Coiled-Tubing Stress Analysis Model
Stress/Drag/Hydraulic/Buckling

(CSTRESS1)

Theory and User's Manual

By

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Table of Contents

Table of Contents (Cont'd.)

Table of Contents (Cont'd.)

1. Introduction

The coiled-tubing stress analysis (coiled-tubing stress/drag/hydraulic/buckling) windows applications program (CSTRESS1) has been developed by Maurer Engineering Inc. as part of the DEA-67 project to "Develop and Evaluate Slim-Hole and Coiled-Tubing Technology." This program, coded in Visual Basic 1.0, is written for use with IBM or IBM compatible computers and must run with Microsoft Windows 3.0 or later version.

1.1 MODEL DESCRIPTION

CSTRESS1 is an integrated computer program of drag force, hydraulics, buckling, and triaxial stress analysis. It is a major rewrite of the coiled-tubing model, not just an update. The features of CSTRESS1 are listed below.

1.1.1 General Features

1. MS Windows applications.
2. Five operations: pick up (logging), slack off (logging), pick up (drilling — tripping), slack off (drilling — tripping), and drill.
3. Supports both color and monochrome monitors.
4. Supports English and metric unit systems.
5. Handles up to fifteen tube segments and twenty well intervals.
6. Coiled-tubing and casing data can be imported from the built-in data base file directly.
7. Enables the user to modify the data base within the program.
8. Allows input of pore and fracture pressures for different well interval.
9. Results, data and graphs, can be output to screen, printer, and disk file.
10. Selectable curves on output graphic presentation.

1.1.2 Drag Force, Axial Load, and Triaxial Stress

1. Computes axial drag on coiled-tubing during pick up, slack off, and drilling.
2. Computes axial load and stress on coiled-tubing during pick up, slack off, and drilling. The axial load and stress is based on tubing pressure, annulus pressure, pipe weight, and frictional force.
3. Bending stress (based on dogleg or helical buckling curvature) can be included in the calculation.
4. Extra frictional force caused by helical buckling can be included in the calculation.
5. Calculates triaxial stress and has both graphics and text output.
6. Calculates allowable working stress and pressure for biaxial and API stress criteria with graphic output.
7. Calculates maximum cable load.

1.1.3 Hydraulics

1. Calculates internal and external pressures on the tubing at various locations during tripping and drilling.
2. Calculates bottom-hole pressure and ECD during tripping.
3. Calculates ECD corresponding to the total pressure along the wellbore.
4. Plots pore and fracture pressures along the wellbore (optional).
5. Calculates pressure loss of the coiled tubing remaining on the reel.
6. Calculates the required pump horsepower.

1.1.4 Buckling

1. For compressive loads, the onset of 1) sinusoidal buckling, 2) helical buckling, and 3) limiting yield stress are indicated.
2. Two sinusoidal buckling criteria can be evaluated: 1) Exxon's equation, and 2) Texas A&M University's equation.
3. Two helical buckling criteria can be evaluated: 1) Rice University's equation, and 2) Texas A&M University's equation.

1.1.5 Tortuosity

1. Survey data can be ''tortured'' (add tortuosity along the trajectory of wellpath).
2. Allows insertion of equally spaced stations to survey data.
3. Different tortuosity amplitude and cycle lengths can be applied up to five wellpath intervals.

1.2 COPYRIGHT

1.3 DISCLAIMER

No warranty or representation is expressed or implied, with respect to these programs or documentation, including their quality, performance, merchantability, or fitness for a particular purpose.

2. Theory and Equations

2.1 AXIAL DRAG

The drag model is based on a simple mathematical model, developed by Exxon Production Research (Johancsik et al., 1984). The model assumes the loads on the tubing result solely from effects of gravity and frictional drag resulting from contact of the tubing with the wall of the hole. These frictional forces are the products of the normal force acting between the tubing and the wellbore and the coefficient of friction (friction factor). Two contributions to the normal force are considered for this model: 1) the effects of gravity on the tubing and 2) the effects of tension and compression acting through curvatures in the wellbore. Although bending may make minor contributions to normal force, its effect is neglected in this model.

The model considers the tubing to be made up of short segments joined by connections which transmit tension, compression and torsion, but not bending moment. The basic equations of friction are applied to each segment with the calculations starting at the bottom of the tubing and proceeding upward to the surface. Each short element thus contributes small increments of axial drag and weight. These forces are summed to produce the total loads on the tubing. For this version of CSTRESS, torsion is not taken into consideration.

2.1.1 Introduction to the Variables

Figure 2-1 is a simple free-body diagram of a single element of the tubing.

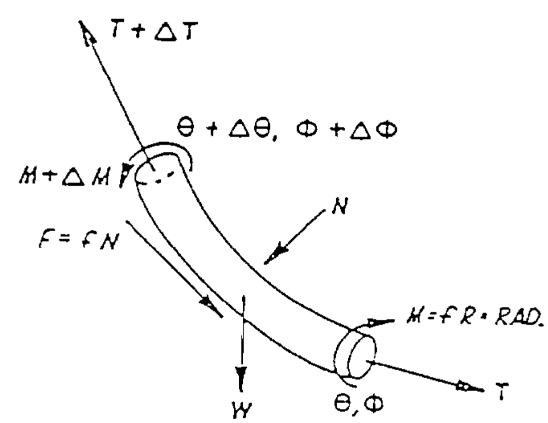


Figure 2-1. Free-Body Diagram of a Single Element

where:

f	=	Friction Factor
F	=	Axial Friction Force
M	=	Torque = 0 for Coiled Tubing
N	=	Normal Force
T	=	Tension
R	=	Effective Radius of Element
W_{T_M}	=	Buoyancy Weight of Coiled Tubing or Weight in Mud
W_{C_M}	=	Buoyancy Weight of Loose Cable in Coiled Tubing
θ	=	Inclination Angle
$\bar{\theta}$	=	Average Inclination Angle
ϕ	=	Azimuth Angle
Δ	=	Incremental Values

2.1.2 Derivation of the Equations

When a loose cable is suspended inside the coiled tubing, the weight of the cable is suspended by the reel while the weight of the tubing and frictional drag are suspended by the injector head (hook load). Therefore, the weight of the cable effects the weight term in the normal force equation (Eq. 2-1), but does not effect the weight term in the tension increment equation (Eq. 2-2).

In analyzing each segment, the first requirement is to calculate the magnitude of the normal force, N, as follows:

$$N = \left[\left(T\Delta\phi \sin\bar{\theta}\right)^2 + \left(T\Delta\theta + \left[W_{T_M} + W_{C_M}\right] \sin\bar{\theta}\right)^2 \right]^{1/2} \quad (2\text{-}1)$$

The tension increment is then calculated as follows:

$$\Delta T = W_{T_M} \cos\bar{\theta} \pm F \quad (2\text{-}2)$$

$$F = fN \quad (2\text{-}3)$$

$$\text{or } \Delta T = W_{T_M} \cos\bar{\theta} \pm fN \quad (2\text{-}4)$$

In this equation, the plus sign is used for upward motion (meaning axial drag adds to the effect of gravity), and the minus for downward motion (meaning axial drag subtracts from the effect of gravity).

2.1.3 Consideration of Multi-Element Cases

As the calculation procedure takes place, T + ΔT becomes T for the element above the present calculation point and ΔT contributes to the overall sum. When completed, the analysis yields tensile loads as functions of depth along the string.

2.2 APPLYING THE DRAG MODEL TO A STRING OF COILED TUBING

To apply the mathematical model in the stepwise fashion as shown earlier, it is necessary to specify the following information for each element:

1. Physical size and weight
2. Spatial orientation
3. Nature of motion
4. Tensile load at the bottom of the element
5. Friction factor

The following paragraphs discuss each of these and relate them to tubing design or operational parameters, whichever is applicable.

