PIPESTAR

Pipe Stress Analysis
for the HP-41

PipeStar Development Company

April 1988

Dear PipeStar User:

Thank you for selecting PipeStar. We hope that you will find it useful for your purposes. In an effort to keep you informed of any upgrades or enhancements, and to enable us to better serve you in the future, it would be helpful to us if you would detach this page from the binding, or make a copy of it, and type or print the information requested below, and mail it to:

PipeStar Development Company
P.O. Box 497
Hunt, TX 78024
USA

Thank you for taking the time to do this.

PipeStar 2.02 Owner Registration

Name:______________________________

Title:______________________________

Company:______________________________

Mailing Address:______________________________

City/State/Zip:______________________________

Country:______________________________

Phone:______________________________

Purchase date and price:______________________________

Purchased from (name and country):______________________________

How did you hear about PipeStar:______________________________

Comments; other programs you would like to see for the HP-41 (use additional paper if needed):______________________________

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PipeStar

Version 2.02

Owner's Manual

April 1988

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PipeStar Development Company reserves the right to offer upgrades and enhancements to the software for no additional charge, or for a charge to be determined at the sole discretion of PipeStar Development Company.

ABOUT THE AUTHOR OF PIPESTAR

Jack Stone, the founder of PipeStar Development Company, has worked for over seven years in the petro-chemical industry performing pipe stress analysis and developing pipe stress analysis computer programs. He received his B.S. degree in Mechanical Engineering from Texas A&M University in 1978, and is currently working towards a graduate degree at Texas Tech University. Jack Stone is also a Registered Professional Engineer in the State of Texas, U.S.A.

ACKNOWLEDGMENT

The author would like to thank Dave Malek for his practical counsel drawn from his vast experience in the field of pipe stress analysis, and to Clifford Sterns for his expert technical assistance in the writing of machine code for the HP-41. The author is also grateful for the mainframe computer runs that Dave Malek and many others were able to provide to verify the accuracy of PipeStar.

PipeStar Development Company and J.D. Stone
P.O. Box 497
Hunt, Texas 78024
U.S.A.

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Preface

Piping flexibility analysis is basically the analysis of a statically indeterminate space frame. Such an analysis may be performed using the finite element method. This approach provides the analytical basis for many current computer programs. Though this is a powerful tool for the piping analyst, it has never before been gainfully employed in a handheld calculator/ computer (except in earlier versions of this same program). That is the purpose of the program presented herein.

This program, PipeStar 2.02, which is contained within a 16K EPROM module, has been developed for use with the Hewlett-Packard HP-41, with extended memory, and with or without a printer. It will analyze piping systems for thermal, weight, and pressure stresses in compliance with either ANSI/ASME B31.1 or B31.3 Piping Code. It will also accept English, Metric, or user-defined units. Using finite element analysis (FEA) as mentioned above, it also has the same accuracy as many mainframe computer programs.

PipeStar can solve a single problem with over 200 data points modeled as 3-anchor systems with up to 12 restraints, or as 2-anchor systems with up to 18 restraints. Among its capabilities, it can model skew lines, spring hangers, expansion joints, and elastic end conditions, and includes in the output comparisons of how resultant stresses comply with the Code allowable stresses.

PipeStar should prove to be a powerful, convenient, and user-friendly tool for the piping designer and stress analyst involved with piping layouts and stress checks. It should certainly replace approximate methods for analyzing pipe, such as the cantilever beam method, the area-moment method, the elastic center method, charts, graphs, etc. When compared to other programs written for larger computers, there are two major advantages that PipeStar has:

1. **Cost**: This is the bottom line in any business entity. Not only is PipeStar **much less** expensive than programs written for larger computers, the hardware required to run it (the HP-41) is also much less expensive than a larger computer.

2. **Availability**: Because of the small physical size of the HP-41, its battery power, and its resultant portability, PipeStar may be used in an office, in the field, or even at home where there may not be ready access (or any access at all) to, or room for, a computer terminal or a microcomputer.

Though this manual has been written to be as explanatory and as easy to read as possible, some fundamentals to using the HP-41 (e.g., the use of the gold shift key or the meaning of the X-register) may not have been explained in great detail; the user should consult the HP-41 Owner's Manual if he has questions concerning such matters.

A few conventions have been adopted in the writing of this manual and these are listed as follows:

- The term "HP-41" is used generically in this manual, unless otherwise specified, to refer to the HP-41C, HP-41CV, and HP-41CX (or Hewlett-Packard Series 40) family of handheld computers (or advanced programmable calculators; Hewlett-Packard uses both descriptions).

- HP-41 functions are printed in capital letters (e.g., CRFLD).

- Function keys are indicated by the function printed in capital letters and enclosed within brackets (e.g., [R/S]).

- The term "elbow" is used to signify both elbows and pipe bends.

- "XM" is used as an acronym for Extended Memory.

- Units are not always included in the text since more than one type of unit may be used for any measurement with PipeStar (e.g., "a length of 123." instead of "a length of 123. feet").

In aiding the learning process, or in refreshing oneself with PipeStar, one may want to consider first trying an Example Problem shown later in this manual, or referring to the Appendices toward the end of the manual.

Though PipeStar can analyze some problems in under ten seconds, more complex problems with many degrees of freedom may require a couple of minutes to run, even though PipeStar is written in machine code. To reduce this time, the user may want to consider having his HP-41 "speeded up". A speed increase of over twice the normal HP-41 speed may be attained (depending on the model HP-41) by physically modifying the hardware. The details of this procedure will not be discussed here. However, if the user is interested, he may contact either of the sources shown on the following page for more information on this matter. To fully utilize PipeStar, at least one Extended Memory module is also recommended for the HP-41.

EduCALC Mail Store
27953 Cabot Road
Laguna Niguel, CA 92677
USA
(714) 582-2637

Bill Rudersdorf
215 Hawthorne
Houston, TX 77006
USA
(713) 522-6220

EduCALC can also provide kits whereby a user may modify his HP-41 himself.

Every effort has been made to ensure that PipeStar will perform as indicated in this documentation. It has been verified against many other mainframe and microcomputer programs (in fact, "bugs have been identified in other programs during the verification process). However, as with any complex program, there may still be some subtle "bugs" in the program. Any observations of any "bugs" in the program or the manual, or any other comments, suggestions, and/or questions are welcome and appreciated and will be responded to. The following address and phone number may be used in this regard:

PipeStar Development Company
P.O. Box 497
Hunt, TX 78024
USA
Phone: (512) 238-4579 (subject to change)

Installing the PipeStar Module

CAUTION: Prior to inserting or removing the PipeStar module, always ensure that the HP-41 is turned off!

Note: If using an HP-41C (instead of an HP-41CV or HP-41CX), a single quad memory module must be used to provide the memory required by PipeStar (in addition to an extended functions/memory module for either the HP-41C or the HP-41CV).

Installing the PipeStar Module:

1. Turn the HP-41 calculator off!

2. Remove the port cover of one of the two ports nearest the battery side of the HP-41 (this would be either port 3 or port 4 per the numbering scheme shown on the bottom of the HP-41). (It may also be desirable to save the port cap.)

3. Gently insert the module into the selected port (3 or 4).

4. Turn the calculator on.

5. Initialize the HP-41 by executing the function "PS". Any programs or data stored in main memory may be lost (XM will not be affected); therefore, one may want to take precautions to prevent such loss by first recording such data elsewhere (such as in XM, or external mediums such as magnetic cards, tape, disks, etc.)

Removing the PipeStar Module:

1. Turn the HP-41 calculator off!

2. Grasp the module and pull it out (and re-insert the port cap if desired).

If there are problems using the module after installation, try removing any other modules (except Extended Memory modules, a quad memory module, an HP-IL module, a Timer module, or a card reader) installed in the HP-41, starting with modules in ports 3 or 4 first. If an Extended Functions/Memory module is used, it must be plugged into either port 1 or 2. Also, if the "BAT" annunciator is displayed, PipeStar will not run (this is to prevent damaging the calculator if the program is executed for a complex problem that would require running the calculator on low power for an extended period of time).

For technical reference, PipeStar uses XROM numbers 12, 13, 14, and 15 (decimal).

Initialization

Before PipeStar can be used, the calculator must be "initialized" as discussed in greater detail below. The simplest way to do this is to follow the steps listed below (it is assumed that the module has been installed and that it is acceptable to lose the contents of the calculator memory):

1. turn the calculator off,

2. hold down the back-arrow key (the key just above the digit 9 key) and turn the calculator back on ("MEMORY LOST" will be displayed at this point),

3. execute "PS" (press [XEQ] [ALPHA] PS [ALPHA]).

Once the above steps have been followed, PipeStar is ready to be used. The remainder of this section is provided for those interested in knowing more about initialization, but it is not necessary to read it before using the program.

The above initialization procedure has cleared the calculator memory, set the memory SIZE to 256, assigned the 20 function keys of PipeStar to the top two rows of keys on the keyboard, put the calculator in the USER mode, displayed the first HELP screen, and prepared the calculator so PipeStar may create its own data file in XM if the user doesn't do so by the time he starts entering data. The user may now continue pressing the [R/S] key and following the prompts as described later in the manual, or he may start entering geometry by pressing the "PDL" key (top left) and continue from there.

As alluded to above, PipeStar will create its own data file in XM when needed if the user doesn't do so. It will name that file "PS-DATA" and size it as large as possible with the memory available. This data file is necessary because it is where PipeStar will store all data input by the user.

The user may of course create, size, and name his own data file if desired (discussed below) and PipeStar will use that file, or if the user creates multiple data files, PipeStar will use the current working file that the calculator is "pointed" to. If the calculator is pointed to an ASCII or Program file, then "FL TYPE ERR" will be displayed on the screen. The user will then need to reset the file pointer as described next.

When there are multiple data files, PipeStar must know which file to work with. The user may specify which file by "setting" the HP-41 to the desired file before executing PipeStar. If a new file has just been created, then that will be the file the HP-41 is set to. If another file is desired, then it may be specified by executing the EMDIR function, or the CATALOG 4 function if using an HP-41CX. An XM directory listing will then be displayed. When the desired file is displayed, the [R/S] or the [ON] key may be pressed to terminate the listing. The last file displayed will then be the one the HP-41 is set to and that PipeStar will use.

A data file from a previous (though different) problem may be used for a new problem (the previous data may, of course, have to be overwritten, or cleared using the CLFL function).

If a user desires to create his own XM data file himself as discussed above, there are two functions available to him to do this: MAXFL and CRFLD. The latter function is an HP-41 function and the user should refer to HP-41 Owner's Manual for details about that. When using CRFLD though, a user may specify whatever file size he wants (e.g., 100). If the file is sized too small or too large for the required input data, PipeStar will automatically re-size it as needed. The exact size that would be needed varies and will not be discussed here.

A user may also use the PipeStar MAXFL function (located on the shifted roll-down key - the FIRST ~~second~~ key from the left on the second row). This is the same as the HP-41 CRFLD function except that the user doesn't need to specify a file size; PipeStar will automatically size it as large as possible with the memory available. As with CRFLD, the user does need to specify a file name in the Alpha register before executing the function.

For most cases, MAXFL would probably be preferable over CRFLD. With the latter, if a file is sized too small, then every time a new piece of data is input and stored in XM, PipeStar will have to resize the file for the new data. Depending on what else is in XM, this could slow the input processing speed when data is first input. On the other hand, even though MAXFL will probably oversize a file, after a user has entered all data and pressed the [R/S] key after the last "EJ" (Expansion Joint) prompt, PipeStar will delete all unused data registers for the optimal file size. The final result would be the same with either CRFLD or MAXFL.

Multiple data files may be created in the fashion described above and stored simultaneously in extended memory. Depending on the amount of extended memory available and the size of each data file, it would be possible to store over 10 data files simultaneously.

Using PipeStar

Preliminary Comments

As discussed in the two preceding sections, the PipeStar module must first be installed in the calculator, and the calculator must be initialized before PipeStar may be executed. A printer should not be connected to the HP-41 while data is being input.

Once the above items are in order, the pertinent User Flags (i.e., Flags 00 through 05) should be Set or Cleared as appropriate. The functions of these flags are summarized below; they are covered in greater detail later in this section.

Flag 00:	Clear:	Use English units*
	Set:	Use Metric or User-defined units*
Flag 01:	Clear:	Comply with ANSI B31.3 (petrochemical)
	Set:	Comply with ANSI B31.1 (power piping)
Flag 02:	Clear:	Do not perform thermal analysis
	Set:	Perform thermal analysis
Flag 03:	Clear:	Do not perform weight analysis
	Set:	Perform weight analysis
Flag 04:	Clear:	Do not display extra data
	Set:	Display extra data
Flag 05:	Clear:	PipeStar calculates new k and i factors
	Set:	PipeStar does not calculate new k and i factors

* When Flag 00 is Clear, English units are used, as described below. If Flag 00 is Set, then the units used can be metric or whatever the user desires as long as unitary consistency is maintained between the basic length and force units and combinations of such units (e.g., stress is a force divided by a length squared) (for metric use, millimeters and newtons are suggested as basic length and force units - radians must be used for angular measurements).

