Alternate Approach in Analyzing Structures Utilizing LabVIEW

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Abstract

In the presented paper a new approach for investigating the behavior of structures subjected to loads is proposed. In this unconventional and interesting method of analysis, classical theoretical methods in analyzing structures are formulated using the programming features of LabVIEW to yield the desired output. The LabVIEW software tool is primarily developed by National Instruments, Inc. to aid the investigators in controlling laboratory instrumentations and in acquiring experimental data. Aside from the main utility of LabVIEW related to data acquisition and instrumentation, this tool can also be used as a great programming and computing tool to obtain the solution to many engineering related problems. In the presented paper, LabVIEW solutions for analyzing a statically determinate beam and a statically indeterminate frame are included. These examples illustrate the power, utility, and the manner in which the features available in this software tool can effectively be employed to solve structural analysis problems. The presented examples also demonstrate how program inputs such as beam and loading parameters can conveniently be altered using a variety of visual controls in LabVIEW to obtain the needed results in any desired format. These results, for example, could be the variation of shear force, and bending moment, or the distribution of slope, and deflection along the length of structural members. The faculty teaching courses in structural analysis can effectively use these developed programs while lecturing in classroom to quickly generate different scenarios to further enhance the students' understanding of the course topics. The LabVIEW software also contains a collection of powerful tools that enables the user to import other files such as spreadsheets and MATLAB script files into the LabVIEW environment. This is one of the most attractive and useful features of LabVIEW. In several recent publications by the author other approaches for analyzing structures employing the MATLAB and EXCEL software tools were discussed. The presented paper also illustrates how LabVIEW can effectively be employed to further enhance the functionality and effectiveness of these developed files in analyzing structures.

I. Introduction

The submitted paper focuses on exploring various capabilities and useful programming features of LabVIEW related to solving structural analysis problems. The paper further illustrates the manner in which some of the tools in this software can be employed to further enhance the teaching effectiveness of the instructor and elevate student learning.

The powerful and attractive programming feature of LabVIEW software is relatively easy to use, and this tool offers a number of valuable capabilities that are unavailable in other programming environments. A relatively long list of some of the more important features of this software tool is included and discussed in another publication by the author[2]. A few of the most important advantages of LabVIEW are discussed below.

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The LabVIEW programs also referred to as virtual instruments (VIs) have two main components, the front panel and the block diagram. The front panel basically serves as an interface between the user and the VI. This easy-to-operate and user friendly interface is one of the most attractive features of LabVIEW which is unavailable in many other software/programming environments. Through using LabVIEW's front panel, the input and output of the VIs can be controlled and displayed in any desired fashion using various visual controls and indicators available in LabVIEW. Several sample controls and indicators are shown in the front panel of the example problems presented in Figures 2, 4, 6, 8, and 11. The computations within the VIs are performed via the instructions provided in the block diagram. In this diagram, a series of programming nodes are placed and wired together to perform the needed operations. The block diagrams of the VIs for the example problems of this paper are provided in Figures 3, 5, 7, 9, and 12.

When teaching a structural analysis course in the classroom or laboratory environments, the instructors can use the front panel of the developed VIs to conveniently alter various structure, support, and loading parameters, and instantaneously generate any specific numerical results or needed plots. These results can aid the instructor to better illustrate and discuss the behavior structures subjected to various conditions. The discussion and interaction generated from the use of these VIs creates more interest among the students, elevates students' understanding of the course topics, enhances the student-instructor interactions, and ultimately leads to a more active and engaging teaching and learning environment.

The created VIs can also be supplied to the students to further enhance the utility and effectiveness of these educational programs. Students can run these VIs on their own and play a more active role in educating themselves. They may also use these VIs to perform a check on the validity of the hand solutions they develop for the assigned homework problems.

LabVIEW has also a number of other attractive and useful features for solving structural engineering problems as will be demonstrated by the sample programs included in this paper. The front panel and the block diagrams of the presented VIs further illustrate some of the more powerful capabilities of this great computing tool. Note in the presented paper, the detailed "how-to" instructions in regards to the creation of LabVIEW programs are not included. To learn more about these details the reader is encouraged to refer to other excellent sources of information on LabVIEW such as the text book listed in the bibliography[1].

In the block diagrams of the VIs presented in this paper, as much as possible, labels are used to identify various LabVIEW functions. Also, a number of additional written comments are placed on each diagram to further aid the reader in understanding the basic operations and tasks performed. The VIs developed in this study will be provided to the instructors who are scheduled to teach the Structural Analysis and Strength of Material courses at Georgia Southern University in the fall semester of 2004.

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II. Analysis of a Statically Determinate Beam

In this section of the paper the procedure for determining the shear and moment diagrams and plotting the variation of the slope and deflection of the beam using LabVIEW is discussed. This procedure is illustrated through presenting the solution for a sample beam and loading condition shown in Figure 1(a).

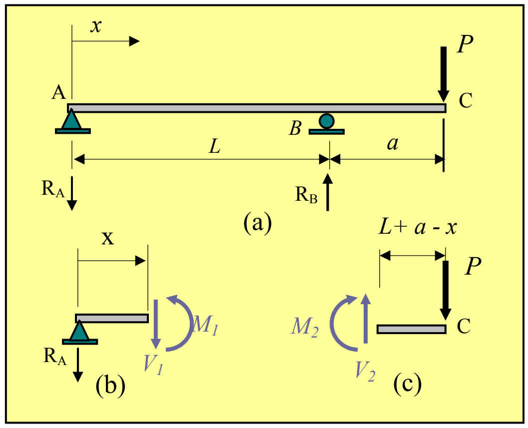

Figure 1. Free Body Diagrams for the Beam

Writing the force and moment equilibrium equations for the free body diagrams of the two sections of the beam shown at the bottom of Figure 1, the following expressions for the shear force V and bending moment M can be established.

$0 \le x \le L$ $\qquad$ $L \le x \le L + a$

$$V_1 = \frac{-Pa}{L} \qquad (1) \qquad\qquad V_2 = P \qquad (3)$$

$$M_1 = \frac{-Pax}{L} \qquad (2) \qquad\qquad M_2 = -P(L + a - x) \qquad (4)$$

Upon substituting for the moments M_1 and M_2 in the differential equations for the two segments of the beam shown below:

$0 \le x \le L$ $\qquad$ $L \le x \le L + a$

$$EIv_1'' = M_1 \qquad (5) \qquad\qquad EIv_2'' = M_2 \qquad (6)$$

the following two specific equations are obtained for the beam under consideration. In these expressions E, and I are respectively the modulus of elasticity and moment of inertia of the beam. All other parameters in the equations are as defined in Figure 1.

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$0 \le x \le L$ $\qquad$ $L \le x \le L + a$

$$EIv_1'' = \frac{-Pax}{L} \qquad (7) \qquad\qquad EIv_2'' = -P(L + a - x) \qquad (8)$$

Upon employing the method of successive integration and enforcing the boundary conditions:

$$v_1(x = 0) = 0 \qquad (9) \qquad\qquad v_2(x = L) = 0 \qquad (10)$$

and the continuity equations:

$$v_1(x = L) = v_2(x = L) \qquad (11) \qquad\qquad v_1'(x = L) = v_2'(x = L) \qquad (12)$$

the following equations are obtained for the slope v' and deflection v for the two segments of the beam. Note that the boundary conditions and continuity equations listed above respectively indicate that there is no deflection at the pin and roller supports, and that at the roller support there is only one single value for the slope and one single value for the deflection.