2.2.1 Physical Size and Weight

One aspect of physical size is the length of the element. When a stepwise solution is applied, this will be the size of each "step" as the solution process marches up the tubing. The outside and inside diameters of the elements are needed to calculate stress and buckling criteria. These are obtained from a physical description of the tubing. The weight of the element, adjusted for the effects of buoyancy, is part of the tensile force balance.

2.2.2 Spatial Orientation

Spatial orientation refers to the values for inclination and azimuth angle at both ends of the element. These can be obtained from wellbore survey information.

2.2.3 Nature of Motion

The nature of the motion is necessary to determine what effect the drag force has. If the string is moving up, the drag force adds to the weight component of tension. When downward motion is present, the drag force subtracts from the weight component.

In terms of actual operations, upward motion occurs when raising the string of tubing (i.e., picking up or coming out of the hole). Downward motion corresponds to lowering the string (i.e., slacking off, drilling, or going in the hole).

2.2.4 Loads at the Bottom of Each Element

The tensile drag at the lower end of the element must be known prior to calculation of the element. Remember, the model takes the increment of tension due to drag and weight and adds this to the tension value found at the lower end of the element. However, this information does not have to be supplied for every element because the model uses the value calculated for the upper end of the current element as the initial value for the lower end of the next element. Thus, the boundary conditions of the tensile drag at the bottom of the string are all that must be provided.

The values used for boundary conditions at the bottom of the coiled-tubing string will depend upon the operation being simulated. When the string is going into the hole, (slack off or drill), the bottom of the string is in compression. When the string is coming out of the hole, the bottom of the string is in tension. The following are the factors that affect bottom boundary conditions for each operation being simulated.

1. Pick up (logging): Consists of logging tool weight and bottom tool drag.
2. Slack off (logging): Consists of logging tool weight and bottom tool drag.
3. Pick up (drilling, tripping): Consists of bottom tool drag.
4. Slack off (drilling, tripping): Consists of bottom tool drag.
5. Drill: Consists of bottom tool drag and weight-on-bit.

2.2.5 Loads at the Top of the Coiled Tubing

Stuffing box drag is a load applied both during pick up and slack off. It simulates the frictional drag in the seal of a stuffing box or lubricator. It has no effect on the tension loading of the tubing below the stuffing box. It increases tension in the tubing above the stuffing box during pick up operations and decreases tension when slacking off.

Coiled-tubing reels keep a constant back tension on coiled-tubing which is called pick-up reel back tension and slack-off reel back tension. This back tension reduces the load read on the transducers at the injection head. The back tension is always in the same direction, whereas friction in the stuffing box gland changes direction from pick up to slack off.

2.2.6 Friction Factor

The friction factor is a very important number because it is the one parameter that characterizes the surface-to-surface interaction central to the mathematical model. A great amount of work has gone into obtaining and verifying values of friction factor for predictive work. A few comments at this point will facilitate a better understanding of the application of friction factors to coiled tubing. The exact value of the friction factor applicable to a situation is a function of many things, including drilling fluid type and composition, formation type (in open hole), casing material and condition (in cased hole), and tubing material and condition (e.g., roughness). At a single point in time, the mud type and composition in the well are constant but significant changes may be taking place in portions of both cased and open hole. Thus, in certain cases, it may be necessary to use two friction factors, one for the tubing/casing interaction and one for the tubing/formation interaction.

2.2.7 Cable Load

The maximum tensile cable load, T_c, at the top of the cable equals:

$$T_c = TVD_{cable} \times W_c \qquad (2\text{-}5)$$

where:

T_c = Maximum Cable Tensile Load
TVD_{cable} = Maximum TVD of Cable
W_c = Cable Buoyed Weight

This tensile load is supported by the reel and not by the injector head.

2.3 AXIAL STRESS AND LOAD

The torque and drag model mentioned previously considers only the effects of mechanical force or drag force. It does not consider compressive loads imposed on the tubing string as a result of hydrostatic pressure. The model gives correct results for torque and drag and buckling calculations but not for mechanical strength failures and burst and collapse estimates. Therefore, load contribution due to hydraulic pressure must be considered.

2.3.1 Load at Bottom

A hydrostatic or buoyant compressive force acts on the bottom of the tube. This force is caused by the hydrostatic pressure in the liquid at the bottom of the hole. The magnitude of this force is given by

$$F_{hb} = -\frac{\pi}{4}\left(P_{ob} \times OD^2 - P_{ib} \times ID^2\right) \tag{2-6}$$

F_{hb} = Compressive load acting on the end of the tubing string
P_{ob} = Bottom tube annual pressure
P_{ib} = Bottom tube inside pressure
OD = Bottom tube outside diameter
ID = Bottom tube inside diameter

When hydraulic force combines with logging tool weight, BHA drag, or weight-on-bit it becomes bottom-boundary load.

2.3.2 Axial Load

To calculate axial load, you would modify Eqs. 2-2 to 2-4. Since hydrostatic pressure is considered in the bottom-boundary load, the buoyancy force should not affect pipe weight contribution in the axial direction. For normal force (lateral side load), buoyancy must be considered. In analyzing each segment, Eqs. 2-1 to 2-4 become:

$$N = \left[\left(T \Delta\phi \sin\bar{\theta}\right)^2 + \left(T \Delta\theta + \left[W_{T_M} + W_{C_M}\right] \sin\bar{\theta}\right)^2 \right]^{1/2} \tag{2-7}$$

It is the same as Eq. 2-1, the tension increment is calculated as follows:

$$\Delta T_a = W_{T_a} \cdot \cos\bar{\theta} \pm F \tag{2-8}$$

$$F = f\,N \quad \text{or} \tag{2-9}$$

$$\Delta T_a = W_{T_a} \cdot \cos\bar{\theta} \pm f\,N \tag{2-10}$$

where:

ΔT_a = Axial load (tension) increment
W_{Ta} = Tubing weight in air
N = Normal force
f = Friction factor
F = Axial friction force

2.3.3 Hook Load

Hook load measured at the injector head equals:

Hook Load (Pick up) = $T_P + F_D - F_R$
Hook Load (Slack off) = $T_S - F_D - F_R$
Hook Load (Drill) = $T_D - F_D - F_R$

where:

T_P = Pick-up Tensile Tubing Load below Stuffing Box
T_S = Slack-off Tensile Tubing Load below Stuffing Box
T_D = Drill Tensile Tubing Load below Stuffing Box
F_D = Stuffing Box Drag
F_R = Reel Back Tension

This hook load is applied to the tubing by the injector head. The hook load does not include the force to support the cable since the cable is supported by the reel and not by the injector head.

