Developing Instructional Modules For Analyzing Structures

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Abstract

In this paper the development of modules for teaching structural analysis concepts utilizing Flash and MATLAB software is discussed. Each of the two software components is specifically selected to accomplish a certain task and achieve a particular goal in terms of student course development. Using the Flash software, short multimedia lessons can be created to clarify the theoretical formulation and the steps involved in the solution of the problem. Powerful animation tools and other special features of this capable software are ideally suited for presenting this material to the students in a clear, organized, and appealing fashion. The MATLAB component of the created modules is designed in order to further extend the students' comprehension of the course concepts and to provide them with additional insight into understanding and predicting the behavior of structures. Effective programming features of MATLAB can be utilized to create flexible interactive script files capable of analyzing a variety of beam and loading conditions based on the input from the user. The instructor can use these capable scripts files in the classroom to create a variety of scenarios for promoting student-instructor interaction and for generating more interest. To further extend the effectiveness and utility of the discussed modules, the produced Flash movie files and the MATLAB script files can be placed on the course web site to allow the students full access to this useful educational material. To clarify the utility and usefulness of the discussed procedure, one sample module for the determination of influence lines and analysis of a beam subjected to moving loads is included in this paper.

I. Introduction

The development and utilization of instructional modules for complementing a structural analysis course is presented and discussed in the presented paper. These modules contain two main components consisting of Flash and MATLAB. A brief overview of some of the basic functions and utilities of the two software is provided below to better prepare the readers in understanding the scope of the proposed project.

Flash, a software tool developed by the Macromedia Inc., is commonly used for producing multimedia documents for the web. This software can also be used as an alternate approach for creating elaborate multimedia movies files (slide shows) for professional presentations and conferences. When developing Flash movies, a variety of other software pieces such as image, sound, and movie capturing/editing software can aid the designers in creating more effective movies.

The MATLAB software, a powerful computing tool developed by the MathWorks, Inc., is utilized in a number of educational institutions around the world for solving mathematics and engineering related problems. Abundance of useful built-in functions and a user-friendly interactive computing environment of this software has made it the popular tool of choice for investigating a variety of problems in the engineering field. In a paper published by the author in the Proceedings of the 2002 ASEE Annual Conference[1], the utility of some of the features of MATLAB in solving several basic structural engineering problems were presented and discussed. The content of this paper was also discussed at the ASEE/SEFI/TUB International Colloquium in Berlin, Germany in Oct. of 2002,

In the project proposed in this paper, special capabilities of Flash and MATLAB have been exploited to produce effective and powerful instructional modules for analyzing more involved structural engineering problems. The Flash files in these modules are produced in order to outline and describe the theoretical formulation and the steps involved in the solution of the problem in an organized and easy-to-understand manner using a multimedia approach. The function of some of the various features of these Flash files is briefly outlined below.

1. Inserted short video clips in the Flash movies, taken from actual situations, will capture the interest of students and aid them in better relating theoretical problems to real life situations.
2. Graphic files and created animations in the modules will help students with the visualization of the solution for more complicated problems.
3. Inserted audio clips in the Flash movies provide additional help and insight into the problems as well as offering various other helpful suggestions, tips, and/or warnings.
4. Hyperlinks in the produced Flash Movies allow users to access a variety of other supporting documents related to the problem, including the developed MATLAB script files.
5. Navigational buttons placed in the Flash movies allow the users to conveniently access any particular section of the produced module at any time.
6. The produced Flash movies can easily be saved in variety formats such as Flash executable files (.exe files) and/or Flash WWW files (.html files) and made available to the students. These files can be viewed on any computer with or without the Flash software installed.

The instructors can effectively utilize the created Flash movies in the classroom using a computer projection system to complement their teachings and to enhance the students' understanding of the topics and concepts. These files can also be made accessible to the students by sending them the executable files electronically or by placing the html version of the files on the course web site. The students can utilize these files at any convenient time, at any location with an Internet connection, for as many times as necessary to fully understand the concepts.

