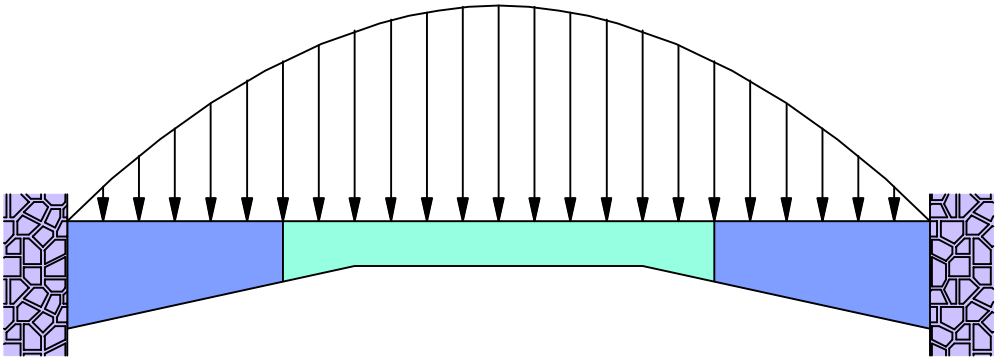
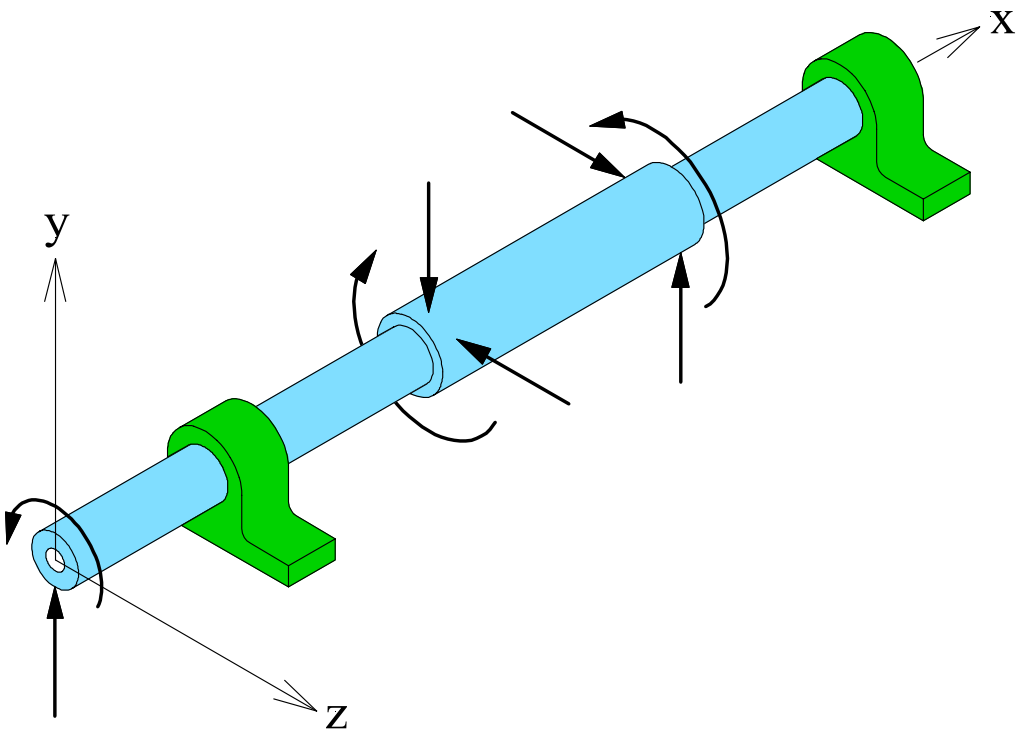
BeamShaft User's Manual





Version: 2.2

Library ID: 1707

Checksum: # 30180d

Library size: 60791 bytes

Language: User RPL

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Contents

Overview

The BeamShaft library is an HP 48GX application for analyzing beams subjected to a transverse loading or shafts under combined bending and torsion. The program computes the reactions at the supports and shear, bending moment, slope, deflection, and shaft maximum shearing stress at a user-specified number of increments.

- Execute the programs from any directory.
- Use any consistent units; results are in terms of the same length and force units as the input.
- Cantilever members may have the support located at either end. The following support types are permitted for members with two or more supports: all supports pinned, left end fixed, or both ends fixed. Overhangs are allowed.
- The loading may include any combination of concentrated loads; applied moments; and uniform, linear, and nonlinear distributed loads. Shafts may be subjected to a horizontal transverse loading and/or a torsional loading, in addition to the vertical loading.
- A variable modulus of elasticity is allowed.
- The cross section may be constant, stepped or continuously varying.
- Redundant reactions and the slope and deflection are computed by the moment-area method.
- You can plot the diagrams, find the maximum and minimum values, and display or print any portion of the output. Results are rounded to seven significant digits.

Introduction

Installing the Library

1. Download the library to the HP 48.
2. Recall the library to the stack.
3. Purge the variable that contains the library.
4. Store the library in any available port. For instance, execute 0 [STO] to store it in port 0.
   Note: The programs execute somewhat faster when the library is stored in port 0 or 1.
5. Turn the calculator off, then on again to attach the library to the HOME directory.

Accessing the Programs

a) Press [→] [LIBRARY] BEAM Shaft to display the first page of the program menu.

b) Alternatively, assign the program « 1707 MENU » to a user key; press that user key to display the program menu.

The menu consists of two pages. Press [NXT] to toggle between the two pages.

Removing the Library

1. Switch to the HOME directory.
2. Enter the library number 1707.
3. Press [←] [LIBRARY] DETACH to detach the library from the HOME directory.
4. Enter :n: 1707, where n is the number of the port where the library is stored.
   Alternatively, enter :&: 1707 to search all ports.
5. Press [←] [PURG] to purge the library from port memory.

Running the Programs

The LOADS, TORQ, BEAM and SHAFT programs calculate and store the results. Use the other programs for plotting, viewing and printing the results.

Beam Problem

1. Run LOADS to compute the reactions at the supports and the shear and bending moment at a user-specified number of increments. The beam length, number of increments, support locations, and at least one load must be entered. For a statically indeterminate beam of variable EI, variable E and/or variable I data are also needed in order to determine the reactions.

2. To compute the slope and deflection, execute BEAM after running LOADS. Unless previously defined, the following input is required: flexural rigidity type, modulus of elasticity and moment of inertia. BEAM uses the bending moment data generated by LOADS to calculate the slope and deflection at each increment.

Shaft Problem

1. Run LOADS for a beam with a circular cross section. LOADS computes the reactions at the supports and the shear and bending moment at a user-specified number of increments.

   Run TORQ for shafts subjected to a horizontal and/or torsional loading, in addition to the vertical loading. TORQ computes the reactions at the supports and the shear, bending moment and equivalent torque at a user-specified number of increments.

   The shaft length, number of increments, support locations, and at least one load in the vertical *xy* plane must be entered. For a statically indeterminate shaft of variable EI, variable E and/or variable diameter data are also needed in order to determine the reactions.

2. To compute the slope, deflection and stress, execute SHAFT after running LOADS or TORQ. Unless previously defined, the following input is required: flexural rigidity type, modulus of elasticity, outside diameter and inside diameter. SHAFT uses the bending moment and equivalent torque data generated by LOADS or TORQ to calculate the slope, deflection, and bending stress or maximum shearing stress at each increment.

Entering Data

A command line prompt is used to input a single value. Key in a number or anything that evaluates to one value and press ENTER.

Input forms are used when the required input consists of two or three values. The input forms accept real numbers, variable names and algebraic expressions as valid input.

Input data is entered on the stack when an indefinite number of arguments is allowed—for support locations, loads, variable E data, and variable cross section properties. Enter any number of support locations in any order. For all other stack input, enter the data in the sequence indicated by the prompt. For example, the prompt X_M...? indicates that any number of applied moments may be entered in any order, but each moment M must be immediately preceded by its location X. Similarly, the prompt X1_X2_W...? indicates that any number of uniform and/or nonlinear distributed loads may be entered in any order, but each load W must be immediately preceded by the start and end locations (X1 and X2 in either order). The menu keys activated for stack input are described in the following table:

Stack Prompt Menu

Key	Description
L/2	Length/2. Enters the location of the midpoint.
L	Length. Enters the location of the right-hand end.
OVER or $\bar{x}$	Over Command. Copies the object on stack level 2 to stack level 1. Enters the independent variable name used in algebraic expressions for nonlinear distributed loads and continuously varying cross sections.
?	ENTER causes the prompt to disappear. ? displays the prompt again.
CANCL	Displays a Cancel? prompt. Press YES to cancel program execution. ← CANCL cancels without confirmation.
OK	Resumes program execution. If you switch to a different menu while the program is halted for stack input, press ← CONT when ready to continue.

Enter nonlinear distributed loads and continuously varying beam moments of inertia (or shaft diameters) as algebraic expressions with $\bar{x}$ as the independent variable. If you enter and store an expression before executing the program, press α → X to insert the independent variable. Use the $\bar{x}$ menu key as a shortcut when you key in an expression at the prompt.

Some error checking is performed for all data entry. An error message is displayed for invalid input and the user is required to correct the problem before continuing. Use the Interactive Stack (STACK ▲) if editing upper levels of the stack is necessary.

Program Reference

This section consists of an alphabetical listing of the programs in the library. The following information is included:

- a brief description of what the program does
- the required input
- any optional input
- any user flags that affect its operation
- the output
- additional information about the program
- examples

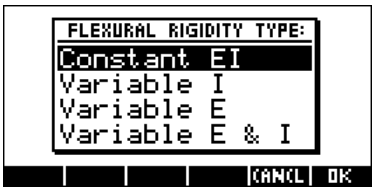
BEAM

Beam: Computes the slope and deflection for constant or variable EI beams. For beams of constant cross section, you have the option to also compute the bending stress.

Input:

- Statically determinate beam.

  Highlight the flexural rigidity type and press ENTER.



- Statically indeterminate beam.

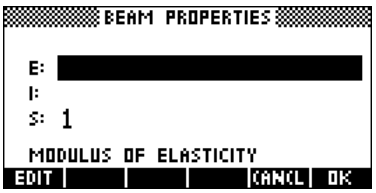
  The flexural rigidity type is already defined.

- **Constant EI**

  Enter the modulus of elasticity E, moment of inertia I, and section modulus S.

  Enter real numbers, variable names, or algebraic expressions in these fields. Press NXT CALC to calculate a value.

  Bending stress is not computed when the default value of 1 is used for the section modulus.



- **Variable I**

  - Enter a value for the modulus of elasticity E.

    Press ENTER with the command line empty to cancel.

  - Statically determinate beam.