2.3.4 Axial Stress

Axial stress without bending stress which is exerted by wellbore dogleg or helical buckling is:

$$\sigma_a = T_a \ / \ \text{cross section area or} \quad (2\text{-}11)$$

$$\sigma_a = T_a \ / \ \left[\frac{\pi}{4}\left(OD^2 - ID^2\right)\right] \quad (2\text{-}12)$$

where:

σ_a = Axial stress

T_a = Axial load

2.3.5 Axial Load and Axial Drag

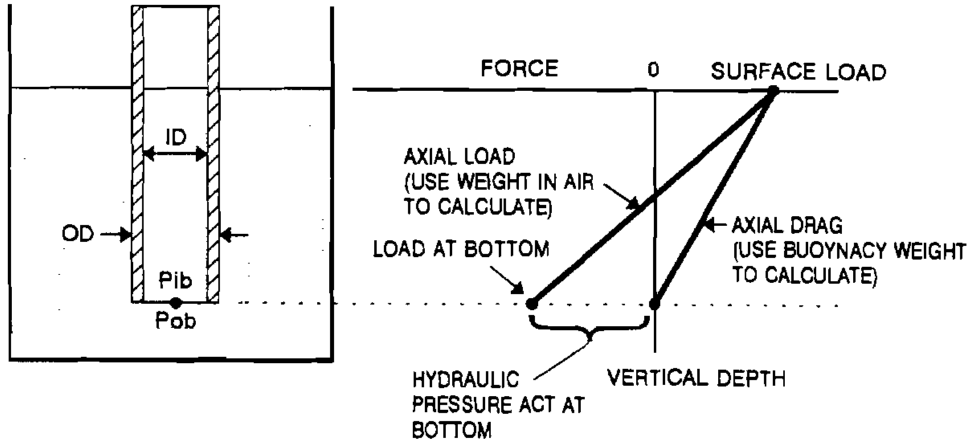


Figure 2-2. Compare Axial Load and Axial Drag

Shown in Figure 2-2 is a steel tube in water. At the bottom of the tube, the inside and outside pressures are equal. Axial load curve and axial drag curve that intersect at water level can easily be found. For axial drag calculation, tube buoyancy weight (weight in water) is used. For calculating axial load, weight in air and hydraulic pressure at the bottom of the tube are used.

2.4 BENDING STRESS

Bending stress can be exerted by either wellbore dogleg or helical buckling. The bending stress from dogleg is shown below:

$$\sigma_{DL} = (\pi \cdot E \cdot DL \cdot OD)/432000 \qquad (2\text{-}13)$$

where:

- σ_{DL} = Bending stress exerted by dogleg (psi)
- E = Elastic modulus (psi)
- DL = Dogleg (°/100 ft)
- OD = Tube outside diameter (in.)

If the tubing is in helical bending, the path of tubing is not only following the wellbore, but is also following the spiral shape (Lubinski et al., "Helical Buckling of Tubing Sealed in Packer" *Journal of Petroleum Technology*, June, 1992). The pitch of helical buckling can be estimated due to axial drag. After the pitch is obtained, the curvature of the tube with helical buckling can be found.

- r = Clearance
- P = Pitch of helical buckling
- k = Curvature of the tube with helical buckling
- σ_{hel} = Bending stress due to helical buckling

E = Elastic modulus
I = Moment of inertia
HID = Hole diameter
T = Axial drag
OD = Tube outside diameter

$$P = \left[\frac{8EI\pi^2}{T} \right]^{1/2} \tag{2-14}$$

$$r = \frac{HID - OD}{2} \tag{2-15}$$

$$k = \frac{4\pi^2 r}{P^2 + 4\pi^2 8^2} \tag{2-16}$$

$$\sigma_{hel} = \frac{E \cdot k \cdot OD}{2} \tag{2-17}$$

σ_{hel} is the helically buckled tube's bending stress, so in the helical buckling section of coiled tubing, the bending stress will be σ_{hel} (Eq. 2-17) rather than σ_{DL} (Eq. 2-13).

2.5 HYDRAULICS ANALYSIS

The models most commonly used in the drilling industry to describe fluid behavior are the Bingham plastic and power-law models. They can be used to calculate frictional pressure drop, swab and surge pressures, etc. The hydraulic calculation in CSTRESS1 is based on equations derived in *Applied Drilling Engineering* (Bourgoyne et al., 1986) and API SPEC 10. The more sophisticated Herschel-Buckley model has not been included in this program because of lack of experimental data, but it will be considered in the future version.

2.5.1 Bingham Plastic Model

The Bingham plastic model is defined by Eq. 2-18 and is illustrated in Figure 2-3.

$$\begin{aligned} \tau &= \mu_p \dot{\gamma} + \tau_y \quad ; \quad \tau > \tau_y \\ \dot{\gamma} &= 0 \quad ; \quad \tau_y \geq \tau \geq -\tau_y \\ \tau &= \mu_p \dot{\gamma} - \tau_y \quad ; \quad \tau < -\tau_y \end{aligned} \tag{2-18}$$

where:

τy = Yield stress
μ_p = Fluid viscosity
τ = Shear stress
$\dot{\gamma}$ = Shear rate

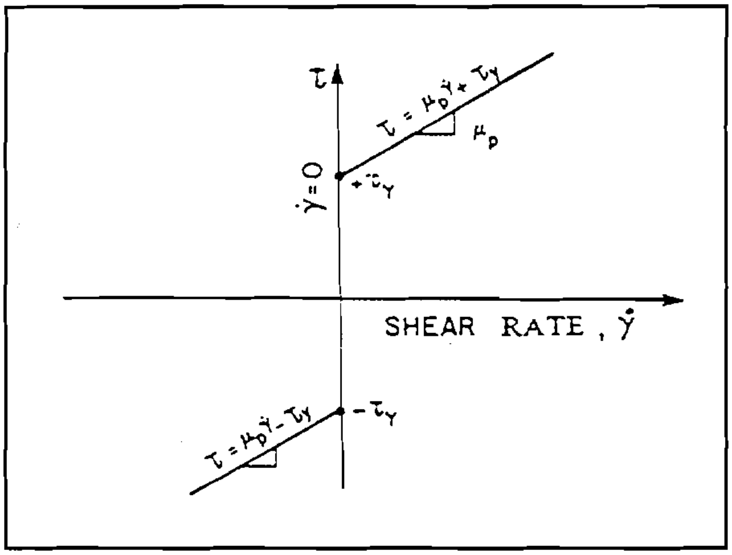


Figure 2-3. Shear Stress Vs. Shear Rate for a Bingham Plastic Fluid (Bourgoyne et al., 1986)

As shown in Figure 2-3, a threshold shear stress known as the yield point (τ_y) must be exceeded before mud movement is initiated.

The mud properties μ_p and τ_y are calculated from 300- and 600-rpm readings of the viscometer as follows:

$$\mu_p = \theta_{600} - \theta_{300} \qquad \tau_y = \theta_{300} - \mu_p \tag{2-19}$$

where:

θ_{600}, θ_{300} = shear readings at 600 and 300 rpm, respectively.

Calculation of frictional pressure drop for a pipe or annulus requires knowledge of the mud flow regime (laminar or turbulent).

1. Mean Velocity

The mean velocities of fluid are calculated by Eq. 2-20 and 2-21.

For pipe flow:

$$\bar{v} = \frac{Q}{2.448d^2} \tag{2-20}$$

For annular flow:

$$\bar{v} = \frac{Q}{2.448\left(d_2^2 - d_1^2\right)} \qquad (2\text{-}21)$$

Where:

$\bar{v}$ = Mean velocity, ft/sec

Q = Flow rate, gal/min

d = Pipe diameter, in.

d_2 = Casing or hole ID, in.

d_1 = Drill string OD, in.

2. Hedstrom Number

The Hedstrom number, N_{HE}, is a dimensionless parameter used for fluid flow regime prediction.

For pipe flow:

$$N_{HE} = \frac{37{,}100\,\rho\,\tau_y\,d^2}{\mu_p^2} \qquad (2\text{-}22)$$

For annular flow:

$$N_{HE} = \frac{24{,}700\,\rho\,\tau_y\,(d_2 - d_1)^2}{\mu_p^2} \qquad (2\text{-}23)$$

Where:

ρ = Mud weight, lb/gal

3. Critical Reynolds Number

The critical Reynolds number marks the transition from laminar flow to turbulent flow. The correlation between Hedstrom number and critical Reynolds number is presented in Figure 2-4. The data in Figure 2-4 have been digitized in the program for easy access.