Once the concepts and procedures are mastered using Flash movies, the interactive MATLAB script files associate with the modules can be utilized to further enhance the students' knowledge. The developed MATLAB files will provide further insight into the solution of

problems and enables the students to better understand the behavior of beam subjected to various conditions. The instructor can effectively utilize these files to further promote the in-class discussions and interactions, and therefore create a more active and stimulating learning environment. The students themselves can also access and run the developed interactive programs and benefit tremendously from the experience. Additionally, the student may utilize these files as a way to perform a check on the accuracy of their developed hand solutions for various problems.

The modules described by the above procedure using Flash and MATLAB can be developed for each of the classical approaches used for studying structures in a structural analysis course. One sample module related to the analysis of moving loads on a beam is included and discussed in this paper.

II. Analysis of a Beam Subjected to Moving Loads –Theoretical Formulation

One of the more important topics discussed in any traditional structural analysis textbook such as the ones listed in the bibliography[2-5], is related to the analysis of moving loads acting on the structure. To perform this analysis it is necessary to develop the "influence line" for the structure. The influence line illustrates the variation of either the support reaction, shear force, or moment at any particular point on the structure subjected to a moving unit load.

The development of the module in regards to plotting of influence lines and analysis of moving loads is described in this section of the paper through presenting the solution for a sample problem. This problem is taken from the textbook[2] of a structural analysis course taught at Georgia Southern University. The solution for a collection of structural engineering problems such as the one presented below can be included in the created modules to fully discuss the topics and complement the text.

For a truck passing over a bridge as shown in Figure 1, determine the following: (a) the influence lines for the shear and moment at point K indicated on the figure, (b) the maximum negative shear force and moment at point K for the case when P_2 is acting over this point, and (c) The absolute maximum live moment acting on the bridge due to the moving loads indicated. Note that to compute the maximum moment in part c, it is first required to determine the location of the loads, as well as, the location of the point on the beam at which the absolute maximum moment occurs.

Prior to discussing the Flash and MATLAB component of the module, the development of the theoretical formulation of the problem is first presented.
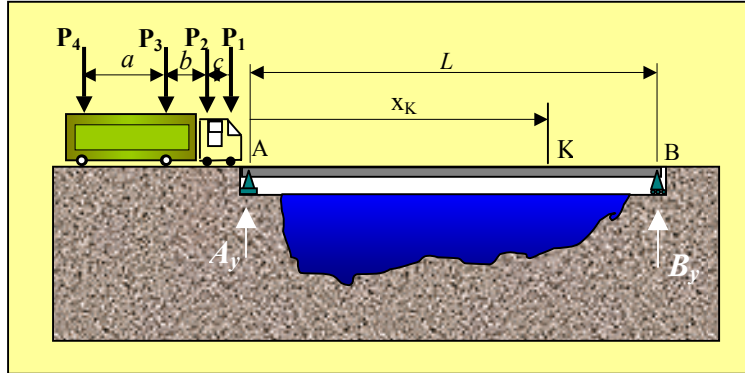
Figure 1. Moving Load acting on the Beam

The procedure for obtaining the influence lines for the shear and moment at any particular point K on the beam, requires that a moving unit load as shown in Figure 2 is applied to the beam and the algebraic expressions for the support reactions A_y and B_y are first obtained. These expressions are provided in Eqs. 1 and 2.
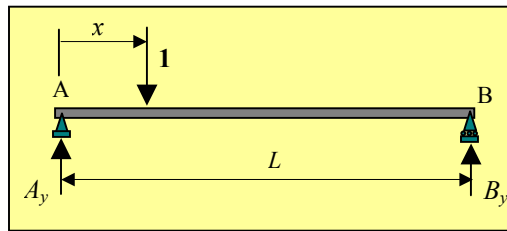

