

Simulation for the study of beam deflection in strength of materials

Alamgir Choudhury
Western Michigan University

Christian Ochei
Robert Rice
Cuyahoga Community College

Abstract

The diversity of student background in two-year institutions is a limiting factor in realizing the course objectives of the strength of materials class. Specifically, teaching beam deflection theory has been difficult and time consuming in the traditional manner. Instead of focusing on only theory and routine problem solving techniques in the class, the introduction of beam deflection simulation and computer programming generates student interest in the subject. Visual input from the graphical simulation draws student attention to the underlying cause of deflection and eventual comprehension of the theory. By studying the effects of beam characteristics and loading conditions on the nature of the deflection curve, students develop insight on deflection and its parameters. Flexible instruction material is developed on how to use existing deflection tools as well as create similar application programs. Simultaneous study of deflection theory, practice of exercise problems and experimentation with deflection simulation have improved student learning in the area. This simulation and programming task replaces previous laboratory experiment on wooden beam deflection. Therefore, curriculum objectives are achieved without utilizing additional laboratory time.

1. Introduction

At Cuyahoga Community College (CCC), Strength of Materials is a required course for the mechanical engineering technology and architecture/construction technology programs. Beam deflection theory and the associated exercise problems are an indispensable part of a traditional strength of materials curriculum in similar programs. The subject is taught using both moment-area and superposition methods [1,2]. While the moment-area method uses properties of bending moment diagram area, the superposition technique requires the combined use of existing deflection equations for standard component problems. Though the moment-area technique can be used to solve statically determinate deflection problems in general, the mathematics involved with the process may be burdensome for average students. In the superposition method, the deflection problem is divided into several sub-problems, whose deflection equations are presented in the superposition chart [1]. Successful use of the technique requires correct

development of the sub-problems and the existence of their deflection equations in the chart. In some cases development of the sub-problems requires significant experience and can be difficult for many students. Past experience in the classroom indicates that the average students at CCC tend to avoid the use of the moment-area technique mainly because of its detailed mathematical nature and prefer the superposition method. During the past decade, the introduction of computer usage has significantly reduced manual computation requirements in many engineering technology classes. In the strength of materials class, the objectives of computer use are:

- (i) Minimize manual computations.
- (ii) Facilitate understanding of theory.
- (iii) Generate student interest in the subject matter.
- (iv) Develop confidence in computer usage for solving technical problems and consequently enhance student skill in a programming language.

The project is comprised of three phases, two of which have already been implemented. In the first phase, students are taught the step-by-step programming for solving example problems in the class. In phase two, students write their own programs to simulate deflection of a given beam problem as laboratory exercise. The tool for the third phase has recently been developed and will be introduced in class during fall semester 2001. Using this tool, students will be able to compare analytical solutions of their homework problems with deflection produced by a computer program.

Similar tools were developed in various schools in the past [3, 4, 6, 8]. Ressler [3] developed "Visual Stress Transformer," a Visual Basic program to animate stress transformation in strength of materials class. Jong and Onggowijaya [5] used Qbasic [6] programming language to simulate four-bar linkage motion in a kinematics class. Others [7, 8, 10] used available commercial software such as Working Model [4] and Spreadsheet either to enhance student learning or to teach students computer applications for solving technical problems. The tool presented here was developed based on the objectives (i)-(iv) outlined above.

The graphics feature available in Visual Basic is suitable for the visual display of deflection calculation. The Visual Basic programming class is also required for graduation in any engineering technology program at CCC. Therefore, Visual Basic is most appropriate as the programming language for the project. This also allows us to implement the project without spending time in teaching the programming language. For students with different backgrounds, programming in Qbasic or C++ is equally encouraged. It is already evident from student grades that their understanding of beam deflection has improved.

2. Student background

CCC is an open-door urban community college with a large diverse student population. Students enrolling in the strength of materials class pursue a two-year associate degree either in mechanical engineering technology or architecture/construction technology.

Student diversity in the programs arises from socio-economic background, age, prior education, aptitude level, math-science background and educational objective. About one third of the students are regular high school graduates while others are working full or part time and returning to school after a break in study. A significant number of these students take only certain classes to enhance their skill in specific areas for professional enhancement. Therefore, at CCC, in any curriculum or teaching-tool development, flexibility is crucial in achieving broader student success.