Data	English	Suggested Metric
Allowable stresses (SC, SH)	psi	N/mm^2 or MPa
Anchor and restraint movements	in	mm
Concentrated weight (CON WT)	lbs	N
Coordinates (X, Y, Z)	ft	mm
Displacements (DX, DY, DZ)	in	mm
EJ pressure thrust area (AREA)	in^2	mm^2
Forces (FX, FY, FZ)	lbs	N
Length of pipe (L)	ft	mm
Modulus of elasticity (E)	psi	N/mm^2 or MPa

Moments (MX, MY, MZ)	ft-lbs	N-mm
Outside diameter of pipe (OD)	in	mm
Pressure, internal gage (P)	psig	N/mm^2 or MPa
Radius of elbow/bend (R)	ft	mm
Spring rates in rotation (R)	ft-lbs/deg	N-mm/rad
Spring rates in translation (K)	lbs/in	N/mm
Stresses (MAX S, S)	psi	N/mm^2 or MPa
Thermal expansion rate (e)	in/ft	mm/mm
Thickness of pipe wall (T)	inches	mm
Weight/Length (W/L)	lbs/ft	N/mm

Program Function Keys

To enhance PipeStar's "friendliness", twenty program functions have been assigned to certain keys on the HP-41 keyboard. This means that with the HP-41 in the USER mode, these keys and their respective functions become activated and enable the user to easily interface with the program.

These program function, or "PF", keys have been assigned to the top two rows of keys on the HP-41 keyboard, with the blue letters A through J written on the lower portion of them. Also provided with PipeStar is a keyboard overlay (see page 16) to assist in recognizing where each Program Function key is located. When any one of these keys is held down momentarily, the program function will be displayed. These PF Keys are described further as follows (the negative sign preceding some keys indicates a shifted key):

PF Key	Display	Program Function
A	PDL	Input: pipe geometry (Point, Direction, Length)
B	PT/CODE	Input: point/code relationships
C	CODE	Input: code data
D	TEE	Input: tee code and stress intensification factors
E	CON WT	Input: concentrated weights
- A	RESTR	Input: restraint data
- B	AM	Input: Anchor movements
- C	EEC	Input: data for elastic end conditions
- D	EJ	Input: data for expansion joints
- E	PRINT	Utility: produces a print out of all I/O
F	ANALYZE	PipeStar calculates forces, moments, and stresses
G	STRESS	Output: stresses and internal forces and moments
H	LOADS	Output: coor., displ., and external forces and moments
I	INSREG	Utility: insert registers
J	DELREG	Utility: delete registers

- F	MAXFL	Utility: create XM data file of maximum size
- G	W/L	Utility: calculate weight/length during input
- H	HELP	Help displays
- I	INSREGX	Utility: insert registers per number in the X-register
- J	DELREGX	Utility: delete registers per number in the X-register

Data Input/Output

All pipe data (except CODE data) should be entered in the same order that the geometry points are entered, and in general, is input (entered) in the following manner:

1. The data point in question is entered into the X-register (the display) (if zero or a nonexistent data point number is entered, PipeStar will default to the first data point).

2. The appropriate PF Key is pressed and PipeStar displays the selected parameter (e.g., "TO P.D=") together with the value (e.g., "1.0") currently stored in memory for that parameter (e.g., "TO P.D=1.0"). If the PF Key does not go directly to the desired parameter (e.g., a Length parameter), then the [R/S] key may also need to be pressed one or more times.

3. If the value for the parameter displayed isn't correct, then the desired value should be entered into the X-register.

4. The [R/S] key is pressed. This will save the last value shown/entered in the display with the last parameter shown in the display. Then the next parameter and value will be displayed.

5. More data may be input by continuing with either Step 1 or Step 3.

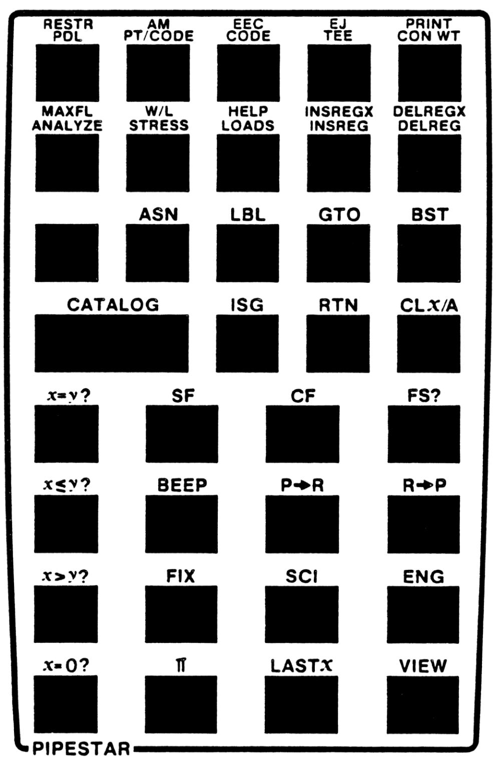
Whenever a value of zero is entered for the first prompt of a set of data and the [R/S] key is pressed, PipeStar will consider that to be the last input for that category of data. For example, after all geometry data is entered (using PDL), if zero is entered after the "TO P.D=" prompt, PipeStar will then stop prompting for anymore PDL data and start prompting for the next category of data which, after PDL, would be "FR P.C=" data.

Output data may be retrieved in a manner similar to the above, except of course that the output data can't be changed.

The rest of this section on "Using PipeStar" will discuss data input/output and general usage in greater detail.

PipeStar Keyboard Overlay

A copy of the keyboard overlay that accompanies PipeStar is shown below. On the actual overlay, the unshifted functions are shown in white immediately above the pertinent keys, and the shifted functions are shown in gold above the unshifted functions above the pertinent keys.



PF Key A: PDL (Point, Direction, and Length of a Pipe Element)

The format used by PipeStar for entering geometry requires two displays (or prompts, or, entries) for each point (shown here with no data in memory):

TO P.D=0.0
L=0.000

Every pipe member may be described as going FROM one point TO another. PipeStar assumes that every point is FROM the previous point entered and therefore only prompts for the "TO" point, hence the prompt above. Since this creates a problem at the first point and the beginning of the last branch off a tee, this is accommodated by entering no direction "TO" that point (discussed below).

For PipeStar to display the "TO P.D" prompt, the user should first enter the point desired, or "0" to go to the first point, and then press PF Key A. (If the point in the display doesn't exist in memory, PipeStar will go to the default point which will be the first point.)

With the "PT.DIR" prompt in the display, the point number and direction may be entered for the pipe member starting at that point. The point number should be entered as the integer portion of the entry, and the direction should be entered as the fractional, or decimal, portion of the entry. A user may number a piping system in any fashion he desires, as long as he uses positive whole numbers (up to nine digits may be used, although only the four least significant digits will be shown during output) for each data point. Direction is entered as a single decimal digit where .1 or .2 or .3 correspond respectively to the X or Y or Z axes.

Skew lines may be entered by using four entries: the TO point would be entered twice. The first time it is entered, one direction parallel to a coordinate axis is indicated and then the length in that direction is given. This is similarly done a second time for a direction and length parallel to a different axis.

Note: PipeStar may model three types of piping elements: straight pipe, and 45° and 90° elbows (with slight tolerances allowed on the angles). These elements may be skewed, or rotated, at any angle as long as they are rotated about only a single axis parallel to one of the three global coordinate axes. Two straight pipe elements may be connected at any angle relative to each other (i.e., not restricted to 45° or 90°) if there is not an elbow between them; if there is an elbow betwen them that is not 45° or 90°, then it can be approximated by setting the bend radius to zero (such an approximation will yield conservative results).

The first anchor and last branch off a tee must be modeled as having no direction (i.e., a direction of zero; e.g. "TO P.D=1.0" for the first anchor). When PipeStar senses that there is no direction, it will not prompt for a length at that point.

It should be noted that if a data point is at an elbow, it is assumed to be at the geometric point where the centerlines (tangents) of the pipe connected to the elbow intersect. Thus, a point need not be modeled at the initial and final "node" points of an elbow. The length, discussed below, should be given to this tangent intersection point.

Once the correct point number and direction have been entered, the [R/S] key may be pressed to proceed to enter the length "L" of that pipe member TO the point entered in the previous display (unless the direction was zero, in which case PipeStar skips the "L" prompt). The length is displayed as the value (positive or negative) stored in memory for that pipe member.

L=0.000

indicates a length of zero for the current point. The correct value may be input by entering it into the display and pressing the [R/S] key. If a value had already been entered for the length at this point and it didn't need to be corrected, then only the [R/S] key would need to be pressed to proceed. (The length stored in memory for a pipe member is accurate to 10 digits although only 3 decimal places are displayed.)

When the [R/S] key is pressed after a point and direction of zero are indicated (where "TO P.D=0.0", as described above), instead of proceeding to the length display, the program will automatically go to the next phase of input: pipe data. This is the same as if PF Key B were pressed which is discussed next.

PF Key B: PT/CODE (Point/Code Relation)

To enter pipe data such as the OD, wall thickness, etc. PipeStar uses a relational method. The data is entered in a "code" format (described a little later) with a code defined by the user. Then at the first point and any point after that where a different code would apply, the user specifies that, using the PT/CODE relationship. This allows a user to enter all the data for a type of pipe only once and then apply it wherever he desires with only one entry.

For example, the pipe before and after a valve could be of one code, and the valve of a different code. All the code data for the pipe would only have to be entered once, and then applied using the PT/CODE relationship twice, or however many times would be necessary. This greatly simplifies entering data and conserves memory.

A prompt for the point and code might appear as:

```
FR P.C=1.01
```

The "FR" indicates the new code will be applied FROM the point given for all pipe members following that point until the end of the piping system or until another point/code is specified. "P.C" is an acronym for Point.Code. The point is entered as the integer portion of the number and the code number is entered as two digit decimal portion of the number. A single-digit code number such as "1" would be entered as ".01".

A zero entry tells PipeStar to proceed to the next category of input: the Code itself.

A PT/CODE may be entered at an elbow too. If it is, then it will be applied by the program starting at the final, or ending, node of the elbow. This is because PipeStar treats an elbow as a part of the preceding straight segment of pipe.

PF Key C: CODE

Certain pipe data used in PipeStar is stored in "Codes" as mentioned above. During this phase of input, PipeStar prompts for the following in the order shown:

CODE	CODE number (from 1 to 99)
OD	Outside Diameter of pipe
T	pipe wall Thickness (with corrosion allowance, if applicable)
R	elbow/bend Radius
E	modulus of Elasticity
e	thermal expansion coefficient
W/L	Weight per Length of pipe (see also page 28)
P	internal design gage Pressure
SC	allowable Stress at Cold temperature
SH	allowable Stress at Hot temperature
K	elbow flexibility factor
I	elbow In-plane stress intensification factor
O	elbow Out-plane stress intensification factor (B31.3 only)

The above pipe data are input in the same manner that the pipe geometry was input. That is, each succeeding value is displayed each time the [R/S] key is pressed. Any data may be changed from what is displayed by entering the correct data and pressing the [R/S] key. (CODEs don't need to be entered in the same order as the geometry; also, PipeStar will calculate the last three entries if the user desires; see the next section).

Note: If zero is entered for both the cold and the hot allowable stresses, then PipeStar will not calculate or display what percent the resultant stress is of the allowable stress (discussed later in the manual).

Though PipeStar will lead into code data input following the last PT/CODE entry, one may go directly into pipe code input by entering into the display the data point desired and then pressing PF Key C.

Similarly to how pipe geometry was handled in the previous section, when all pipe data has been input, then the last CODE entry should be set to (or left as) zero.

Pipe Data: k and i factors

The k and i (elbow flexibility and stress intensification) factors that PipeStar uses may be calculated by PipeStar for a 45° or 90° weld ell or pipe bend in accordance with either ANSI/ASME B31.1 Piping Code (used with power piping) or ANSI/ASME B31.3 Piping Code (used with piping for chemical plants and petroleum refineries).

Flag 01 is used to tell PipeStar which Piping Code to use. To specify that B31.3 Piping Code be used, Flag 01 should be Clear (a small "1" should not be showing in the lower portion of the display); to use B31.1 Code, Flag 01 should be Set (showing a small "1" in the lower portion of the display). This can be remembered by associating the "1" of B31.1 with the "1" of Flag 01 when it is Set.

Two other flags also affect how PipeStar will treat the k and i factors: Flags 04 and 05. Flag 04 tells the program whether or not it should display the k and i factors. If Flag 04 is Set, it will display the k and i factors after the "SH" (hot allowable stress) display. At this point, the user may also input custom, or modify current, k and i factors. With Flag 04 Clear, it will not display the k and i factors. Leaving Flag 04 Clear can simplify data input and save time for users not particularly concerned about the k and i factors.

Flag 05 tells the program whether or not it should calculate new k and i factors from current CODE data (the OD, T, R, E, and P) after the "SH" display. If Flag 05 is Clear, the program will calculate new k and i factors and overwrite any previously stored values; if Flag 05 is Set, the program will not change the k and i values currently stored in memory. It may be useful to Set Flag 05 when the user has input custom k and i factors and wants to ensure that the program doesn't change them.