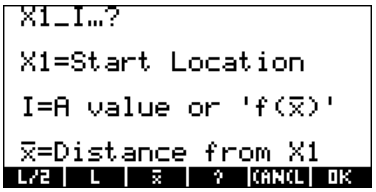
    Enter two arguments per cross section in the following order:

    Section start location X1 _ Moment of inertia I

    One section must start at X1 = 0.

    Enter the moment of inertia as a value or a function of $\overline{x}$.

    Press OK when ready to continue.

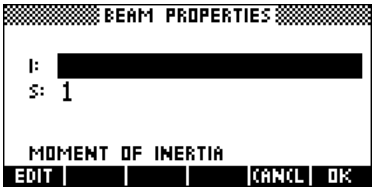


  - Statically indeterminate beam.

    BEAM uses the variable I data that were used for computing the reactions.

- **Variable E**

  Enter the moment of inertia I and section modulus S.



  - Statically determinate beam.

    Enter two values per material section in the following order:

    Section start location X1 _ Modulus of elasticity E

    One section must start at X1 = 0.

    Press OK when ready to continue.

  - Statically indeterminate beam.

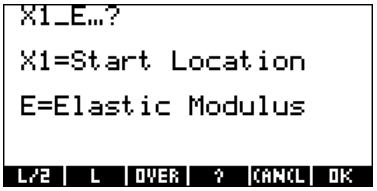
    BEAM uses the variable E data that were used for computing the reactions.

- **Variable E and I**
  - Statically determinate beam.
    - Enter two values per material section in the following order:

      Section start location X1 _ Modulus of elasticity E

      One section must start at X1 = 0.

      Press OK when ready to continue.



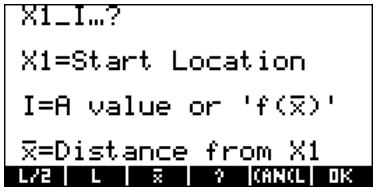
    - Enter two arguments per cross section in the following order:

      Section start location X1 _ Moment of inertia I

      One section must start at X1 = 0.

      Enter the moment of inertia as a value or a function of $\overline{x}$.

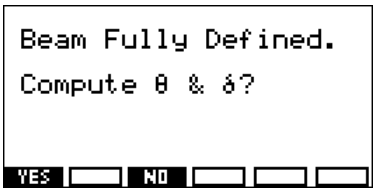
      Press OK when ready to continue.



  - Statically indeterminate beam.

    Press YES to compute the slope and deflection or NO to cancel.

    BEAM uses the variable E and variable I data that were used for computing the reactions.



Affected by user flags: 2

Remarks: LOADS must be executed to calculate the bending moment *M* data prior to executing BEAM, which overwrites any current slope, deflection and bending stress data.

BEAM calculates M/EI at each increment, then integrates the data to compute the slope and deflection at each increment.

For beams of constant cross section, the bending stress $\sigma_b = M/S$ is also computed—unless the default value of one is entered for the section modulus *S*.

When flag 2 is clear, BEAM plots the slope & deflection diagram.

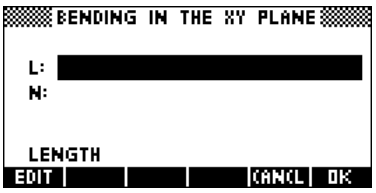
LOADS

Loads: Computes the reactions, shear, and bending moment for members subjected to bending in a single plane.

Input:

- Enter the length L and number of increments N.

  Results are calculated at an increment of L / N .



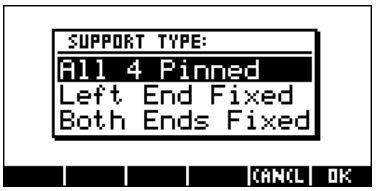
- Input one or more support locations.

  Define a cantilever member by entering only one support location, the left or right end. Specify an overhang by not entering a support location for the end(s) with an overhang.

  Press OK when ready to continue.

- A single support is automatically fixed. For members with an overhang at the left end, the program makes all supports pinned. Otherwise, select the support type.

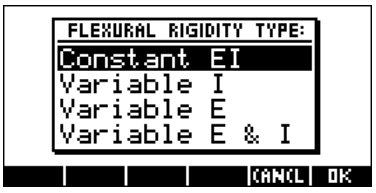
  Both Ends Fixed is an option only when both ends are supported.



- For statically indeterminate members, choose the flexural rigidity type.

  - Constant EI.

    Material and cross section properties are not required for calculating the reactions.



  - If E is variable, enter two values per material section in the following order:

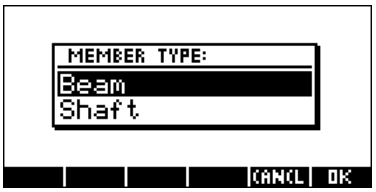
    Section start location X1 _ Modulus of elasticity E

    One section must start at X1 = 0.

    Press OK when ready to continue.

- If I is variable, choose the member type.

  Note: The TORQ program is intended for shaft problems and does not display this prompt.



  - ♦ Beam.

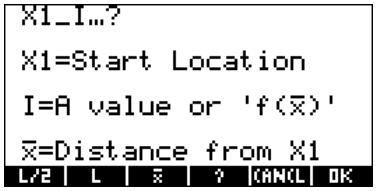
    Enter two arguments per cross section in the following order:

    Section start location X1 _ Moment of inertia I

    One section must start at X1 = 0.

    Enter the moment of inertia as a value or a function of $\overline{x}$.

    Press OK when ready to continue.



  - ♦ Shaft (circular cross section).

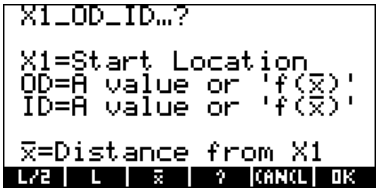
    Enter three arguments per cross section in the following order:

    Section start location X1 _ Outside diameter OD _ Inside diameter ID

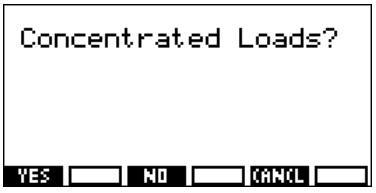
    One section must start at X1 = 0.

    Enter the diameters as values or functions of $\overline{x}$.

    Press OK when ready to continue.



- ■ Press YES or NO for concentrated loads.

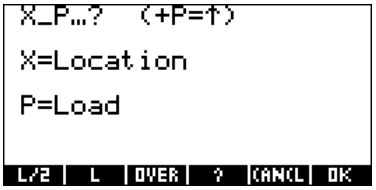


  If YES, enter two values per load in the following order:

  Location X _ Load P

  Leave the stack empty to continue without entering concentrated loads.

  Press OK when ready to continue.



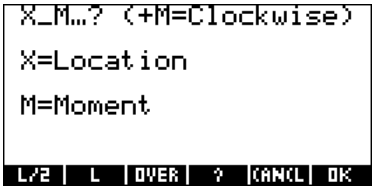
- Press YES or NO for applied moments.

If YES, enter two values per load in the following order:

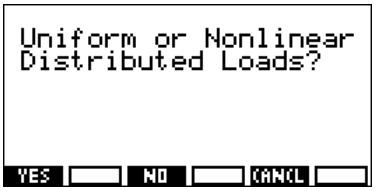
Location X _ Moment M

Leave the stack empty to continue without entering applied moments.

Press OK when ready to continue.



- Press YES or NO for uniform and/or nonlinear distributed loads.



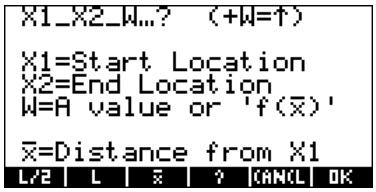
If YES, enter three arguments per load in the following order:

Start location X1 _ End location X2 _ Load W

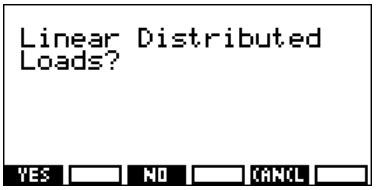
Enter uniform loads as real numbers and nonlinear loads as functions of $\overline{x}$.

Leave the stack empty to continue without entering uniform or nonlinear loads.

Press OK when ready to continue.



- Press YES or NO for linear distributed loads.



If YES, enter four values per load in the following order:

Start location X1 _ Start load W1 _ End location X2 _ End load W2

Leave the stack empty to continue without entering linear loads.

Press OK when ready to continue.

Affected by user flags: 1 and 2

Remarks: Once the loads have been entered, any existing results in the current directory will be overwritten. To save current results and run LOADS for another problem, switch to a different directory.

The program calculates the reactions, then superposes the effect of each load and reaction to compute the shear and bending moment at N increments. The reactions for statically indeterminate members are determined by the moment-area method.

When user flag 1 is clear, the user-entered number of increments is an approximate value; the program may adjust it (see appendix F).

Increasing the number of increments will often improve the accuracy—up to the point where the accumulation of round-off errors begins to take over. For more increments, however, the programs generate more data. Thus, more time and memory are required to compute and store the results. A hundred or so increments will usually attain sufficient accuracy. But it depends on the number and type of supports, loading, variable cross sections, etc.

When user flag 2 is clear, LOADS plots the shear & moment diagram. Press a key to exit the plot.

± MAX

Max Value: Returns the maximum or minimum value—the one of greater absolute value or the positive value when the maximum and minimum are of equal magnitude.

Input:

- Optional: Enter start and end locations (X1 and X2) before pressing ±MAX.
- Select the desired result from the list of current options.

Affected by user flags: 3

Remarks: When there are valid locations on stack levels 1 and 2, the max value between those two points is returned to the stack, tagged with X1≤X≤X2 Ymax, where Y is the result symbol. Otherwise, the stack is ignored and the max value over the entire length of the member is returned, tagged with Ymax. EVAL removes the tag.

When user flag 3 is clear, slope output is converted to degrees θ°; otherwise, slope is in radians θ.

M&M

Max and Min: Displays the maximum and minimum values and their locations.

Input: Select the desired results from the list of current options.