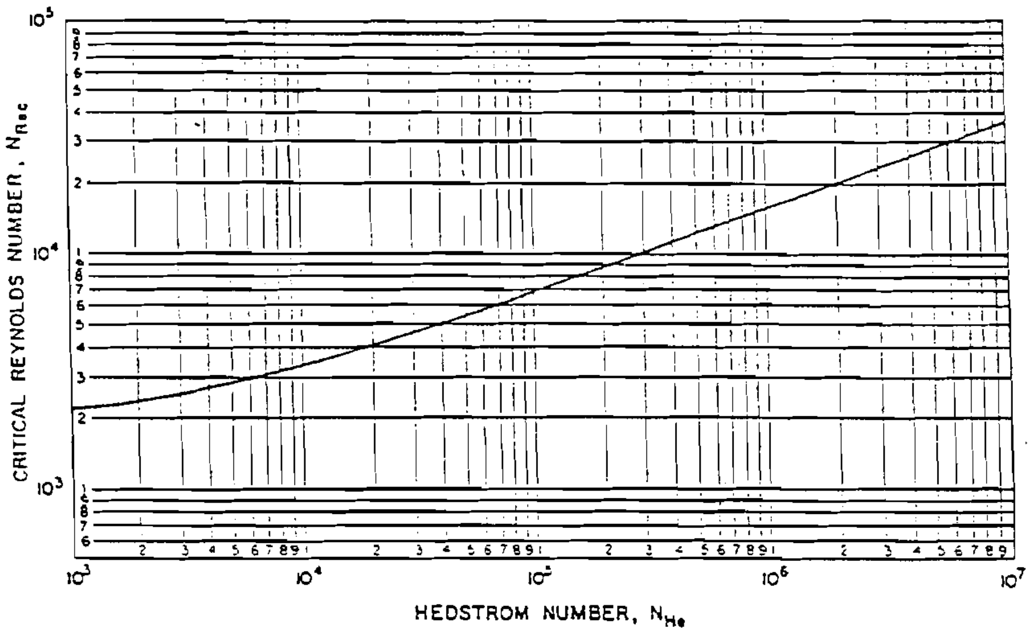


Figure 2-4. Critical Reynolds Numbers for Bingham Plastic Fluids (Bourgoyne et al., 1986)

4. Reynolds Number

Reynolds number, N_{Re}, is another common dimensionless fluid flow parameter.

For pipe flow:

$$N_{Re} = \frac{928 \rho \bar{v} d}{\mu_p} \tag{2-24}$$

For annular flow:

$$N_{Re} = \frac{757 \rho \bar{v} (d_2 - d_1)}{\mu_p} \tag{2-25}$$

5. Frictional Pressure Drop Calculation

For pipe flow, the frictional pressure drop is given by:

(1) Laminar flow (N_{Re} < Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{\mu_p \bar{v}}{1500\ d^2} + \frac{\tau_y}{225\ d} \tag{2-26}$$

(2) Turbulent flow ($N_{Re} \geq$ Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{f \rho \bar{v}^2}{25.8d} \tag{2-27}$$

where f is the friction factor given by

$$\sqrt{\frac{1}{f}} = 4 \log \left(N_{Re} \sqrt{f} \right) - 0.395 \qquad (2\text{-}28)$$

For annular flow, the frictional pressure drop is:

(1) Laminar flow (N_{Re} < Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{\mu_p \bar{v}}{1000\ (d_2 - d_1)^2} + \frac{\tau_y}{200(d_2 - d_1)} \qquad (2\text{-}29)$$

(2) Turbulent flow ($N_{Re} \geq$ Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{f \rho \bar{v}^2}{21.1\ (d_2 - d_1)} \qquad (2\text{-}30)$$

where f is determined using Eq. 2-28.

2.5.2 Power-Law Model

The power-law model is defined by Eq. 2-31 and illustrated in Figure 2-5.

$$\tau = K\dot{\gamma}^n \qquad (2\text{-}31)$$

where:

K = Consistency index, equivalent centipoise (see Bourgoyne et al., 1986)

n = Flow behavior index, dimensionless

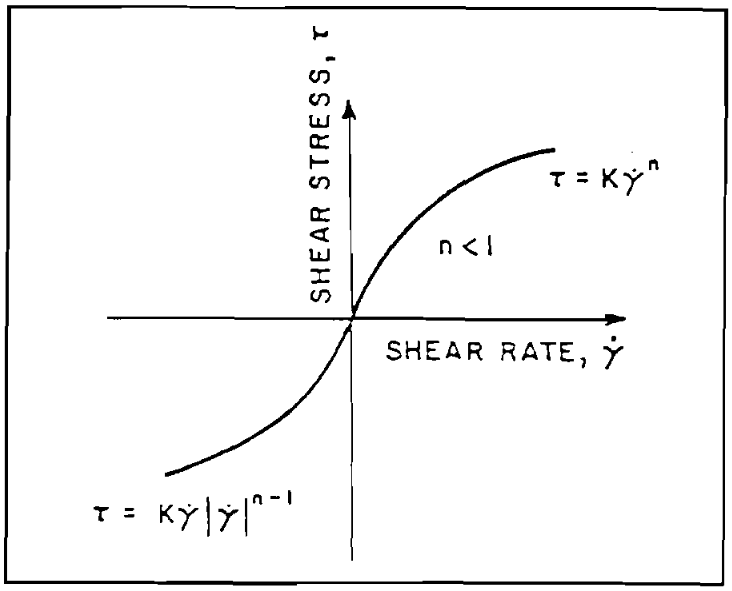


Figure 2-5. Shear Stress Vs. Shear Rate for a Power-Law Fluid (Bourgoyne et al., 1986)

The fluid properties n and K are calculated as follows:

$$n = 3.32 \log \frac{\theta_{600}}{\theta_{300}} \tag{2-32}$$

$$K = \frac{510\ \theta_{300}}{511^n} \tag{2-33}$$

The critical Reynolds number must be determined before the frictional pressure drop can be calculated.

1. Mean Velocity

For pipe flow:

$$\bar{v} = \frac{Q}{2.448 d^2} \tag{2-34}$$

For annular flow:

$$\bar{v} = \frac{Q}{2.448\left(d_2^2 - d_1^2\right)} \tag{2-35}$$

2. Critical Reynolds Number

The critical Reynolds number can be read from Figure 2-6 for a given flow behavior index n.

