Computer education of influence lines for continuous beams
by Richard Andrew Ehlert

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University

Abstract:
The education of fundamental engineering principles through increased use of general purpose analysis computer programs is a topic of concern among educators. The student must maximize learning efficiency if computer literacy and fundamental concepts are to be learned simultaneously.

A user-friendly, interactive, color-graphics computer program has been developed for teaching the fundamental concept of influence lines for continuous beams. The theorem of three moments and moment-area theorems are the fundamental principles presented, developed, and applied throughout the program.

Results of two types of problems using the computer program are presented. The two problems indicate the numerous capabilities for use of the program in teaching influence line concepts to students.

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FOR CONTINUOUS BEAMS

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Richard Andrew Ehlert

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Nov. 25, 1985
Date

Chairperson, Graduate Committee

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Date November 25, 1985

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TABLE OF CONTENTS

TABLE OF CONTENTS—Continued

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A	point at which influence line is developed
A_n, A_{n+1}	elastic weight diagram area, spans n and n+1 respectively
${}_{n+1}A_o$	shear at left end of span n+1 when unit load occupies span n+1
${}_nB_o$	shear at right end of span n when unit load occupies span n
E	modulus of elasticity
I_n, I_{n+1}	moment of inertia, spans n and n+1 respectively
M	internal beam moment
M_ℓ	support moment at left end of span n
M_{n-1}, M_n, M_{n+1}	support moment, supports n-1, n, and n+1 respectively
M_o	single-span moment due to unit load, measured at point where influence line is developed
M_r	support moment at right end of span n
M_x	moment at point of unit load application
P	concentrated point load
R	sum of elastic weight diagram reactions on either side of a given support
$R_{\ell,n}$, $R_{\ell,n+1}$	left reaction of elastic weight diagram, spans n and n+1 respectively
R_n	beam reaction at support n
$R_{r,n}$, $R_{r,n+1}$	right reaction of elastic weight diagram, spans n and n+1 respectively
V	internal beam shear
V_ℓ	shear at left end of span n

$V_{\ell,n}$, $V_{\ell,n+1}$	shear left of supports n and n+1 respectively
V_o	simple-span shear due to unit load, measured at point where influence line is developed
V_r	shear at right end of span n
$V_{r,n-1}$, $V_{r,n}$	shear right of supports n-1 and n respectively
V_x	shear at point of unit load application
a_n, a_{n+1}	distance to unit load from left end of span, spans n and n+1 respectively
b_n, b_{n+1}	distance to unit load from right end of span, spans n and n+1 respectively
c_n, c_{n+1}	distance to elastic weight diagram centroid from left end of span, spans n and n+1 respectively
d_n, d_{n+1}	distance to elastic weight diagram centroid from right end of span, spans n and n+1 respectively
ℓ_n, ℓ_{n+1}	span length, spans n and n+1 respectively
n-1, n, n+1	span or support numbers
x	distance from left end of span to point where influence line is developed in that span
Δ_{n-1}, Δ_n, Δ_{n+1}	settlement at supports n-1, n, and n+1 respectively
Δ_o	simple-span deflection due to unit load, measured at point where influence line is developed
Δ_x	deflection at point of unit load application
θ_{n-1}	beam rotation to right of support n-1
θ_n	beam rotation to left of support n
θ'_n	beam rotation to right of support n
θ_{n+1}	beam rotation to left of support n+1

ABSTRACT

The education of fundamental engineering principles through increased use of general purpose analysis computer programs is a topic of concern among educators. The student must maximize learning efficiency if computer literacy and fundamental concepts are to be learned simultaneously.

A user-friendly, interactive, color-graphics computer program has been developed for teaching the fundamental concept of influence lines for continuous beams. The theorem of three moments and moment-area theorems are the fundamental principles presented, developed, and applied throughout the program.

Results of two types of problems using the computer program are presented. The two problems indicate the numerous capabilities for use of the program in teaching influence line concepts to students.

CHAPTER I

INTRODUCTION

The integration of computer usage into engineering curriculums presents educators and practicing engineers with an important question: How well do graduating engineers understand fundamental engineering concepts? Current engineering programs at universities throughout the country incorporate general purpose analysis computer codes as aids in teaching engineering principles [5,7,9,19]. This has led to what Yener and Ting refer to as the "black box approach" to educating engineers [21].