Affected by user flags: 3 and 5

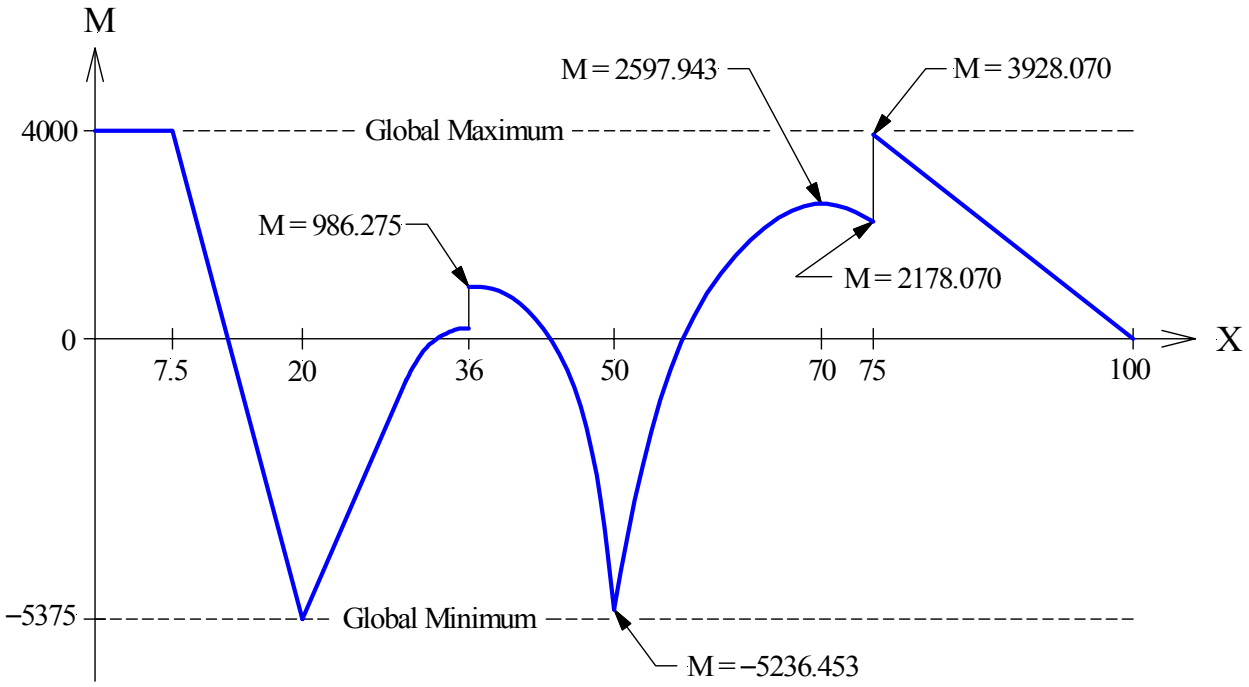
Flag 5 clear: Global max and min mode finds the absolute maximum and minimum values.

Flag 5 set: Local max and min mode finds the following local extreme values (if any exist):

- the endpoint(s), when the diagram has a nonzero slope there
- points where the slope is positive on one side and negative on the other
- discontinuities, if the diagram has a positive slope on both sides of the discontinuity, but decreases across the discontinuity or vice versa

Remarks: Results are displayed in the Output Screen environment (see appendix E).
When user flag 3 is clear, slope data are converted to degrees θ°; otherwise, slope is in radians θ.

Example: M&M output for the bending moment diagram shown.



Flag 5 clear

```
:X: M max & min
:0<X≤7.5: 4000
:20.0: -5375
#FMT|    |PRPG|    |    |EXIT
```

Flag 5 set

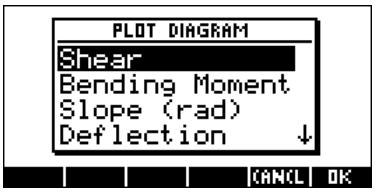
```
:X: M local max/min  ↓
:20.0: -5375.000
:36.0: 986.275
:50.0: -5236.453
:70.0: 2597.943
:75.0: 2178.070
:75.0: 3928.070
#FMT|    |PRPG|PRALL|    |EXIT
```

```
:X: M local max/min  ↑
:36.0: 986.275
:50.0: -5236.453
:70.0: 2597.943
:75.0: 2178.070
:75.0: 3928.070
:100.0: 0.000
#FMT|    |PRPG|PRALL|    |EXIT
```

PLOT

Plot Diagram: Plots the selected diagram, titles it with the appropriate symbol, and labels the *x*-axis with the length and the vertical axis with the maximum and minimum values.

Input: Select a diagram.



Affected by user flags: None

Remarks: Use one of the following methods to exit the plot:

- Press a shifted key (or followed by some other key) to exit and print the plot.

  Press YES at the Print Diagram? prompt when ready to print or NO to cancel.

- Press PICTURE to enter the PICTURE environment and activate the graphics cursor.

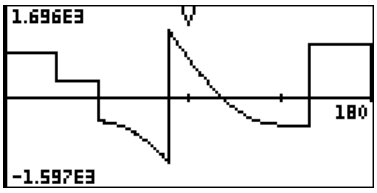
  Press CANCL to exit.

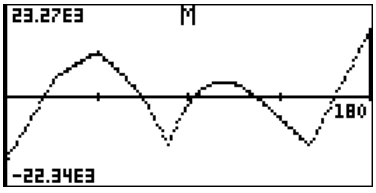
- Press PICTURE or PICTURE to enter the PICTURE environment, then exit and print the diagram.

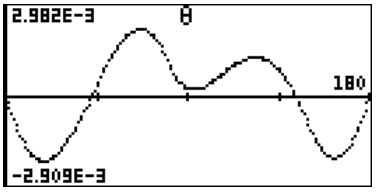
- Press any other unshifted key to simply exit.

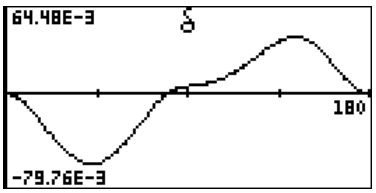
After exiting, the last plot can be displayed again by pressing PICTURE.

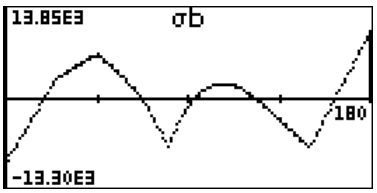
Examples: Plots of shear, bending moment, slope, deflection and bending stress diagrams.











PRINT

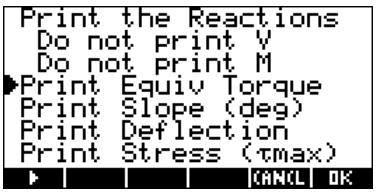
Print Results: Prints the specified results.

Input:

- Optional: Enter specific locations on the stack before pressing PRINT.
- Select the results that you want to print.
  The ▲ and ▼ keys move the selection pointer ▸ up and down.

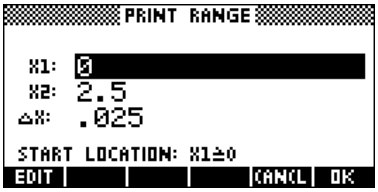
  Press ▸ or ▶ to toggle printing on/off for the current selection (right-shifted sets all results to "Do not print…" and left-shifted resets all to "Print…").

  Press ENTER or OK to continue.

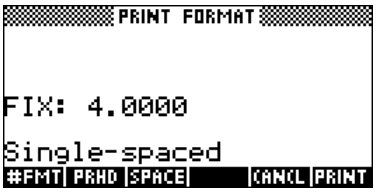


- Input the print range (unless you entered locations on the stack).
  Enter the start location X1, end location X2, and increment ΔX.

  Press ENTER with the default values to print all data for the previously selected results.



- Set the print format.
  - Press #FMT (or +/-) repeatedly to cycle the number format from FIX to SCI to ENG to STD and back to FIX. The 0 through 6 keys set the number of decimal places.



  - PRHD prompts for a print header and activates alpha lock.
    - Key in a header.
      Use ↱ ↵ (new line) for entering multiple lines.
    - Leave the command line empty for no header.
    - Press ENTER to save and return to the format screen.

  - SPACE toggles double-spaced printing on and off.
- Press ENTER or PRINT when ready to begin printing.

Affected by user flags: 3

Remarks: To print results for a few specific locations, enter the locations on the stack before executing PRINT. Objects on the stack that are not valid locations are disregarded.

When user flag 3 is clear, slope data are converted to degrees θ°; otherwise, slope is in radians θ.

System flag –37 determines the default line spacing; clear flag –37 before executing PRINT to make single-spaced printing the default. System flag –34 must be clear when using an IR printer.

Printing speed is controlled by the print Delay parameter (↰ I/O PRINT PRTPAR).

QUERY

Query Results: Displays all current results for one location or returns one result to the stack.

Affected by user flags: 3 and 4

Flag 4 clear: All current results mode.

Input: Enter a location. Press ENTER with the command line empty to cancel.
The location and results are displayed in the Output Screen environment (see appendix E).

Flag 4 set: One result mode.

Input:

- Select the results that you want to query from the list of current options.
- Enter a location. Press ENTER with the command line empty to cancel.

The value is returned to the stack tagged with the location and result symbol.

Remarks: The location is rounded to the nearest increment.
When user flag 3 is clear, slope output is converted to degrees θ°; otherwise, slope is in radians θ.

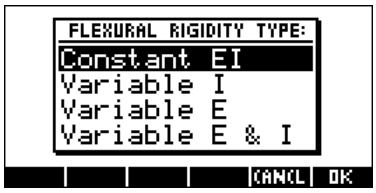
REACT

Reactions: Displays the calculated reactions.
Input: None
Affected by user flags: None
Remarks: Results are displayed in the Output Screen environment (see appendix E).

SHAFT

Shaft: Computes the slope, deflection, and bending stress or maximum shearing stress for members with a circular cross section.

Input:



- Statically determinate shaft.
  Highlight the flexural rigidity type and press ENTER.

- Statically indeterminate shaft.

  The flexural rigidity type is already defined.

- **Constant EI**

  Enter the modulus of elasticity E, outside diameter OD, and inside diameter ID.

  Enter real numbers, variable names, or algebraic expressions in these fields. Press NXT CALC to calculate a value.

  The default is ID = 0 for a solid shaft.

- **Variable I**
  - Enter a value for the modulus of elasticity E.

    Press ENTER with the command line empty to cancel.

  - Statically determinate shaft.

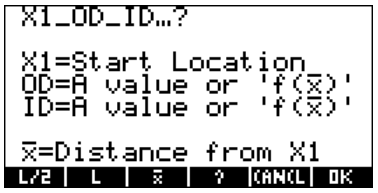
    Enter three arguments per cross section in the following order:

    Section start location X1 _ Outside diameter OD _ Inside diameter ID

    One section must start at X1 = 0.

    Enter the diameters as values or functions of $\overline{x}$.

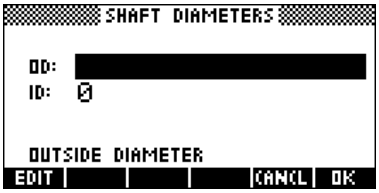
    Press OK when ready to continue.



  - Statically indeterminate shaft.

    SHAFT uses the variable diameter data that were used for computing the reactions.

- **Variable E**
  - Enter the outside diameter OD and inside diameter ID.