Figure 2. Free Body Diagram of the Beam

$$A_y = 1 - \frac{x}{L} \qquad (1) \qquad\qquad B_y = \frac{x}{L} \qquad (2)$$

Then, the free body diagrams for the section of the beam to the left of point K needs to be considered for the two cases when x is just to the left of K ($x = x_K^-$), and when x is just to the right of the K ($x = x_K^+$) as shown in Figure 3. Writing the force and equilibrium equations for each of these free body diagrams, the algebraic expressions for the shear at K (V_K) and moment at K (M_K) for the two cases when $0 \leq x \leq x_K$ and $x_k \leq x \leq L$ can be determined. These expressions are provided in Eqs. 3 through 6. Using these equations, the general form of the influence lines for the shear and moment at K can be obtained as shown in Figure 4.
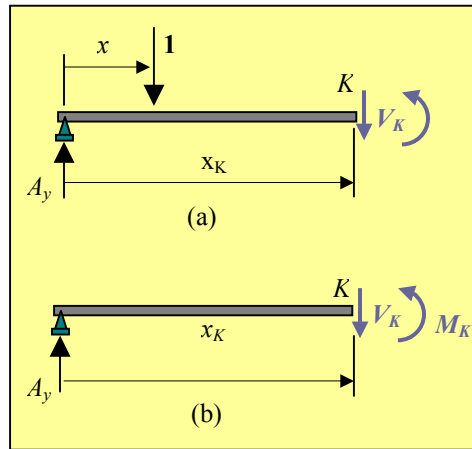
Figure 3. Free Body Diagram for the Left Section of the Beam

$$0 \le x \le x_K \qquad\qquad\qquad x_k \le x \le L$$

$$V_K = \frac{-x}{L} \qquad (3) \qquad\qquad V_K = 1 - \frac{x}{L} \qquad (4)$$

$$M_K = x\left(\frac{-x_K}{L} + 1\right) \qquad (5) \qquad\qquad M_K = \left(1 - \frac{x}{L}\right)x_K \qquad (6)$$

In part (b) of the stated example problem, the computation of the maximum shear and moment at point K is requested. In order to obtain the solution for this part, the values of loads P_1, P_2, P_3, and P_4 should be multiplied by the corresponding ordinates of the influence line plots for the shear and the moment at point K. By referring to Figure 4 and performing this operation, the maximum negative shear and the moment at K are obtained as shown in Eqs. (7) and (8).

$$(V_K)_{max} = p_1\left[1 - \left(\frac{x_K + c}{L}\right)\right] + p_2\left[\frac{-x_K}{L}\right] + p_3\left[\frac{-(x_K - b)}{L}\right] + p_4\left[\frac{-(x_K - a - b)}{L}\right] \qquad (7)$$

$$(M_K)_{max} = p_1\left[1 - \frac{(x_K + c)}{L}\right]x_K + p_2\left[\left(1 - \frac{x_K}{L}\right)(x_K)\right]$$
$$+ p_3\left[\left((x_K - b)(\frac{-x_K}{L} + 1)\right)\right] + p_4\left[\left((x_K - a - b)(\frac{-x_K}{L} + 1)\right)\right] \qquad (8)$$
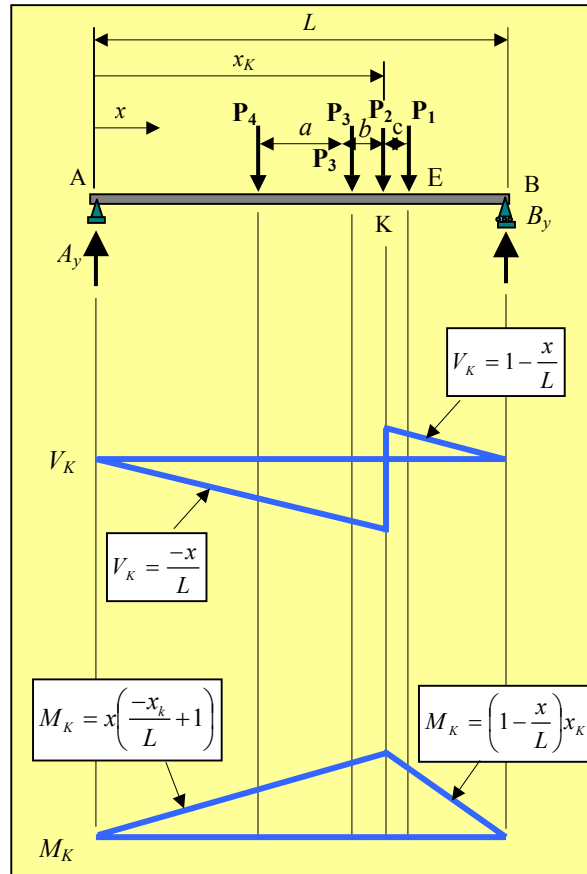
Figure 4. General Influence Lines for Shear and Moment at Point K on the Beam