$0 \le x \le L$ $\qquad$ $L \le x \le L + a$

$$v_1' = \frac{-P}{6EIL}(3ax^2 - aL^2) \qquad (13)$$

$$v_2' = \frac{-P}{6EI}\left[-3(L + a - x)^2 + a(3a + 2L)\right] \qquad (15)$$

$$v_1 = \frac{-Pax}{6EIL}(x^2 - L^2) \qquad (14)$$

$$v_2 = \frac{-P}{6EI}\left[(L + a - x)^3 + a(3a + 2L)x + a(-a^2 - 3aL - 2L^2)\right] \qquad (16)$$

The front panel and the block diagram of the VI developed for this problem are presented in Figures 2 and 3. In the front panel of the program, the values of shear, moment, slope, and deflection along the length of the beam is tabulated and plotted for the specific values of data shown. In the presented front panel, the user can conveniently select any particular beam and loading condition, and view the results instantaneously. Utilizing various visual controls and indicators in LabVIEW, problem data can be entered in various ways and displayed in any desired format. In the block diagram of this problem presented in Figure 3, a series of written comments are included to explain some of the more important features, tools, and operations of this VI. The diagram illustrates how the data is read into the program, and processed through various programming nodes of LabVIEW to produce the desired tabulated values and the needed plots.

The theoretical procedure formulated earlier for determination of the expressions for shear, moment, slope, and deflection of the beam subjected to a concentrated load can be applied to any other loading condition. Using this method of analysis, Eqs. (17) through (24) are obtained for the case when a uniform distributed load is acting over the entire length of the given overhanging beam. The front panel and block diagram for the VI developed for this case is presented in

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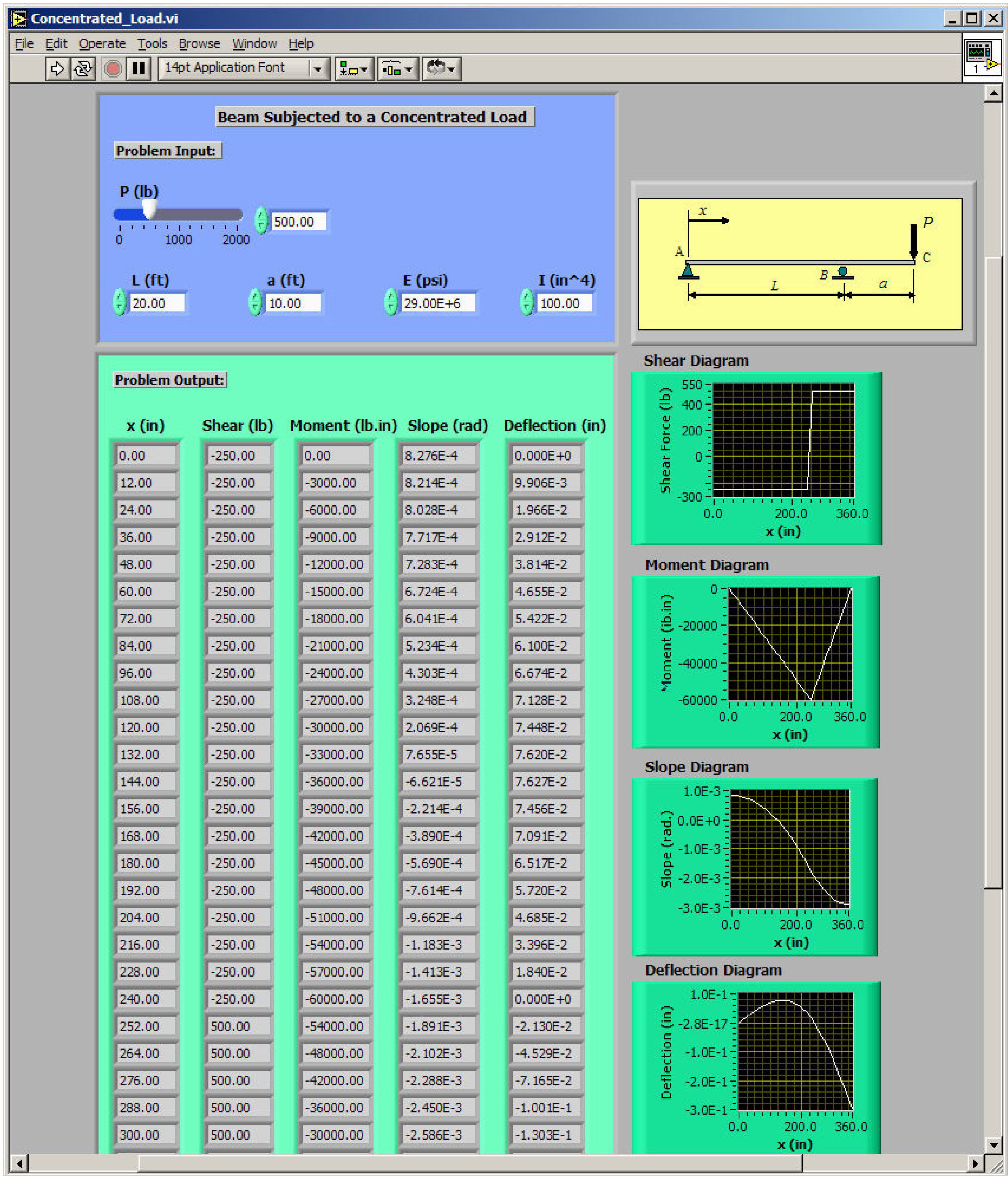

x (in)	Shear (lb)	Moment (lb.in)	Slope (rad)	Deflection (in)
0.00	-250.00	0.00	8.276E-4	0.000E+0
12.00	-250.00	-3000.00	8.214E-4	9.906E-3
24.00	-250.00	-6000.00	8.028E-4	1.966E-2
36.00	-250.00	-9000.00	7.717E-4	2.912E-2
48.00	-250.00	-12000.00	7.283E-4	3.814E-2
60.00	-250.00	-15000.00	6.724E-4	4.655E-2
72.00	-250.00	-18000.00	6.041E-4	5.422E-2
84.00	-250.00	-21000.00	5.234E-4	6.100E-2
96.00	-250.00	-24000.00	4.303E-4	6.674E-2
108.00	-250.00	-27000.00	3.248E-4	7.128E-2
120.00	-250.00	-30000.00	2.069E-4	7.448E-2
132.00	-250.00	-33000.00	7.655E-5	7.620E-2
144.00	-250.00	-36000.00	-6.621E-5	7.627E-2
156.00	-250.00	-39000.00	-2.214E-4	7.456E-2
168.00	-250.00	-42000.00	-3.890E-4	7.091E-2
180.00	-250.00	-45000.00	-5.690E-4	6.517E-2
192.00	-250.00	-48000.00	-7.614E-4	5.720E-2
204.00	-250.00	-51000.00	-9.662E-4	4.685E-2
216.00	-250.00	-54000.00	-1.183E-3	3.396E-2
228.00	-250.00	-57000.00	-1.413E-3	1.840E-2
240.00	-250.00	-60000.00	-1.655E-3	0.000E+0
252.00	500.00	-54000.00	-1.891E-3	-2.130E-2
264.00	500.00	-48000.00	-2.102E-3	-4.529E-2
276.00	500.00	-42000.00	-2.288E-3	-7.165E-2
288.00	500.00	-36000.00	-2.450E-3	-1.001E-1
300.00	500.00	-30000.00	-2.586E-3	-1.303E-1