  - Statically determinate shaft.

    Enter two values per material section in the following order:

    Section start location X1 _ Modulus of elasticity E

    One section must start at X1 = 0.

    Press OK when ready to continue.

  - Statically indeterminate shaft.

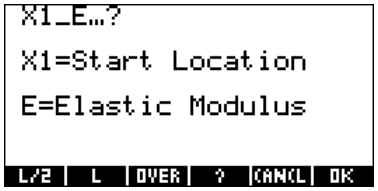
    SHAFT uses the variable E data that were used for computing the reactions.

- **Variable E and I**
  - Statically determinate shaft.
    - Enter two values per material section in the following order:

      Section start location X1 _ Modulus of elasticity E

      One section must start at X1 = 0.

      Press OK when ready to continue.



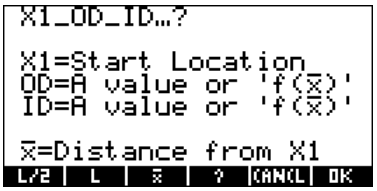
    - Enter three arguments per cross section in the following order:

      Section start location X1 _ Outside diameter OD _ Inside diameter ID

      One section must start at X1 = 0.

      Enter the diameters as values or functions of $\overline{x}$.

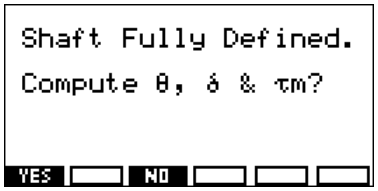
      Press OK when ready to continue.



  - Statically indeterminate shaft.

    Press YES to compute the slope, deflection and stress or NO to cancel.

    SHAFT uses the variable E and variable diameter data that were used for computing the reactions.



Affected by user flags: 2

Remarks: LOADS or TORQ must be executed to calculate the bending moment *M* data prior to executing SHAFT, which overwrites any current slope, deflection and stress data.

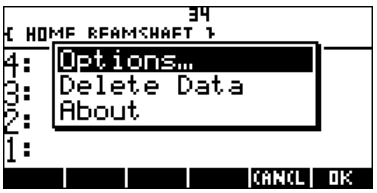
SHAFT calculates M/EI at each increment, then integrates the data to compute the slope and deflection at each increment. For shafts subjected to a vertical and horizontal loading, TORQ stores bending moment data for each plane: M_y and M_z. SHAFT generates complex $(M_z/EI, M_y/EI)$ data, integrates the data to compute complex slope (θ_z, θ_y) and deflection (δ_z, δ_y) data, and converts them to resultant slope $\sqrt{\theta_y^2 + \theta_z^2}$ and deflection $\sqrt{\delta_y^2 + \delta_z^2}$.

The bending stress $\sigma_b = Mr/I$ is computed for shafts subjected to a transverse loading only. The maximum shearing stress $\tau_m = T_e r/J$ is calculated for shafts under combined bending and torsion.

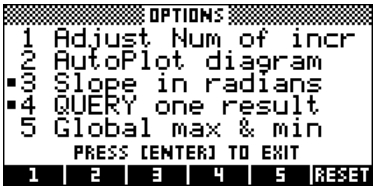
When user flag 2 is clear, SHAFT plots the slope & deflection diagram.

TOOLS

Tools Menu:



Options: Displays the user options screen.



Access: TOOLS ENTER

Affected by user flags: None

Remarks: The options screen allows you to view and change the user flag settings that affect the operation of some programs. A ■ to the left of the flag number indicates the flag is set. The text to the right describes the current mode. The user flag modes are defined in appendix F.

The 1 through 5 keys toggle the corresponding flag and mode description.

RESET restores all the default settings (clears user flags 1 through 5).

Once you have the desired settings, press ENTER to exit the options screen.

A numerical annunciator at the top of the display indicates the corresponding user flag is set.

Delete Data: Purges output data from the current directory.

Access: TOOLS ▼ ENTER

Input: YES or NO

Affected by user flags: None

Remarks: Press YES to purge all program-created variables and clear any user flags set by the programs (flags 31 through 60).

About: Displays the software version and copyright message.

Access: TOOLS ▲ ENTER

Affected by user flags: None

Remarks: Press ON (CANCEL) to return to the stack display.

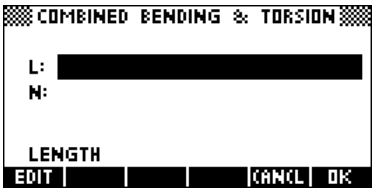
TORQ

Torques: This program is similar to the LOADS program, but it permits a horizontal and/or torsional loading, in addition to the vertical loading. It computes the reactions, shear and bending moment for both planes, and the equivalent torque.

Input:

- Enter the length L and number of increments N.

  Results are calculated at an increment of L / N.

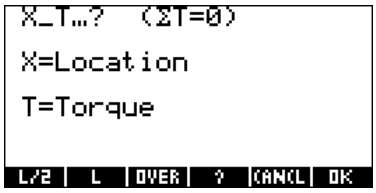


- Input support information, material and cross section properties, and loads for the vertical *xy* plane as described in the LOADS entry.
- Optional: Input loads for the horizontal *xz* plane in the same manner.
- Optional: Input torques.

  Enter two values per torque in the following order:

  Location X _ Torque T

  The summation of torques must equal zero.



Affected by user flags: 1 and 2

Remarks: Once the loads have been entered, any existing results in the current directory will be overwritten**.** To save current results and run TORQ for another problem, switch to a different directory.

For shafts subjected to a vertical and horizontal loading, the reactions, shear and bending moment output are resultant values (the square root of the sum of the squares of the vertical and horizontal components).

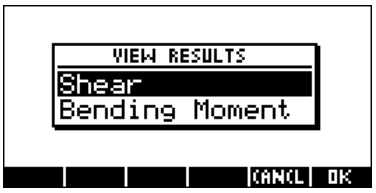
When torques are applied, the equivalent torque $T_e = \sqrt{M^2 + T^2}$ is also computed.

VIEW

View Results: Displays the specified results.

Input:

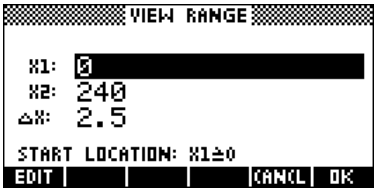
- Optional: Enter specific locations on the stack before pressing VIEW.
- Select the results that you want to view.



- Input the view range (unless you entered locations on the stack).

  Enter the start location X1, end location X2, and increment ΔX.

  Press ENTER with the default values to display all the data.



Affected by user flags: 3

Remarks: Results are displayed in the Output Screen environment (see appendix E).

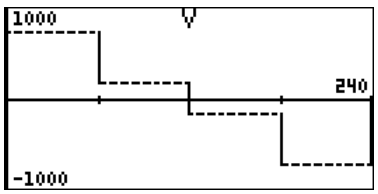
To view results for a few specific points, enter the locations on the stack before executing VIEW. Objects on the stack that are invalid locations, such as tagged numbers, are ignored.

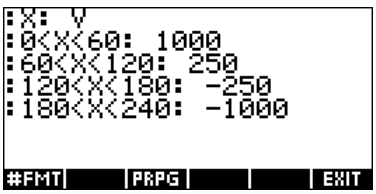
Two values are returned at discontinuities—the left- and right-hand limits. When the diagram is constant on some interval and the default minimum increment is used, VIEW displays the interval and the value for that interval.

ENTER copies the currently displayed values to the stack, each tagged with the location or interval. ← →NUM removes the tag.

When user flag 3 is clear, slope data are converted to degrees θ°; otherwise, slope is in radians θ.

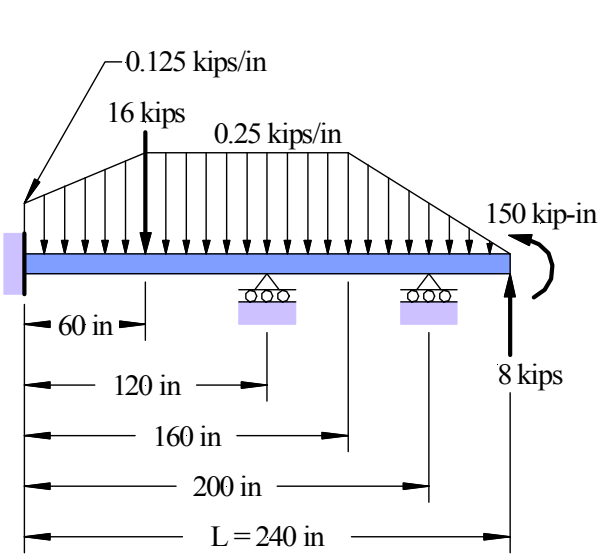
Example: PLOT and VIEW output for a vertical shear diagram.



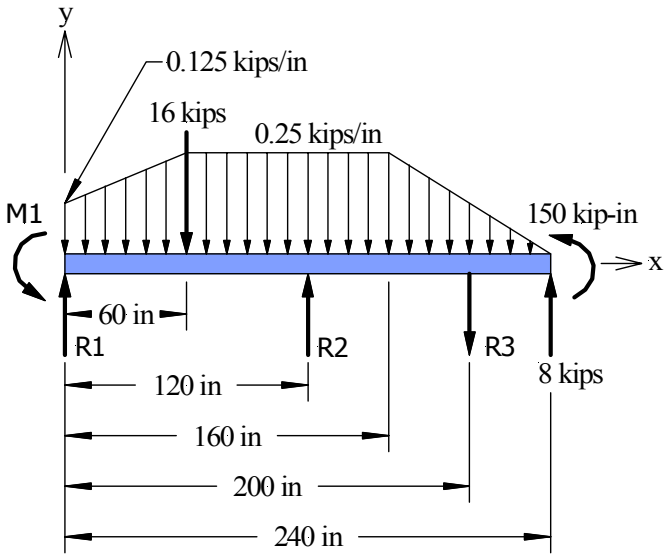


Example Problems

Example 1: Constant EI Beam



Beam and Loading



FBD

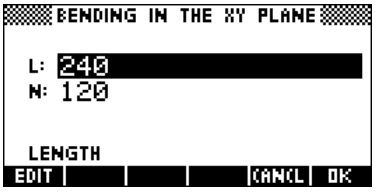
E = 29000 ksi I = 127 in^4 S = 31.2 in^3

Compute the reactions, shear and bending moment.

1) Press LOADS.

2) Enter 240 for the length L and a value for the number of increments N.

Press ENTER or OK



3) Input the three support locations.

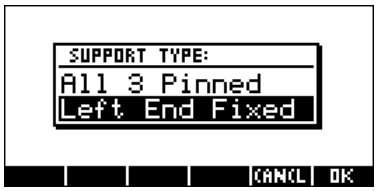
0 SPC 120 SPC 200

OK

4) Select Left End Fixed.