3. Previous method

At CCC, the strength of materials is a three-hour semester course. Beam deflection is covered over a two-week period in a total of eight hours of lecture and laboratory. In the past, the task consisted of lecture, problem solving, laboratory exercise and lab report writing. The topics were covered in sequence of

- (i) Deflection theory
- (ii) Deflection calculation by using bending moment diagram area
- (iii) Deflection calculation by superposition method
- (iv) Laboratory experiment to verify deflection versus load relationship in a simply supported wooden beam.

The average student's performance was generally poor in this area, especially, in part (ii) of the sequence. Many students tried to avoid this part of the course because of the extensive computation required in the method.

4. New method

Recently, the newer textbooks come with the programming tools that can be used to calculate deflection in a specific beam problem. Some texts also include application program development examples. Because of the broad objective of this project, we required a more comprehensive tool that could achieve all the goals outlined in section 1. The project is implemented in three phases, namely, (a) application program development lesson, (b) laboratory exercise and (c) use of a general programming tool.

4.1 Application program development lesson

At the beginning of this step an example problem is analyzed in the class by using both moment-area and superposition methods. Next, based on the deflection equations already developed, the step-by-step procedure for development of a simple Visual Basic program for the example problem is taught. For most students with Visual Basic background, learning of such programming comes naturally. To maintain flexibility for students with weaker programming backgrounds, such program development lessons in Qbasic are also made available. The Qbasic version of an example program is shown in Figure 1. By executing the program for various deflection parameters, e.g. moment of inertia of beam cross section, modulus of elasticity of material and magnitude, nature and location of

load, students can also study the effect of these parameters on nature of deflection curve and magnitude of deflection. Besides visualization, such experimentation also helps students develop intuition on the nature of deflection and effects of beam parameters on deflection. In absence of such tools similar outcomes would be achieved only after extensive practice.

```

1000 REM
1050 CLS
1100 REM set the values of the constants
1110 DIM X(200), DELTA(200)
1300 INPUT ; " Enter value of force P "; P
1305 PRINT " "
1308 PRINT " "
1310 INPUT ; " Enter the distributed force W in kip/ft "; W
1400 EI = 2.46 * 10000 * 144
1500 W = W / 12
1600 L = 120
1800 M = P * 36
1810 THB1 = W * L ^ 3 / (24 * EI)
1820 THB2 = -M * L / (3 * EI)
1880 THB = THB1 + THB2
1900 FOR I = 1 TO 156
2000 X(I) = I
2100 NEXT I
2200 FOR I = 1 TO 120
2300 D1 = W * X(I) * (L ^ 3 - 2 * L * X(I) ^ 2 + X(I) ^ 3) / (24 * EI)
2400 D2 = -M * X(I) * (L ^ 2 - X(I) ^ 2) / (6 * EI * L)
2500 DELTA(I) = D1 + D2
2600 NEXT I
2700 L1 = 36
2800 FOR I = 121 TO 156
2900 D3 = -THB * (X(I) - 120)
3000 D4 = P * ((X(I) - 120) ^ 2) * (3 * L1 - (X(I) - 120)) / (6 * EI)
3100 DELTA(I) = D3 + D4
3200 NEXT I
3300 SCREEN 0, 0, 0
3350 REM COLOR 3,1
3400 PRINT " x(in)"; " delta(in)"; " x(in)"; " delta(in) "; " x(in)";
3500 PRINT "
3600 PRINT " "
3700 FOR I = 1 TO 52
3800 XL1 = X(I)
3900 XL2 = X(I + 52)
4000 DEL1 = DELTA(I)
4100 DEL2 = DELTA(I + 52)
4200 XL3 = X(I + 104)
4300 DEL3 = DELTA(I + 104)
4700 PRINT USING "#####.#####"; XL1; DEL1; XL2; DEL2; XL3; DEL3
4800 NEXT I
4900 SCREEN 9, 0, 0
5000 FOR I = 2 TO 156
5100 A = X(I - 1) * 3.8
5200 B = DELTA(I - 1) * 200 + 150
5300 C = X(I) * 3.8
5400 D = DELTA(I) * 200 + 150
5500 REM plots deflection curve on the screen
5600 LINE (0, 150)-(600, 150), 7, , &HFFF0
5610 LINE (A, B)-(C, D), 7, , &HFFFF
5700 NEXT I
5708 REM SCREEN 2,0,0
5710 PRINT "Deflection curve for P = "; P; " kips and w = "; W * 12; " kips/ft.
5800 REM SCREEN 0,0,0