Figure 2. Front Panel of the VI Created for Analyzing
a Beam Subjected to a Concentrated Load

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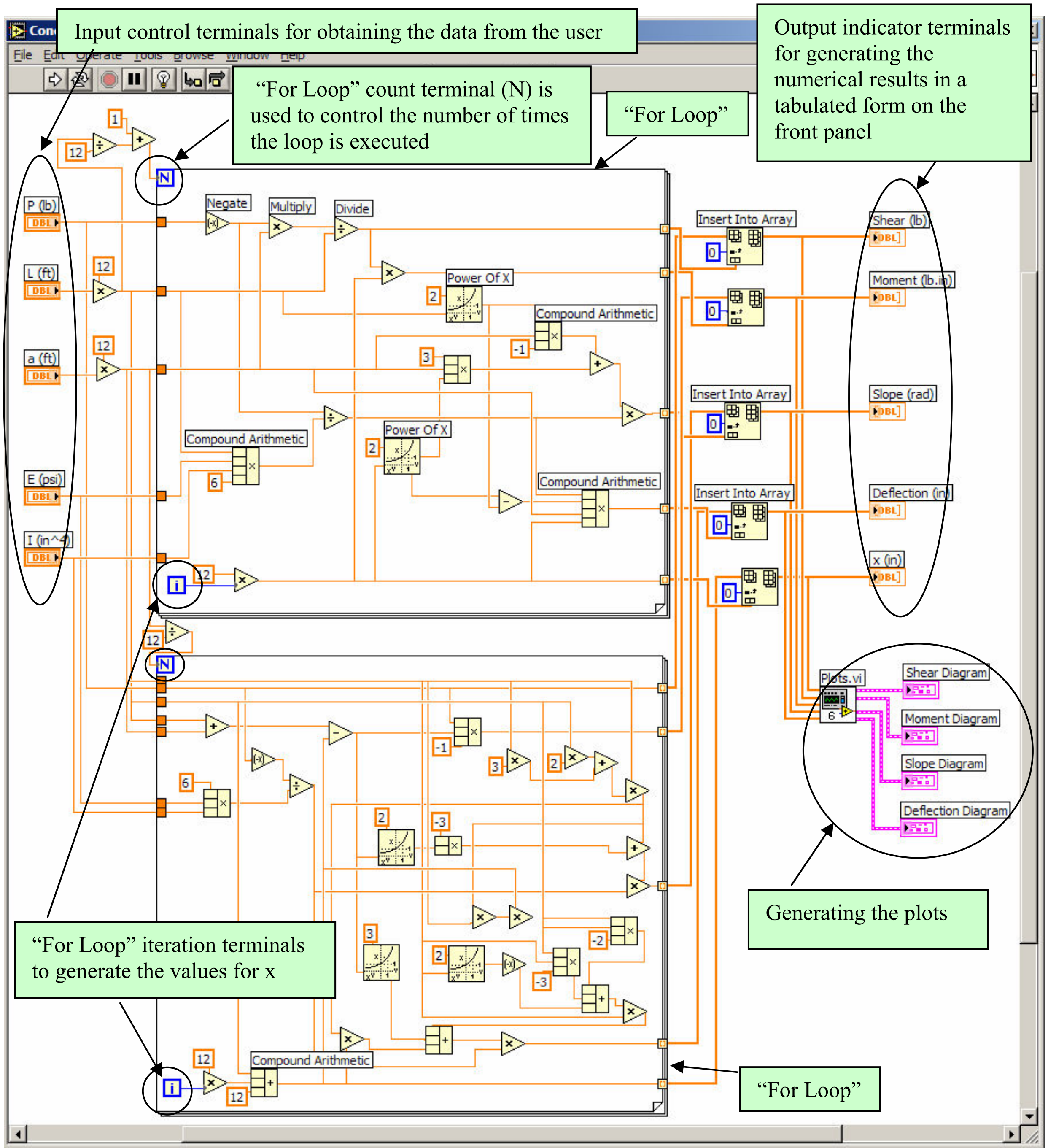

Figure 3. Block Diagram of the VI Created for Analyzing a Beam Subjected to a Concentrated Load

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Figures 4 and 5. As it is noted in Figure 5, an approach different than the one used in the previous example is followed. This is purposely done in order to demonstrate some of the other useful capabilities of LabVIEW. The block diagram of the VI for this problem utilizes an imported MATLAB script file to compute the values of shear, moment, slope, and deflection for different generated values of x. This VI then makes a call to another subVI to create the plots. The block diagram of the called subVI is presented in Figure 5 (b). Note that the development of MATLAB script files for analyzing structures was discussed in two earlier publications of the author[3,4].

$$V_1 = \frac{-w}{2L}(a^2 - L^2) - wx \tag{17}$$

$$v_1' = \frac{-w}{24EIL}\left[4Lx^3 + 6(a^2 - L^2)x^2 - L^2(2a^2 - L^2)\right] \tag{19}$$

$$M_1 = \frac{-wx^2}{2} - \frac{w}{2L}(a^2 - L^2)x \tag{18}$$

$$v_1 = \frac{-wx}{24EIL}\left[Lx^3 + 2(a^2 - L^2)x^2 - L^2(2a^2 - L^2)\right] \tag{20}$$

$L \le x \le L + a$

$$V_2 = w(L + a - x) \tag{21}$$

$$v_2' = \frac{-w}{24EI}\left[-4(L + a - x)^3 - (L^3 - 4La^2 - 4a^3)\right] \tag{23}$$

$$M_2 = \frac{-w(L + a - x)^2}{2} \tag{22}$$

$$v_2 = \frac{-w}{24EI}\left[(L + a - x)^4 - (L^3 - 4La^2 - 4a^3)x - (a^4 - L^4 + 4L^2a^2 + 4La^3)\right] \tag{24}$$

The results for a new case, a beam subjected to a combined distributed and concentrated load, are presented in the front panel of the VI depicted in Figure 6. The block diagram for this VI is provided in Figures 7. As observed in Figure 7, calls are made to the two subVIs discussed earlier to compute the results for the concentrated and distributed loading cases. The results from these cases are then superimposed using several special functions of LabVIEW (bundle and unbundle functions) to yield the final computed values for the combined loading case.

The front panel and block diagram of an alternate VI to analyze a beam subjected to a combined loading case is presented in Figures 8 and 9 to further illustrate the power and capabilities of LabVIEW. In Figure 9, the values of shear, moment, slope, and deflection along the length of the beam for the distributed load case is imported from a previously created spreadsheet. The special application of Excel in solving structural analysis problems was discussed in an earlier work of the author[5].