Since Flag 05 isn't shown on the display, PipeStar will indicate when it is Set by displaying "NO CALC K+I" before it proceeds to the k and i factors. If that is acceptable, then the [R/S] key may be pressed to continue (without PipeStar calculating new k and i factors) or Flag 05 may be cleared and then the [R/S] key pressed.

Note: When using B31.3 Code (Flag 01 Clear), there are two stress intensification factors used for an elbow: one for the In-plane moment and one for the Out-plane moment. These are displayed by PipeStar with the acronyms "I" and "O" respectively. When using B31.1 Code (Flag 01 Set), a single stress intensification factor is used for all three moments (in-plane, out-plane, and axial) of an elbow. PipeStar will then display only one stress intensification factor and specify it with the acronym "I" (for Intensification instead of In-plane).

PF Key D: TEE

This key is activated for three anchor systems to enter the type of tee to model and to calculate the stress intensification factors at the tee.

PipeStar can model four types of tees and the first prompt for a tee will be for the tee code that PipeStar should use. Either a 1, 2, or a 3 should be entered for the code here (Tee Code 1 may represent two different tee types as shown below). These signify the following:

Tee Code 1 = Weld tee per ANSI B16.9, or, a welded-in contour insert
Tee Code 2 = Reinforced fabricated tee with pad or saddle
Tee Code 3 = Unreinforced fabricated tee

The display for the tee type will also be followed by W, R, or U to signify respectivly a Weld tee, a Reinforced fabricated tee, or an Unreinforced fabricated tee. If a number other than a 2 or a 3 is entered PipeStar will change it to a Tee Type 1.

Flags 01, 04 and 05 are used with tees similarly as described above with elbows.

Note: The stress intensification factors for a tee are calculated based on the OD and T of the header pipe as specified per ANSI/ASME Code. However, in the rare case where a branch off a tee is rotated about an axis not parallel to the header, the i factors will be calculated based on the OD and T of the first line connected to the tee; therefore, in such a case, if the branch has a different OD and T than the header, it should not be modeled as the first line connected to the tee.

PF Key E: CON WT (Concentrated Weight)

This function allows a user to enter a concentrated weight at a data point, such as the center or the end points of a valve or flange. There are just two prompts for this: one to enter the point number, and one to enter the weight. Weight will be applied in the negative Y direction at the point specified (weight may be applied upward, in the positive Y direction, by specifying a negative weight).

PF Key Shift-A: RESTR (Restraints)

This function allows for the entry of restraint data. The prompt format is "R P.D". The data point number of the restraint (which should not be at an elbow) is entered as the integer portion of the number, and the global direction as the single-digit decimal portion.

To simplify restraint input, Y-restraints may be modeled by specifying only the data point number without a direction. If any number other than a .1 or a .3 (an X or a Z) is specified for the direction (i.e., a .0, .2, etc.), PipeStar will model the restraint in the Y direction.

The next prompt "K" allows for the entry of flexibility or spring rates in units of force/length. An entry of zero will be interpreted as completely rigid instead of completely flexible. The prompt after the "K" is "D" and allows for the entry of restraint Displacement or movement. Both K and D are applied in the direction of the restraint as indicated in the first prompt.

Note: Restraint flexibilities and restraint movements are not applied during weight-only runs.

If a spring rate is applied to a restraint, then after PipeStar analyzes the system (for other than weight-only cases), it will provide the deflection at that spring restraint. As a modeling technique then, a "dummy" restraint with close to zero flexibility (usually unitary flexibility is sufficient, see Example Problem 5) could be modeled at any point to determine the **free movement** or **deflection** at that point (since there would be negligible force from the spring restraint at that point, the deflection would be essentially "free"). A user should be aware though that too small a flexibility (e.g., 0.0001) may introduce mathematical instability into the matrix that PipeStar generates and this could result in numerical error, although probably not more than a few percent.

PipeStar can handle a maximum of up to 24 degrees of freedom which means that with 2-anchor systems, up to 18 restraints may be modeled; with 3-anchor systems, up to 12 restraints may be modeled.

CAUTION: If modeling 2-anchor systems with over 13 restraints or 3-anchor systems with over 7 restraints, do not press [R/S] to stop the program during execution, or all XM data may be lost. This may also occur, when modeling such a system, if the program is stopped due to an input data error causing an error message to be displayed (see page 61; for this reason it may be a good idea to first run such a problem without any restraints to be sure there are no input data errors).

When modeling systems as described in the caution above, PipeStar uses extended memory to store part of the matrix it generates. If there is not enough room in XM for it to do this, then the error message "NO ROOM" will appear in the display and the program will stop.

PF Key Shift-B: AM (Anchor Movements)

This function allows for the entry of anchor movements and uses four prompts. The first prompt asks for the anchor point number and the next three prompts ask for the displacements D in the X, Y, and Z directions.

Note: Anchor movements are not applied during weight-only runs.

PF Key Shift-C: EEC (Elastic End Conditions)

This function allows one to enter the elasticity of the ends, or anchors, of the piping system. This function consists of seven prompts. The first prompt asks for the point number of the end/anchor for the EEC to be applied to. The next three prompts ask for the translational flexibility K to be applied in the directions of the X, Y, and Z axes. The next three prompts ask for the Rotational flexibility R to be applied about the X, Y, and Z axes. As with restraint flexibility, an entry of zero indicates complete rigidity.

As a modeling technique, it may be desirable, during weight-only runs, to use elastic end conditions to simulate **free anchors** (i.e., supporting no loads) (e.g., when they are connected to rotating equipment and spring hangers are being sized, see Example Problem 5) by entering unitary values for all six elasticities (normally, during weight-only runs, elastic end conditions would probably not be used, except as just mentioned, to model free anchors).

Another modeling technique could perhaps be used when elastic end conditions need to be applied to **skewed** anchors. In such a case, it may be easier to model an expansion joint of negligible length (e.g., 0.001 feet or mm) immediately adjacent to and colinear with the anchor to simulate elastic end conditions. This takes advantage of the local coordinate axes that expansion joints use which allows them to be skewed as discussed next.

PF Key Shift-D: EJ (Expansion Joints)

Expansion joint data is entered similarly to the EEC data described above. The main difference is that, following the EJ prompt, there is a prompt for the cross-sectional AREA that pressure thrust should be applied to. Also, the point number entered should be the point modeled at the beginning of the expansion joint.

Note: If a flexibility of zero is entered in any direction, PipeStar will use the flexibility in that direction that it would have used had the expansion joint been regular pipe. Furthermore, all other pipe properties (e.g., weight and thermal expansion) will be applied to an expansion joint as with any other pipe member.

Note: Pressure thrust is not applied to expansion joints during thermal-only runs; however, it is applied during weight-only and combined T+W+P runs (its effects may be negated if desired by setting the EJ pressure thrust AREA equal to zero).

If modeling a **skew** expansion joint, then PipeStar uses a form of local coordinate-axes to input the directions of the flexibilities (this is the only place where PipeStar uses such local coordinate-axes). The three possible cases which may be modeled are described below (the "plane" referred to is the plane that the element is rotated in) :

1. Rotation about the X-axis: The Y-axis is treated as being the axial axis; the X-axis is treated as being the in-plane axis; the Z-axis is treated as being the out-plane axis.

2. Rotation about the Y-axis: The X-axis is treated as being the axial axis; the Y-axis is treated as being the in-plane axis; the Z-axis is treated as being the out-plane axis.

3. Rotation about the Z-axis : The X-axis is treated as being the axial axis; the Z-axis is treated as being the in-plane axis; the Y-axis is treated as being the out-plane axis.

This concludes all input of data. If the [R/S] key is pressed at the conclusion of EJ data, PipeStar will calculate how many unused registers there are in the current data file and delete them to save memory. Then it will start over with the first data entry prompt, "PDL", and continue as before and display all the data last entered.

PF Key Shift-E: PRINT

When a printer is attached to the calculator, this function will print all the input data and output data together. It will not affect the values stored for the k and i factors for elbows or tees, but it will print them regardless of the status of Flag 04 (the display flag).

At the completion of printing the input data, the output data will be printed without stopping to re-calculate the external forces and moments. The internal forces and moments at each point will be printed according to the status of Flag 04. The coordinates at anchors will be printed without regard to the status of Flag 04.

The print function may be used without a printer attached to examine the version of PipeStar being used, the status of the ANSI Code being used, the units being applied, and the type of run that will be made (thermal, weight, or T+W+P).

PF Key F: ANALYZE

Before using PipeStar to analyze a piping system, Flags 02 and 03 must first be Set or Cleared to specify either a thermal or a weight run. As discussed above, Flag 02 should be Set to specify a thermal run, and Flag 03 should be Set to specify a weight run. If both Flags 02 and 03 are Set, then PipeStar will run a combined loadings case (i.e., with thermal, weight, and pressure factors all combined). If neither Flag 02 nor 03 is Set, then PipeStar will Set both of them and proceed accordingly when PF Key F is pressed (discussed below).

Once all input data has been entered and the pertinent Flags have been Set as described above (including Flags 00 and 01), the main portion of the program may be executed to assemble and analyze the input data and calculate the external forces and moments, and the maximum stress of the piping system. This may be done by simply pressing PF Key F. No further user interface is needed during this phase of program execution. Execution time may vary from under ten seconds to several minutes depending on the complexity of the problem and the type of HP-41 (some HP-41's have been "speeded-up," see pages 8 and 9).

As the program is progressing, various displays will appear indicating the status of progress. Thus, for a problem with five data points, the following displays may appear:

THERMAL CASE (or "WEIGHT CASE" or "T+W+P CASE")
TO POINT 2
TO POINT 3
TO POINT 4
TO POINT 5
SOLVING EQNS
STRESS CALCS
MAX 29 9,476.

After the last display, the program is finished and stops. The forces, moments, and stresses of the piping system, which are discussed next, are then available.

PipeStar may be stopped anytime during these calculations, or during the stress routine which follows, before completion, by pressing the [R/S] key. There is one exception to this which was mentioned during the discussion on restraints (see page 22).

PF Key G: STRESS (Stresses and Internal Forces and Moments)

Entering a point number and then pressing PF Key G will give the stress at a point according to the status of Flags 02 and 03. If "0" or any nonexistent data point number is entered and PF Key G is pressed, the maximum stress will be displayed, which might appear as follows:

```
MAX 16  1,234.
```

The first number (16) represents the percent (rounded up) of the allowable stress that the maximum stress is. The second number (1,234.) represents the actual maximum resultant stress of the piping system.

Concerning the percentages given for any stress, if no allowable stresses were entered by the user during CODE data input, then only the stress will be displayed. If a negative percentage is calculated by PipeStar (e.g., from a negative allowable resulting when pressure stress is greater than the SH during a weight-only run), then PipeStar will display the greatest negative percentage (e.g., a -50 would be greater than a -30).

After the "MAX" display, the POINT location of the MAX is shown, e.g.,

```
POINT=7
```

Following the MAX and POINT displays, the stresses will be shown for every point. The display will be similar in format to the MAX display except that the "MAX" will be replaced by the point number. If the point is at an elbow, then the stress will be given first for the initial node point of the elbow, then the final node point. Such node point numbers will be appended with an "I" or an "F" respectively, e.g.,

```
3I  20  2,491.
3F  11  1,337.
```

Three stresses will be given at tees: one for each branch of the tee in the order that the geometry was entered by the user.

If the user desires, he can set Flag 04 and then PipeStar will also give the **internal forces and moments** for each node point following the stress display. (If a force or moment is less than 0.5, it will be displayed as zero; however, by pressing [CLX], the actual value will be shown in the X-register.) For Example Problem 1 (page 33), PipeStar would display the internal forces and moments for the first point, when Flag 04 is Set, as follows:

1 28 7,774.
FX=-2,285.
FY=-1,540.
FZ=1,301.
MX=-11,066.
MY=14,679.
MZ=-6,116.

It should be noted that PipeStar gives the stresses, forces, and moments at the "initial" side of a node point as though the point were the end of the preceding pipe element. The effects of different pipe sizes, restraints, and concentrated weights at a point are treated as being at the beginning of the next pipe element.

The **signs** given the internal forces and moments are given as though they were what the following pipe was acting onto that point. The signs (±) given to the moments are given according to the "right-hand rule" as it would be applied to a standard axis orientation (e.g., a +X moment would "rotate" from the +Y axis to the +Z axis).

PF Key H: LOADS (External Forces and Moments)

This portion of the program gives all the external forces and moments of the piping system (i.e., at the anchors and restraints). The signs applied to these loads represent what the **pipe is acting onto** the anchor or restraint. For example, if the display showed:

4 FY=-1,000.

it would mean that the pipe is "trying to push" **down** onto a restraint at point 4 with 1,000 force units (e.g., pounds, newtons).