```

Figure 1
Qbasic version of an example program

x(in)	delta(in)	x(in)	delta(in)	x(in)	delta(in)
1.0000	0.0060	53.0000	0.2084	105.0000	0.0633
2.0000	0.0121	54.0000	0.2087	106.0000	0.0587
3.0000	0.0181	55.0000	0.2090	107.0000	0.0542
4.0000	0.0241	56.0000	0.2090	108.0000	0.0496
5.0000	0.0300	57.0000	0.2090	109.0000	0.0452
6.0000	0.0360	58.0000	0.2087	110.0000	0.0407
7.0000	0.0419	59.0000	0.2084	111.0000	0.0363
8.0000	0.0477	60.0000	0.2078	112.0000	0.0320
9.0000	0.0536	61.0000	0.2071	113.0000	0.0277
10.0000	0.0593	62.0000	0.2063	114.0000	0.0235
11.0000	0.0651	63.0000	0.2053	115.0000	0.0193
12.0000	0.0707	64.0000	0.2042	116.0000	0.0153
13.0000	0.0763	65.0000	0.2029	117.0000	0.0113
14.0000	0.0818	66.0000	0.2015	118.0000	0.0074
15.0000	0.0873	67.0000	0.1999	119.0000	0.0037
16.0000	0.0927	68.0000	0.1982	120.0000	-0.0000
17.0000	0.0980	69.0000	0.1964	121.0000	-0.0035
18.0000	0.1032	70.0000	0.1944	122.0000	-0.0069
19.0000	0.1083	71.0000	0.1923	123.0000	-0.0102
20.0000	0.1133	72.0000	0.1900	124.0000	-0.0134
21.0000	0.1183	73.0000	0.1877	125.0000	-0.0165
22.0000	0.1231	74.0000	0.1852	126.0000	-0.0195
23.0000	0.1278	75.0000	0.1825	127.0000	-0.0223
24.0000	0.1324	76.0000	0.1798	128.0000	-0.0251
25.0000	0.1369	77.0000	0.1769	129.0000	-0.0278
26.0000	0.1413	78.0000	0.1739	130.0000	-0.0304
27.0000	0.1456	79.0000	0.1708	131.0000	-0.0329
28.0000	0.1497	80.0000	0.1676	132.0000	-0.0353
29.0000	0.1538	81.0000	0.1643	133.0000	-0.0376
30.0000	0.1577	82.0000	0.1609	134.0000	-0.0399
31.0000	0.1615	83.0000	0.1574	135.0000	-0.0420
32.0000	0.1651	84.0000	0.1537	136.0000	-0.0442
33.0000	0.1686	85.0000	0.1500	137.0000	-0.0462
34.0000	0.1720	86.0000	0.1462	138.0000	-0.0482
35.0000	0.1752	87.0000	0.1424	139.0000	-0.0501
36.0000	0.1783	88.0000	0.1384	140.0000	-0.0519
37.0000	0.1813	89.0000	0.1344	141.0000	-0.0537
38.0000	0.1841	90.0000	0.1302	142.0000	-0.0555
39.0000	0.1868	91.0000	0.1261	143.0000	-0.0572
40.0000	0.1893	92.0000	0.1218	144.0000	-0.0589
41.0000	0.1917	93.0000	0.1175	145.0000	-0.0605
42.0000	0.1939	94.0000	0.1132	146.0000	-0.0621
43.0000	0.1960	95.0000	0.1088	147.0000	-0.0636
44.0000	0.1979	96.0000	0.1043	148.0000	-0.0651
45.0000	0.1997	97.0000	0.0998	149.0000	-0.0666
46.0000	0.2013	98.0000	0.0953	150.0000	-0.0681
47.0000	0.2028	99.0000	0.0908	151.0000	-0.0695
48.0000	0.2041	100.0000	0.0862	152.0000	-0.0710
49.0000	0.2053	101.0000	0.0816	153.0000	-0.0724
50.0000	0.2063	102.0000	0.0771	154.0000	-0.0738
51.0000	0.2071	103.0000	0.0725	155.0000	-0.0752
52.0000	0.2078	104.0000	0.0679	156.0000	-0.0766

Deflection for P = 12 kips and w = 5 kips/ft.