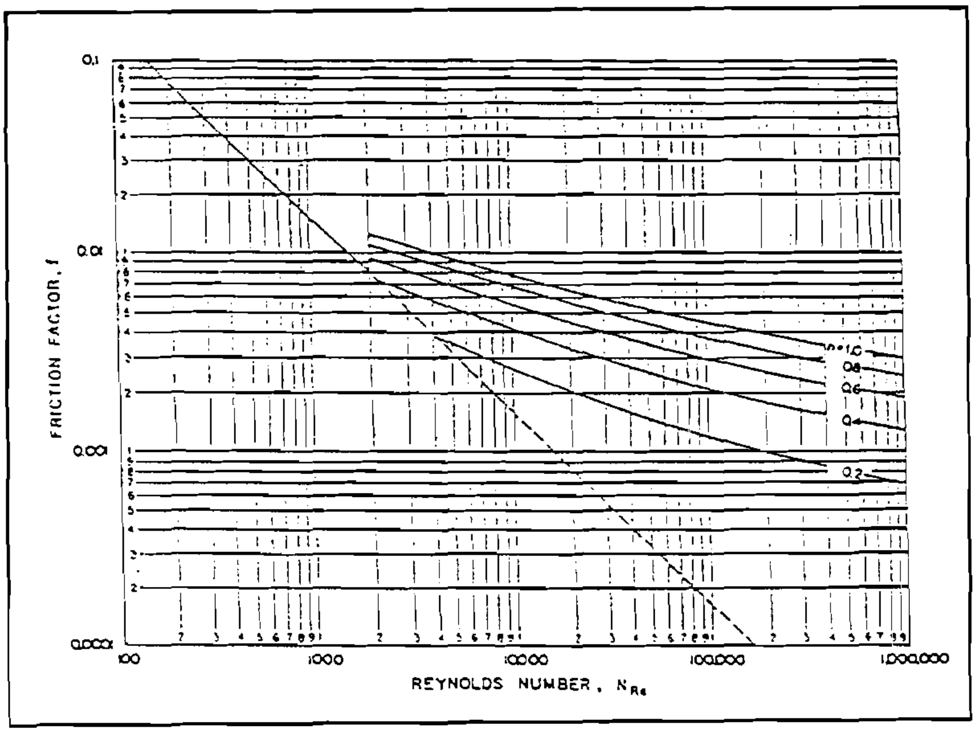


Figure 2-6. Friction Factors for Power-Law Fluid Model (Bourgoyne et al., 1986)

The data in Figure 2-6 can be approximated by the following (Leitão et al., 1990):

Critical N_{Re} = 4200	for $n < 0.2$	
Critical N_{Re} = 5960 - 8800 n	for $0.2 \leq n \leq 0.45$	(2-36)
Critical N_{Re} = 2000	for $n > 0.45$	

3. Reynolds Number

For pipe flow:

$$N_{Re} = \frac{89,100 \rho \bar{v}^{(2-n)}}{K} \left[\frac{0.0416\, d}{3 + 1/n}\right]^n \tag{2-37}$$

For annular flow:

$$N_{Re} = \frac{109,000 \rho \bar{v}^{(2-n)}}{K} \left[\frac{0.0208\,(d_2 - d_1)}{2 + 1/n}\right]^n \tag{2-38}$$

4. Frictional Pressure Drop Calculation

For pipe flow:

(1) Laminar flow: (N_{Re} < Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{K \bar{v}^n}{144,000\, d^{(1+n)}} \left[\frac{3 + 1/n}{0.0416}\right]^n \tag{2-39}$$

(2) Turbulent flow (N_{Re} ≥ Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{f \rho \bar{v}^2}{25.8\, d} \tag{2-40}$$

where the frictional factor f is given by:

$$\sqrt{\frac{1}{f}} = \frac{4.0}{n^{0.75}} \log \left(N_{Re} f^{(1-n/2)}\right) - \frac{0.395}{n^{1.2}} \tag{2-41}$$

For annular flow:

(1) Laminar flow: (N_{Re} < Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{K \bar{v}^n}{144,000\, (d_2 - d_1)^{(1+n)}} \left[\frac{2 + 1/n}{0.0208}\right]^n \tag{2-42}$$

(2) Turbulent flow (N_{Re} ≥ Critical N_{Re})

$$\frac{dP_f}{dL} = \frac{f \rho \bar{v}^2}{21.1\, (d_2 - d_1)} \tag{2-43}$$

where f is calculated using Eq. 2-41.

2.5.3 Bit Pressure Drop

There are *three assumptions made to calculate bit pressure drop:*

1. The change in pressure due to change in elevation is negligible.

2. Upstream velocity is negligible compared to nozzle velocity.
3. Frictional pressure drop across the nozzle is negligible.

Nozzle velocity equals

$$V_n = \frac{Q}{3.117\,A_T} \tag{2-44}$$

where:

V_n = Nozzle velocity, ft/sec
Q = Flow rate, gal/min
A_T = Total nozzle area, $in.^2$

and bit pressure drop equals

$$\Delta P_b = \frac{\rho Q^2}{12{,}032\ C_d^2\ A_T^2} \tag{2-45}$$

where:

C_d = discharge coefficient factor (recommended value = 0.95) (Bourgoyne et al., 1986)

The hydraulic horsepower (HHP) and the impact force (F_i) at the bit are

$$HHP = \frac{\Delta P_b\, Q}{1714} \tag{2-46}$$

$$F_i = 0.01823\ C_d\ Q\sqrt{\rho\,\Delta P_b} \tag{2-47}$$

The total pressure drop in the system equals:

$$P_{total} = \sum P_p + \sum P_a + \Delta P_b \tag{2-48}$$

Where:

$\sum P_p$ = Summation of pressure losses inside the pipe
$\sum P_a$ = Summation of pressure losses in the annulus

Therefore, the pump horsepower (PHP) is

$$PHP = P_{total}\,\frac{Q}{1714} \tag{2-49}$$

where:

ΔP_{surf} = surface equipment pressure loss, psi
Q = flow rate, gal/min

2.5.4 Equivalent Circulating Density

Of particular importance is the equivalent circulating density (ECD) at a certain depth. The ECD is the density of fluid that will produce the same hydrostatic pressure as the circulating pressure at that point (bottom of the hole) i.e.,

$$ECD = \frac{P_o}{0.052 \times TVD} \quad \text{(lb/gal)} \tag{2-50}$$

where:

P_o = Pressure at the point, psi
TVD = True vertical depth at the point, ft

2.6 SURGE AND SWAB PRESSURES

Equations 2-26 through 2-30 and 2-39 through 2-43 have been presented for frictional pressure drop calculation, the first set for a Bingham plastic fluid and the second for a power-law fluid. These models can also be applied to determine surge and swab pressures if the running speed of the drill pipe is known. Surge pressure is the pressure increase caused by lowering pipe into the well. Pressure decrease, resulting from withdrawing pipe from the well, is called swab pressure.

For a closed pipe, the estimated annular velocity is (Moore, 1974):

$$v = \left[K + \frac{d_1^2}{d_2^2 - d_1^2} \right] v_p \tag{2-51}$$

where:

v_p = Pipe running speed, ft/min
v = Average annular fluid velocity, ft/min
K = Clinging constant (recommended value = 0.45).

Moore suggested using maximum fluid velocity to take into account the acceleration and deceleration of the pipe. In general, the maximum fluid velocity equals:

$$V_m = 1.5v \tag{2-52}$$

Surge and swab pressures are calculated by substituting maximum fluid velocity for mean velocity in the previously presented frictional pressure drop equations.

Of particular importance is the equivalent circulating density (ECD) due to surge and swab pressures. The calculation of ECD can be performed using Eq. 2-50.

2.7 BUCKLING THEORY

The compressive loads required to initiate the onset of sinusoidal, helical, and spring theory buckling are indicated on the graphic output of the slack-off plots. The significance of these three stages of buckling is as follows:

2.7.1 Sinusoidal Buckling

As compressive force is increased on a length of tubing lying along the bottom of an inclined hole, a point is reached where the tubing will assume a sinusoidal configuration along the bottom of the hole (Figure 2-7). The critical force required to achieve this is calculated using either the Exxon formula presented in Eq. 2-53 (Dawson and Paslay, *Journal Petroleum Technology*, October 1984, 1734 - 1738) or the Texas A&M University formula presented in Eqs. 2-55 — 2-57 (Wu and Juvkam-Wold, ASME Paper 93-PET-7).

where:

F_{csin}	=	Critical axial load to begin sinusoidal buckling, lbf
E	=	Elastic modulus, psi
I	=	Moment of inertia of tubing cross section, inches^4
r	=	Radial clearance between tubing and borehole, inches
θ	=	Inclination of hole, degrees
$\bar{\theta}$	=	Average inclination of hole section, degree
W_{mud}	=	Unit pipe weight in mud, lbf/in.
R	=	Radius of the curvature, in.

