos [49] studied the application of spreadsheets in analysis and optimization of systems and processes in the teaching of hydraulic and thermal engineering. Grabow and McCornik [50] proposed an algorithm in Excel for water quality and allocation management. Bhattacharjya [51] shows the application of the Excel solver in computation of critical

depth of an open channel section. Bhattacharjya [40] solved the groundwater flow simulation model by using the embedded optimization approach and Excel solver. The presented methodology is simple in concept and can be used by graduate and undergraduate students to solve groundwater flow problems with a minimal computational burden. Zanelidin and El-Ariss [52] used spreadsheets in two areas in civil engineering namely construction management and structural engineering. These applications in the former area includes: 1) Construction data management, 2) Time-cost tradeoff (TCT) analysis, 3) Optimum markup estimation, 4) Simulating and scheduling construction activities with uncertain durations, 5) Scheduling linear and repetitive projects, 6) Schedule and cost control, and 7) Optimization of construction operations. The contributions in the latter area are the structural calculations of reactions, internal forces, stresses, strains, deflections, and slopes. Barati [53] calibrated Muskingum parameters using Excel Solver. Sana [54] elaborated the enhancements in the curricula of hydrology, water resources and coastal engineering by including short VBA programs. In his study, typical examples of such program usage includes: 1) Calculations of friction factor, 2) Design of open channels, 3) Design of sanitary sewers, 4) Calculation of cumulative infiltration by Green-Ampt formula, and 5) Solution of wave dispersion relation. This improvement, like other mentioned improvement in the curricula, would encourage students to fully utilize the advanced features of Excel, which subsequently leads to improvement in the corresponding engineering fields. More recently, Oke et al. [55] compared Microsoft Excel solver with several techniques for solving linear theory equations in pipe network analysis. According to the results of this paper, it was finally concluded that Microsoft Excel solver is the overall best method among all the considered methods. In next sections, two new applications of Excel in civil engineering field are described.

III. APPLICATION OF EXCEL IN FINDING PEAK GROUND ACCELERATION CONTOURS

In earthquake engineering, empirical relations were proposed based on earthquake data bases for computing Peak Ground Acceleration (PGA). These highly nonlinear equations relate PGA to distance from the fault (R), surface wave magnitude (M), and other involving parameters. In case the PGA values are computed for an area, the obtained PGA contour plot can provide suitable information for design new project in the corresponding area. Finding PGA contour map becomes more complex when the area under consideration is limited with several faults. As an example, a right triangular location with sides equal to 100 km is surrounded by three faults right at its sides. In order to solve this problem with Excel and VBA program, first a table containing the point coordinates, distances from faults, PGA, attenuation for each fault, occurrence, and probability should

be prepared in cells of Excel (Fig. 1). Secondly, the proper attenuation relationship, e.g. Donovan (303 Instrumental Values) [56], should be considered. The selected equation should be solved for each point in the area considering a desirable period of structure, e.g., 50 years. A code using Newton-Raphson scheme for solving highly nonlinear attenuation relation is just shown in Fig. 2. This code can be placed in the VBA environment. The values of PGA, M, N, and P can be computed by running the mentioned code. Afterwards, a built-in plotter in Excel, so called “D-Plot”, was utilized to plot PGA contour lines for the area under

width is considered. It is assumed that a 25 m³/s flow is being carried in the channel with Manning coefficient equal to 0.012. In case, the side slopes are 1.5H:1V and a controlling structure raises the water depth equal to 5.5m at the downstream end. The objective is to find the water surface profile along the channel upstream of the structure