If the run made is not weight-only, and if there are any deflections at any restraints (i.e., from spring hangers and/or restraint movements), then these deflections will be shown also, immediately following the respective restraint force display. E.g.,

4 FY=-1,000.
4 DY=-0.2164

When using PipeStar, results at points can be looked at selectively. This can be done by simply entering the desired point number into the X-register (it should show in the display) and then pressing either PF Key G or H (for stresses or loads respectively). If "0" is entered in such a fashion and "STRESS" is executed, then PipeStar will begin with the "MAX ..." display and continue from there as described above. Likewise, the MAX will be displayed if a point is entered that doesn't exist.

If the "LOADS" function is executed after entering a point into the X-register, then PipeStar will first search for an anchor with the point number entered. If there isn't an anchor with that point number, then it will search for a restraint with the point number entered. If a restraint isn't found, then the program will default to the first anchor.

The coordinates are also given for the anchors when Flag 04 is Set. The above results and more may be recalled from Registers 00 through 12. See Appendix D for more details.

PF Key Shift-F: MAXFL

This function was described earlier in the manual relating to the initialization procedure (see page 12), so it won't be discussed again here.

PF Key Shift-G: W/L (Weight/Length)

There is one more function that may aid in inputting CODE data into PipeStar: "W/L" - a subroutine that may be called when the program prompts for W/L. If the value of W/L isn't readily known when it is prompted for, PF Key Shift-G may be pressed and then PipeStar will prompt for the densities of the pipe itself and the pipe contents, and the thickness and density of any insulation that may be on the pipe. The prompts are listed as follows (R/S would be pressed after each and the units used should be consistent):

D/P	Enter the Density of the Pipe material here
D/C	Enter the Density of the pipe Contents here
T/I	Enter the Thickness of the Insulation here
D/I	Enter the Density of the pipe Insulation here

PipeStar will store the above values in Registers 12 through 15 while data is being input; however, if those registers contain zero (as they may initially), then PipeStar will suggest values for the densities of carbon steel pipe, water contents, and calcium silicate insulation (using lb/in^3 if Flag 00 is Clear, or, N/mm^3 if Flag 00 is Set). If zero insulation thickness is indicated, then PipeStar will not prompt for the insulation density. Since this routine is designed to be called while CODE data is being entered, PipeStar assumes and uses the pipe OD and wall thickness specified with the pertinent CODE and thus doesn't again prompt for those values.

After pressing [R/S] following the last prompt, the W/L subroutine will return to the main program and display the calculated W/L of pipe. If Flag 00 is Clear, then the displayed value will have been multiplied by 12 to yield pounds per foot (accurate if all densities, diameters, and thicknesses have been entered using inches). Following the W/L display the [R/S] key may be pressed again to proceed with further data input, or [W/L] (PF Key Shift-G) may be pressed again to repeat the process just discussed.

PF Key Shift-H: HELP

This key will do the same thing as executing "PS" as described earlier in this manual (see page 11). It will initialize the HP-41 for PipeStar and then display various screens showing what the different flag settings mean and what the tee codes are.

PF Keys I and J: Inserting and Deleting Registers

There are four functions (written by Clifford Sterns) designed to simplify the editing of pipe data input:

INSREG	PF Key I
DELREG	PF Key J
INSREGX	PF Key Shift-I
DELREGX	PF Key Shift-J

The "INS" functions insert blank registers where the file pointer is currently located and move all other registers after that point to higher-numbered registers. The "DEL" functions do the exact opposite. The functions without the "X" following them insert/delete a number of registers equal to the number found in Register 00 (PipeStar inserts the number normally needed in Register 00). The functions with the "X" following them take the number from the X-register instead (useful if a user wants to use his own number). These functions may, incidentally, be used by a user in his own programs if he likes.

Perhaps the best way to describe how to use these functions is to give an example; they are really very simple to use. If, after entering a complete problem of say 100 data entries, a user should decide that he would like to add a new data point (PDL input) after the third data point already entered, there could be two ways to do it.

1. The user could just go to third data point, where he wants the new data point to be, and then enter it like he wants it. But that would overwrite what was already there and he would have to then re-enter all the data that followed that point.

2. Another, simpler, approach would be to just go to where he wants the new data to be. Then a user could just press PF Key I (INSREG). Then PipeStar would make the appropriate room at that point for a new data point entry and move everything else in memory after that point up or down to make the room.

PipeStar will put the correct number of registers to be inserted in Register 00 so the user can use INSREG or DELREG without worrying about what number of registers need to be inserted or deleted. If the user is working with PDL data for example, that number would be 2 because there are two prompts for each complete entry ("TO P.D=" and "L="). For Code data, that number would be 13, etc.

A user may however want to insert/delete more than one complete set of data or a number of registers other than what PipeStar enters in Register 00. In that case he could enter the number in the X-Register and execute either INSREGX or DELREGX. In the above example, if a user wanted to enter 4 new PDL points, he could just enter 8 in the X-Register (4 points multiplied by 2 registers per point) and execute INSREGX (the same result would be obtained by simply executing INSREG four times). If a user is not sure what number he should use for a category (e.g., "2" for each PDL), he may recall the correct number from Register 00 and then multiply that number by what ever he wants.

If this is still a little confusing, it may help to understand how data is stored in Extended Memory. All input data is stored in a single XM data file. The first three registers of the file are reserved for tee data; after that, all other data is stored sequentially in the same order that PipeStar prompts the user for it. Whatever PipeStar is prompting for also represents where the file pointer is pointing. When one of the insert/delete functions is executed, then, starting at where the file pointer is pointing, registers will be inserted or deleted. All the following registers in the entire file (i.e., data that the user would be subsequently prompted for) will be moved up or down accordingly and the file resized as needed. For this reason, it is also necessary to ensure that registers are inserted or deleted at the beginning of a category of data (e.g., registers for CODE data should be inserted or deleted right after the CODE prompt, not after the OD, T, or R prompts). A user may want to try these functions out a few times to get a good feel for them.

There is also a technique that could be employed to negate the effects of data without deleting it. That is to assign a data point number that doesn't exist to the data. Then PipeStar will ignore it and all similar data following it. For example, if there are three anchors with elastic end conditions (EEC's) modeled in a piping system, and the second and third EEC's need to be ignored during a weight-only run, then this could be done by assigning a point number that doesn't exist (e.g., 999) to the second expansion joint. The data for the last two EEC's would still be resident as data, but they would be ignored. (Even though the third EEC may have a valid point number, PipeStar won't "see" any EEC's after the second one.) To reinstate the EEC's, just re-assign the correct data point to the second EEC.

Example Problems

Five example problems with printouts are provided to demonstrate how PipeStar might be used to model various piping configurations. These example problems are summarized as follows:

Problem #1:
- page 33
- includes annotated keystroke listing
- ANSI B31.1
- anchor movements

Problem #2:
- page 38
- same as Example Problem #1 but with Metric units

Problem #3:
- page 40
- includes annotated printout
- ANSI B31.3
- three-anchor
- combined loadings (T+W+P)
- spring hangers
- skew lines
- internal pressure
- expansion joints
- elastic end conditions

Problem #4:
- page 46
- ANSI B31.3
- hinge (expansion) joints
- skewed anchor

Problem #5:
- page 49
- ANSI B31.3
- free anchors
- elastic end conditions
- three-anchor
- spring hangers
- skew lines

The modeling techniques used to work through these problems should not be regarded as the only, or even the best, way that such problems may be worked. There may actually be several different modeling techniques that could be used, yielding various "correct" results. In any case, PipeStar should be as accurate as the modeling techniques used.

Note: In all of these example problems, Flag 04 was Clear; therefore, no internal forces and moments have been printed out. **Internal forces and moments** at any node point may be displayed, or printed out, though, by ensuring that Flag 04 is Set when the stress value for a node point is displayed (see pages 26 - 27 for further discussion).

Example Problem 1

This example problem involves a simple piping configuration with anchor movements; see the accompanying configuration drawing on the following page. An annotated keystroke listing showing how to input this problem is provided.

Before starting any problem, the user should always ensure that the status of User Flags 00 - 05 is correct (of course, the calculator should also be initialized if this hasn't been done already; see page 11). The initial status of User Flags 00 - 05 for this problem is listed as follows:

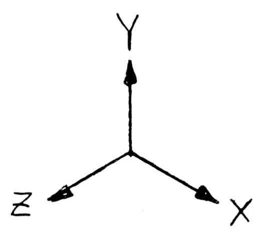
Flag 00: Clear (English units will be used)
Flag 01: Set (B31.1 Code will be used)
Flag 02: Set (calculate thermal stresses)
Flag 03: Clear (do not include weight calculations)
Flag 04: Clear (the k and i factors do not need to be displayed)
Flag 05: Clear (PipeStar will calculate the k and i factors)

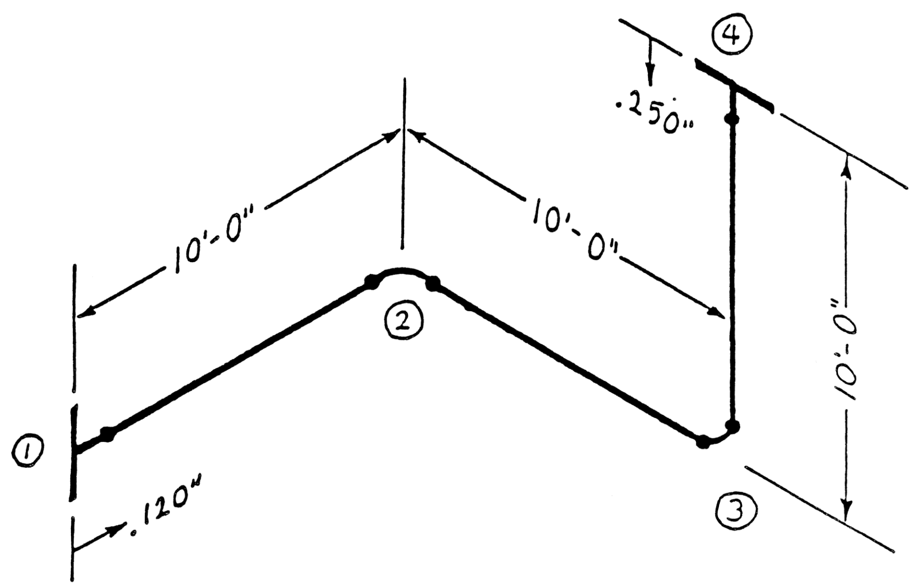
This problem will be done using both English and Metric units; the English version will be done first; therefore, Flag 00 should be Clear initially. As indicated on the configuration drawing, this problem should be done using ANSI/ASME B31.1 Power Piping Code; therefore, Flag 01 should be Set.

The displays shown in the keystroke listings (e.g., "L=0.000") are listed assuming that the initial values of all the registers in the data file used are zero. This would be the case after a new data file has been created. Different values may appear if a data file has been used before; if this is the case, there is no problem; previously stored values may be overwritten as easily as values of zero. If the user desires, a data file may still be cleared to all zeros by entering the data file name in the ALPHA register and then executing the CLFL function.

Piping Configuration for Example Problem 1

Pipe Outside Diameter: OD = 10.75 in.
Pipe Wall Thickness: T = 0.365 in.
Elbow Radius: R = 1.25 feet
Modulus of Elasticity: E = 27.9 X 10^6 psi
Thermal Expansion @ 350°F: e = 0.0226 in./ft.
ANSI/ASME Code: B31.1





The keystrokes necessary to input data and retrieve output with Example Problem 1 are listed below. The USER mode should be selected to use the PF Keys.