In part (c) of the presented problem, the absolute maximum live moment acting on the bridge due to the moving loads indicated is to be computed. To compute this moment, the magnitude and the location of the resultant moving loads can be determined using figure 5.

$$F_R = P_1 + P_2 + P_3 + P_4 \tag{9}$$

$$\bar{x} = \frac{p_2(c) + p_3(b+c) + p_4(a+b+c)}{F_R} \tag{10}$$

It has been established in the literature[2] that the absolute maximum live moment acting on a simply supported beam occurs under one of the applied concentrated forces when this force and the resultant force are placed at the same distance from the centerline of the beam. For this reason, each of the forces acting on the beam should be placed at equal distances from the centerline of the beam and the moment under each force should be computed. The absolute maximum moment on the beam is the largest of all the moments computed in this fashion.

For the presented sample problem, when the forces P_1 and F_R are placed at the same distance away from the centerline of the beam as shown in Figure 5, the expression for the internal moment M_1 under the load P_1 using the moment equilibrium equation can be obtained as:

$$M_1 = A_y(x_1) - p_2(c) - p_3(b+c) - p_4(a+b+c).$$

(11)

where

$$A_y = \frac{F_R(L/2 + \bar{x}/2)}{L}$$

(12)

Note that the expression for A_y can be obtained by writing the moment equilibrium equation of the beam around point B.
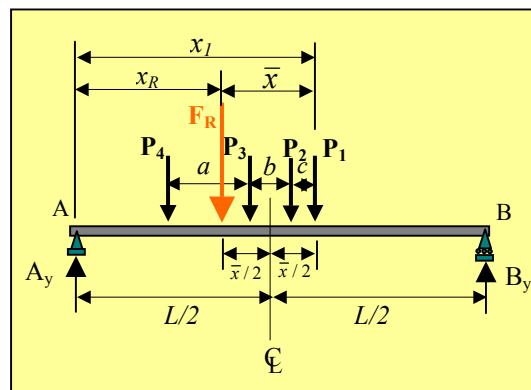

Figure 5. Forces P_1 and F_R Placed Equidistant from the Centerline of the Beam

In a similar fashion, as stated previously, each of the other concentrated forces acting on the beam (i.e., P_2, P_3, P_4) and the resultant force F_R should also be placed at equal distances away from the centerline of the beam and the moments under each of these load must also be formulated separately for each case. Formulas for these cases are not presented in the paper, but are developed and used in the MATLAB script file to obtain the absolute maximum moment.

III. Analysis of a Beam Subjected to Moving Loads –The Developed Module

In the module created for this problem, the theoretical formulation is included and discussed in a Flash movie. This movie (analogous to an elaborate multimedia slide presentation) outlines the detailed steps needed in solving the problem in a clear, organized, and easy-to-understand manner. In producing this movie, audio, video, and animations are employed to further enhance the created module. Inserted short digital video clips in the movies, captured from real situations, will help the students take notice of the importance of the real life nature of the problem, and appreciate the utility of the proposed method of analysis. The short audio clips