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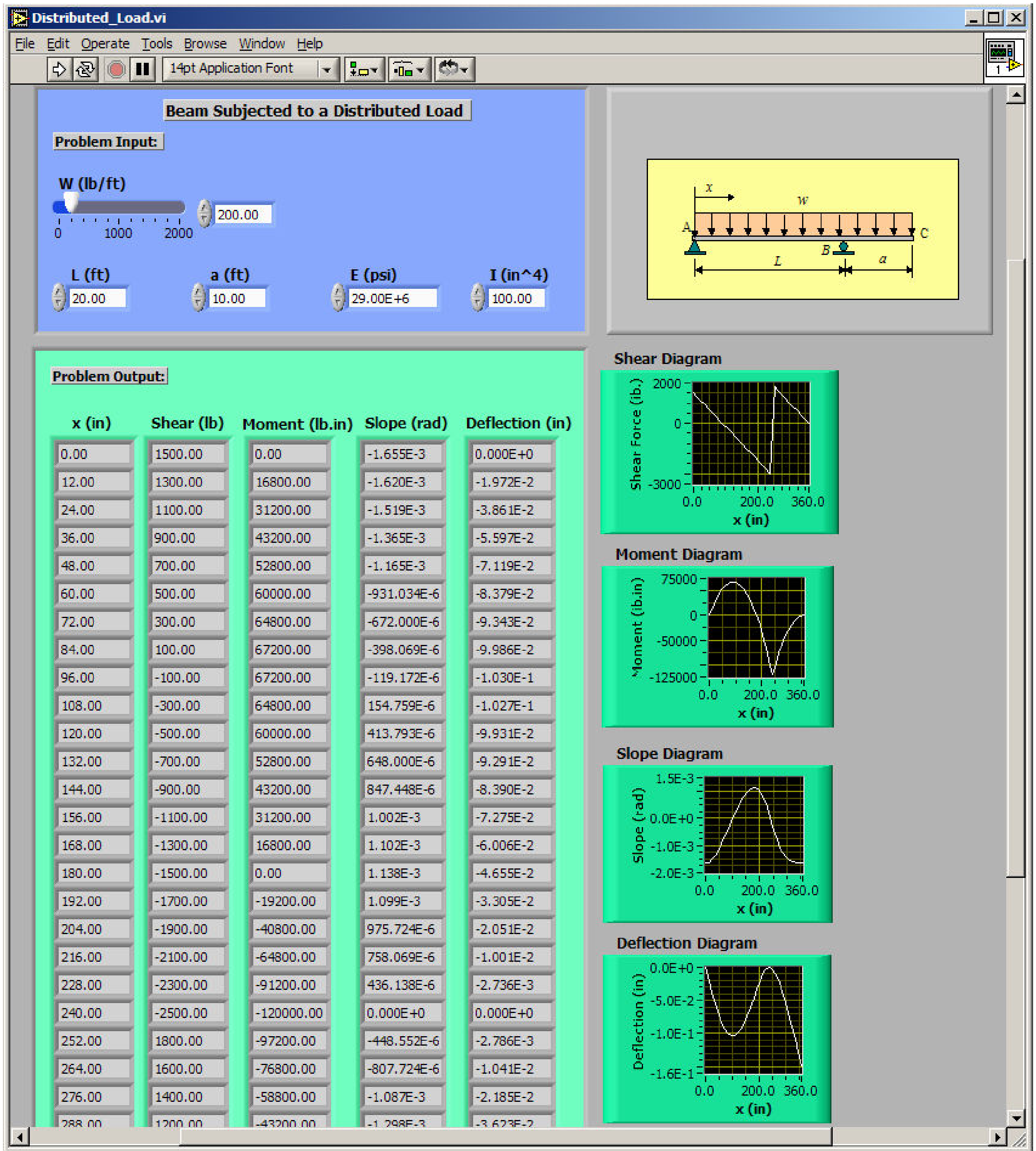

Figure 4. Front Panel of the VI Created for Analyzing
a Beam Subjected to a Distributed Load

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(a)

(b)

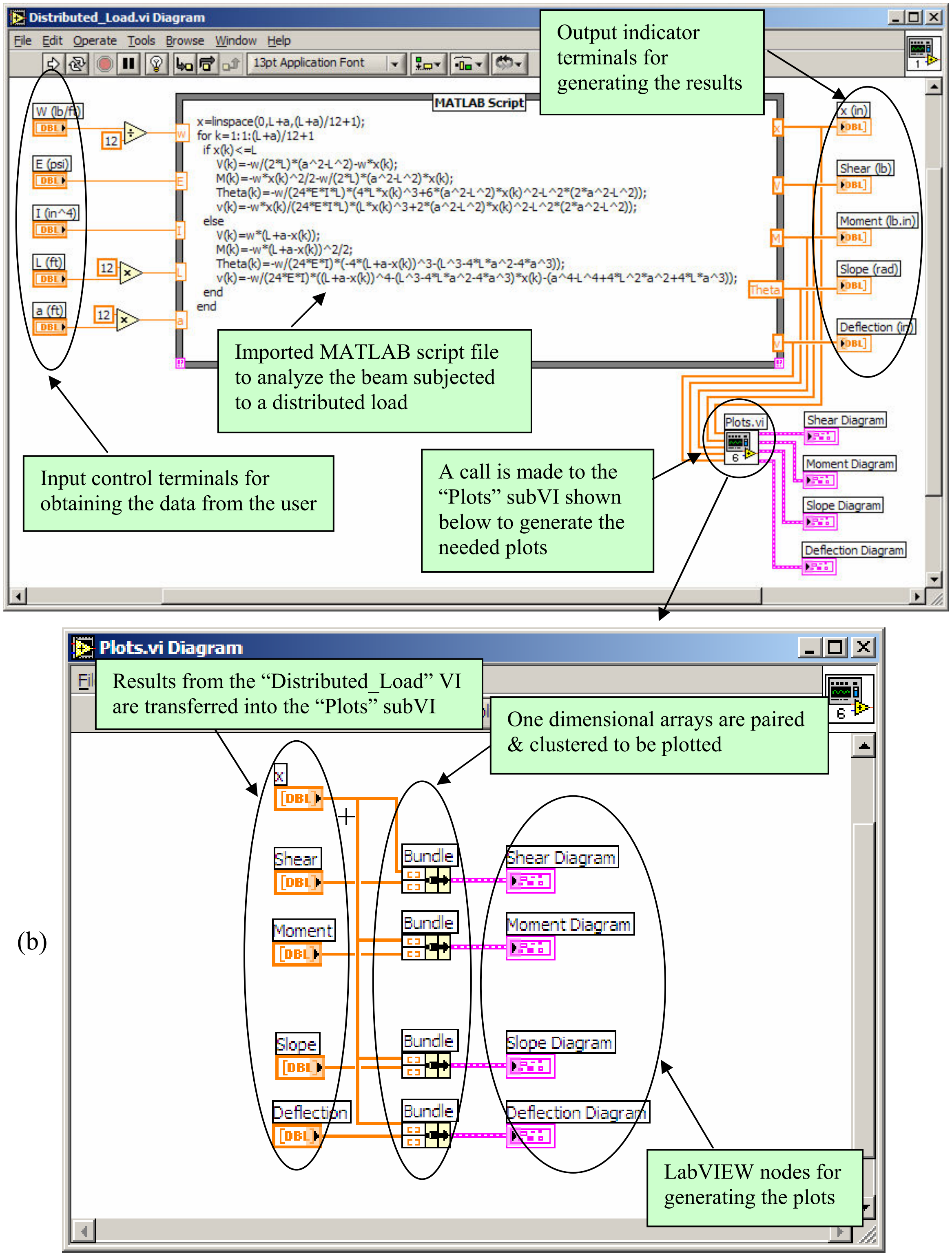

Figure 5. Block Diagrams of the VI and SubVI Created for Analyzing a Beam Subjected to a Distributed Load