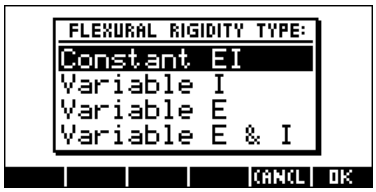
▼

ENTER



5) Select Constant EI.

ENTER



6) Press YES at the Concentrated Loads? prompt.

7) Input the location and load for each of the two concentrated loads.

60 SPC –16 SPC 240 SPC 8

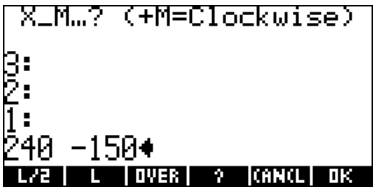
OK

8) Press YES at the Applied Moments? prompt.

9) Input the location and moment.

240 SPC –150

OK



10) Press YES at the Uniform or Nonlinear Distributed Loads? prompt.

11) Input the start location, end location, and uniform load value.

60 SPC 160 SPC –.25

OK

12) Press YES at the Linear Distributed Loads? prompt.

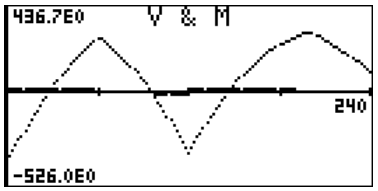
13) Input the two linear loads.

0 ENTER −.125 ENTER 60 ENTER −.25 ENTER

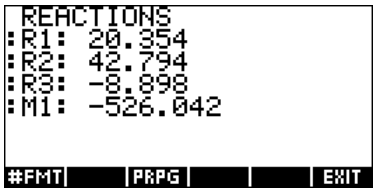
160 OVER L 0

OK

The program computes the reactions, shear and bending moment.
If flag 2 is clear, it plots the two diagrams to the same scale.
Press a key to exit the plot.

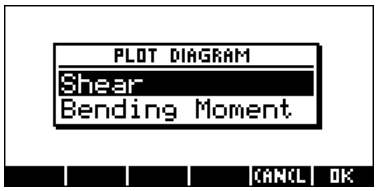


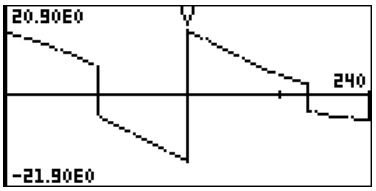
REACT displays the reactions (kips and kip-in).

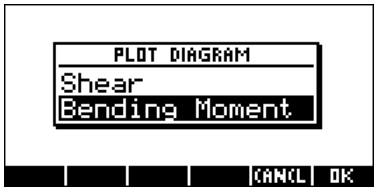


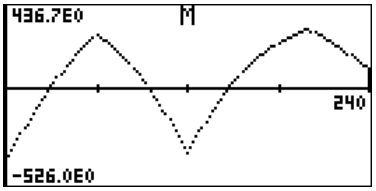
Plot the shear and bending moment diagrams separately.

Press NXT to toggle to the second menu page and execute PLOT.







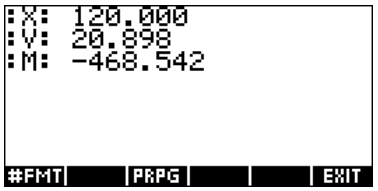


Display the results for the midpoint $X = L/2$.

QUER Y

L/2

ENTER

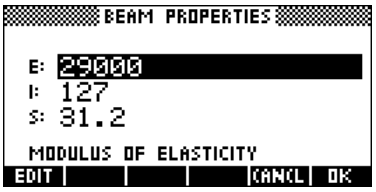


Execute BEAM to compute the slope, deflection and bending stress.

1) Press BEAM.
2) Input the modulus of elasticity E, moment of inertia I, and section modulus S.

   29 EEX 3 ENTER 127 ENTER 31.2 ENTER

   Press ENTER.



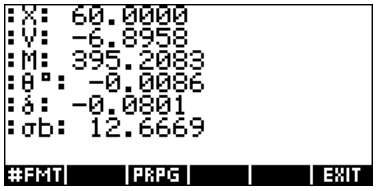
The program computes the results and plots the slope & deflection diagram (if flag 2 is clear).

Display the results for $X = L/4$.

QUER Y

L 4 ÷

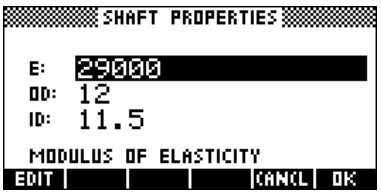
ENTER



Change the beam cross section to a pipe of 12 inch outside diameter and 11.5 inch inside diameter and recalculate the slope, deflection and bending stress.

1) Press SHAFT.
2) Input the modulus of elasticity E, outside diameter OD, and inside diameter ID.

   ENTER

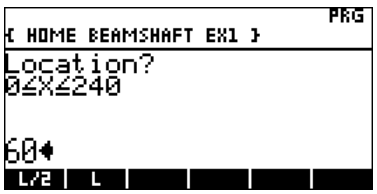


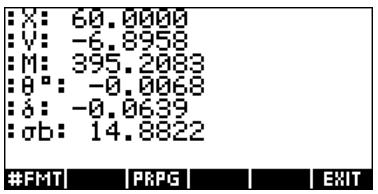
Display the new results for X = 60.

QUER Y

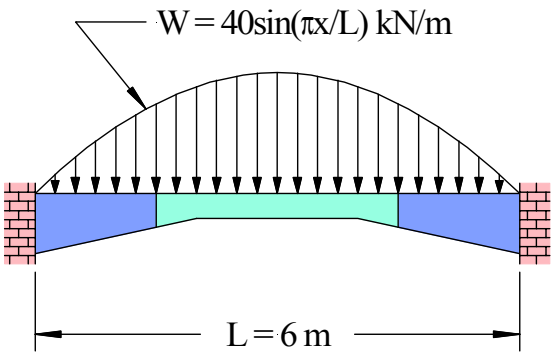
60

ENTER

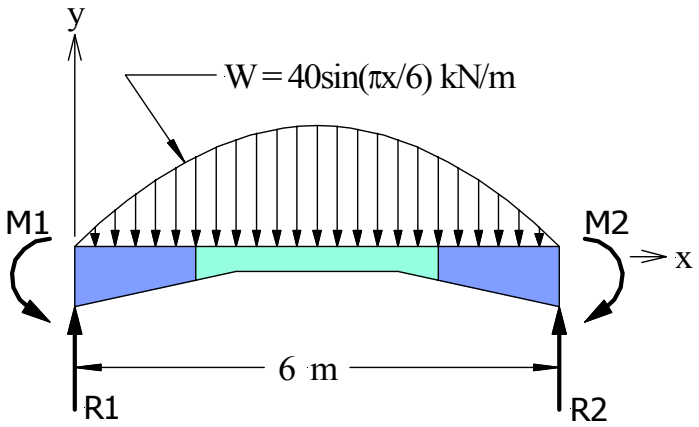




Example 2: Variable EI Beam



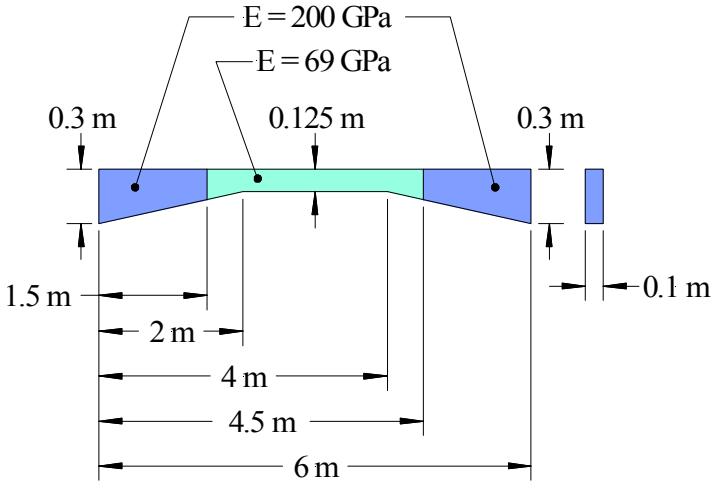
Beam and Loading



FBD

The beam has a constant width w of 0.1 m and a variable depth d. Enter the moment of inertia for each continuously varying section as a function of the distance from the section start location $f(\bar{x})$. For example, the moment of inertia expression for the first section ($0 \le X < 2$), where the depth varies linearly, is derived from the equation of a line $y = mx + b$ as follows:

$$d = \frac{0.125 - 0.3}{2 - 0}\bar{x} + 0.3 = 0.3 - 0.0875\bar{x}$$



Beam Dimensions and Moduli of Elasticity

$$I = \frac{wd^3}{12} = \frac{0.1}{12}d^3 = (8.33333333333E-3)(0.3 - 0.0875\bar{x})^3$$

Modulus of Elasticity and Moment of Inertia Input Data

Start Location X1 (m)	**Modulus of Elasticity** E (kN/m^2)	**Moment of Inertia** I (m^4)	**Variables**
0	2×10^8	'K*(.3-.0875*x̄)^3'	$K = \frac{0.1}{12} = 8.33333333333E-3$
1.5	69×10^6	…	
2	…	$K(.125)^3$	
4	…	'K*(.125+.0875*x̄)^3'	$\bar{x}$ = Distance from X1
4.5	2×10^8	…	

For this example problem, store the moment of inertia data before executing LOADS as follows:

1. Store the value 8.33333333333E–3 in the variable K.
2. Key in the following program containing the section start location and moment of inertia for each of the three cross sections:

   « 0 'K*(.3–.0875*x̄)^3' Press [α] [→] X to insert the independent variable x̄.
   2 K .125 3 ^ *
   4 'K*(.125+.0875*x̄)^3' » Checksum: # 60210d

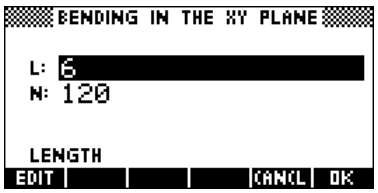
3. Store the program in the variable I.

Run LOADS to compute the reactions, shear and bending moment.

1) Press LOADS.

2) Enter 6 for the length L and a value for the number of increments N.

   Press [ENTER] or OK.



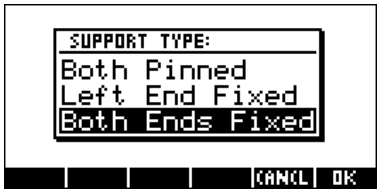
3) Input the two support locations.