Display	Keystrokes	Comments
0.0000	[PF Key A]	begin entering PipeStar data
TO P.D=0.0	1 [R/S]	first "TO" point has no direction
TO P.D=0.0	2.3 [R/S]	direction to second point is in the Z
L=0.000	10 [CHS] [R/S]	length (feet) (negative) from point 1 TO point 2, includes elbow
TO P.D=0.0	3.1 [R/S]	
L=0.000	10 [R/S]	
To P.D=0.0	4.2 [R/S]	
L=0.000	10 [R/S]	
TO P.D=0.0	[R/S]	for last point, leave point as zero
FR P.C=0.00	1.01 [R/S]	for point 1, code 1 will be used
FR P.C=0.00	[R/S]	last FR P.C should be left as zero
CODE=0	1 [R/S]	the following data will define code 1
OD=0.000	10.75 [R/S]	inches
T=0.000	.365 [R/S]	inches
R=0.000	1.25 [R/S]	feet
E=0.00E0	27.9 [EEX] 6 [R/S]	psi using ENG notation
e=0.000000	.0226 [R/S]	thermal expansion coefficient (in/ft)
W/L=0.000	[R/S]	no weight applied to this problem
P=0.	[R/S]	no pressure applied to this problem
SC=0.	20000 [R/S]	cold allowable stress (psi)
SH=0.	15000 [R/S]	hot allowable stress (psi)
CODE=0	[R/S]	
CW PT=0	[R/S]	there is no concentrated weight in this problem
R P.D=0.0	[R/S]	there are no restraints in this problem
AM PT=0	1 [R/S]	there is an anchor movement at point 1
DX=0.0000	[R/S]	there is no AM in the X-direction
DY=0.0000	[R/S]	
DZ=0.0000	.12 [CHS] [R/S]	
AM PT=0	4 [R/S]	
DX=0.0000	[R/S]	
DY=0.0000	.25 [CHS] [R/S]	
DZ=0.0000	[R/S]	
AM PT=0	[R/S]	
EEC PT=0	[R/S]	there are no elastic end conditions in this problem
EJ PT=0	[R/S]	there are no expansion joints in this problem

TO P.D=1.0	[PF Key F]	PipeStar will wrap around and start over with the first input; rather than review all input data again, PF Key F may be pressed to analyze the problem
THERMAL CASE		PipeStar indicates how the analysis is progressing
TO POINT 2		
TO POINT 3		
TO POINT 4		
SOLVING EQNS		
STRESS CALCS		
MAX 34 9,544.	[R/S]	this indicates that PipeStar is finished with the analysis and the program stops; the display shows the stress (9,544. psi) that is the maximum percentage (34%) of the Code allowable stress
POINT=3I	[R/S]	the MAX is located at the initial node at the elbow at point 3
STRESS CALCS		this is displayed momentarily while the stress calculations are being performed
1 28 7,774.	[R/S]	the first number is the point number (1); the second number is the percent of the allowable stress that the stress is (28); the last number is the actual stress (7,774. psi)
STRESS CALCS		
2I 31 8,836.	[R/S]	the initial node point at the elbow at point 2
STRESS CALCS		
2F 33 9,302.	[R/S]	the final node point at the elbow at point 2
STRESS CALCS		
3I 34 9,544.	[R/S]	
STRESS CALCS		
3F 31 8,879.	[R/S]	
STRESS CALCS		
4 24 6,743.	[R/S]	
ANCHOR=1	[R/S]	the forces & moments acting onto anchor 1 follow
FX=-2,285.	[R/S]	pounds
FY=-1,540.	[R/S]	
FZ=1,301.	[R/S]	
MX=-11,066.	[R/S]	foot-pounds
MY=14,679.	[R/S]	
MZ=-6,116.	[R/S]	
ANCHOR=4	[R/S]	the forces & moments acting onto anchor 2 follow
FX=2,285.	[R/S]	
FY=1,540.	[R/S]	
FZ=-1,301.	[R/S]	

MX=8,667. [R/S]
MY=-4,838. [R/S]
MZ=13,558. [R/S]
MAX 34 9,544. this routine wraps back around to the MAX

The internal forces and moments at any individual point may be examined by setting Flag 04, entering the point number in question into the X-register, and pressing PF Key G. Similarly, the external loads onto any anchor or restraint (not in this problem) may be examined, except that PF Key H would be pressed instead of PF Key G.

The printout for the above problem is shown below. It should be noted that the "O"ut-plane stress intensification factor did not print since B31.1 Code was used. The above problem is discussed using Metric units on the next page in Example Problem 2.

```
PIPESTAR 2.02
CODE=B31.1
UNITS=ENGL.
CASE=THERMAL

 1:14 PM
02/05/88

TO P.D=1.0
TO P.D=2.3
L=-10.000
TO P.D=3.1
L=10.000
TO P.D=4.2
L=10.000
TO P.D=0.0

FR P.C=1.01
FR P.C=0.00

CODE=1
OD=10.750
T=0.365
R=1.250
E=27.9E6
e=0.022600
W/L=0.000
P=0.
SC=20,000.
SH=15,000.
K=8.126
I=2.605

CODE=0

CW PT=0

R P.D=0.0

AM PT=1
DX=0.0000
DY=0.0000
DZ=-0.1200

AM PT=4
DX=0.0000
DY=-0.2500
DZ=0.0000

AM PT=0

EEC PT=0

EJ PT=0

MAX 34  9,544.
POINT=3I

1  28  7,774.
2I 31  8,836.
2F 33  9,302.
3I 34  9,544.
3F 31  8,879.
4  24  6,743.

ANCHOR=1
X=0.000
Y=0.000
Z=0.000
FX=-2,285.
FY=-1,540.
FZ=1,301.
MX=-11,066.
MY=14,679.
MZ=-6,116.

ANCHOR=4
X=10.000
Y=10.000
Z=-10.000
FX=2,285.
FY=1,540.
FZ=-1,301.
MX=8,667.
MY=-4,838.
MZ=13,558.
```

Example Problem 2

This problem is the same as Example Problem 1, except that Metric units are used; therefore, Flag 00 should be Set. The status of Flags 01 - 05 would be the same as in Problem 1. For this problem, millimeters will be used for units of length and newtons will be used for units of force. The conversions from the pertinent English to Metric units are listed below.

1 inch = 25.4 mm
1 foot = 304.8 mm
1 pound = 4.4482 newtons
1 psi = 0.006894724 N/mm^2 (MPa)
1 ft-lb = 1,355.81136 N-mm

Since the input procedure is the same as that used for Example Problem 1 (of course, the numbers would be different), a keystroke listing will not be repeated here. Instead, just a printout of the problem, with the above Metric conversions, is shown on the next page. Flag 28 (the decimal point flag) was Cleared for this printout, as it might often be by a user who also uses Metric units.

The printout for Example Problem 2 is shown below:

```
PIPESTAR 2.02
CODE=B31.1
UNITS=METRIC
CASE=THERMAL

 1:19 PM
02/05/88

TO P,D=1,0
TO P,D=2,3
L=-3.048,000
TO P,D=3,1
L=3.048,000
TO P,D=4,2
L=3.048,000
TO P,D=0,0

FR P,C=1,01
FR P,C=0,00

CODE=1
OD=273,050
T=9,271
R=381,000
E=192,E3
e=0,001883
W/L=0,000
P=0,000
SC=138,
SH=103,
K=8,126
I=2,605
```

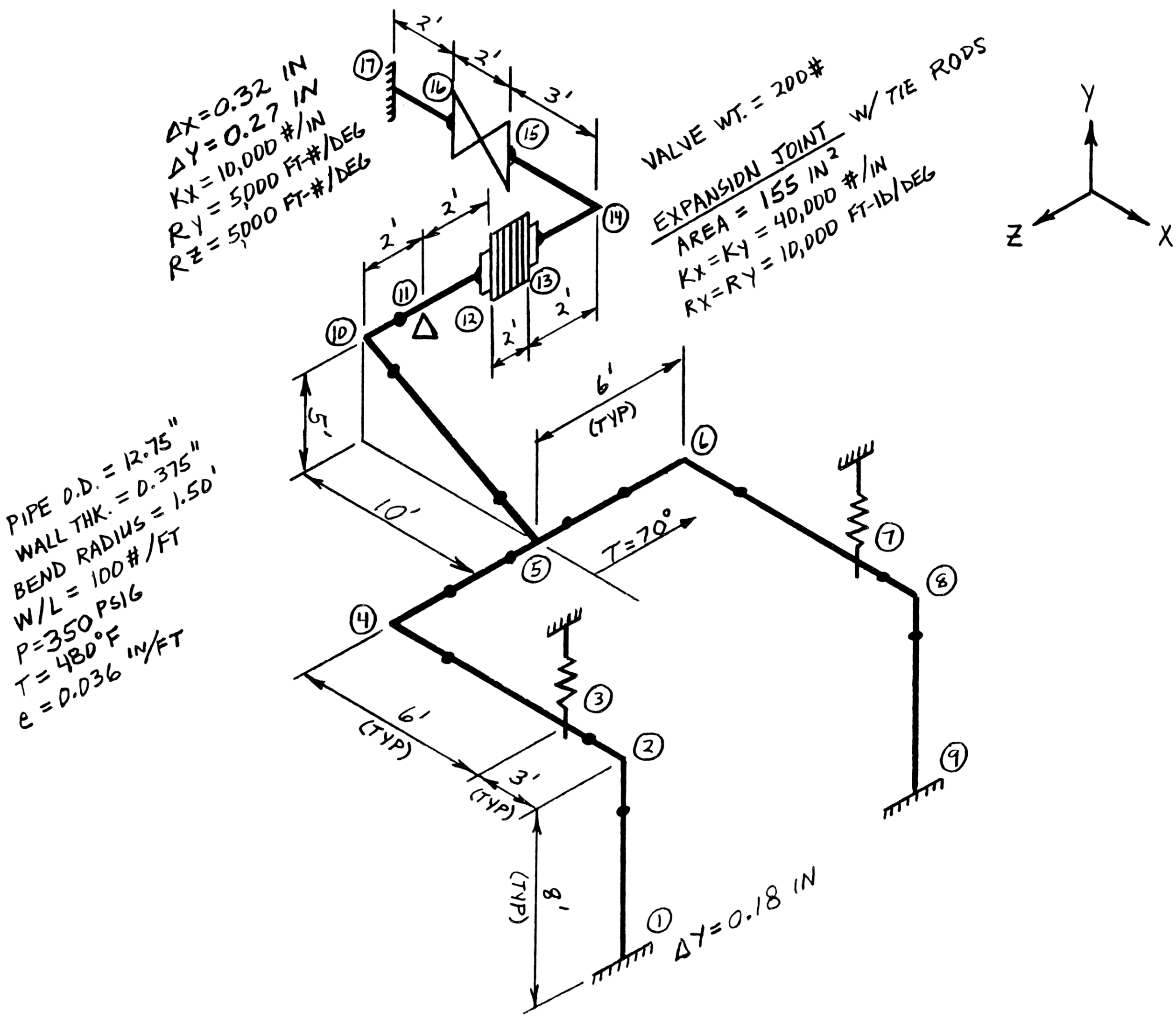
```
CODE=0

CW PT=0

R P,D=0,0

AM PT=1
DX=0,0000
DY=0,0000
DZ=-3,0480

AM PT=4
DX=0,0000
DY=-6,3500
DZ=0,0000

AM PT=0

EEC PT=0

EJ PT=0
```

```
MAX 34  66,
POINT=3I

1  28  54,
2I 31  61,
2F 33  64,
3I 34  66,
3F 31  61,
4  24  46,

ANCHOR=1
X=0,000
Y=0,000
Z=0,000
FX=-10.163,
FY=-6.852,
FZ=5.785,
MX=-15.003.897,
MY=19.902.289,
MZ=-8.292.510,

ANCHOR=4
X=3.048,000
Y=3.048,000
Z=-3.048,000
FX=10.163,
FY=6.852,
FZ=-5.785,
MX=11.751.306,
MY=-6.559.487,
MZ=18.382.721,
```

Example Problem 3

The piping configuration for Example Problem 3 is shown below followed by an annotated printout. English units are used and a combined-loads (T+W+P) case is run and analyzed per ANSI/ASME B31.3.

Note: This problem requires 134 registers for the input data and, therefore, can't be done without an Extended Memory (XM) module. To simplify the problem for use without an XM module, the EEC and the EJ entries may be left out. Results will be different, but the interpretation of the results given in the annotation will be the same. The MAX for this problem without the EEC and the EJ will be 57% and 24,726. psi (if this MAX is obtained then all other results should be correct also).



An annotated printout of the input and output for Example Problem 3 is shown below:

Printout	Notes
PIPESTAR 2.02	
CODE=B31.3	ANSI/ASME Code B31.3
UNITS=ENGL.	English units
CASE=T+W+P	this is a combined-loading case (i.e., thermal, weight, and pressure; flags 2 and 3 are set)
1:52 PM	time and date are displayed when using HP-41's with time
02/05/88	functions
TO P.D=1.0	.0 represents no direction going TO point 1
TO P.D=2.2	the pipe going to point 2 is in the y-direction
L=8.000	the pipe going to point 2 is 8 feet long, including the elbow radius
TO P.D=3.,1	
L=-3.000	
TO P.D=4.1	
L=-6.000	
TO P.D=5.3	
L=-6.000	
TO P.D=6.3	
L=-6.000	
TO P.D=7.1	
L=6.000	
TO P.D=8.1	
L=3.000	
TO P.D=9.2	
L=-8.000	
TO P.D=5.0	the beginning of the last branch, like the first point, would have zero direction
TO P.D=10.1	
L=-10.000	
TO P.D=10.2	notice how the skew line to point 10 is entered
L=5.000	
TO P.D=11.3	
L=-2.000	
TO P.D=12.3	
L=-2.000	
TO P.D=13.3	
L=-2.000	
TO P.D=14.3	
L=-2.000	
TO P.D=15.1	
L=-3.000	
TO P.D=16.1	
L=-2.000	
TO P.D=17.1	
L=-1.000	
TO P.D=0.0	