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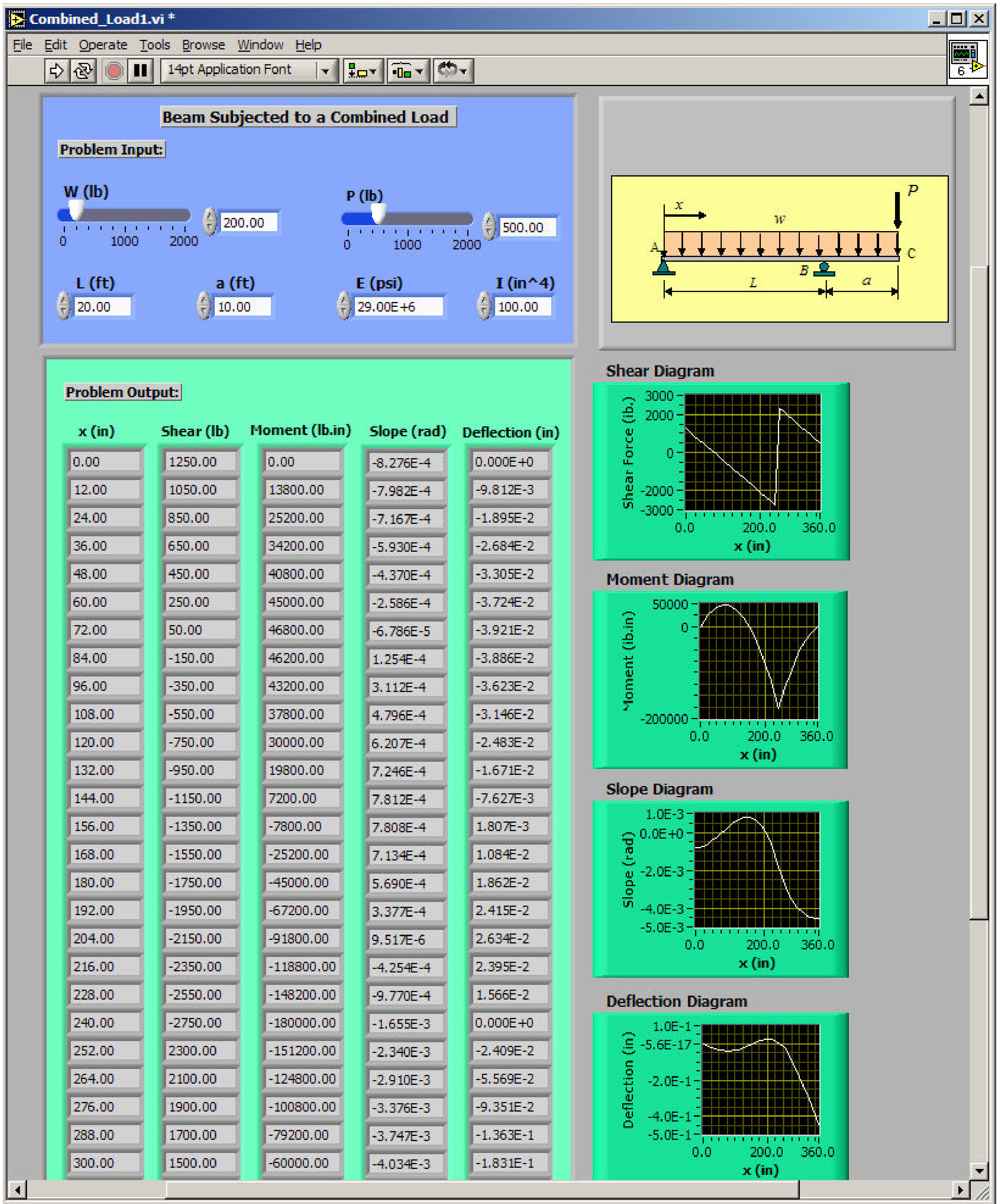

Figure 6. Front Panel of the VI Created for Analyzing
a Beam Subjected to a Combined Load

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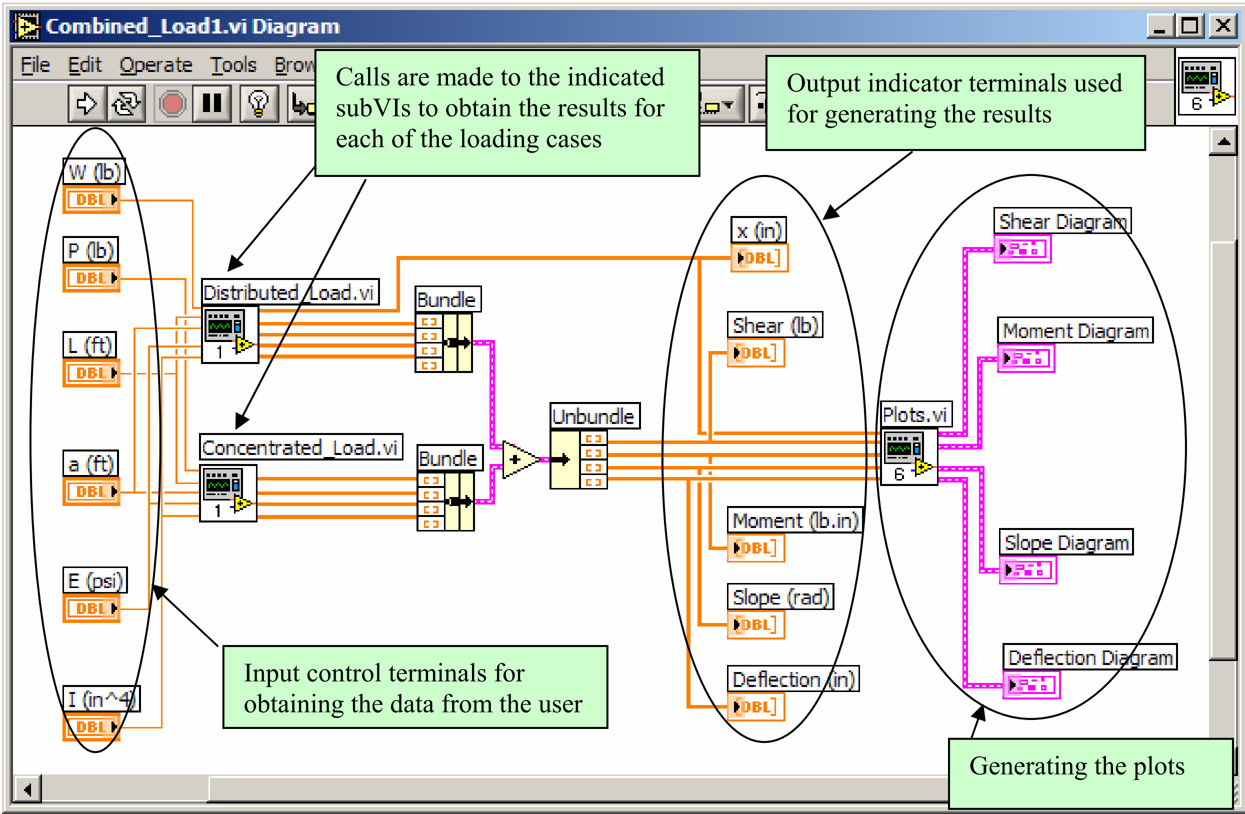

Figure 7. Block Diagrams of the VI Created for Analyzing
a Beam Subjected to a Distributed Load

It should be stated that the special tool used for importing the spreadsheet in the block diagram of Figure 9 requires that the created spreadsheet is first converted to a text file. It should additionally be commented that there are available VIs developed by National Instruments, Inc. that allow the user to directly import the data from Excel or other similar programs.