In Exxon's equation, if the inclination angle is zero, then the sinusoidal buckling critical load is zero. In the program CSTRESS, if the inclination is less than 3°, the program uses 3° instead of the inclination (Eq. 2-54).

Exxon

$$F_{csin} = 2\left[\frac{E \cdot I \cdot W_{mud} \cdot \mathrm{Sin}\ (\bar{\theta})}{r}\right]^{1/2} \qquad \left(\text{for } \theta > 3°\right) \tag{2-53}$$

Exxon

$$F_{csin} = 2\left[\frac{E \cdot I \cdot W_{mud} \cdot \mathrm{Sin}\ (3)}{r}\right]^{1/2} \qquad \left(\text{for } \theta <= 3°\right) \tag{2-54}$$

For the vertical, slant, and curved sections, A&M uses three equations for each situation to find the critical buckling load.

A&M

$$F_{cin} = 0.85 \left(E \cdot I \cdot W_{mud}^2\right)^{1/3} \qquad \text{(for vertical)} \qquad (2\text{-}55)$$

A&M

$$F_{csin} = 2 \cdot \left[\frac{E \cdot I \cdot W_{mud} \cdot \sin(\theta)}{r}\right]^{1/2} \qquad \text{(for slant)} \qquad (2\text{-}56)$$

A&M

$$F_{csin} = \frac{4 \cdot E \cdot I}{r \cdot k}\left[1 + \left[1 + \frac{r \cdot R^2 \cdot W_{mud} \cdot \sin(\theta)}{4\,E\,I}\right]^{1/2}\right] \qquad \text{(for curved)} \qquad (2\text{-}57)$$

$$R = \frac{18000}{\pi \cdot DL} \times 12 \qquad (2\text{-}58)$$

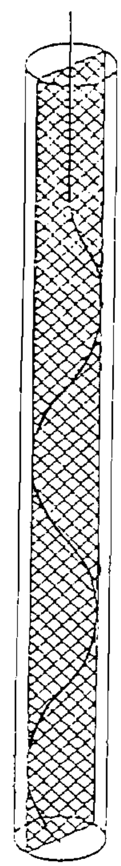


Figure 2-7. Sinusoidal Buckling

2.7.2 Helical Buckling

If the axial compressive load is increased beyond the point where sinusoidal buckling occurs, helical buckling will eventually result. In helical buckling, the tubing forms a helix along the wall of the hole, the pitch of the helix decreasing as compressive load increases (Figure 2-8).

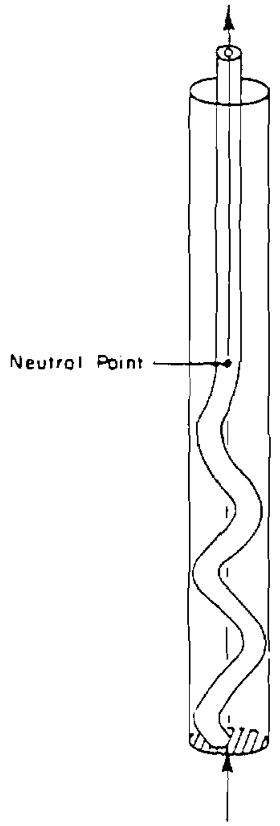


Figure 2-8. Helical Buckling

The critical force required to achieve helical buckling is calculated using either the Rice University formula presented in Eq. 2-59 (Chen, Lin, and Cheatham, 1989, "An Analysis of Tubing and Casing Buckling in Horizontal Wells," OTC 6037) or the Texas A&M University formula presented in Eqs. 2-61 — 2-63 (Wu and Juvkam-Wold, ASME Paper 93-PET-7).

Rice

$$F_{chel} = 2 \cdot \sqrt{2} \cdot \left[\frac{E \cdot I \cdot W_{mud} \cdot \sin(\theta)}{r} \right]^{1/2} \qquad (\text{for } \theta > 3°) \qquad (2\text{-}59)$$

Rice

$$F_{chel} = 2 \cdot \sqrt{2} \cdot \left[\frac{E \cdot I \cdot W_{mud} \cdot \sin(3)}{r} \right]^{1/2} \qquad (\text{for } \theta <= 3°) \qquad (2\text{-}60)$$

A&M

$$F_{chel} = 2.85 \left(E \cdot I \cdot W_{mud}^2 \right)^{1/3} \qquad (\text{for vertical}) \qquad (2\text{-}61)$$

A&M

$$F_{chel} = 2 \left(2 \cdot \sqrt{2} - 1 \right) \left[\frac{E \cdot I \cdot W_{mud} \cdot \sin(\theta)}{r} \right]^{1/2} \qquad (\text{for slant}) \qquad (2\text{-}62)$$

A&M

$$F_{chel} = \frac{12 \cdot E \cdot I}{r \cdot R} + \frac{4 \cdot E \cdot I}{r \cdot R} \left[4 \cdot \left[1 + \frac{r \cdot R^2 \cdot W_{mud} \cdot \sin(\theta)}{8 E I} \right]^{1/2} - \left[1 + \frac{r \cdot R^2 \cdot W_{mud} \cdot \sin(\theta)}{4 \cdot E \cdot I} \right]^{1/2} \right] \tag{2-63}$$

From Exxon's and Rice's formulas (Eqs. 2-53 and 2-59), helical buckling begins when the axial compressive force is 1.414 ($\sqrt{2}$) times the value of sinusoidal critical buckling load.

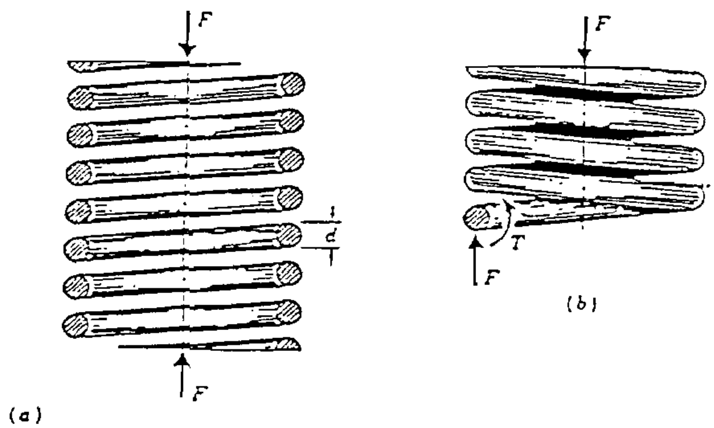
2.7.3 Spring Theory Buckling

If compressive axial load is increased beyond that required to initiate helical buckling, the pitch of the helix decreases until a point is reached where the shear stress loading of the tubing will equal its minimum yield shear stress (Figure 2-9). This is calculated using Equation 2-64 which is based on the theory of helical springs under compression. (See A.M. Wahl, *"Mechanical Springs,"* 2nd edition, McGraw Hill Book Company, New York, 1963.)

$$F_{cspr} = \frac{\pi d^2 t}{4 \left[\frac{2D}{d} + 1 \right]} \tag{2-64}$$

where:

F_{cspr} = Critical force required to raise maximum shear to equal minimum yield shear, lbs
d = Tubing diameter, inches
D = Hole diameter, inches
t = Minimum yield in shear, psi. This is equal to half of the tensile yield.



(a) Axially loaded helical spring; (b) free-body diagram showing that the wire is subjected to a direct shear and a torsional shear.