FR P.C=1.01	beginning at point 1, code 1 will be used
FR P.C=5.02	beginning at point 5, code 2 will be used (for cold pipe)
FR P.C=5.01	note how code was applied twice at tee; code can be applied at the tee at point 5 (going to point 10) only if another code is applied somewhere between (and including) point 5 (going to point 6) and point 9.
FR P.C=15.03	code 3 will be used for the valve
FR P.C=16.01	the point after the valve will have hot standard pipe
FR P.C=0.00	
CODE=1	this code will be used for hot standard pipe
OD=12.750	outside diameter (inches)
T=0.375	pipe wall thickness (inches)
R=1.500	bend radius (feet)
E=27.9E6	modulus of elasticity (psi)
e=0.036000	thermal expansion rate (in/ft)
W/L=100.000	weight per length (lb/ft)
P=350.	internal design pressure (gage; psi)
SC=20,000.	allowable stress at cold temperature
SH=15,000.	allowable stress at hot temperature
K=8.710	flexibility factor
I=2.622	in-plane stress intensification factor
O=2.185	out-plane stress intensification factor
CODE=2	this code will be used for the cold standard pipe
OD=12.750	
T=0.375	
R=1.500	
E=27.9E6	
e=0.000000	no thermal expansion since this is cold pipe
W/L=100.000	
P=350.	
SC=20,000.	
SH=20,000.	SH = SC for cold pipe
K=8.710	
I=2.622	
O=2.185	
CODE=3	this code will be used to model the valve
OD=12.750	
T=0.375	
R=0.000	since there are no elbows where this code is used, it is not necessary to enter a radius
E=100.E6	a higher stiffness is used to approximate the valve
e=0.036000	
W/L=0.000	a distributed load could have been applied to simulate the valve and would have been more accurate; however, the valve weight was instead modeled as two point loads as discussed below
P=350.	
SC=20,000.	
SH=15,000.	
K=1.000	

`I=1.000`	
`O=1.000`	
`CODE=0`	
`TEE CODE=1 W`	this is weld tee as specified by the "1" and the "W"
`I=1.879`	
`O=2.172`	
`CW PT=3`	this will apply a concentrated weight at point 3 (as a modeling technique for T+W+P, a negative (upward) concentrated weight is used at the spring hangers at points 3 and 7 to simulate pre-loading of the springs so that the pipe weight will be supported, but thermal expansion may be absorbed)
`WT=-3,000.`	concentrated weight (pounds)
`CW PT=7`	
`WT=-3,000.`	
`CW PT=15`	the valve weight is modeled here as two point loads at points 15 and 16
`WT=100.`	
`CW PT=16`	
`WT=100.`	
`CW PT=0`	
`R P.D=3.0`	y-restraint at point 3; note how this y-support was modeled without a direction; if a .1 or a .3 isn't specified for an X or Z restraint, PipeStar assumes the restraint is a Y support
`K=500.`	this is the spring rate (lbs/in)
`D=0.0000`	restraint movement would be applied here (inches)
`R P.D=7.0`	
`K=500.`	
`D=0.0000`	
`R P.D=11.0`	
`K=0.`	zero spring rate is treated as completely rigid
`D=0.0000`	
`R P.D=0.0`	
`AM PT=1`	anchor movement at point the first anchor, point 1
`DX=0.0000`	
`DY=0.1800`	anchor displacement in the y direction (inches)
`DZ=0.0000`	
`AM PT=17`	anchor movement at the third anchor, point 17
`DX=0.3200`	
`DY=0.2700`	
`DZ=0.0000`	
`AM PT=0`	

EEC PT=17	elastic end conditions at the third anchor, point 17
KX=10,000.	translational flexibility (lbs/in)
KY=0.	an entry of zero is treated as complete rigidity
KZ=0.	
RX=0.	
RY=5,000.	rotational flexibility (ft-lbs/degree)
RZ=5,000.	

EEC PT=0

EJ PT=12	expansion joint beginning at point 12
AREA=0.	this expansion joint has tie-rods so it is assumed that pressure
KX=0.	won't have any effect on it, so AREA was ignored
KY=40,000.	translational flexibility (lbs/in)
KZ=40,000.	
RX=0.	when zero is entered, PipeStar will apply the stiffness of regular
RY=10,000.	pipe
RZ=10,000.	rotational flexibility (ft-lbs/degree)

EJ PT=0

MAX 35 15,232.	the stress that is the maximum percentage of the allowable
POINT=5	stress (15,232 psi is 35% of the allowable); at point 5

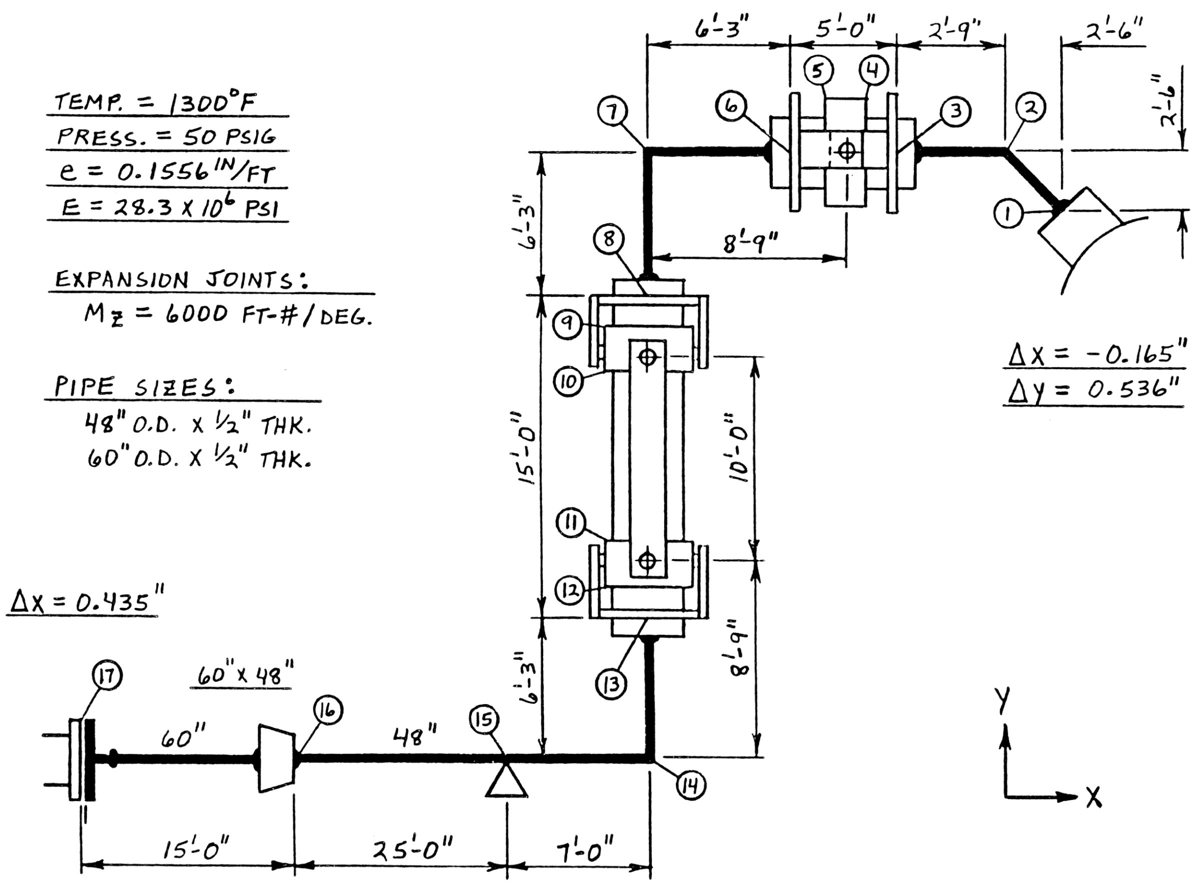
1	27	11,695.	the percent (27%) and stress (11,695 psi) at point 1
2I	24	10,294.	this is the initial node at the elbow at point 2
2F	33	14,034.	this is the final node at the elbow at point 2
3	15	6,401.	
4I	28	12,136.	
4F	21	9,152.	
5	35	15,232.	this is the branch of the tee coming from point 4
5	11	5,285.	this is the branch of the tee going to point 6
6I	14	6,878.	
6F	14	6,997.	
7	9	4,424.	
8I	9	4,448.	
8F	8	3,828.	
9	9	4,352.	
5	32	13,599.	this is the branch of the tee going to point 10
10I	34	14,664.	
10F	30	12,952.	
11	14	5,803.	
12	7	3,016.	
13	13	5,254.	
14I	27	11,680.	
14F	31	13,479.	
15	12	5,036.	
16	7	2,979.	
17	7	2,858.	

ANCHOR=1	the first anchor, point 1
X=0.000	these are the global geometric coordinates, useful for checking
Y=0.000	that geometry was correctly input
Z=0.000	
FX=5,818.	these are the forces acting onto the anchor at point 1
FY=-2,768.	
FZ=2,897.	
MX=15,454.	these are the moments acting onto the anchor at point 1
MY=9,619.	
MZ=-28,103.	
ANCHOR=9	
X=0.000	
Y=0.000	
Z=-12.000	
FX=-284.	
FY=1,516.	
FZ=873.	
MX=5,029.	
MY=2,259.	
MZ=970.	
ANCHOR=17	
X=-25.000	
Y=13.000	
Z=-14.000	
FX=-5,534.	
FY=-791.	
FZ=-3,770.	
MX=429.	
MY=1,491.	
MZ=-1,110.	
3 FY=174.	the force the pipe is exerting onto the restraint at point 3
3 DY=0.3482	the displacement at restraints is displayed whenever it is not
7 FY=1.	zero
7 DY=0.0012	
11 FY=1,136.	

Example Problem 4

The piping configuration for Example Problem 4 is shown below, and the printout is shown on the following pages. English units are used and a thermal analysis is performed per ANSI/ASME B31.3. This problem shows how hinge joints might be modeled, and is taken from a real problem. Each of the three bellows in this problem is modeled as one foot long. The hinged portion is modeled without any thermal expansion since it doesn't get as hot as the rest of the pipe. The two hinge joints between points 8 and 13 can also rotate about the X-axis, but this is not important here.

This problem as printed out, requires 128 Extended Memory (XM) data registers. If an XM module is not being used, then only 124 XM data registers will be available to work with. To accommodate this, the anchor movements at point 17 may be removed and subtracted from the anchor movements at point 1 (i.e., DX=-0.6000 at point 1).



```
PIPESTAR 2.02
CODE=B31.3
UNITS=ENGL.
CASE=THERMAL

 2:48 PM
02/05/88

TO P.D=1.0
TO P.D=2.2
L=2.500
TO P.D=2.1
L=-2.500
TO P.D=3.1
L=-2.750
TO P.D=4.1
L=-2.000
TO P.D=5.1
L=-1.000
TO P.D=6.1
L=-2.000
TO P.D=7.1
L=-6.250
TO P.D=8.2
L=-6.250
TO P.D=9.2
L=-2.000
TO P.D=10.2
L=-1.000
TO P.D=11.2
L=-9.000
TO P.D=12.2
L=-1.000
TO P.D=13.2
L=-2.000
TO P.D=14.2
L=-6.250
TO P.D=15.1
L=-7.000
TO P.D=16.1
L=-25.000
TO P.D=17.1
L=-15.000
TO P.D=0.0

FR P.C=1.01
FR P.C=3.02
FR P.C=6.01
FR P.C=8.02
FR P.C=13.01
FR P.C=16.03
FR P.C=0.00
```

```
CODE=1
OD=48.000
T=0.500
R=6.000
E=28.3E6
e=0.155600
W/L=0.000
P=50.
SC=20,000.
SH=3,700.
K=22.973
I=4.747
O=3.956

CODE=2
OD=48.000
T=0.500
R=0.000
E=28.3E6
e=0.000000
W/L=0.000
P=50.
SC=20,000.
SH=3,700.
K=1.000
I=1.000
O=1.000

CODE=3
OD=60.000
T=0.500
R=0.000
E=28.3E6
e=0.155600
W/L=0.000
P=50.
SC=20,000.
SH=3,700.
K=1.000
I=1.000
O=1.000

CODE=0

CW PT=0
```