The result for the concentrated load case in the block diagram presented in Figure 9 is obtained by calling the subVI discussed earlier in the paper. The procedure for combining, displaying, and plotting the results is the same as described in the previous VIs.

It should be noted that additional provisions can easily be made in the developed virtual instruments to compute the maximum stresses acting on the beam to make sure that these values are not exceeding the allowed limits. These VIs can serve as a great tool for designing beams.

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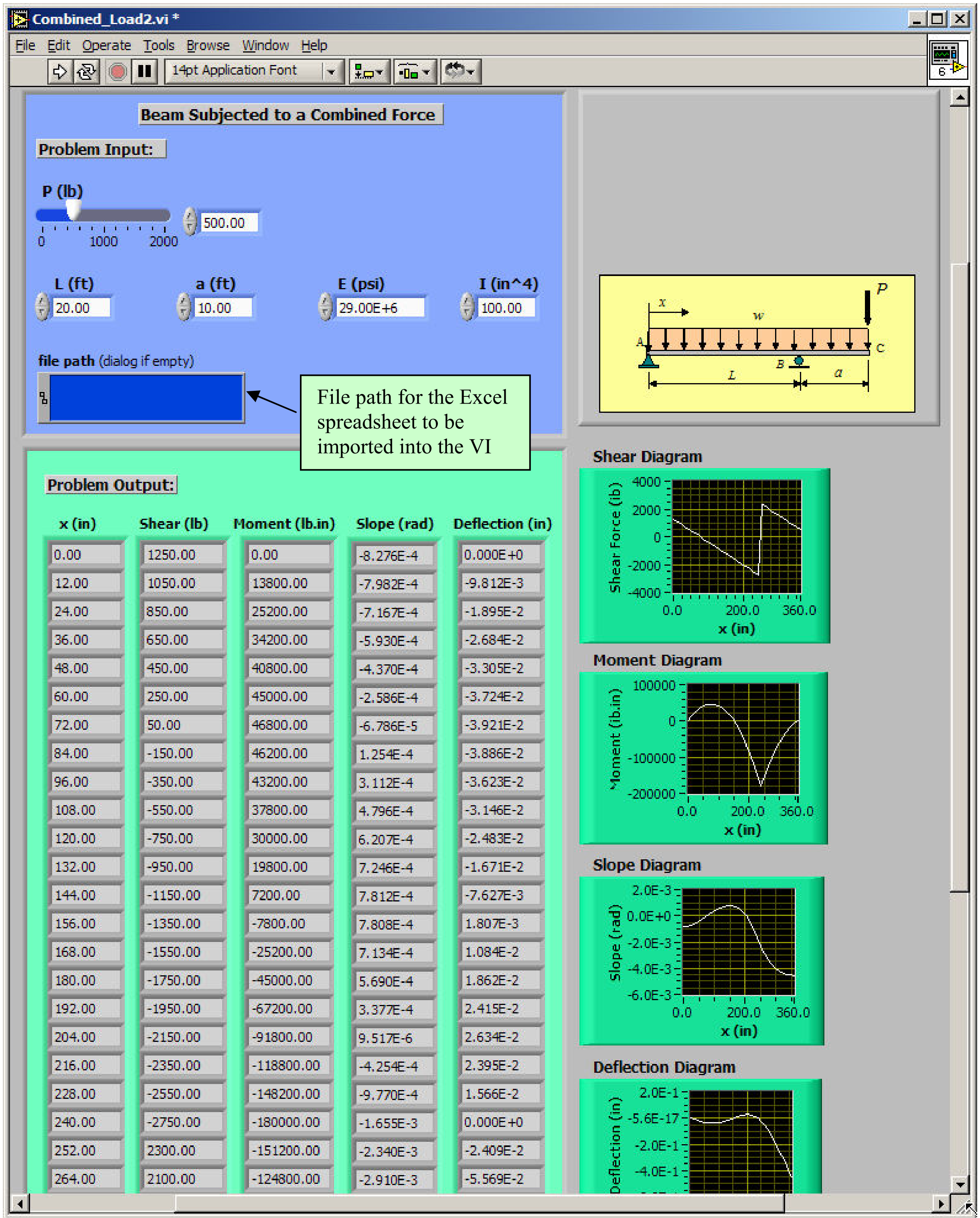

x (in)	Shear (lb)	Moment (lb.in)	Slope (rad)	Deflection (in)
0.00	1250.00	0.00	-8.276E-4	0.000E+0
12.00	1050.00	13800.00	-7.982E-4	-9.812E-3
24.00	850.00	25200.00	-7.167E-4	-1.895E-2
36.00	650.00	34200.00	-5.930E-4	-2.684E-2
48.00	450.00	40800.00	-4.370E-4	-3.305E-2
60.00	250.00	45000.00	-2.586E-4	-3.724E-2
72.00	50.00	46800.00	-6.786E-5	-3.921E-2
84.00	-150.00	46200.00	1.254E-4	-3.886E-2
96.00	-350.00	43200.00	3.112E-4	-3.623E-2
108.00	-550.00	37800.00	4.796E-4	-3.146E-2
120.00	-750.00	30000.00	6.207E-4	-2.483E-2
132.00	-950.00	19800.00	7.246E-4	-1.671E-2
144.00	-1150.00	7200.00	7.812E-4	-7.627E-3
156.00	-1350.00	-7800.00	7.808E-4	1.807E-3
168.00	-1550.00	-25200.00	7.134E-4	1.084E-2
180.00	-1750.00	-45000.00	5.690E-4	1.862E-2
192.00	-1950.00	-67200.00	3.377E-4	2.415E-2
204.00	-2150.00	-91800.00	9.517E-6	2.634E-2
216.00	-2350.00	-118800.00	-4.254E-4	2.395E-2
228.00	-2550.00	-148200.00	-9.770E-4	1.566E-2
240.00	-2750.00	-180000.00	-1.655E-3	0.000E+0
252.00	2300.00	-151200.00	-2.340E-3	-2.409E-2
264.00	2100.00	-124800.00	-2.910E-3	-5.569E-2

Figure 8. Front Panel of an Alternate VI Created for Analyzing a Beam Subjected to a Combined Load