inserted in the module aid the instructor in emphasizing the more significant points and steps involved in the problem. Created animations in the module are used to help the students with the visualization and comprehension of the problem. In developing the solution for part (c), animations were used to place each of the applied forces at particular locations on the beam in a manner discussed previously to compute the absolute maximum live moment. Three screen-shots of several frames of a developed Flash movie for the presented problem are presented in Figures 6 and 7. The file in Figure 6 illustrates the movie in the production stage. At this stage the file can be edited using various tools in the software. Once the movie is produced it can then be saved as an executable file as shown in figure 7. The executable files can be played on any computer with or without the Flash software installed. As mentioned previously the produced Flash files can also easily be converted to html files and placed on the Web.
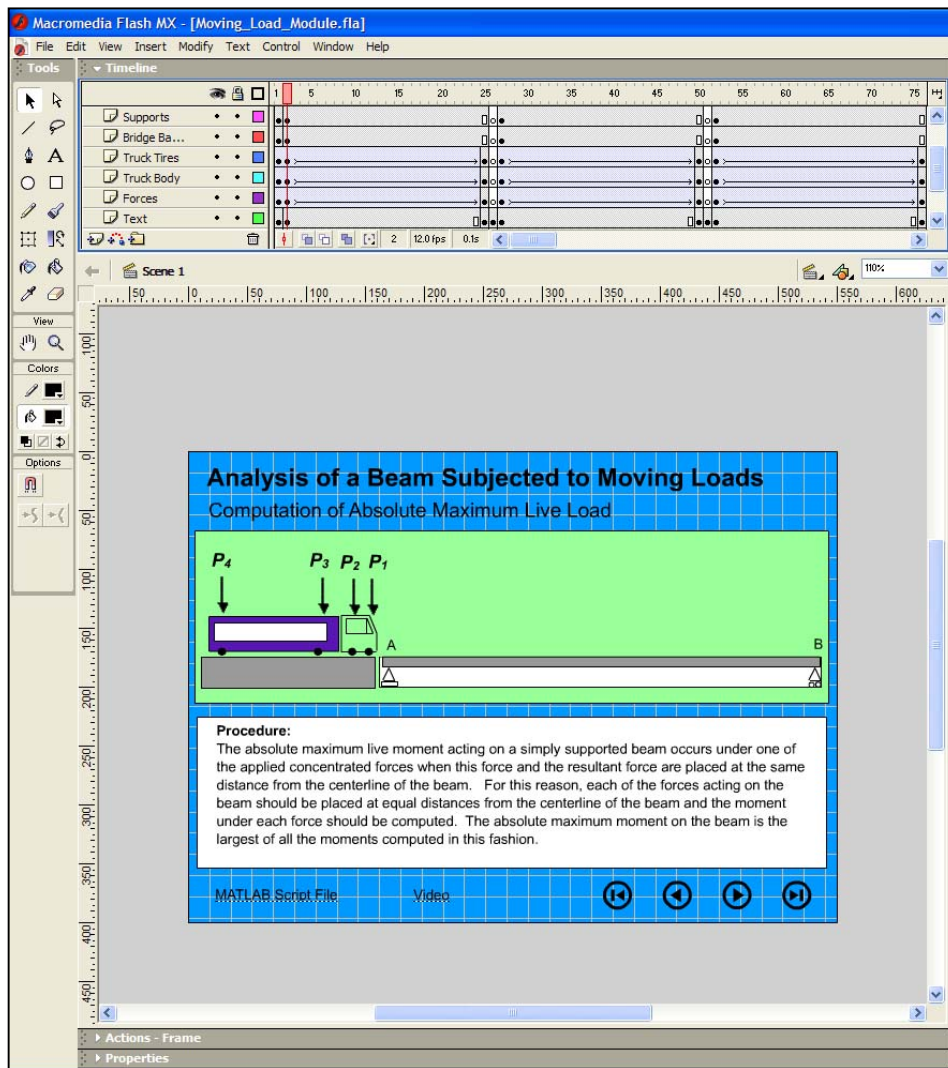