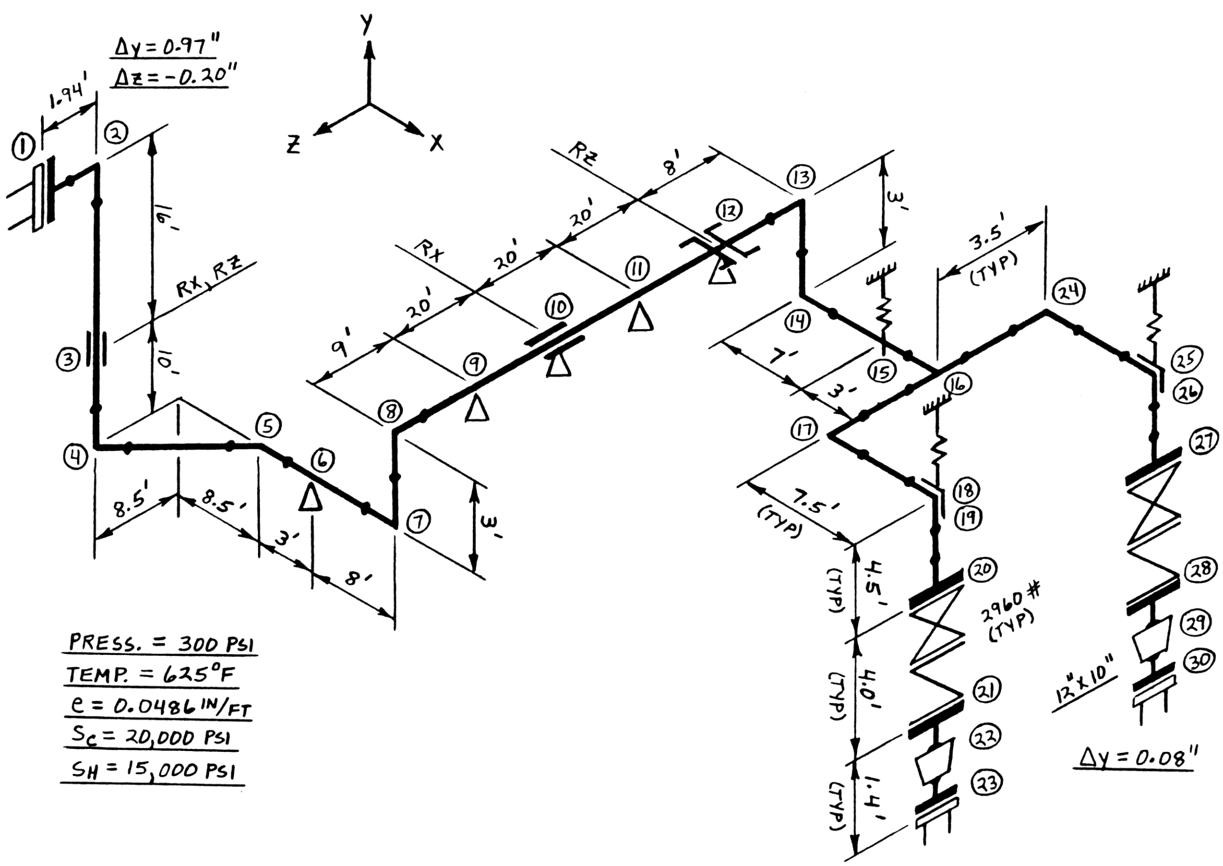
```
R P.D=15.0
K=0.
D=0.0000

R P.D=0.0

AM PT=1
DX=-0.1650
DY=0.5360
DZ=0.0000

AM PT=17
DX=0.4350
DY=0.0000
DZ=0.0000

AM PT=0

EEC PT=0

EJ PT=4
AREA=0.
KX=0.
KY=0.
KZ=0.
RX=0.
RY=0.
RZ=6,000.

EJ PT=9
AREA=0.
KX=0.
KY=0.
KZ=0.
RX=0.
RY=0.
RZ=6,000.

EJ PT=11
AREA=0.
KX=0.
KY=0.
KZ=0.
RX=0.
RY=0.
RZ=6,000.

EJ PT=0
```

```
MAX 22  5,461.
POINT=2I

1    6  1,314.
2I  22  5,461.
2F   8  1,993.
3    2  383.
4    1  108.
5    1  30.
6    2  305.
7I   7  1,613.
7F  13  3,167.
8    3  646.
9    2  480.
10    2  397.
11    2  351.
12    2  435.
13    3  601.
14I  12  2,951.
14F   6  1,397.
15    1  156.
16    1  3.
17    1  62.

ANCHOR=1
X=0.000
Y=0.000
Z=0.000
FX=6,076.
FY=10,064.
FZ=0.
MX=0.
MY=0.
MZ=-96,042.

ANCHOR=17
X=-63.500
Y=-25.000
Z=0.000
FX=-6,076.
FY=-465.
FZ=0.
MX=0.
MY=0.
MZ=-7,156.

15 FY=-9,599.
```

Example Problem 5

The piping configuration for Example Problem 5 is shown below, and the printout is shown on the following pages. English units are used and, initially, a thermal analysis is run per ANSI/ASME B31.3 (pp. 50 - 51), followed by a weight analysis (pp. 52 - 53). The Weight per Length (W/L) used in this problem was calculated using the standard default values in the W/L subroutine and an insulation thickness of 3 inches. This problem requires 189 Extended Memory (XM) data registers and can not be done without an XM module. To avoid potentially losing XM data per the caution when modeling, as here, more than 19 degrees of freedom (see the restraint caution on page 22), it might be a good idea to first run this problem without any restraints to ensure that there are no geometry, code, or length errors.

Notice that elastic end conditions that were applied to the first anchor during the thermal run were removed during the weight run. Also, notice how elastic end conditions were applied to the anchors at points 23 and 30 to simulate free anchors during the weight run (this was done to determine how much weight the spring hangers at points 19 and 26 would need to support so that the anchors would carry no load, a desireable result since they are connected to pump nozzles). Also, notice how the lengths of pipe to points 8 and 14 were changed from 3.000 feet to 3.001 feet so that there would be no zero-length of straight pipe between the elbows at points 7, 8, 13, and 14.



```
PIPESTAR 2.02
CODE=B31.3
UNITS=ENGL.
CASE=THERMAL

 3:44 PM
02/05/88

TO P.D=1.0
TO P.D=2.3
L=-1.940
TO P.D=3.2
L=-16.000
TO P.D=4.2
L=-10.000
TO P.D=5.1
L=8.500
TO P.D=5.3
L=-8.500
TO P.D=6.1
L=3.000
TO P.D=7.1
L=8.000
TO P.D=8.2
L=3.001
TO P.D=9.3
L=-9.000
TO P.D=10.3
L=-20.000
TO P.D=11.3
L=-20.000
TO P.D=12.3
L=-20.000
TO P.D=13.3
L=-8.000
TO P.D=14.2
L=-3.001
TO P.D=15.1
L=7.000
TO P.D=16.1
L=3.000
TO P.D=17.3
L=3.500
TO P.D=18.1
L=7.500
TO P.D=19.2
L=-2.000
TO P.D=20.2
L=-2.500
TO P.D=21.2
L=-4.000
TO P.D=22.2
L=-0.700
TO P.D=23.2
L=-0.700
TO P.D=16.0
TO P.D=24.3
L=-3.500
TO P.D=25.1
L=7.500
TO P.D=26.2
L=-2.000
TO P.D=27.2
L=-2.500
TO P.D=28.2
L=-4.000
TO P.D=29.2
L=-0.700
TO P.D=30.2
L=-0.700
TO P.D=0.0

FR P.C=1.01
FR P.C=20.02
FR P.C=21.01
FR P.C=22.03
FR P.C=16.01
FR P.C=27.02
FR P.C=28.01
FR P.C=29.03
FR P.C=0.00

CODE=1
OD=12.750
T=0.375
R=1.500
E=27.9E6
e=0.048600
W/L=109.957
P=300.
SC=20,000.
SH=15,000.
K=8.797
I=2.653
O=2.211

CODE=2
OD=12.750
T=0.375
R=0.000
E=300.E6
e=0.048600
W/L=0.000
P=300.
SC=20,000.
SH=15,000.
K=1.000
I=1.000
O=1.000

CODE=3
OD=10.750
T=0.365
R=0.000
E=27.9E6
e=0.048600
W/L=84.596
P=300.
SC=20,000.
SH=15,000.
K=1.000
I=1.000
O=1.000

CODE=0

TEE CODE=1 W
I=1.879
O=2.172

CW PT=20
WT=2,960.
CW PT=27
WT=2,960.
CW PT=0

R P.D=3.1
K=0.
D=0.0000

R P.D=3.3
K=0.
D=0.0000

R P.D=6.0
K=0.
D=0.0000

R P.D=9.0
K=0.
D=0.0000

R P.D=10.1
K=0.
D=0.0000

R P.D=10.0
K=0.
D=0.0000
```

```
R P.D=11.0
K=0.
D=0.0000

R P.D=12.0
K=0.
D=0.0000

R P.D=12.3
K=0.
D=0.0000

R P.D=15.0
K=1.
D=0.0000

R P.D=19.0
K=1.
D=0.0000

R P.D=26.0
K=1.
D=0.0000

R P.D=0.0

AM PT=1
DX=0.0000
DY=0.9700
DZ=-0.2000

AM PT=23
DX=0.0000
DY=0.0800
DZ=0.0000

AM PT=30
DX=0.0000
DY=0.0800
DZ=0.0000

AM PT=0

EEC PT=1
KX=0.
KY=0.
KZ=100,000.
RX=80,000.
RY=50,000.
RZ=0.

EEC PT=0
```

```
EJ PT=0

MAX 71  20,254.
POINT=8F

1   13   3,542.
2I  26   7,372.
2F  18   5,082.
3   21   5,982.
4I  33   9,457.
4F  43   12,356.
5I   6   1,693.
5F  15   4,282.
6   14   3,985.
7I  66   18,904.
7F  35   9,989.
8I  35   9,959.
8F  71   20,254.
9   22   6,173.
10   15   4,240.
11   10   2,794.
12    6   1,458.
13I   9   2,443.
13F   4   1,002.
14I   4   1,029.
14F   6   1,540.
15    8   2,107.
16   22   6,243.
16   18   5,121.
17I  16   4,429.
17F  10   2,830.
18I   6   1,518.
18F  11   3,133.
19    6   1,468.
20   10   2,764.
21   17   4,857.
22   19   5,224.
23   29   8,193.
16    2   484.
24I   8   2,182.
24F   9   2,417.
25I  22   6,122.
25F  17   4,672.
26   10   2,788.
27   11   2,892.
28   16   4,582.
29   18   4,969.
30   28   7,866.
```

```
ANCHOR=1
X=0.000
Y=0.000
Z=0.000
FX=354.
FY=1,499.
FZ=-825.
MX=462.
MY=-12,166.
MZ=-4,361.

ANCHOR=23
X=37.000
Y=-35.900
Z=-83.940
FX=-1,838.
FY=385.
FZ=549.
MX=5,257.
MY=1,041.
MZ=19,702.

ANCHOR=30
X=37.000
Y=-35.900
Z=-90.940
FX=1,585.
FY=-856.
FZ=-1,867.
MX=-15,529.
MY=-9,017.
MZ=-7,861.

3 FX=-2,117.
3 FZ=4,020.
6 FY=-3,324.
9 FY=2,477.
10 FX=2,015.
10 FY=-799.
11 FY=94.
12 FY=524.
12 FZ=-1,877.
15 FY=0.
15 DY=0.2154
19 FY=0.
19 DY=0.4640
26 FY=0.
26 DY=0.4638
```

```
PIPESTAR 2.02
CODE=B31.3
UNITS=ENGL.
CASE=WEIGHT

 4:02 PM
02/05/88

TO P.D=1.0
TO P.D=2.3
L=-1.940
TO P.D=3.2
L=-16.000
TO P.D=4.2
L=-10.000
TO P.D=5.1
L=8.500
TO P.D=5.3
L=-8.500
TO P.D=6.1
L=3.000
TO P.D=7.1
L=8.000
TO P.D=8.2
L=3.001
TO P.D=9.3
L=-9.000
TO P.D=10.3
L=-20.000
TO P.D=11.3
L=-20.000
TO P.D=12.3
L=-20.000
TO P.D=13.3
L=-8.000
TO P.D=14.2
L=-3.001
TO P.D=15.1
L=7.000
TO P.D=16.1
L=3.000
TO P.D=17.3
L=3.500
TO P.D=18.1
L=7.500
TO P.D=19.2
L=-2.000
TO P.D=20.2
L=-2.500
TO P.D=21.2
L=-4.000
TO P.D=22.2
L=-0.700
TO P.D=23.2
L=-0.700
TO P.D=16.0
TO P.D=24.3
L=-3.500
TO P.D=25.1
L=7.500
TO P.D=26.2
L=-2.000
TO P.D=27.2
L=-2.500
TO P.D=28.2
L=-4.000
TO P.D=29.2
L=-0.700
TO P.D=30.2
L=-0.700
TO P.D=0.0

FR P.C=1.01
FR P.C=20.02
FR P.C=21.01
FR P.C=22.03
FR P.C=16.01
FR P.C=27.02
FR P.C=28.01
FR P.C=29.03
FR P.C=0.00

CODE=1
OD=12.750
T=0.375
R=1.500
E=27.9E6
e=0.048600
W/L=109.957
P=300.
SC=20,000.
SH=15,000.
K=8.797
I=2.653
O=2.211

CODE=2
OD=12.750
T=0.375
R=0.000
E=300.E6
e=0.048600
W/L=0.000
P=300.
SC=20,000.
SH=15,000.
K=1.000
I=1.000
O=1.000

CODE=3
OD=10.750
T=0.365
R=0.000
E=27.9E6
e=0.048600
W/L=84.596
P=300.
SC=20,000.
SH=15,000.
K=1.000
I=1.000
O=1.000

CODE=0

TEE CODE=1 W
I=1.879
O=2.172

CW PT=20
WT=2,960.
CW PT=27
WT=2,960.
CW PT=0

R P.D=3.1
K=0.
D=0.0000

R P.D=3.3
K=0.
D=0.0000

R P.D=6.0
K=0.
D=0.0000

R P.D=9.0
K=0.
D=0.0000

R P.D=10.1
K=0.
D=0.0000

R P.D=10.0
K=0.
D=0.0000
```

```
R P.D=11.0
K=0.
D=0.0000

R P.D=12.0
K=0.
D=0.0000

R P.D=12.3
K=0.
D=0.0000

R P.D=15.0
K=1.
D=0.0000

R P.D=19.0
K=1.
D=0.0000

R P.D=26.0
K=1.
D=0.0000

R P.D=0.0

AM PT=1
DX=0.0000
DY=0.9700
DZ=-0.2000

AM PT=23
DX=0.0000
DY=0.0800
DZ=0.0000

AM PT=30
DX=0.0000
DY=0.0800
DZ=0.0000

AM PT=0

EEC PT=23
KX=1.
KY=1.
KZ=1.
RX=1.
RY=1.
RZ=1.

EEC PT=30
KX=1.
KY=1.
KZ=1.
RX=1.
RY=1.
RZ=1.

EEC PT=0

EJ PT=0

MAX 20  2,492.
POINT=2I

1   11  1,370.
2I  20  2,492.
2F  11  1,337.
3    3  308.
4I   4  494.
4F   4  502.
5I   2  193.
5F   7  767.
6    8  920.
7I   2  131.
7F   2  204.
8I   2  180.
8F   2  163.
9   13  1,586.
10    7  848.
11    9  1,072.
12    8  900.
13I   1  79.
13F   2  177.
14I   2  204.
14F   1  70.
15    9  1,030.
16    4  465.
16    8  989.
17I   3  317.
17F   4  489.
18I   4  455.
18F   1  38.
19    1  41.
20    2  212.
21    1  9.
22    1  4.
23    1  6.E-3
16    8  946.
24I   3  313.
24F   5  574.
25I   4  480.
25F   1  39.
26    1  43.
27    2  212.
28    1  9.
29    1  4.
30    1  7.E-3

ANCHOR=1
X=0.000
Y=0.000
Z=0.000
FX=47.
FY=-3,565.
FZ=-85.
MX=-4,978.
MY=-124.
MZ=105.

ANCHOR=23
X=37.000
Y=-35.900
Z=-83.940
FX=0.
FY=0.
FZ=0.
MX=0.
MY=0.
MZ=0.

ANCHOR=30
X=37.000
Y=-35.900
Z=-90.940
FX=0.
FY=0.
FZ=0.
MX=0.
MY=0.
MZ=0.

3 FX=-46.
3 FZ=85.
6 FY=-1,910.
9 FY=-2,392.
10 FX=-1.
10 FY=-2,023.
11 FY=-2,272.
12 FY=-1,936.
12 FZ=0.
15 FY=-2,648.
19 FY=-3,973.
26 FY=-3,996.
```