   0 [SPC] 6

   OK

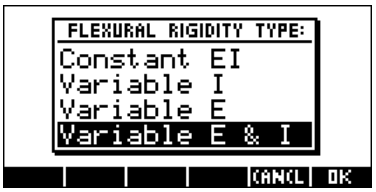
4) Press [▲] to highlight Both Ends Fixed.

   Press [ENTER].



5) Press ▲ to highlight Variable E & I.

Press ENTER.



6) Input the start location X1 and modulus of elasticity E for each of the three material sections.

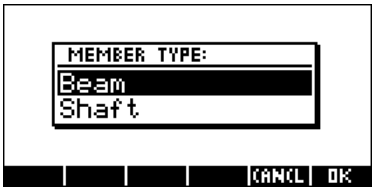
0 SPC 2 EEX 8 SPC 1.5 SPC 69 EEX 6 SPC

4.5 SPC 2 EEX 8

OK

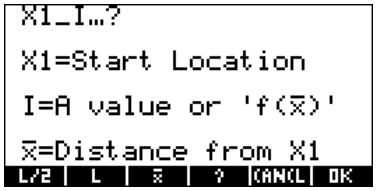
7) Select Beam.

ENTER

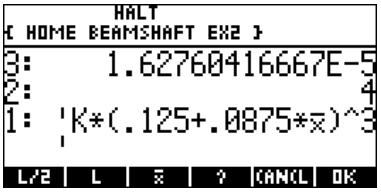


8) Input the moment of inertia data.

α I ENTER 8



OK



9) Press NO at the Concentrated Loads? prompt.

10) Press NO at the Applied Moments? prompt.

11) Press YES at the Uniform or Nonlinear Distributed Loads? prompt.

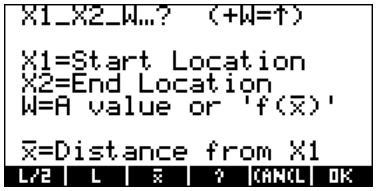
12) Input the load data.

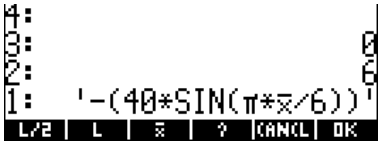
Enter the start and end locations: 0 L

Assemble the load expression:

40 +/- ← π x̄ × 6 ÷ SIN ×

OK





13) Press NO at the Linear Distributed Loads? prompt.

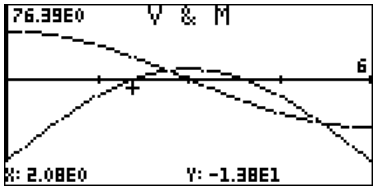
The program computes the results and plots the shear & moment diagram.

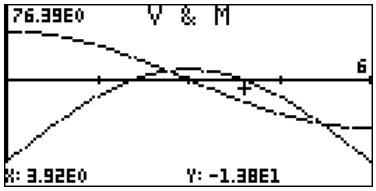
Find the locations where the bending moment is zero:

Press PICTURE ◀ to enter the PICTURE environment and activate the graphics cursor. Press + or (X,Y) to turn on the cursor coordinate display and use the arrow keys to move the cursor.

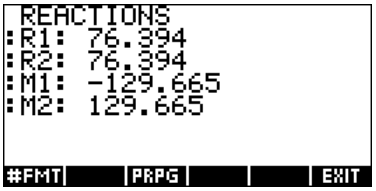
The bending moment diagram crosses the *x*-axis at approximately X = 2.1 m and X = 3.9 m.

Press ON CANCEL to exit the PICTURE environment.

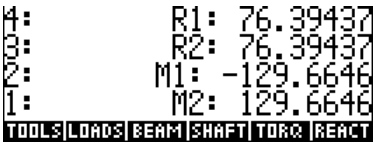




REACT displays the reactions (kN and kN-m).



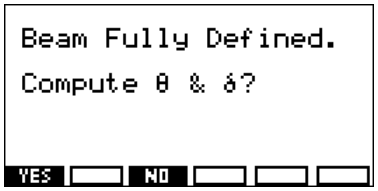
ENTER copies the reaction results to the stack and EXIT returns to the stack display.



Execute BEAM to compute the slope and deflection.

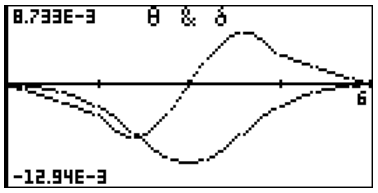
BEAM

YES



The program computes the results and plots the slope & deflection diagram.

Press a key to exit the plot.



Display the maximum and minimum slope.

Press NXT to display the second menu page.

M&M

Highlight Slope (deg).

ENTER

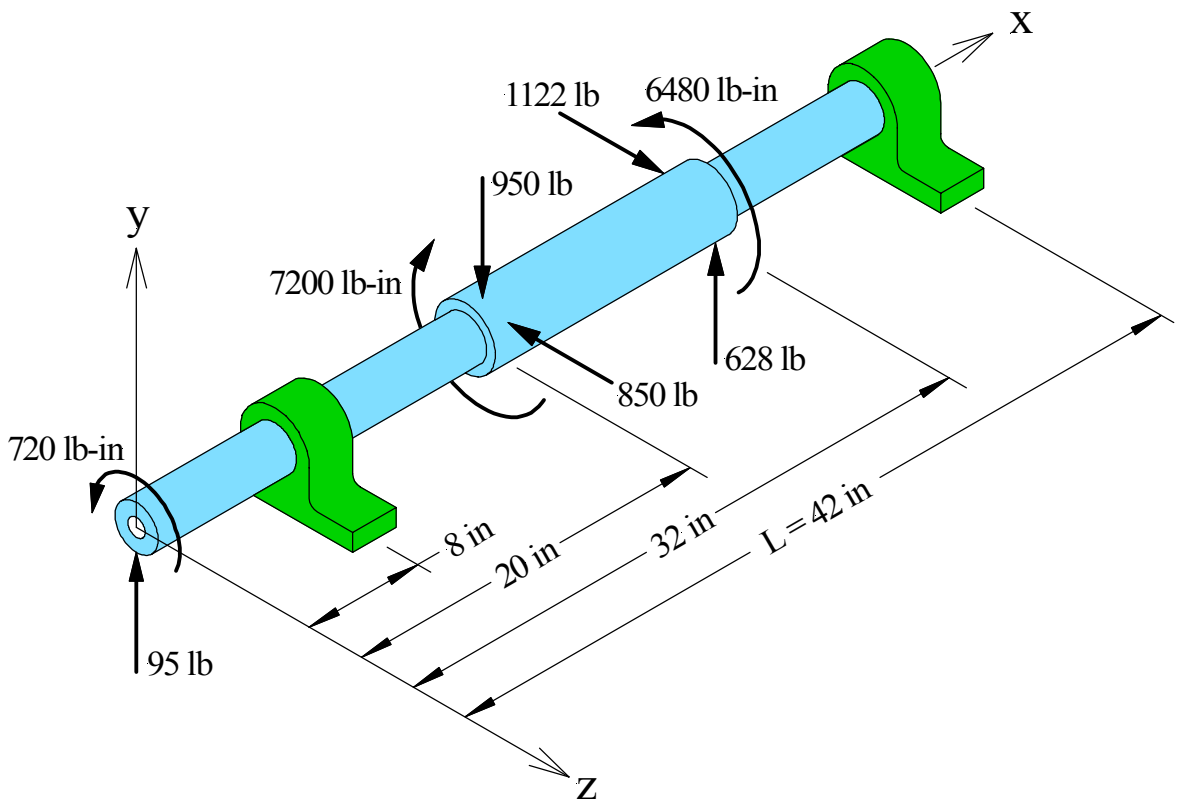
The maximum slope is ±0.5 degrees at X = 2.1 and X = 3.9 m.

Find the maximum deflection (m).

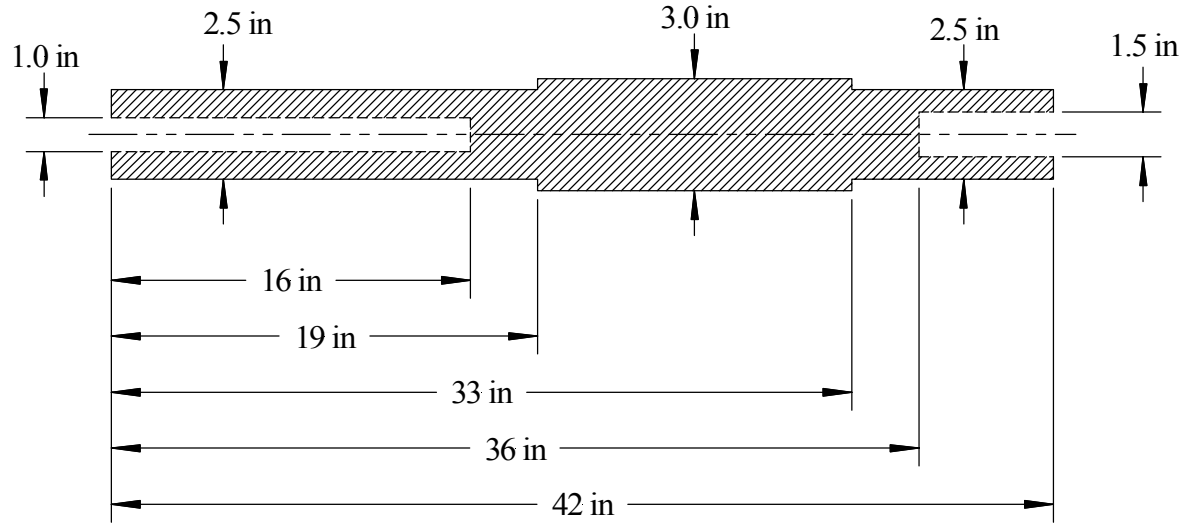
±MAX

ENTER

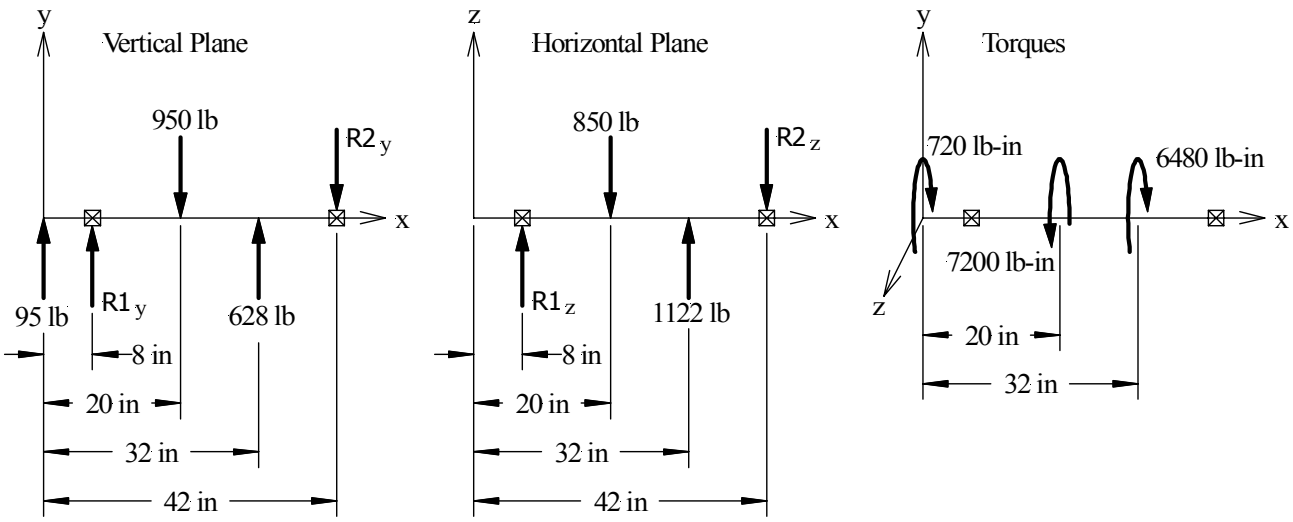
Example 3: Stepped Shaft



Shaft Loading. The loads exerted by gears and pulleys resolved into the vertical, horizontal, and torque components.