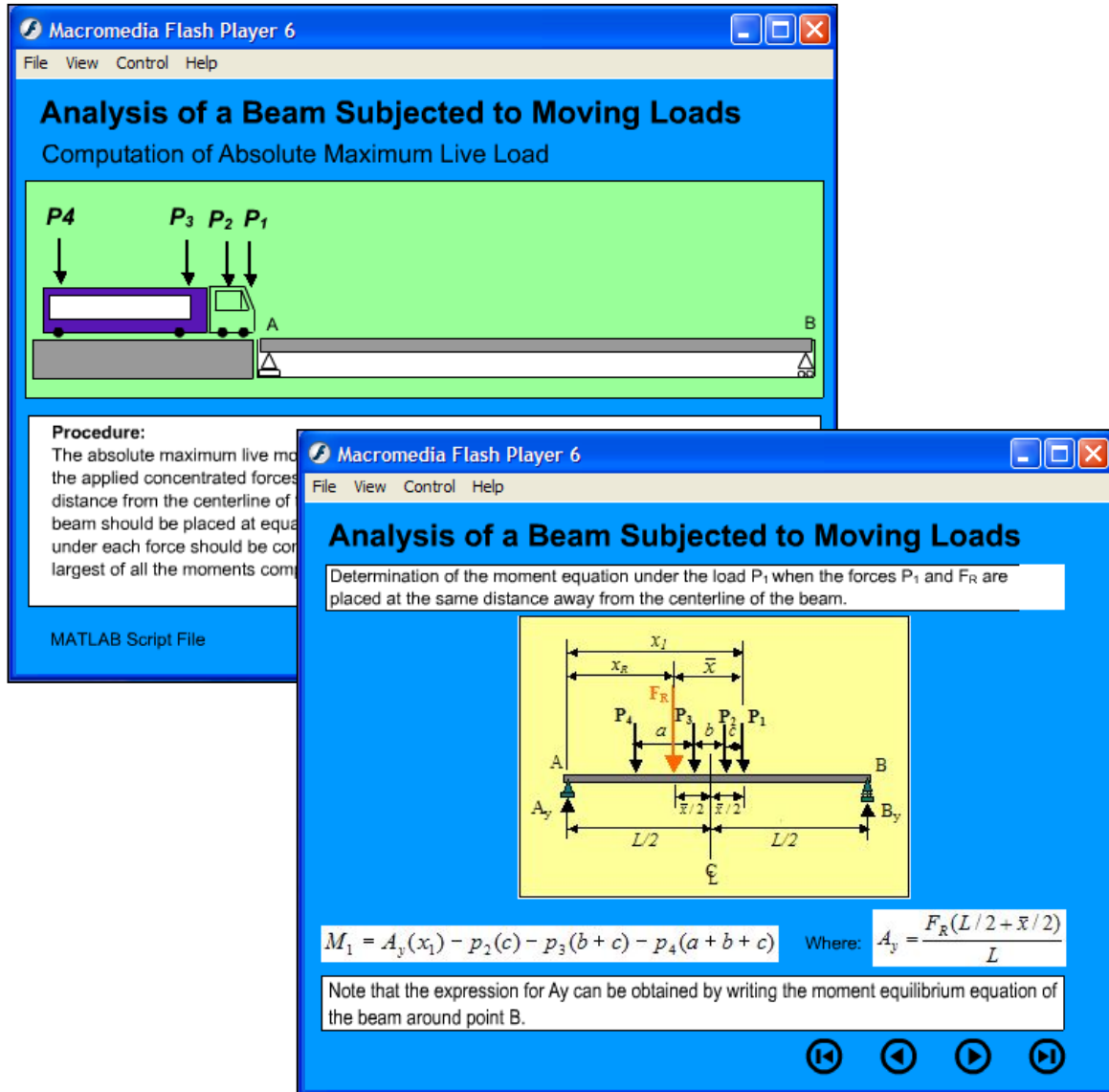Figure 6. Screen-shot of a Flash Movie in the Production Stage