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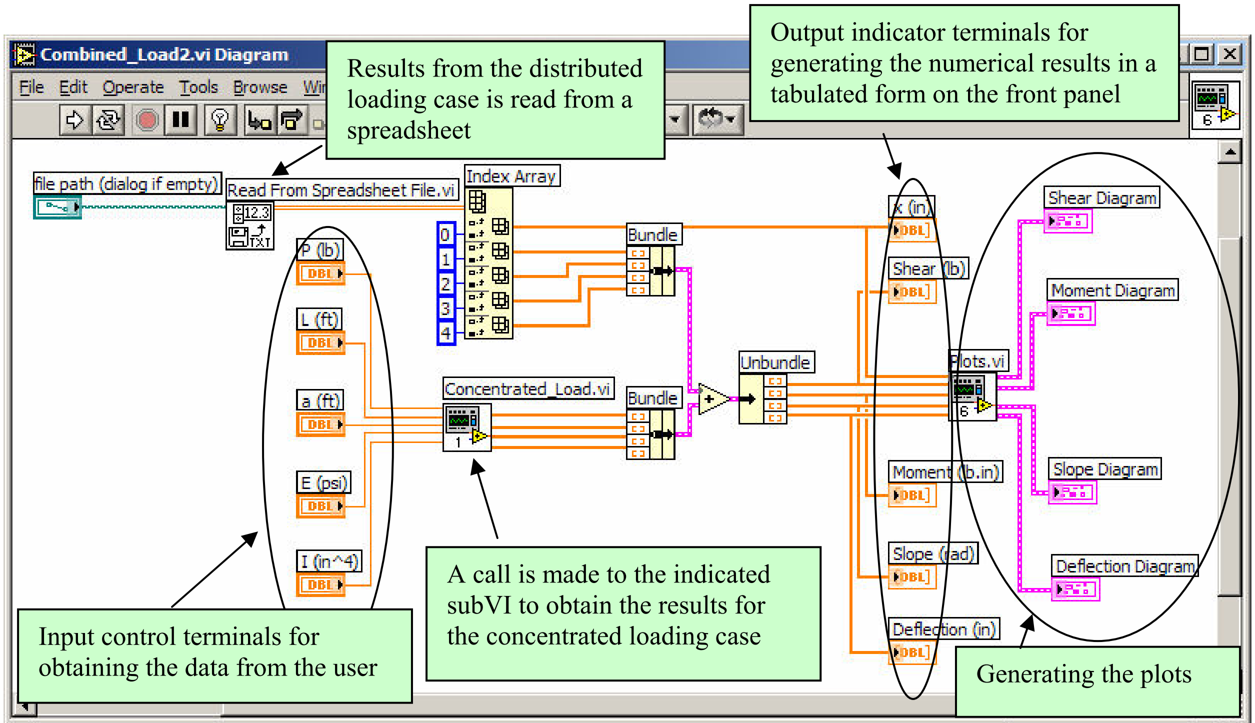

Figure 9. Block Diagram of an Alternate VI Created for Analyzing a Beam Subjected to a Combined Load

III. Analysis of a Statically Indeterminate Frame

In this section of the paper the LabVIEW solution for analyzing a sample statically indeterminate frame using the method of slope-deflection is presented and discussed. This sample problem is taken from a text book[6] used for teaching a structural analysis course at Georgia Southern University. Suppose that for the frame depicted in Figure 10, the moments at the ends of members AB, BC, and BD (M_{BA}, M_{BD}, M_{DB}, M_{BC}, and M_{CB}) are to be computed.

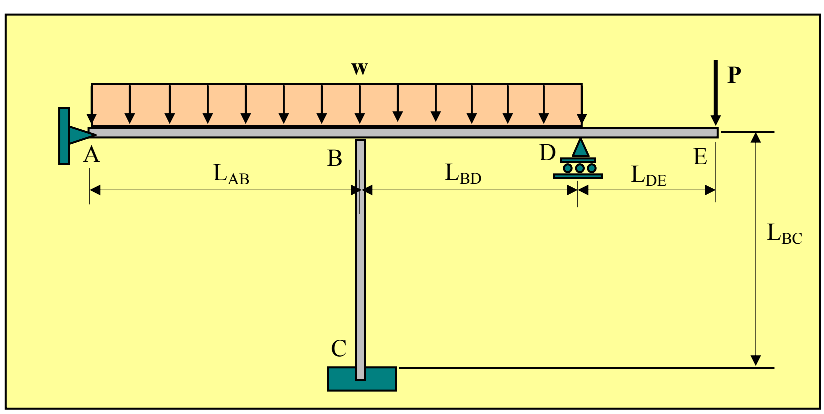

Figure 10. A Statically Indeterminate Frame

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Applying the well-known slope-deflection method to members AB, BC, and BD of the frame, the following expressions for the end-moments of the members are obtained.

$$M_{BA} = 3Ek_{AB}\theta_B + (FEM)_{BA} \quad (25)$$

$$M_{BD} = 4Ek_{BD}\theta_B + 2Ek_{BD}\theta_D + (FEM)_{BD} \quad (26)$$

$$M_{DB} = 4Ek_{BD}\theta_D + 2Ek_{BD}\theta_B + (FEM)_{DB} \quad (27)$$

$$M_{BC} = 4Ek_{BC}\theta_B + (FEM)_{BC} \quad (28)$$

$$M_{CB} = 2Ek_{BC}\theta_B + (FEM)_{CB} \quad (29)$$

In these expressions, M, E, k, θ, and FEM are respectively, member end-moments, modulus of elasticity, member relative-stiffness factors, joint angular displacements, and member fixed-end moments. The values of the fixed-end moments in the above expressions for the given beam and loading conditions can be obtained using the following equations. These equations are tabulated in any elementary structural analysis text[6].

$$(FEM)_{BA} = wL_{AB}^{2}/8 \quad (30)$$

$$(FEM)_{BD} = -wL_{BD}^{2}/12 \quad (31)$$

$$(FEM)_{DB} = wL_{BD}^{2}/12 \quad (32)$$

$$(FEM)_{BC} = 0 \quad (33)$$

$$(FEM)_{CB} = 0 \quad (34)$$

The relative-stiffness of the frame members can be computed by dividing the moments of inertia of each member by the corresponding length of the member, as shown below.

$$k_{AB} = I_{AB}/L_{AB}, \; k_{BD} = I_{BD}/L_{BD}, \; k_{BC} = I_{BC}/L_{BC} \quad (35)$$

In order to compute the member end-moments, moment equilibrium equations of joints B and D shown below should also be considered to provide the two additional equations needed.

$$M_{BA} + M_{BC} + M_{BD} = 0 \quad (36)$$

$$M_{DB} + pL_{DE} = 0 \quad (37)$$

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The Eqs. (25) through (29) together with Eqs. (36) and (37) can be expressed in the matrix form as the following system of linear equations. Using this set of equations, member end-moments M_{BA}, M_{BD}, M_{DB}, M_{BC}, and M_{CB}, as well as, angular displacements θ_B and θ_D can be computed.

$$\begin{bmatrix} -3Ek_{AB} & 0 & 1 & 0 & 0 & 0 & 0 \\ -4Ek_{BD} & -2Ek_{BD} & 0 & 1 & 0 & 0 & 0 \\ -2Ek_{BD} & -4Ek_{BD} & 0 & 0 & 1 & 0 & 0 \\ -4Ek_{BC} & 0 & 0 & 0 & 0 & 1 & 0 \\ -2Ek_{BC} & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{Bmatrix} \theta_B \\ \theta_D \\ M_{BA} \\ M_{BD} \\ M_{DB} \\ M_{BC} \\ M_{CB} \end{Bmatrix} = \begin{Bmatrix} (FEM)_{BA} \\ (FEM)_{BD} \\ (FEM)_{DB} \\ (FEM)_{BC} \\ (FEM)_{CB} \\ 0 \\ pL_{DE} \end{Bmatrix} \tag{38}$$

The front panel and the block diagram of the VI developed for this problem is presented in Figures 11 and 12. In the block diagram of the problem, various built-in functions of LabVIEW are employed to compute and assemble the matrix shown on the left-hand side of the equal sign and the fixed-end-moment column-vector on the right side in Eq. (38). A special LabVIEW function placed in the block diagram then enables the VI to compute the end moments of the frame. The output indicators placed in the block diagram display the computed moments next to each structure joint in the front panel at locations convenient for user access. To the extent possible, the elements on the block diagram are labeled to enable the reader to understand some of the basic operations of the VI.