Table I
Deflection table for an example problem

4.2 Laboratory exercise

This part of the process replaces the old laboratory exercise on deflection measurement of a wooden beam due to transverse load. Instead, individual students are required to develop an application program to simulate deflection of a given beam problem. Figure 2 and 3 show a typical problem and the corresponding output. The problem is generally similar to the example presented in section 4.1 and requires a clear understanding prior to this new program development. Students who have taken the computer-programming class before fall semester 1998 are familiar with Qbasic instead of Visual Basic programming language. They develop their lab program based on the Qbasic version of the example program presented in section 4.1. During the final week students make class presentations of their work. The outcomes are often mixed. Above-average students generally develop innovative programs and present deflection of the beam under various loading conditions using impressive multimedia effects. Students with weaker academic and computer backgrounds attempt to modify the example program of section 4.1 to present their solutions. Nevertheless, compared to the old method, the new technique achieves our learning objectives better.

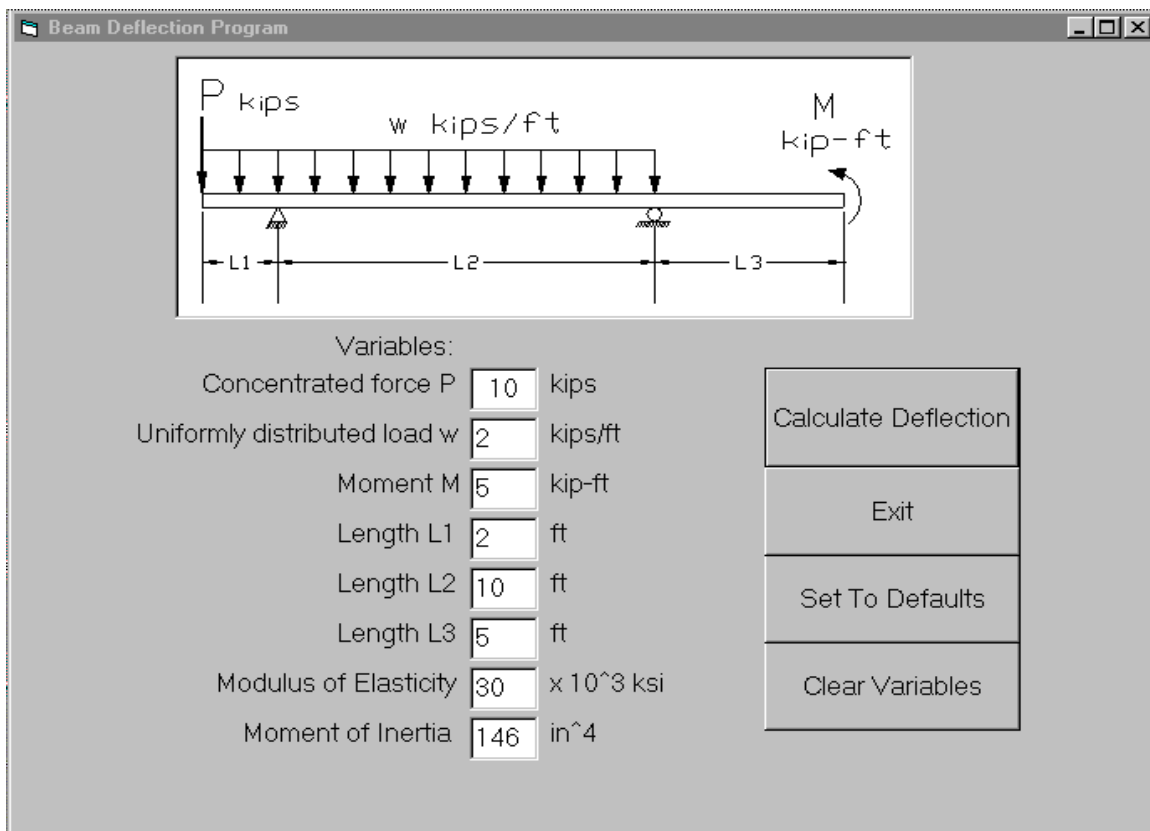


Figure 2
Typical laboratory exercise problem

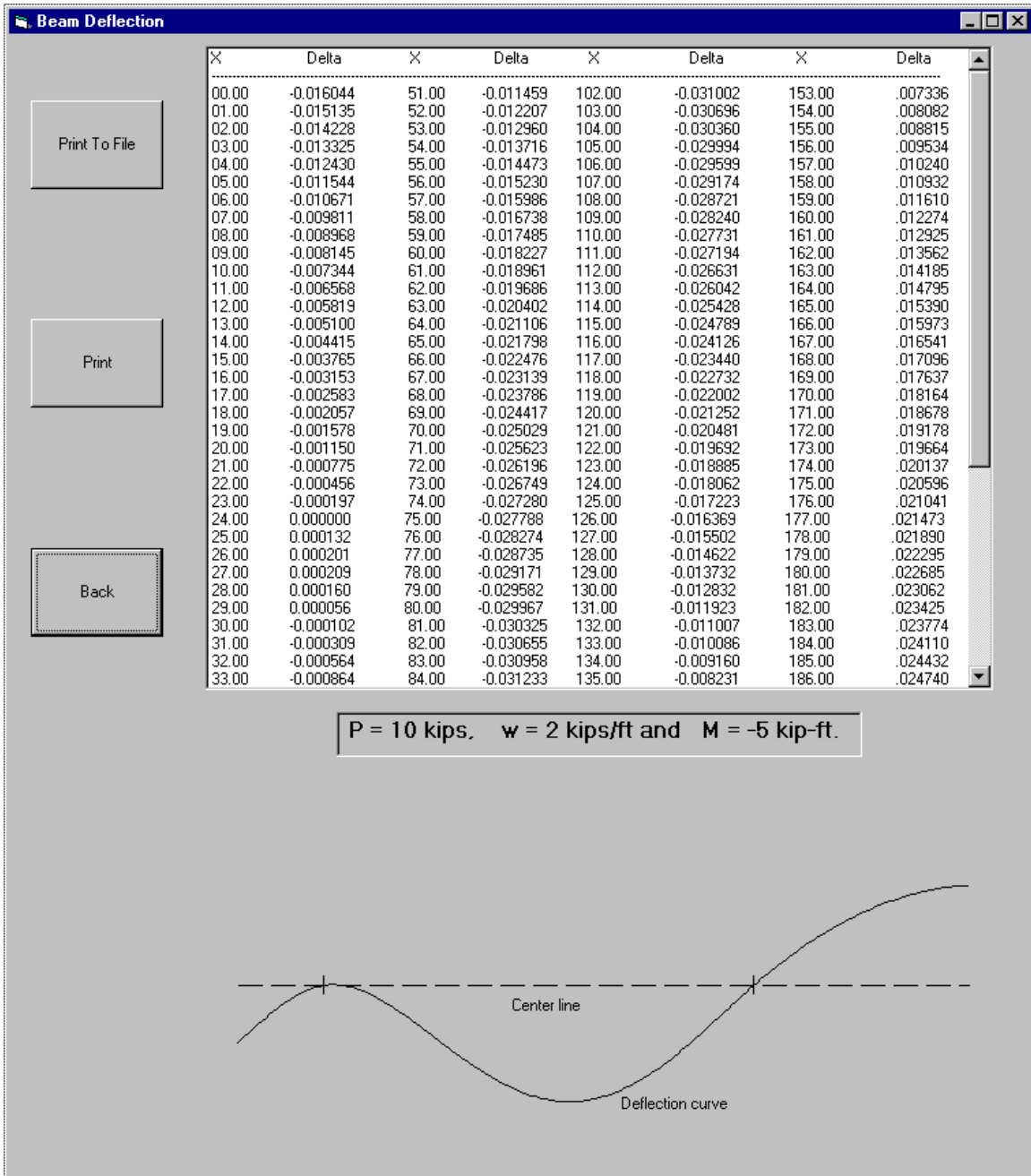


Figure 3
Typical output of a Visual Basic laboratory problem

4.3 General programming tool

This Visual Basic program has been developed recently for students to verify deflection calculations of most homework assignments. An executable file created from the general Visual Basic deflection program will be available for student use. Therefore, use of this program does not require prior programming experience, and students can familiarize