This "black box approach" has resulted in two diversions from quality engineering education. First, time normally spent on understanding fundamental engineering concepts is being spent on learning and using the software and hardware capabilities [12,13,15]. Knowing the capabilities allows the students to solve complex problems in minimal amounts of time. Secondly, students often accept computer solutions of complex problems without an ability to interpret and verify their validity. The combination of these two educational deficiencies can lead to a student misconception that knowledge of fundamental principles is unnecessary for engineering applications.

Influence Line Computer Program

The computer program listed in Table 8 (Appendix C) is an example of how the "black box" education of engineers can be reversed. The program was developed to serve as a teaching aid in the instruction of influence lines for continuous beams. Included within the program are three concepts fundamental to the education of influence lines:

(1) Presentation and application of theory.

(2) Interactive student computation of influence line ordinates.

(3) Application of influence lines.

History of Influence Lines

The analysis of continuous beams is believed to have been first published by Navier in his paper *Lecons* in 1826. Actual application of Navier's analysis came in 1850 with the design and construction of the Britannia Bridge over the Menai Straits by Robert Stephenson [6].

In 1857, Clapeyron reviewed continuous bridge development, citing Stephenson's Britannia Bridge as an example, in his work *Comptes Rendus*. Clapeyron is credited with being the first person to recognize that if the bending moments of the supports of a continuous beam were known, then all internal forces and deflections could be known. Even though Clapeyron first presented the theorem of three moments in 1848, it wasn't until 1855 that Bertot achieved priority for publishing the theorem [6].

Although work by Bresse in 1865 and Winkler in 1862 approached the concept of influence lines for continuous beams, it was not until 1906 that Mohr published the concept. Mohr also went on to develop theorems relating beam slope and deflection to elastic weight moment diagrams, known today as the moment-area theorems [6].

The theorem of three moments by Clapeyron and the moment-area theorems by Mohr provide the theoretical basis used in the computer program.

CHAPTER II

EQUATION DEVELOPMENT

Sign Convention

The internal force sign convention used for the development of all equations is shown in Figure 1. All externally applied loads and beam deflections are positive when acting downward. Beam reactions are positive when acting upward.

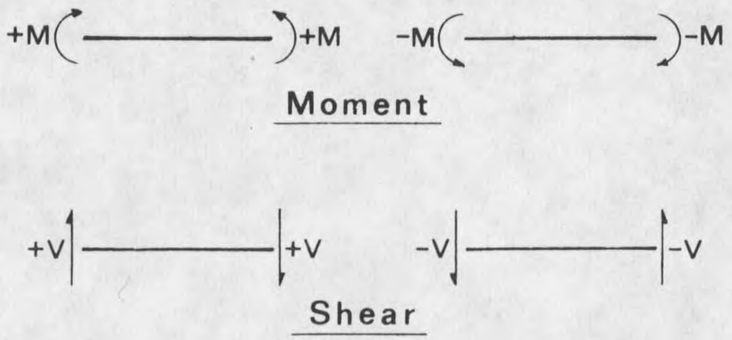

Figure 1. Sign convention.

Three-Moment Equation

The continuous beam shown in Figure 2 is a statically indeterminate structure. One method of reducing the beam in Figure 2 to a statically determinate structure is to solve for the moments at the two interior supports. Application of the general 3-moment equation (Eq. 12, Appendix A) yields:

$$2M_2 \left(\frac{\ell_1}{I_1} + \frac{\ell_2}{I_2}\right) + M_3 \left(\frac{\ell_2}{I_2}\right) = -6R_1 \qquad (1)$$

$$M_2 \left(\frac{\ell_2}{I_2}\right) + 2M_3 \left(\frac{\ell_2}{I_2} + \frac{\ell_3}{I_3}\right) = -6R_2 \qquad (2)$$

where R_1 and R_2 are dependent on the magnitude and location of concentrated load P. Equations 1 and 2 are solved simultaneously for unknown support moments M_2 and M_3, and the beam in Figure 2 is statically determinate. Each span of the beam is also statically determinate, and the internal forces and deflections can be computed at any point on the beam.