Figure 2-9. Axially-Loaded Helical Spring

2.7.4 Which One Do I Use?

As indicated above, the smallest critical force is F_{csin}, the critical compressive force required to initiate sinusoidal buckling. Next largest is F_{chel}, the critical compressive force to change from sinusoidal to helical buckling. The largest of the three critical forces is F_{cspr}, the axial force required to increase the maximum shear in the coiled tubing to equal the minimum yield in shear of the tubing.

Newman, Corrigan, and Cheatham, in SPE 19229, indicate that coiled tubing can be pushed into a hole safely using compressive loads considerably in excess of the sinusoidal buckling threshold calculated by Equations 2-53 — 2-57. In the field cases they report, compressive forces greater than the sinusoidal critical force, F_{csin}, have been used to push coiled tubing into inclined holes. Because of well geometry, they were unable to test compressive forces greater than the helical buckling critical force, F_{chel}. It is their belief that compressive forces larger than the critical helical buckling force, F_{chel}, can safely be used to push coiled tubing into deviated holes, and they are proposing experimental verification of this assumption.

Logging operations by Canadian Fracmaster and Esso Resources Canada in British Columbia have shown that coiled tubing can be safely subjected to buckling forces midway between the helical and spring limits. Recent experience of at least one of the service companies indicates that the critical load calculated from helical spring theory, F_{cspr}, is a reasonable indicator of the near upper limit of safe compressive forces to use to insert coiled tubing into deviated holes. This force is considerably larger than the force required to initiate helical buckling. It has been reported that when F_{cspr} was "exceeded in moderation," no damage to the tubing was observed.

These criteria (F_{csin}, F_{chel}, and F_{cspr}) should be used with caution and as guides rather than as absolute indicators. Judgment based on experience, though sometimes expensive to acquire, is of great value when dealing with such concepts as buckling and all its implications. Buckling does not necessarily imply failure, but indicates the onset of a condition which may precipitate failure.

When more accurate or significant critical buckling load criteria are developed, they will be incorporated into CSTRESS either in addition to, or as replacements for the three criteria presently employed.

2.8 HELICAL FRICTIONAL FORCE AND LOCKUP

Once coiled tubing becomes helically buckled, the tube body will exert extra normal force against the wellbore so helical buckling causes additional frictional force called "helical frictional force." The helical frictional force equation is evaluated in "Frictional Drag Analysis for Helical Buckled Pipes in Extended Reach and Horizontal Wells" (Jiang Wu and Haas C. Juvkam-Wold, 93-PET-8).

$$F_{hel-fric} = \frac{r \cdot (T)^2}{4 \cdot E \cdot I} \cdot \Delta l \cdot f \qquad (2\text{-}65)$$

where:

F_{hel}	=	Helical Frictional Force
E	=	Elastic Modulus
I	=	Moment of Initial
T	=	Axial Compressional Force
r	=	Clearance
f	=	Friction Factor
Δl	=	Segment Length

Equation 2-65 is based on the following assumptions:

1. Axial compressional forces on both ends of the segment are equal which implies that segment length is relatively short.
2. Originally, this equation was derivated for weightless pipe in a straight wellbore.

When axial compressional force is increased, the equation shows that helical frictional force is increased as the square of compressional force. This helical frictional force against the tube moving into the well causes extra axial compressional force for the next (upper) tube segment. If the helical frictional force is large enough, the compressional force is balanced by the helical frictional force no matter how much force is applied at the surface. In this situation, the helical buckling section locks and the tubing string below the helical buckling section cannot move down to the hole.

2.9 TRIAXIAL, BIAXIAL, AND API STRESS ANALYSIS

An element of material subjected to stress σx, σy, and σz in three perpendicular directions is said to be in a state of triaxial stress. A coiled-tubing string subjected to axial load and pressure (external and/or internal) is in a state of triaxial stress (Figure 2-10).

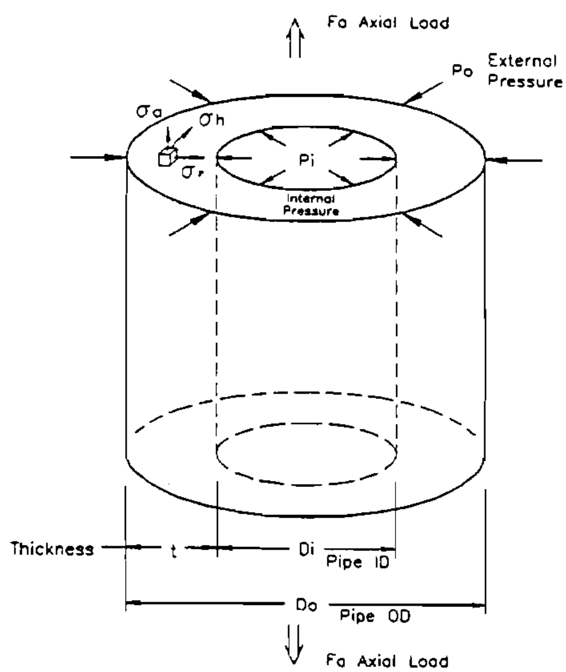


Figure 2-10. Triaxial Stress State

2.9.1 Triaxial Equation

The generally accepted relationship for the effect of axial stress on collapse or burst is based on the distortion energy theory. A closed triaxial design procedure has been developed using Von Mise's and Lame's equations. This present model does not consider torsional effects.

Let E = Elastic Modulus
D_o = Pipe OD
D_i = Pipe ID
r_o = Pipe Outside Radius
r_i = Pipe Inside Radius
σ_s = Yield Stress
σ_a = Axial Stress
P_i = Internal Pressure (psi)
P_o = External Pressure (psi)

The pipe thickness is

$$t = 0.5 \cdot (D_o - D_i) \tag{2-66}$$

The cross area of pipe wall is

$$A = \pi \cdot (D_o^2 - D_i^2)/4 \tag{2-67}$$

Axial stress contains axial force, bending stress, and helical frictional force. According to Lame's equation for a thick tube, the hoop stress σ_h and the radial stress σ_r exerted by internal and external pressures at the cylinder at radius equals r.

$$\sigma_r = \frac{r_i^2 P_i - r_o^2 P_o}{r_o^2 - r_i^2} - \frac{r_i^2 r_o^2 (P_i - P_o)}{r^2 (r_o^2 - r_i^2)} \tag{2-68}$$

and

$$\sigma_h = \frac{r_i^2 P_i - r_o^2 P_o}{r_o^2 - r_i^2} - \frac{r_i^2 r_o^2 (P_i - P_o)}{r^2 (r_o^2 - r_i^2)} \tag{2-69}$$

For most cases, the maximum equivalent stress is at the pipe inside surface. Therefore, the equation can simplified by letting $r = r_i$ and rewriting the equation in pressure and diameter terms so the above equations become

$$\sigma_r = -P_i \tag{2-70}$$

and

$$\sigma_h = \left[\frac{d_o^2 + d_i^2}{d_o^2 - d_i^2}\right] P_i - \left[\frac{2\,d_o^2}{d_o^2 - d_i^2}\right] P_o \qquad (2\text{-}71)$$

let $C = \dfrac{d_o^2}{2 \cdot t \cdot (d_o - t)}$ and Eq. 2-12 becomes

$$\sigma_h = (C - 1)\, P_i - C \cdot P_o \qquad (2\text{-}72)$$

Von Mises's equation is

$$2\,\sigma_V^2 = \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] \qquad (2\text{-}73)$$

where σ_1, σ_2, and σ_3 are three principal stresses, and σ_V is the equivalent stress according to the three principal stresses. Because the stresses σ_r, σ_h, and σ_a are three principal stresses, they can be inserted into Von Mises's equation

$$2\,\sigma_V^2 = \left[(\sigma_a - \sigma_h)^2 + (\sigma_h - \sigma_r)^2 + (\sigma_r - \sigma_a)^2\right] \qquad (2\text{-}74)$$

so the equivalent stress σ_v becomes

$$\sigma_v = \left(1/2\,(\sigma_a - \sigma_h)^2 + (\sigma_h - \sigma_r)^2 + (\sigma_r - \sigma_a)^2\right) \qquad (2\text{-}75)$$