themselves with the use of this program quickly in a single class presentation. The beams can be simply supported, cantilever, or over hanging. The beam geometry and load characteristics are shown in Figure 4, 5 and 6 below. Based on the selection, appropriate beam deflection parameters would be specified. These are lengths, moment of inertia of cross section, modulus of elasticity, magnitude and locations of concentrated/distributed loads and external moment. To solve the problem, students will simply specify beam geometry and loading parameters and run the program. The output will be in the form of a table for deflection versus distance from one end of the beam and corresponding deflection curve. If the analytical solutions produced by the students differ from the computer output, students would be required to locate the source of error in their calculations until the two solutions match. The program will not allow solution of the laboratory problem, which is generally overhanging in one side only.

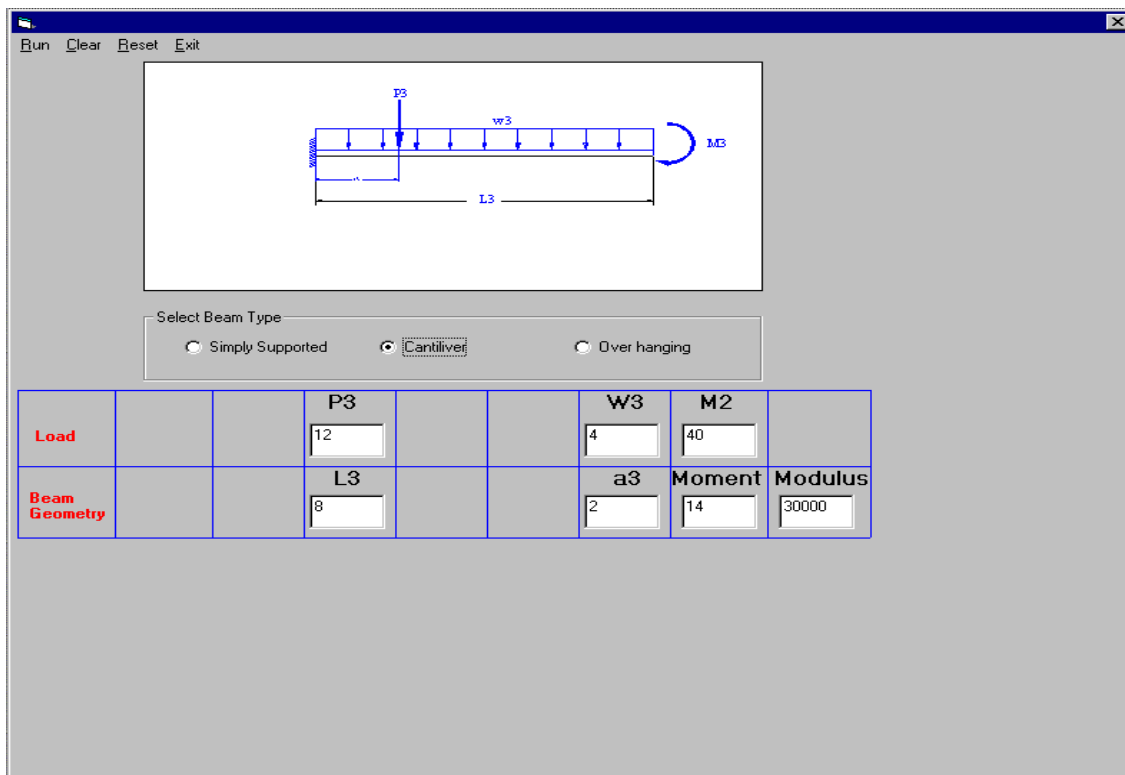


Figure 4
Cantilever beam problem

5. Measurement of student outcomes

All engineering technology programs in CCC have developed a plan for student outcomes assessment. Currently the data for such assessment are being collected from various sources in specific cycles. Analysis of these data relevant to strength of materials class will provide quantitative measurement of student learning improvement due to use of the tool presented here.