Shaft Cross Section



Loading Diagrams

For this example problem, store the loading and cross section data prior to executing TORQ and SHAFT as follows:

Vertical Concentrated Loads

Store the following program containing each location and load in the variable PY:

« 0 95 20 –950 32 628 » Checksum: # 46834d

Horizontal Concentrated Loads

Store the following program containing each location and load in the variable PZ:

« 20 –850 32 1122 » Checksum: # 15720d

Torques

Store either of the following programs containing each location and torque in the variable T:

a) « 0 720 20 –7200 32 6480 » Checksum: # 18114d

b) « 0 –720 20 7200 32 –6480 » Checksum: # 6942d

Shaft Diameters

Store the following program containing each start location, outside diameter and inside diameter in the variable D:

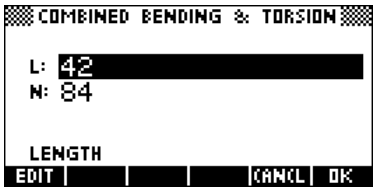
« 0 2.5 1 16 2.5 0 19 3 0 33 2.5 0 36 2.5 1.5 » Checksum: # 40320d

Compute the reactions, shear, bending moment and equivalent torque.

1) Press TORQ .

2) Enter 42 for the length L and a value for the number of increments N.

   Press ENTER or OK .

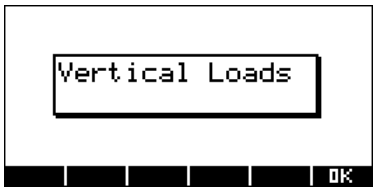


3) Input the two support locations.

   8 SPC 42

   OK

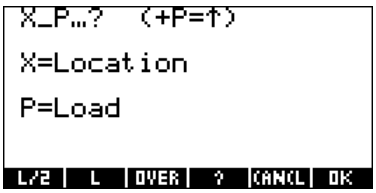
4) Press ENTER or OK .



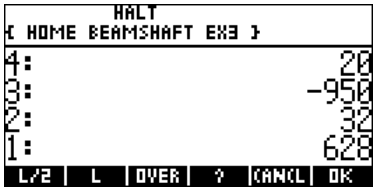
5) Press YES at the Concentrated Loads? prompt.

6) Input the vertical loads.

   α PY ENTER

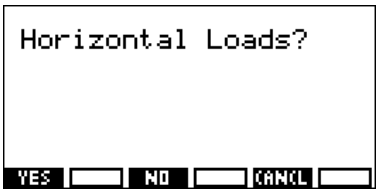


   OK



7) Press NO at the Applied Moments?, Uniform or Nonlinear Distributed Loads? and Linear Distributed Loads? prompts.

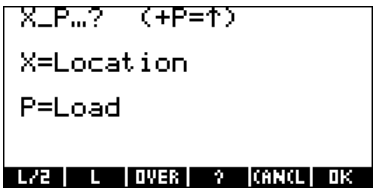
8) Press YES for horizontal loading.



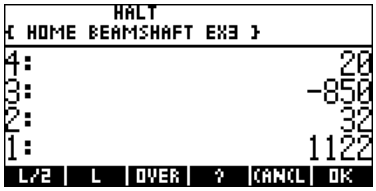
9) Press YES at the Concentrated Loads? prompt.

10) Input the horizontal loads.

α PZ ENTER



OK

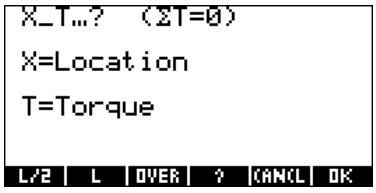


11) Press NO at the Applied Moments?, Uniform or Nonlinear Distributed Loads? and Linear Distributed Loads? prompts.

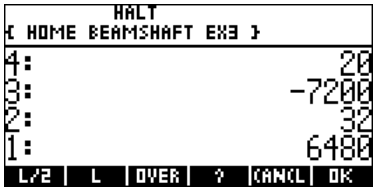
12) Press YES at the Torques? prompt.

13) Input the torques.

α T ENTER



OK



The program computes the following:

- Reactions for the vertical and horizontal planes and the resultant reactions.
- Shear and bending moment for each plane and the resultant shear $\sqrt{V_y^2 + V_z^2}$ and bending moment $\sqrt{M_y^2 + M_z^2}$.
- Torsion and the equivalent torque $\sqrt{M_y^2 + M_z^2 + T^2}$.

When flag 2 is clear, the program plots the intermediate and final results. Press a key (a shifted key, if you want to print the plot) to resume program execution.

REACT displays the resultant reactions (lbs).

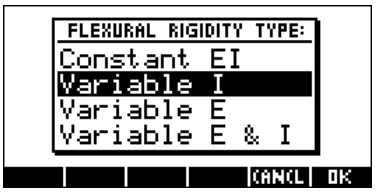
Execute SHAFT to compute the slope, deflection and maximum shearing stress.

1) Press SHAFT .

2) Select Variable I.

   ▼

   ENTER or OK



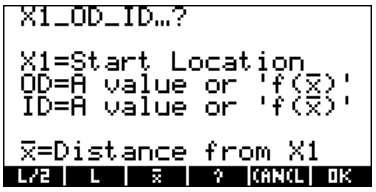
3) Enter the modulus of elasticity (use $E = 29\times10^{6}$ psi).

   29 EEX 6

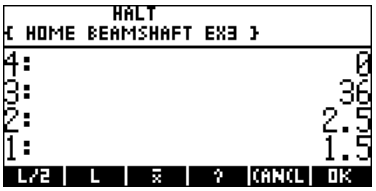
   ENTER

4) Enter the cross section data.

   α D ENTER



   OK



The program computes the resultant slope and deflection, and the maximum shearing stress.

Display the resultant slope at each bearing.

Press NXT to display the second menu page.

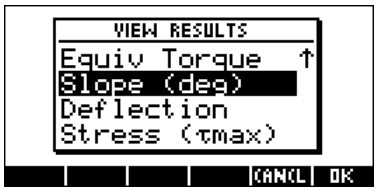
Enter the two bearing locations and execute VIEW.

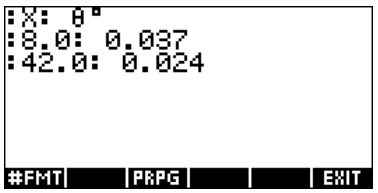
8 ENTER 42

VIEW

Highlight Slope (deg).

ENTER





Find the largest resultant deflection between the two bearings.

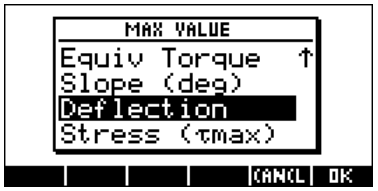
Enter the two bearing locations and execute ±MAX.

8 ENTER 42

±MAX

Highlight Deflection.

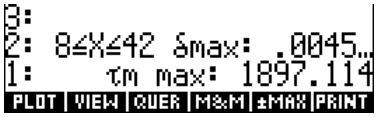
ENTER



Find the maximum value of the maximum shearing stress (psi).