No. Points	x	y	Ra	Rb	Rc	PGA	Mb	Mc	Na	Nb	Nc	P	dp	sumN
1	0	0	0	0	70.71068	1.25	7.587921	7.587921	10.79377	0.001165	0.001165	1.92E-07	0.109961	0.00233
2	10	0	0	10	63.63961	1.09	7.381716	8.185232	10.40429	0.00204	0.00023	5.53E-07	0.107302	0.00227
3	20	0	0	20	56.56854	1.07	7.353818	8.757496	10.17786	0.0022	4.85E-05	1.02E-06	0.1064	0.00225
4	30	0	0	30	49.49747	1.06	7.33967	9.222553	9.947167	0.002287	1.37E-05	1.92E-06	0.108733	0.002302
5	40	0	0	40	42.42641	1.06	7.33967	9.621516	9.70901	0.002287	4.64E-06	3.66E-06	0.108406	0.002295
6	50	0	0	50	35.35534	1.06	7.33967	9.963222	9.444444	0.002287	1.83E-06	7.51E-06	0.108453	0.002296
7	60	0	0	60	28.28427	1.06	7.33967	10.26212	9.146871	0.002287	8.14E-07	1.69E-05	0.108824	0.002304
8	70	0	0	70	21.2132	1.06	7.33967	10.52774	8.80687	0.002287	3.96E-07	4.25E-05	0.109945	0.002329
9	80	0	0	80	14.14214	1.07	7.353818	10.78089	8.424442	0.0022	1.99E-07	0.00012	0.10955	0.002321
10	90	0	0	90	7.071068	1.11	7.409103	11.05342	8.003917	0.001893	9.48E-08	0.000376	0.107284	0.00227
11	100	0	0	100	0	1.25	7.587921	11.43134	7.587921	0.001165	3.4E-08	0.001165	0.109954	0.00233
12	10	10	10	0	70.71068	1.09	8.185232	7.381716	10.58758	0.00023	0.00204	3.36E-07	0.107292	0.00227
13	10	10	10	10	63.63961	0.74	7.600661	7.600661	9.819736	0.001125	0.001125	2.71E-06	0.106539	0.002253
14	10	10	10	20	56.56854	0.65	7.404265	8.004419	9.424792	0.001919	0.000376	7.92E-06	0.108727	0.002302
15	10	10	10	30	49.49747	0.63	7.356879	8.436247	9.16086	0.002182	0.000116	1.62E-05	0.109283	0.002315
16	10	10	10	40	42.42641	0.63	7.356879	8.835181	8.922702	0.002182	3.93E-05	3.1E-05	0.106512	0.002252
17	10	10	10	50	35.35534	0.63	7.356879	9.176915	8.658136	0.002182	1.55E-05	6.36E-05	0.106906	0.002261
18	10	10	10	60	28.28427	0.64	7.38076	9.499693	8.384445	0.002045	6.46E-06	0.000134	0.103506	0.002185
19	10	10	10	70	21.2132	0.65	7.404265	9.788811	8.067951	0.001919	2.95E-06	0.000316	0.105847	0.002238
20	10	10	10	80	14.14214	0.69	7.49475	10.1183	7.761857	0.0015	1.2E-06	0.000726	0.105405	0.002228
21	10	10	10	90	7.071068	0.8	7.71854	10.55934	7.50984	0.000817	3.63E-07	0.00144	0.106727	0.002257
22	10	20	20	0	70.71068	1.07	8.757496	7.353818	10.55968	4.85E-05	0.0022	3.63E-07	0.10637	0.002249
23	10	20	20	10	63.63961	0.65	8.004419	7.404265	9.623323	0.000376	0.001919	4.62E-06	0.10858	0.002299

Fig. 1. The location data, PGA, attenuation, and occurrence values.

consideration (Fig. 3). Since solving the attenuation relation requires several iterations, it takes a great amount of time for an educator to solve this problem by hand while the mentioned code can find the solution in a less than a minute. Since Excel can be linked to lots of programs which enables the user to utilize codes in other programs, like MATLAB, too. Moreover, the capabilities of plotting different kind of figures along with useful add-ins enhance the educator with a variety of choices.

IV. APPLICATION OF EXCEL IN COMPUTING GRADUALLY VARIED FLOW DEPTH

In engineering hydraulics, the calculation of water depth in open channels is one of intentions. In gradually varied flow condition, a first ordinary differential equation governs the value of water depth along the channel. In order to solve this equation, a finite difference scheme, e.g. Euler’s method, can be applied. As an example, a typical channel with a trapezoidal section with a 0.0012 bottom slope, 8m bottom

```

Sub pro()
For H = 3 To 67
    T = 50 ' T = Period of Structure
    Cells(H, 7) = 0.1 ' Initial PGA
    Cells(H, 15) = 0.1
    Do Until Cells(H, 15) < 0.01 ' accuracy of P = 0.01
        Cells(H, 16) = 0 ' Initial sum of N
        For I = 1 To 3 ' # of faults
            j = I + 7 ' M
            K = I + 3 ' R
            L = I + 10 ' N
            Cells(H, j) = 5 ' Initial M
            da = Abs((1.325 * Exp(0.67 * Cells(H, j)) / (Cells(H, K)
+ 25) ^ 1.6) - Cells(H, 7)) ' Initial diff between PGA's
            Do Until da < 0.01 ' Newton method
                Xn = Cells(H, j)
                Cells(H, j) = Xn - (((1.325 * Exp(0.67 * Xn) /
(Cells(H, K) + 25) ^ 1.6) - Cells(H, 7)) / ((0.88775 * Exp(0.67
* Xn) / (Cells(H, K) + 25) ^ 1.6)))
                da = Abs(Cells(H, j) - Xn)
            Loop
            Cells(H, L) = 10 ^ (6.02 - (1.18 * Cells(H, j))) ' Each
new N
            Cells(H, 16) = Cells(H, 16) + Cells(H, L) ' New sum of
N
        Next I
        Cells(H, 14) = 1 - Exp(-T * Cells(H, 16)) ' P
        Cells(H, 15) = Abs(Cells(H, 14) - 0.1) ' dp
        Cells(H, 7) = Cells(H, 7) + 0.01 ' New PGA & accuracy of
PGA = 0.01
    Loop
Next H
End Sub
    
```