Figure 7. Screen-shots of two Frames of a Produced Executable Flash Movie

The MATLAB script file developed for solution of the presented problem based on the approach discussed in the paper is presented in Figure 8. This file is developed in a fashion that when executed it produces a menu to allow the user to indicate the type of task desired as shown in Figure 9. Note that the script file for the problem is formulated in a general form in terms of the beam and loading parameters to obtain a more flexible and powerful program. This program can be used to study a variety of beams and loading conditions. The results produced from the presented script file for the following specific case when: $L = 80$ ft, $a = 20$ ft, $b = 8$ ft, $c = 4$ ft, $x_K = 60$ ft, $P_1 = 6$ kip, $P_2 = 8$ kip, $P_3 = 20$ kip, and $P_4 = 15$ kip. are provided in Figure 10.

```
% Analysis of a Beam Subjected to Moving Loads
% _____
% Program objectives:

% (a) To construct the influence lines for the shear and moment at the given point K on the beam.
% (b) To compute the maximum negative shear and moment at point K for the case when the P2 load
%      is over point K.
% (c) Compute the absolute maximum live moment on the bridge due to the moving loads indicated.
% _____
% Data acquisition:
 p1=input('Enter the magnitude of P1(kip)\n');
 p2=input('Enter the magnitude of P2(kip)\n');
 p3=input('Enter the magnitude of P3(kip)\n');
 p4=input('Enter the magnitude of P4(kip)\n');
 L=input('Enter the length for beam(ft)\n');
 a=input('Enter the dimension a(ft)\n');
 b=input('Enter the dimension b(ft)\n');
 c=input('Enter the dimension c(ft)\n');
 xk=input('Enter the position of the point at which the shear and moment is to be computed (ft)\n');
 choice=menu('Indicate the task to be performed:',...
    'Constructing the influence lines for the shear and moment',...
    'Computing the maximum negative shear and moment for the indicated point',...
    'Compute the absolute maximum live moment on the bridge','All of the above tasks');
 if (choice==1|choice==4)
% _____
%   Plotting the influence lines:
    x=linspace(0,L,L+1);
       for k=1:1:L+1
         if x(k)<=xk
            Vk(k)=-x(k)/L;
            Mk(k)=x(k)*(-xk/L+1);
          else
            Vk(k)=1-x(k)/L;
            Mk(k)=xk-(xk/L)*x(k);
          end
         end

    subplot(2,1,1),plot(x,Vk),title('Influence Line for Shear at Point K'),xlabel('x (ft)'),...
       ylabel('Shear Force (kip)')
    subplot(2,1,2),plot(x,Mk),title('Influence Line for Moment at Point K'),xlabel('x (ft)'),...
       ,ylabel('Moment (kip.ft)')
  end
  if (choice==2|choice==4)
% _____
%   Computing the maximum negative shear and moment at point K when the 8 kip load is over point K.

    shear_K=p1*[1-(xk+c)/L]+p2*[-xk/L]+p3*[-(xk-b)/L]+p4*[-(xk-a-b)/L];
    fprintf('Shear at point K = %5.2f kip\n\n',shear_K)

    moment_K=p1*xk*[1-(xk+c)/L]+p2*xk*[1-(xk/L)]+p3*[(xk-b)*(-xk/L+1)]+p4*[(xk-a-b)*(-xk/L+1)];
    fprintf('Moment at point K = %5.2f kip.ft\n\n',moment_K)
  end
                           (Program is continued on the next Page)
```

Figure 8(a). MATLAB Script File for Analysis of a Beam Subjected to Moving Loads

(Continuation of the program on the previous page)

```
if (choice==3|choice==4)
%   _____
%   Computation of the absolute maximum live moment acting on the bridge:
     fr=p1+p2+p3+p4;
     xb=(p2*c+p3*(b+c)+p4*(a+b+c))/fr;
     for k=1:1:4
       if k==1
%          Case 1: When the P1 load and the resultant load are placed equidistant from the beam's center.
         xp1=L/2+xb/2;
         xfr=L/2-xb/2;
         Ay=fr*(L-xfr)/L;
         M(k)=Ay*xp1-p2*c-p3*(b+c)-p4*(a+b+c);
       elseif k==2
%          Case 2: When the P2 load and the resultant load are placed equidistant from the beam's center.
         xp2=L/2+(xb-c)/2;
         xfr=L/2-(xb-c)/2;
         Ay=fr*(L-xfr)/L;
         M(k)=Ay*xp2-p3*b-p4*(a+b);
       elseif k==3
%          Case 3: When the P3 load and the resultant load are placed equidistant from the beam's center.
         xp3=L/2+(xb-b-c)/2;
         xfr=L/2-(xb-b-c)/2;
         Ay=fr*(L-xfr)/L;
         M(k)=Ay*xp3-p4*a;
       else
%          Case 4: When the P4 load and the resultant load are placed equidistant from the beam's center.
         xp4=L/2+(xb-a-b-c)/2;
         xfr=L/2-(xb-a-b-c)/2;
         Ay=fr*(L-xfr)/L;
         M(k)=Ay*xp4;
       end
     end
     if(M(1)>M(2)& M(1)>M(3) & M(1)>M(4))
       Mmax=M(1);
       fprintf('The maximum moment of %5.3f kip.ft will occur under the load P1, when this load\n',Mmax)
       fprintf('is %5.3f ft away from the left support.\n',xp1)
     elseif(M(2)>M(1)& M(2)>M(3) & M(2)>M(4))
       Mmax=M(2);
       fprintf('The maximum moment of %5.3f kip.ft will occur under the load P2, when this load\n',Mmax)
       fprintf('is %5.3f ft away from the left support.\n',xp2)
     elseif(M(3)>M(1)& M(3)>M(2) & M(3)>M(4))
       Mmax=M(3);
       fprintf('The maximum moment of %5.3f kip.ft will occur under the load P3, when this load\n',Mmax)
       fprintf('is %5.3f ft away from the left support.\n',xp3)
     else
       Mmax=M(4);
       fprintf('The maximum moment of %5.3f kip.ft will occur under the load P4, when this load\n',Mmax)
       fprintf('is %5.3f ft away from the left support.\n',xp4)
     end
end
```