Solution Technique and Stress Calculations

PipeStar uses a form of finite element analysis (FEA), optimized for the HP-41, to accurately analyze piping flexibility. More specifically, PipeStar considers a piping system as being made up of discrete linear elements connected at common points or nodes. It analyzes each element independently and uses the elastic properties of the element being analyzed to relate the forces to the deformations at each end of that element. Matrix methods are then used to combine the elements mathematically and to then determine the behavior of the entire piping system.

In performing its calculations, PipeStar makes some simplifying assumptions which shouldn't significantly affect the accuracy of any calculations. These are listed:

- The force-deformation relations for each structural material are considered to be linear (i.e., the generalized Hooke's law is assumed to be true over the full range of deformation).

- Poisson's ratio is considered to be 0.3 for all materials and temperatures.

- A shear distribution factor of 2.0 is used with all pipe wall thicknesses.

- Bending moment contributions that result from axial forces acting through lateral deformations are neglected.

- The difference between an arc and a chord during structural deformation is neglected.

- The weight of an elbow is modeled as two point loads where half of the elbow weight is applied as a concentrated weight at each end of the elbow.

Once the forces and moments have been calculated for a piping configuration, the stresses may be calculated. It is one of the main purposes of PipeStar to calculate stresses in accordance with the ANSI/ASME B31.1 and B31.3 Piping Codes. The stresses calculated are those that result from thermal expansion, weight loads, and/or pressure. The resultant stresses are also compared to allowable stresses. The equations used to calculate the resultant stresses and the allowable stress compliances are listed on the following page.

PipeStar Stress Equations

Case	ANSI/ASME B31.1
T only	$(1/Z)\,(i)\,(T^2 + M_i^2 + M_o^2)^{0.5}$
W only	$(1/Z)\,(.75\,i)\,(T^2 + M_i^2 + M_o^2)^{0.5}$ where $(.75\,i) \geqq 1$
T+W+P	$(1/Z)\,(i)\,(T^2 + M_i^2 + M_o^2)^{0.5} + S_{lp}$

Case	ANSI/ASME B31.3
T only	$(1/Z)\,[T^2 + (i_iM_i)^2 + (i_oM_o)^2]^{0.5}$
W only	$(1/Z)\,[T^2 + (i_iM_i)^2 + (i_oM_o)^2]^{0.5} + F_a/A_m$
T+W+P	$(1/Z)\,[T^2 + (i_iM_i)^2 + (i_oM_o)^2]^{0.5} + F_a/A_m + S_{lp}$

Case	Compliance Criteria (for both of above codes)
T only	$1.25\,S_c + .25\,S_h$
W only	$S_h - S_{lp}$
T+W+P	$1.25\,(S_c + S_h)$

Notes and definition of terms are on the following page.

Definition of Terms:

Z = section modulus = (PI/32) $(OD^4 - ID^4) / OD$
OD = outside diameter of pipe
ID = inside diameter of pipe
F_a = axial Force
A_m = metal area
S_{lp} = longitudinal pressure stress = $Pd_n^2/(D_n^2 - d_n^2)$
S_c = allowable stress at cold temperature
S_h = allowable stress at hot temperature
d_n = nominal inside diameter
D_n = nominal outside diameter
T = torque
M_i = in-plane bending moment
M_o = out-of-plane bending moment
i = B31.1 stress intensification factor (for weld elbows: $0.9 / h^{2/3}$)
i_i = in-plane stress intensification factor (for weld elbows: $0.9 / h^{2/3}$)
i_o = out-of-plane stress intensification factor (for weld elbows: $0.75 / h^{2/3}$)
h = flexibility characteristic (for weld elbows: tR / r^2)
t = nominal pipe wall thickness
R = bend radius
r = mean radius of pipe

Notes:

During weight-only runs, all restraints are modeled as rigid, and restraint and anchor movements are not applied.

The effects of pressure are included only in the equation for S_{lp} and, except during thermal-only runs, in the calculation of the forces and moments generated by pressure thrust on an expansion joint.

The resultant stresses given are the greater of the tensile stress or the compressive stress at a point; the sign, though, is always made positive. Axial stress (F_a/A_m, R_{12}) and longitudinal pressure stress (S_{lp}, R_{11}) are left with their original signs (+ is tensile, - is compressive).

The formulas given above for i, i_i, i_o, and h are the formulas specified by the codes for welding elbows or pipe bends, and, accordingly, these are the formulas that PipeStar uses when it calculates these factors. Likewise, 1.65/h is used to calculate the flexibility factor k.

The exact equation for the section modulus is used in all cases to calculate stresses, including at tees where the codes suggest a less conservative approximation.

Appendix A
Program Function Keys

The Program Function ("PF") keys used with PipeStar are shown below. These keys have been assigned to the top two rows of keys on the HP-41 keyboard, with the blue letters A through J written on the lower portion of them. The negative sign preceding some keys indicates that the key is a shifted key (the gold shift key must be pressed first). When any one of these keys is held down momentarily, the program function name will be displayed.

Also provided with PipeStar is a keyboard overlay (see page 16) to assist in recognizing where each Program Function key is located.

PF Key	Name	Program Function
A	PDL	Input: pipe geometry (Point, Direction, Length)
B	PT/CODE	Input: point/code relationships
C	CODE	Input: code data
D	TEE	Input: tee code and stress intensification factors
E	CON WT	Input: concentrated weights
- A	RESTR	Input: restraint data
- B	AM	Input: Anchor movements
- C	EEC	Input: data for elastic end conditions
- D	EJ	Input: data for expansion joints
- E	PRINT	Utility: produces a print out of all I/O
F	ANALYZE	PipeStar calculates forces, moments, and stresses
G	STRESS	Output: stresses and internal forces and moments
H	LOADS	Output: coor., displ., and external forces and moments
I	INSREG	Utility: insert registers (per number in Register 00)
J	DELREG	Utility: delete registers (per number in Register 00)
- F	MAXFL	Utility: create XM data file of maximum size
- G	W/L	Utility: calculate weight/length for input
- H	HELP	Help displays
- I	INSREGX	Utility: insert registers per number in the X-register
- J	DELREGX	Utility: delete registers per number in the X-register

Appendix B
Flags

The six USER Flags utilized by PipeStar are listed below.

Flag 00:	Clear:	Use English units
	Set:	Use Metric or User-defined units
Flag 01:	Clear:	Comply with ANSI B31.3 (petrochemical)
	Set:	Comply with ANSI B31.1 (power piping)
Flag 02:	Clear:	Do not perform thermal analysis
	Set:	Perform thermal analysis
Flag 03:	Clear:	Do not perform weight analysis
	Set:	Perform weight analysis
Flag 04:	Clear:	Do not display extra data
	Set:	Display extra data
Flag 05:	Clear:	PipeStar calculates new k and i factors
	Set:	PipeStar does not calculate new k and i factors

Appendix C
Units

When Flag 00 is Clear, English units are used, as described below. If Flag 00 is Set, then the units used can be metric or whatever the user desires as long as unitary consistency is maintained between the basic length and force units and combinations of such units thereof (e.g., stress is a force divided by a length squared) (thermal expansion is unitless) (for metric use, millimeters and newtons are suggested as basic length and force units - radians must be used for angular measurements).

Data	English	Suggested Metric
Allowable stresses (SC, SH)	psi	N/mm^2 or MPa
Anchor and restraint movements	in	mm
Concentrated weight (CON WT)	lbs	N
Coordinates (X, Y, Z)	ft	mm
Displacements (DX, DY, DZ)	in	mm
EJ pressure thrust area (AREA)	in^2	mm^2
Forces (FX, FY, FZ)	lbs	N
Length of pipe (L)	ft	mm
Modulus of elasticity (E)	psi	N/mm^2 or MPa
Moments (MX, MY, MZ)	ft-lbs	N-mm
Outside diameter of pipe (OD)	in	mm
Pressure, internal gage (P)	psig	N/mm^2 or MPa
Radius of elbow/bend (R)	ft	mm
Spring rates in rotation (R)	ft-lbs/deg	N-mm/rad
Spring rates in translation (K)	lbs/in	N/mm
Stresses (MAX S, S)	psi	N/mm^2 or MPa
Thermal expansion rate (e)	in/ft	mm/mm
Wall thickness of pipe (T)	inches	mm
Weight/Length (W/L)	lbs/ft	N/mm

Appendix D
Data Register Addresses

Input data (except for tee data) is stored in extended memory in the same order that it is entered, starting at the fourth XM register. The first three XM registers are reserved for data relating to the tee (whether there's a tee or not). XM input data may be "backed-up" by first transferring it to Main Memory using the GETR function and then transferring it to magnetic cards or other mass storage device (e.g., tape, discs; see the respective Owner's Manual for details).

The following register addresses indicate where selected output data is stored (in main memory). Data pertinent to a particular stress point may be viewed after the stress value for that point has been displayed.

Address	Data Stored
00	Point number (alpha data)
01	FX at the stress point
02	FY at the stress point
03	FZ at the stress point
04	MX at the stress point
05	MY at the stress point
06	MZ at the stress point
07	Percent (100 times the resultant stress/allowable stress)
08	Stress, resultant (this is the displayed stress)
09	Stress, allowable
10	Stress, from bending and torsion combined
11	Stress, from longitudinal pressure, when applicable
12	Stress, from axial force (F_a/A_m), when applicable
16 - 47	usually safe for temporary storage by user during data input and output

Appendix E
Error Messages

The following is a list of error messages that may be generated by the PipeStar module. If other error messages appear, see the appropriate HP-41 Owner's Manual.

Display	Possible Causes
CODE ERROR	▪ A code is not assigned to the first point. ▪ A code number specified is less than or equal to zero. ▪ The point specified for a code is less than or equal to zero. ▪ A code specified doesn't exist. ▪ The OD, T, or E is equal to zero. ▪ The OD is less than 2T.
ERR DOF>24	▪ More than 18 restraints were modeled for a 2-anchor system. ▪ More than 12 restraints were modeled for a 3-anchor system.
GEOMETRY ERR	▪ Two consecutive points have the same point number and direction. ▪ Three consecutive points have the same point number, regardless of direction. ▪ The angle between two pipe elements (with nonzero elbow radius) is not 0°, 45°, or 90° (a small tolerance is allowed). ▪ The point number is zero or negative. ▪ A direction is not defined (not .0, .1, .2, or .3) ▪ The first direction is not zero. ▪ There are more than three anchors. ▪ A 45° elbow is skewed about more than one axis.
LENGTH ERR	▪ The length of a straight pipe element is equal to, or less than, zero (may result from an overlapping elbow radius).
NO ROOM	▪ There are not enough XM data registers available (remedy by going to the end of EJ data and then pressing [R/S] to wrap-around to PDL data input; if this message still appears, then either some XM data files must be purged, or, another XM module must be installed).