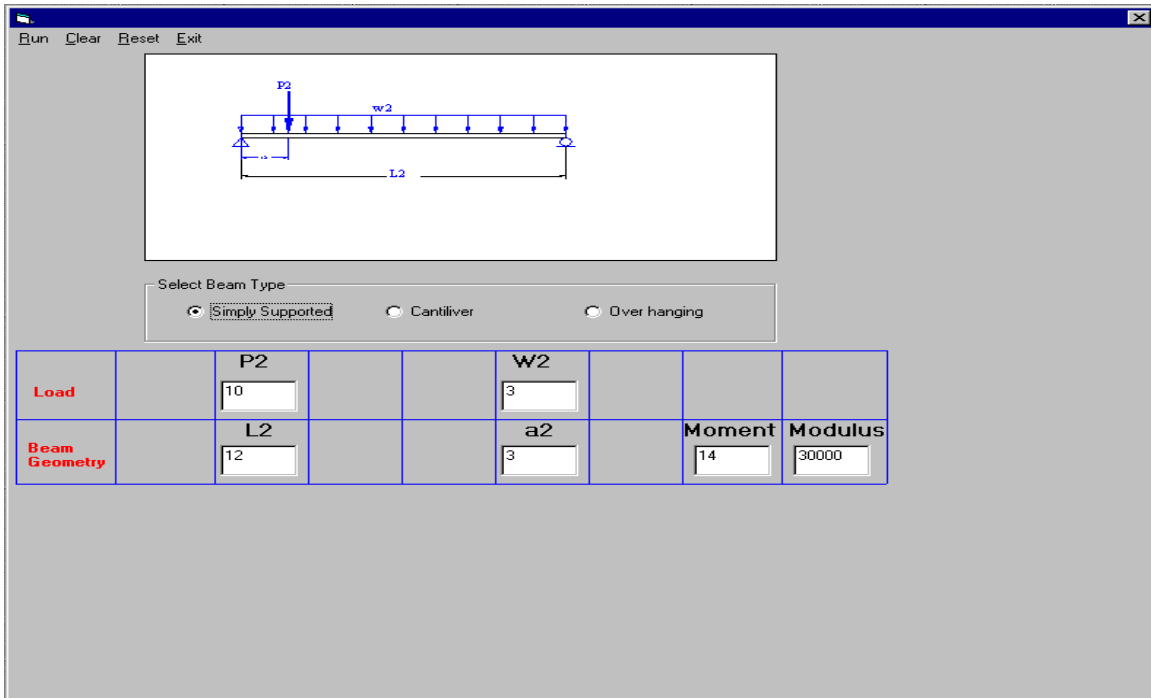


Figure 5
Simply supported beam problem

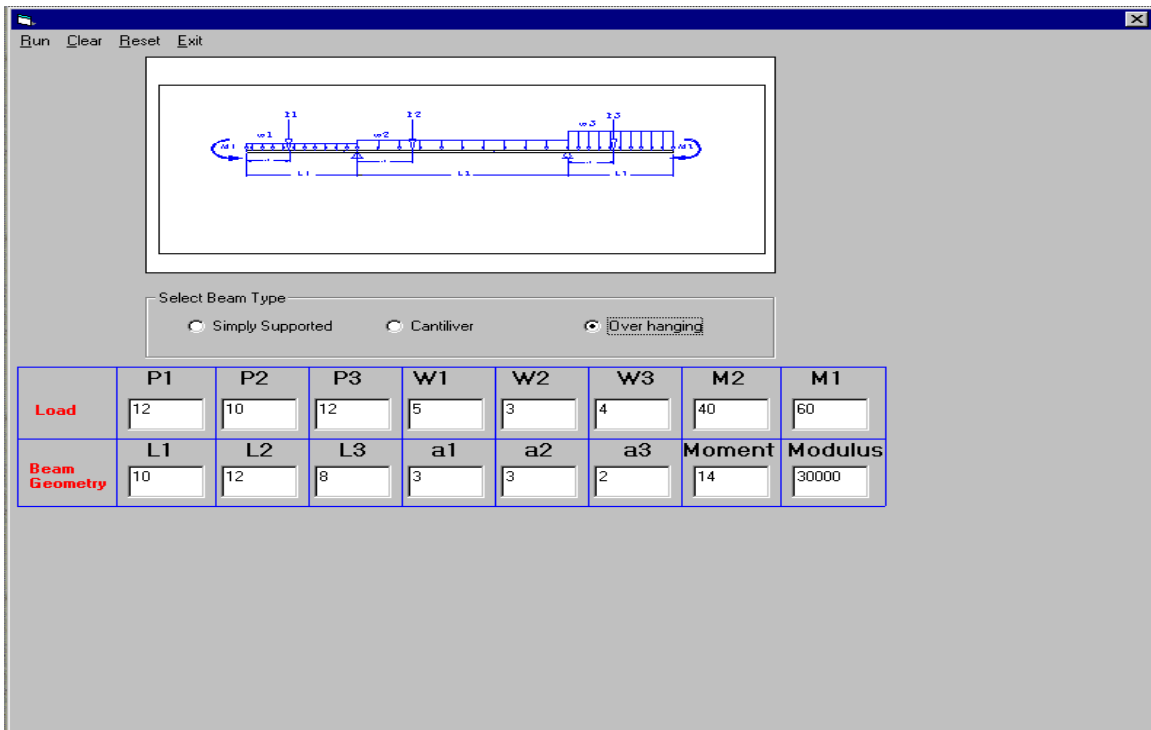


Figure 6
Overhanging beam problem

6. Conclusion

The tool presented here is designed to facilitate learning of beam deflection theory in the strength of materials class and build student confidence in the development and use of computer program for solving deflection problems. We feel that use of commercial software for such lessons would neither be cost effective nor generate similar interest in the subject matter. The MET advisory committee highly recommends use of this tool for teaching beam deflection.

Bibliography

1. Cheng; Hwa-Fa, **Statics and Strength of Materials**, Glenco/Mc-Graw Hill, 1997.
2. Mott; Robert L., **Applied Strength of Materials**, Prentice Hall Inc., 1996.
3. Ressler; Stephen, *The visual stress transformer: An animated computer graphics program for engineering mechanics education*, ASEE conference proceeding, 1996.
4. *Working Model*, Knowledge Revolution Inc., San Mateo, CA, 1998.
5. Jong; I., Onggowijaya; S., *Animated programming with QuickBASIC to aid the teaching kinematics*, ASEE conference proceeding, 1998.
6. *Microsoft Qbasic Bible*, Microsoft Press, Richmond, WA, 1990.
7. Kumar; Ratan, *Teaching dynamics in engineering technology through software tools*, ASEE conference proceeding, 1998.