±MAX

ENTER

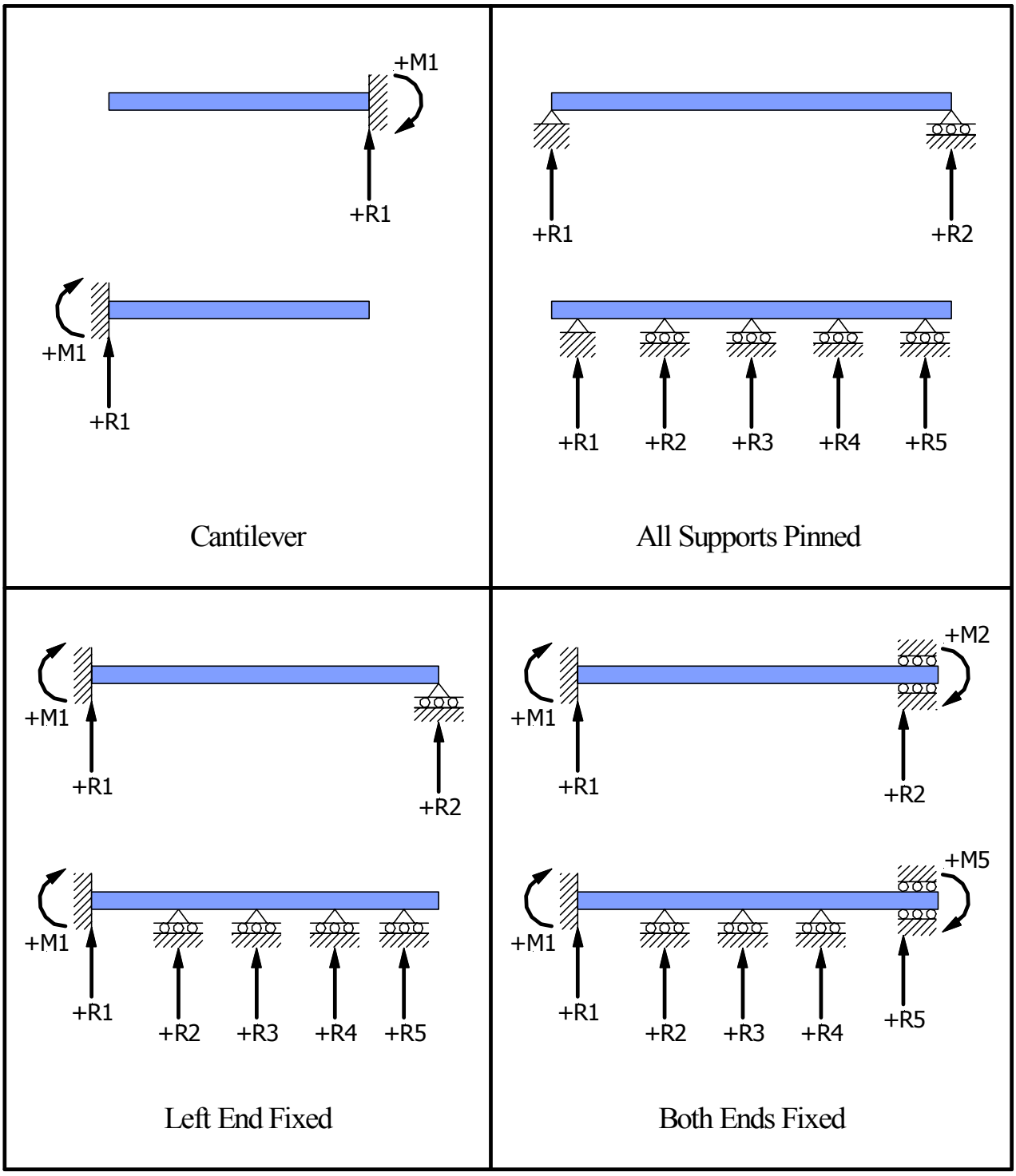


A

Symbols

E	Modulus of elasticity
I	Moment of inertia
ID	Shaft inside diameter
J	Polar moment of inertia
L	Length of beam or shaft
M	Applied moment; bending moment
M1, M2,…	Reactive moments at fixed end supports
N	Number of increments
OD	Shaft outside diameter
P	Concentrated load
r	Shaft outside radius
R1, R2,…	Reactive forces at the supports
S	Section modulus (I/c)
T	Torque; torsion
Te	Equivalent torque
V	Shear due to the transverse loading
W	Uniform or nonlinear distributed load
W1	Linear distributed load start value
W2	Linear distributed load end value
X	Location—distance from the left end of the beam or shaft
X1	Start location
X2	End location
$\bar{x}$	The independent variable used in algebraic expressions for nonlinear distributed loads and continuously varying beam moments of inertia or shaft diameters. $\bar{x}$ = Distance from the start location of a distributed load or varying section
Δx	Increment
δ	Deflection
θ	Slope in radians
$\theta°$	Slope in degrees
σb	Bending stress (normal stress at extreme fiber)
τm	Maximum shearing stress (τ_{max} on Mohr's circle)

Reaction Notation



Sign Convention

Symbol	Description	Sign Convention	
Input		Bending in the Vertical Plane	Bending in the Vertical and Horizontal Planes
P	Concentrated load	+P = Upward	+P = Upward*
M	Applied moment	+M = Clockwise	+M = Clockwise*
W, W1 & W2	Distributed load	+W = Upward	+W = Upward*
T	Torque	ΣT = 0	ΣT = 0
Output			
R1, R2,…	Force reactions	$+R_n$ = Upward	$R_n = \sqrt{R_{n_y}^2 + R_{n_z}^2}$
M1, M2,…	Moment reactions	$+M_n$ = Clockwise	$M_n = \sqrt{M_{n_y}^2 + M_{n_z}^2}$
V	Shear	+V = 	$V = \sqrt{V_y^2 + V_z^2}$
M	Bending moment	+M = 	$M = \sqrt{M_y^2 + M_z^2}$
Te	Equivalent torque	$T_e = \sqrt{M^2 + T^2}$	$T_e = \sqrt{M_y^2 + M_z^2 + T^2}$
θ°	Slope (degrees)	+θ° = Counterclockwise rotation	$\theta° = \sqrt{\theta_y^{\circ 2} + \theta_z^{\circ 2}}$
θ	Slope (radians)	+θ = Counterclockwise rotation	$\theta = \sqrt{\theta_y^2 + \theta_z^2}$
δ	Deflection	+δ = Upward	$\delta = \sqrt{\delta_y^2 + \delta_z^2}$
σb	Bending stress	Beam: $\sigma_b = \frac{M}{S}$ Shaft: $\sigma_b = \frac{Mr}{I}$ $+\sigma_b$ = Bottom fiber in tension	$\sigma_b = \sqrt{\left(\frac{M_y r}{I}\right)^2 + \left(\frac{M_z r}{I}\right)^2} = \frac{Mr}{I}$
τm	Max shearing stress	$\tau_m = \sqrt{\left(\frac{Mr}{2I}\right)^2 + \left(\frac{Tr}{J}\right)^2} = \frac{T_e r}{J}$	$\tau_m = \sqrt{\left(\frac{Mr}{2I}\right)^2 + \left(\frac{Tr}{J}\right)^2} = \frac{T_e r}{J}$

*The same sign convention applies to the horizontal *xz* plane when the plane is viewed rotated 90° about the *x*-axis with the positive *z*-axis upward $^{z}\uparrow\rightarrow_{x}$

D

Reserved Variables

This application uses the global variables listed in the table below. The programs create, overwrite and purge these variables.

Reserved Variable	Variable Type	Contents
ΣDAT	Real Matrix	The bulk of the output data are stored in this variable—the HP 48 statistical matrix reserved variable.
▸Flag	List	The user flag configuration that matches the data in the current directory.
▸MoE	List	Variable modulus of elasticity data for statically indeterminate members.
▸R&M	List	The computed reactions.
▸Sect	List	Variable cross section data for statically indeterminate members.
▸Sup	List	The support locations.
▸X1X2	List	Partial length distributed load start/end locations.
▸ý→∞	List	Diagram discontinuity data.
$\overline{x}$	Real Number or Local Name	The independent variable used in algebraic expressions for nonlinear distributed loads and continuously varying beam moments of inertia or shaft diameters. Used briefly as a global variable when checking for input errors and then purged.

Note: If you copy or move data from one directory to another, any of the above variables that exist in the source directory must be copied or moved to the new directory. If any of these variables are missing from the current directory when they should exist (or do exist when they should not), the program will abandon execution and display an error message.

Output Screen Operations

Key	Description
#FMT	**Number Format.** Press #FMT (or +/-) repeatedly to cycle the display mode from FIX to SCI to ENG to STD and back to FIX.
PRPG	**Print Page.** Prints the current page.
PRALL	**Print All.** Prompts the user to print all pages and indicates the number of pages. This menu label appears only when there are multiple pages.
EXIT	Restores the initial system flag settings and exits to the stack and program menu.
ENTER	Copies the contents of the current page to the stack.
0 – 6	Set the number of decimal places displayed.
◀	Decreases the number of digits displayed. In STD mode, switches to FIX mode. ↰◀ or ↱◀ sets the number format to STD mode.
▶	Increases the number of digits displayed. In STD mode, switches to FIX mode. ↰▶ or ↱▶ sets the number format to STD mode.
▼	Scrolls down one page. At the bottom page, wraps around to the top page.
α▼	Scrolls down one line.
↰▼	Moves to the middle page.
↱▼	Moves to the bottom page.
▲	Scrolls up one page. At the top page, wraps around to the bottom page.
α▲	Scrolls up one line.
↰▲	Moves to the middle page.
↱▲	Moves to the top page.

A down arrow ↓ in the upper-right corner of the display indicates that the top page is currently displayed and more data reside below. Up and down arrows ↑↓ indicate that there are more data above and below. An up arrow ↑ indicates that the bottom page is currently displayed and more data reside above.

Flags

User Option Flags

Flag	Description
1	Number of Increments N. Twenty is the minimum N used, regardless of the value entered or the state of flag one. *Clear:* The user-entered number of increments may be adjusted by LOADS or TORQ according to the following parameters: • The number input by the user. The input value is accepted when it meets all the other criteria. Otherwise, a brief attempt is made to find a number that is close to the input value and does satisfy all or some of the other criteria. • The amount of RAM currently available. The greater the number of increments, the more data generated. Thus, the more memory required. The program limits the number of increments in order to reserve enough RAM so that BEAM or SHAFT can be executed subsequently without running out of memory. • The locations of discontinuities. The program seeks to adjust N so that the locations of most loads, reactions and variable EI section endpoints are a whole number of increments from either end. This tends to improve accuracy slightly. • The length L. The program attempts to find an N that results in an increment $\Delta x = L/N$ with five or fewer decimal places. Round-off errors are minimized when Δx is an exact number such as 0.5, rather than an approximate number such as 0.333333333333. *Set:* The number of increments input by the user is not altered (provided $N \geq 20$).
2	AutoPlot. *Clear:* AutoPlot enabled. LOADS, TORQ, BEAM and SHAFT plot results by superposing two diagrams. LOADS plots the V & M diagram, BEAM and SHAFT plot θ & δ, etc. *Set:* AutoPlot suppressed.
3	Slope Output. Slope data are stored and plotted as radians, regardless of the state of flag 3. *Clear:* ±MAX, M&M, PRINT, QUERY and VIEW convert slope data to degrees. *Set:* Slope output is in radians.
4	Query Mode. *Clear:* QUERY displays all current results for a specified location. *Set:* QUERY returns a specified result to the stack.
5	Max and Min Mode. *Clear:* M&M finds the absolute maximum and minimum values. *Set:* M&M finds local extreme values.

Other User Flags. This application manipulates user flags 31 through 60. These flags are automatically set and cleared as required.

System Flags. This application manipulates the following system flags:
Symbolic Constants (–2), Numerical Results (–3), Binary Integer Wordsize (–5 through –10), Radians Mode (–17), Line Feed (–38), Clock Display (–40), Number of Decimal Digits (–45 through –48), Number Display Format (–49 and –50), and Last Arguments (–55).

The binary integer wordsize is set to 64 bits and left at 64 (the calculator default). All other system flags are restored to their original state before each program finishes executing, or when a program is canceled by pressing CANCL or EXIT, but not when canceled with the ON (CANCEL) key.

G

Assumptions & Limitations

- The largest slope of the deflected member is small compared to one radian and deflections do not substantially alter the overall dimensions.
- Stresses do not exceed the elastic limit.
- Only one support is restrained in the *x*-direction.
- Deflection due to shear is assumed small, relative to the bending deflection, and is neglected.
- Shearing stress caused by transverse loads is assumed insignificant, relative to the bending and torsional stresses, and is neglected in the maximum shearing stress analysis.
- The computed shaft stress does not take into account stress concentrations due to any abrupt changes in the cross section.
- The program evaluates algebraic expressions for nonlinear distributed loads and continuously varying cross sections in radians mode.

H

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