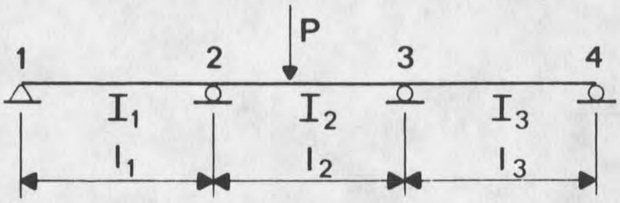

Figure 2. Three-span continuous beam.

Influence Line Equations

Influence lines can be developed for the beam in Figure 2 by setting the concentrated load P equal to unity and moving the load across the beam. Each new position of the unit load generates new values for internal support moments. Thus it is possible to develop expressions for the internal forces and deflections in a given span in terms of the support moments at each end of the span.

Every point on a continuous beam has a unique influence line for the moment, shear, and deflection at that point. Point A in Figure 3 defines the point, in an arbitrary span n, at which an influence line is to be developed. Equations have been developed in Appendix B for computing ordinates of influence lines at point A and are given in Equations 3, 4, and 5. These equations compute the influence line ordinates at the unit load position, assuming point A is located in span n.

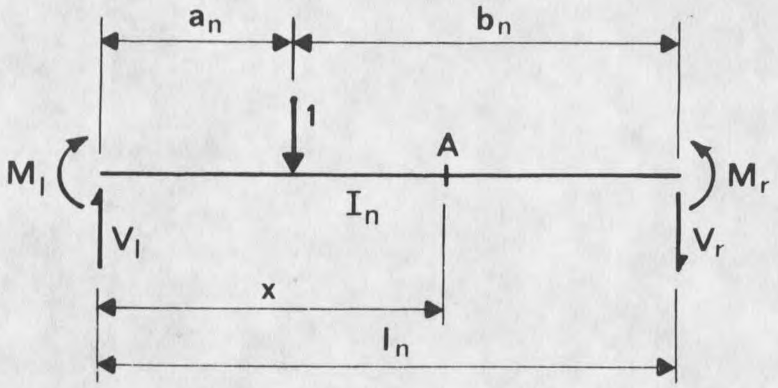

Figure 3. Free-body diagram of span n.

$$M_x = M_o + M_\ell \left(1 - \frac{x}{\ell_n}\right) + M_r\left(\frac{x}{\ell_n}\right) \tag{3}$$

$$V_x = V_o + \frac{M_r - M_\ell}{\ell_n} \tag{4}$$

$$\Delta_x = \Delta_o + \frac{x(\ell_n - x)}{6 E I_n \ell_n} \left[M_\ell (2\ell_n - x) + M_r(\ell_n + x)\right] \tag{5}$$

A general equation for reaction influence lines is also developed in Appendix B, and given in Equation 6. R_n denotes that Equation 6 is used to compute influence line ordinates for a reaction influence line at support n.

$$R_n = {}_nB_o + {}_{n+1}A_o + M_{n-1}\left(\frac{1}{\ell_n}\right) - M_n\left(\frac{1}{\ell_n} + \frac{1}{\ell_{n+1}}\right) + M_{n+1}\left(\frac{1}{\ell_{n+1}}\right) \tag{6}$$

CHAPTER III

COMPUTER PROGRAM

Hardware and Software

The computer program is written in VAX FORTRAN programming language and uses the VAX/VMS operating system, version V4.1 [8]. The program currently operates on a DEC VAX 11/780 minicomputer, and uses a TEKTRONIX 4027 color graphics terminal. A software package called DISSPLA [11] was also implemented to take advantage of the TEKTRONIX 4027 graphics capabilities.

General Characteristics

The computer program in Appendix C was developed with two basic philosophies in mind: (1) to be user-friendly and (2) to be easy to modify. Thus, the program is menu-driven and the user can proceed throughout the program by responding with appropriate alphanumeric or numeric input. All user input is checked for correctness to eliminate problems arising from non-appropriate responses. The computer code contains several comment statements for increasing the readability of the program.

Upon actual running of the program, a main menu as shown in Figure 4 is displayed. Each topic in the main menu is independent of the others and has its own execution menu. Each main menu topic has a unique educational purpose, but all topics should be explored for a complete understanding of influence lines. The content of each main menu topic will now be presented.

```
MAIN MENU
==== ====

(A) INTRODUCTION
(B) DEVELOPMENT OF INFLUENCE LINES
(C) APPLICATION OF INFLUENCE LINES
(D) END OF PROGRAM

PLEASE SELECT ONE OF THE ABOVE: _
```

Figure 4. Computer program main menu.