Fig. 2. The code for solving attenuation relation in VBA

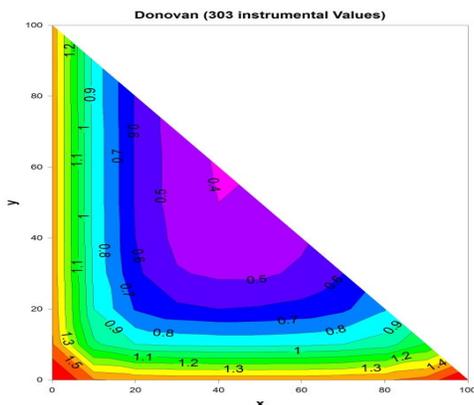


Fig. 3. PGA contour for the area under investigation

	A	B	C	D	E	F	G
1	b	z	Q	S0	n	g	
2	8	1.5	25	0.0012	0.012	9.807	
3							
4	y	A	P	R	V	Sf	S _f ^{ave}
5	5.5	89.375	27.831	3.211	0.280	2.38E-06	5.03E-06
6	4.5	66.375	24.225	2.740	0.452	7.67E-06	1.24E-05
7	3.66	49.373	21.196	2.329	0.608	1.72E-05	2.10E-05
8	3.33	43.273	20.006	2.163	0.693	2.47E-05	3.07E-05
9	3	37.500	18.817	1.993	0.800	3.67E-05	4.38E-05
10	2.75	33.344	17.915	1.861	0.900	5.09E-05	7.88E-05
11	2.25	25.594	16.112	1.588	1.172	1.07E-04	1.35E-04
12	2	22.000	15.211	1.446	1.364	1.64E-04	2.01E-04
13	1.8	19.260	14.490	1.329	1.558	2.39E-04	3.01E-04
14	1.6	16.640	13.769	1.209	1.803	3.64E-04	4.73E-04
15	1.4	14.140	13.048	1.084	2.122	5.82E-04	6.69E-04
16	1.3	12.935	12.687	1.020	2.319	7.55E-04	8.76E-04
17	1.2	11.760	12.327	0.954	2.551	9.98E-04	

Fig. 4. The implementation of direct method for calculating water surface profile

using Excel. First the finite difference scheme should be implemented in Excel cells. For instance, Fig. 4 shows the application of direct method in Excel spreadsheet. In this figure, the involving parameters are defined by naming cells. Therefore, this problem can be solved for any other value of these parameters just by changing the value of these cells. This provides a great opportunity for educators to track down the solution for any other parameter values. The results of water surface profile were computed for four schemes including: 1) Direct method, 2) Euler's method, 3) Modified Euler's method, and 4) Fourth order Runge-Kutta. The results were plotted in Fig. 5 using Excel.

V. CONCLUSION

The successful application of various complicated engineering problems in spreadsheets like Excel reveals the inevitable potential of these programs for educational purposes. The ease of use, powerful add-ins, and robust environment of spreadsheets like Excel makes it favorable for educational purposes in different engineering fields.

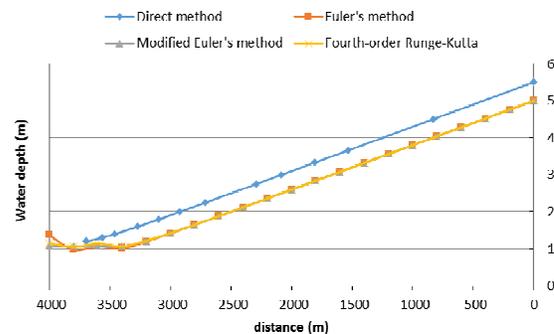


Fig. 5 Water surface profile computed in Excel spreadsheet using different schemes

Since the literature is full of application of spreadsheet for engineering problems, the instructors and stakeholders should paid especial attention to these kinds of programs. In this paper, the appraisal of such programs in mechanical, electrical, chemical, and civil engineering was reviewed. Additionally, two new applications of Excel in earthquake and hydraulic engineering were proposed to encourage instructors as well as students to use this tool in their own works. Finally, this paper was intended to once again highlight the importance of use of spreadsheets in engineering educational systems.

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