8. Boronkay; T, Earley; R, *Simulation software in a dynamics laboratory*, ASEE conference proceeding, 1998.
9. Sprague, M., **Using Visual Basic**, South-Western Educational Publishing, 1997.
10. Prusak; Zbigniew, *Simulation using spreadsheets in the engineering technology curriculum – satisfying multiple learning objectives*, ASEE conference proceeding, 1999.

ALAMGIR CHOUDHURY

Alamgir A. Choudhury taught engineering technology at Cuyahoga Community College, Cleveland, Ohio, since 1990. He has BS, MS and PhD in mechanical engineering. His interest includes computer applications in curriculum, MCAE, instrumentation, fluid power and mechanics. He is also a Registered Professional Engineer in the State of Ohio and affiliated with **ASME**, **ASEE** and **TAP**. Currently he is teaching at Western Michigan University, Kalamazoo, Michigan.

CHRISTIAN OCHEI

Christian Ochei is an assistant professor of manufacturing and industrial technology at Cuyahoga Community College. He teaches CAD/CAM, computer programming and industrial technology classes and training courses.

ROBERT RICE

Robert Rice is completing his degree in mechanical engineering technology from Cuyahoga Community College in Spring 2001 and plans to continue for a bachelor's degree in University of Akron. Currently he is practicing as a production engineer in Solon, Ohio.