Introduction

The introduction segment of the program is intended to acquaint the user with all information necessary for program execution. This segment also serves as an introduction to concepts used later in the development and application segments. As shown in Figure 5, the user can choose from a variety of sub-topics. Each sub-topic contributes to a total understanding of program execution and continuous beam influence lines.

```
INTRODUCTION MENU
============ ====

(A) Continuous presentation of all introductory material
(B) Program purpose
(C) Graphical definition of a continuous beam
(D) Graphic examples of influence lines
(E) Presentation of theory
(F) Limitations
(G) Nomenclature
(H) Return to Main Menu

PLEASE SELECT ONE OF THE ABOVE: _
```

Figure 5. Computer program introduction menu.

Development of Influence Lines

The purpose of this segment is two-fold in nature: (1) present to the user a development of influence line equations from fundamental theorems and (2) allow the user to apply the influence line equations and develop any particular influence line. Sub-topics

(A) and (B) in Figure 6 present the development of influence line equations for the user. Sub-topic (C) in Figure 6 is interactive, and allows the user to specify data for a 2, 3, or 4-span continuous beam. Sub-topic (D) in Figure 6 is also interactive and the user must correctly answer questions dealing with variables in the influence line equations. Any incorrect user input results in a repeat of the previous question. An example problem using sub-topics (C) and (D) is presented in Chapter IV.

```
DEVELOPMENT MENU
=========== ====

(A) Concept of influence lines
(B) Influence line equations
(C) Beam physical data input
(D) Computation of influence line ordinates
(E) Return to Main Menu

PLEASE SELECT ONE OF THE ABOVE: _
```

Figure 6. Computer program development menu.

Application of Influence Lines

The application segment of the program allows the user to define a particular continuous beam problem and use his knowledge of influence lines to determine maximum internal forces and deflections. Through an educated trial and error procedure, the user can determine which dead load and live load combination produces worst cases.

Figure 7 shows sub-topics available to the user in the application segment. Sub-topic (A) in Figure 7 allows user definition of a specific continuous beam. Sub-topic (B) in Figure 7 allows viewing of any influence line for the beam specified in sub-topic (A). Sub-topic (C) in Figure 7 allows the user to specify a variety of dead and live loads for the beam specified in sub-topic (A). Sub-topic (D) in Figure 7 allows the user to define or re-define the beam loads, and view moment, shear, or deflection curves for the beam. An example problem using the application segment is presented in Chapter IV.

APPLICATION MENU
================

(A) Beam physical data input
(B) Display of influence lines
(C) Beam load data input
(D) Application of DL & LL to influence lines
(E) Return to Main Menu

PLEASE SELECT ONE OF THE ABOVE: _

Figure 7. Computer program application menu.

Limitations

Graphical aesthetics and scope of work have resulted in imposing several limitations on types of continuous beams and loads. These limitations are provided for the user in the introduction segment of the computer program.

Computation of all influence lines and their respective ordinates is restricted to span tenth-points. Figure 8 shows the tenth-point numbering system used throughout the computer program. In addition, all moment envelope, shear envelope, and deflection curve ordinates are computed at span tenth-points.

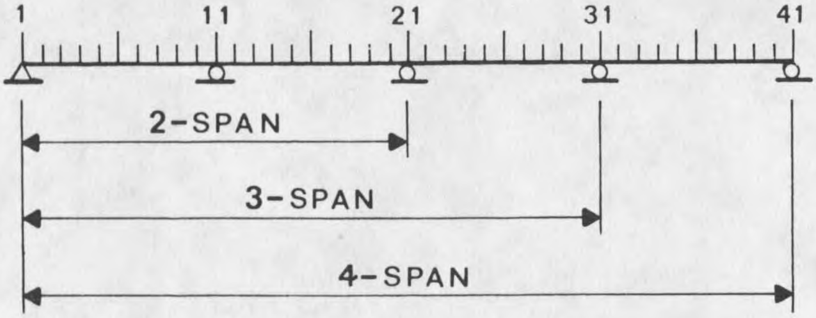

Figure 8. Span tenth-points.