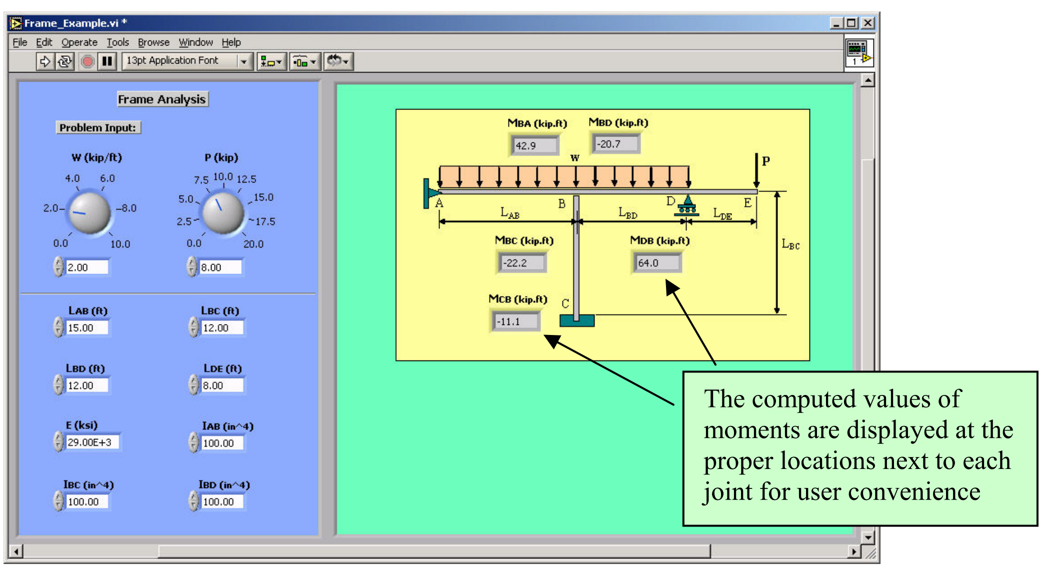

Figure 11. Front Panel of the VI Created for Analyzing a Frame

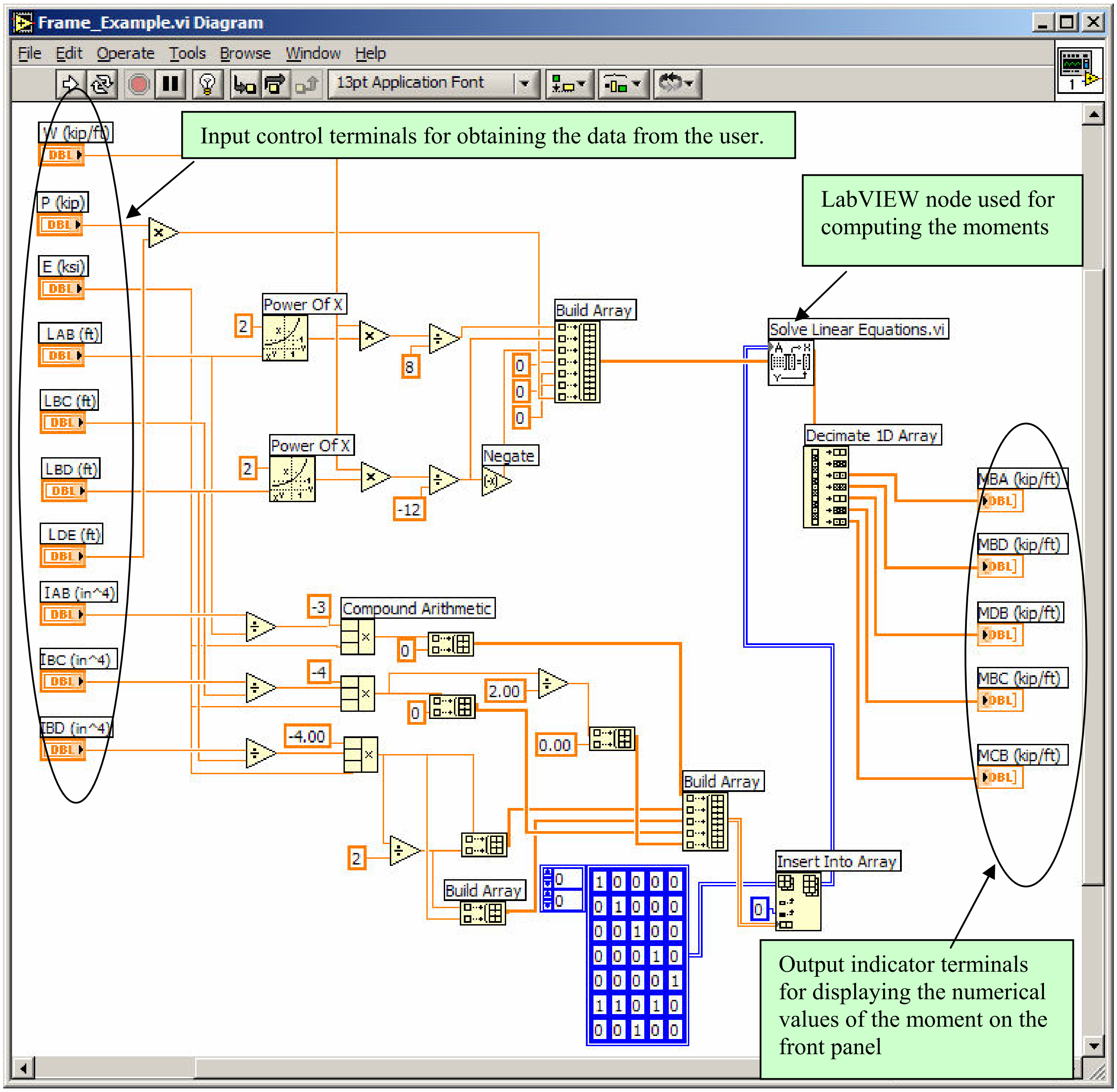

Figure 12. Block Diagram of the VI Created for Analyzing a Frame

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IV. Summary & Conclusion

In the presented paper the development and utility of LabVIEW virtual instruments for solving structural analysis problems were presented and discussed. The solutions for several example problems were included in the paper to clearly establish some of the more important and useful capabilities of this software tool related to solving structural engineering problems. The paper also illustrated the ease with which other data types and programs such as spreadsheet files, or MATLAB script files can be imported and used in the developed VIs. This is perhaps one of the more attractive and useful features of LabVIEW, since previously created data and programs need not be recreated in LabVIEW to be utilized. Virtual instruments similar to ones developed and presented in this paper can be developed for other available classical methods of analysis or other problem types. The created virtual instrument can serve as a valuable educational tool for the instructor and for students alike. The instructor can use these VIs during the classroom to further elevate student learning. The students can also use the developed VIs on their own outside the classroom to further enhance their own understanding of the course topics. It might be of interest to also state that using the "Professional Development System" version of LabVIEW, stand-alone executable files can be created that run on any computer with or without LabVIEW installed.

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