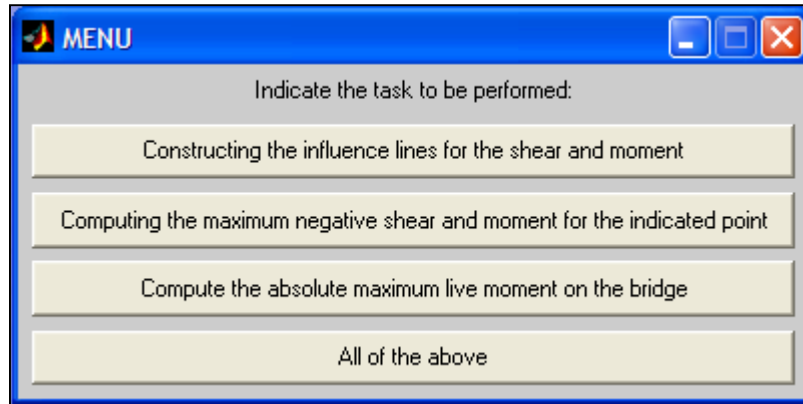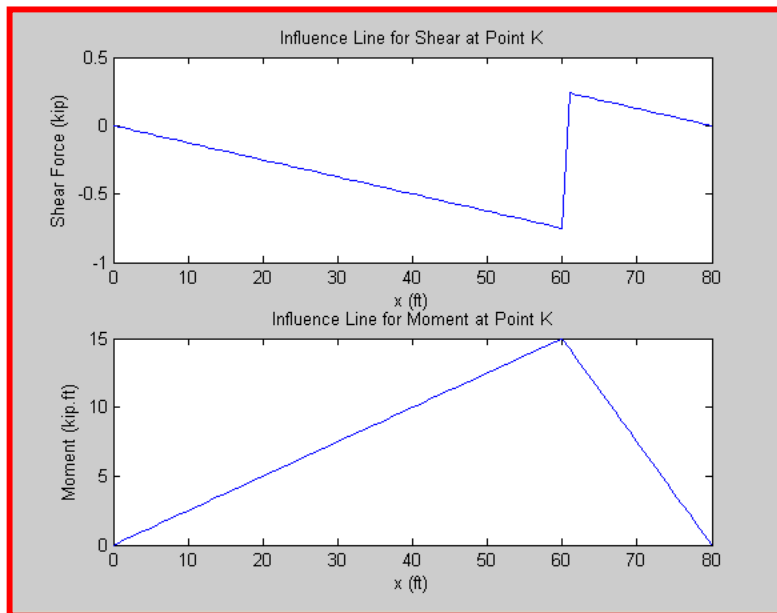Figure 8(b). MATLAB Script File for Analysis of a Beam Subjected to Moving Loads

Figure 9. Screen-shot of the Menu Created by the Developed MATLAB Script File

Maximum Shear & Moment:

Shear at point K = -23.80 kip

Moment at point K = 572.00 kip.ft

Absolute Maximum Live Moment:

The maximum moment of 763.715 kip.ft will occur under the load P3, when this load is 41.673 ft away from the left support.

Figure 10. MATLAB Results for the Presented Problem

IV. Summary and Conclusion

In the submitted paper the development of an instructional module for complementing a structural analysis course was presented and discussed. An example was also included in the paper to further illustrate the process. The developed modules can be used effectively in creating a rich, stimulating, and engaging learning environment. An environment that fosters more student-instructor interactions, and promotes student learning. The rationale and the utility for creating each of the two main components of the module, Flash and MATLAB, were outlined in the paper to illustrate the significance of the project. Other than the module for the analysis of moving loads discussed in the paper, other components of similar modules for several other classical structural engineering approaches such as the "Slope-Deflection Method" and "Moment-Distribution Method" methods have also been developed and documented. More support in terms of faculty time for completing these modules are needed.

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