Combine Eqs. 2-70 and 2-71 with Eq. 2-74 and rearrange the terms in the equation.

$$P_o = \frac{-\sigma_a + 2\,C\,P_i - P_i \pm \sqrt{-3\,\sigma_a^2 - 6\,\sigma_a P_i - 3\,P_i^2 + 4\,\sigma_V^2}}{2\,C} \qquad (2\text{-}76)$$

or

$$P_i = \frac{C\,\sigma_a - 2\,\sigma_a + 2\,C^2 P_o - C\,P_o \pm \sqrt{-3\,C^2 \sigma_a - 6\,C^2 \sigma_a P_o - 3\,C^2 P_o^2 + 4\,(C^2 - C + 1)\,\sigma_V^2}}{2\,(C^2 - C + 1)} \qquad (2\text{-}77)$$

In Eqs. 2-76 and 2-77, if σ_V is replaced with σ_s (yield stress), the solutions P_o and P_i are the limited collapse and burst pressures.

Mathematically, there are two solutions for P_o from Eq. 2-76 (for positive and negative square roots), but in practicality only positive real number(s) represent the collapse pressure P_o. There can be one, two, or no solution(s) for the collapse pressure design. When bending stress is considered, caused by wellbore dogleg or helical buckling, the σ_a in Eq. 2-76 is either:

σ_a = Minimum Axial Stress (σ_{amin}) = Average Axial Stress - Bending Stress

or

σ_a = Maximum Axial Stress (σ_{amin}) = Average Axial Stress + Bending Stress

This results in the solution(s) for collapse pressure design with minimum and maximum bending stress effects.

Note, when σ_a is replaced by σ_{amin} and σ_{amax}, both σ_{amin} and σ_{amax} can have the positive square root solution. If this happens, the smaller value of the two positive square root solutions is the upper boundary of collapse design. In the same way, the larger value from the two negative square root solutions is the lower-pressure boundary of the collapse design.

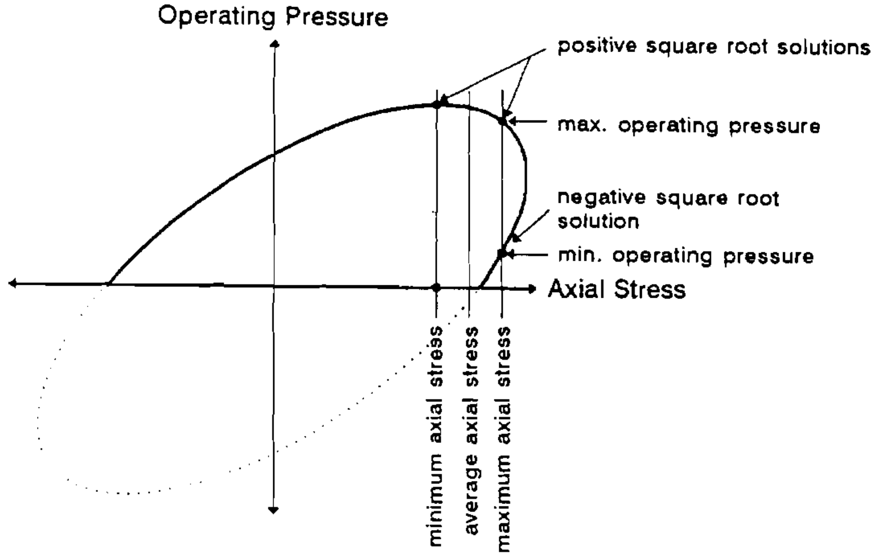


Figure 2-11. Bending Stress Effects on Burst Pressure Design

2.9.2 Biaxial Equation

To disregard the internal pressure on collapse pressure design, let P_i = O and Eq. 2-76 is simplified.

$$P_o = \frac{\sigma_a \pm \sqrt{\sigma_a^2 - 4(\sigma_a^2 - \sigma_V^2)}}{-2C} \tag{2-80}$$

If σ_a and σ_V are replaced by σ_{amin} (Eq. 2-78), σ_{amax} (Eq. 2-79), and σ_s (yield stress), Eq. 2-80 produces the collapse design pressure for biaxial stress analysis.

Let P_o = O in Eq. 2-77 and it becomes

$$P_i = \frac{(C - 2)\sigma_a \pm \sqrt{-3C^2\sigma_a^2 + 4(C^2 - C + 1)\sigma_V^2}}{2(C^2 - C + 1)} \tag{2-81}$$

The above equation is the burst design pressure for biaxial stress analysis.

where

$$C = \frac{d_o^2}{2 \cdot t \cdot (d_o - t)} \tag{2-82}$$

2.9.3 API Equation

API Bulletin, 5C3, 1989, "Formulas and Calculations For Casing, Tubing, Drill Pipe and Line Pipe Properties" (see for details) lists all API standard equations for axial stress limits, burst pressure limits, and four collapse pressure range limits.

Depending on the D/t ratio (diameter over thickness) of pipe, the collapse-tension curves for biaxial and API methods are different. Equations 2-68 and 2-69 are called Lame equations, they are derived from the thick tube stress (small D/t value). The API collapse pressure formula for the plastic zone is derived by statistical regression analysis from more than 2400 casing collapse tests. The API collapse pressure formula for transition zone is determined by the curve fitting. This formula is used to determine minimum collapse pressure between its tangency to the elastic collapse pressure curve and its intersection with the plastic collapse pressure curve. The choice of triaxial, biaxial, or API criteria is left to the user.

3. Tortuosity

3.1 MODEL DESCRIPTION

When planning a well, the surveys generated from geometric considerations, i.e., kick-off point, build rate, path shape, etc., are smooth curves, whereas actual wells contain doglegs and other irregularities that increase torque and drag. When these "smooth curves" are input into the torque and drag model, the model predicts torque and drag values that are lower than those in actual wells containing doglegs and other irregularities.

In the past, when "smooth" curves were used, the friction factors were artificially increased (e.g., from 0.22 to 0.29) to correspond to the increased torque due to hole irregularities. This technique gives good approximations of the actual torque, but it has the limitation that it predicts zero torque and zero frictional drag in vertical portions of the well, regardless of the friction factor, because the lateral loads are zero in these "smooth" vertical sections. The CSTRESS program calculates only the drag force.

A very simple and elegant way to handle this problem been developed by Exxon, and was reported to us by Dr. Rap Dawson.

To add tortuosity to the wellpath, a sinusoidal variation, whose period length (or cycle length) is Δl, is added to both inclination and azimuth angle. This is in the form

$$\text{Tortuosity} = T \sin(2\pi MD / \Delta l) \qquad (3\text{-}1)$$

where:

T	=	Amplitude or tortuosity number in degrees
MD	=	Measured depth (ft)
Δl	=	Period length or cycle length for 2π

In addition, the inclination angle is modified so that it will not become less than zero, since negative inclination angles are not allowed.

The amplitude or tortuosity number T of the sinusoidal variation is varied according to the hole conditions. Exxon has found that a tortuosity of T = 1 represents typical field conditions.

If the untortured survey data are of equal space and the value of measured depth for each survey station is $n \times \frac{\Delta l}{2}$ where n is any integer, then after calculation the survey data will not be tortured.

This is verified in Eq. 3-1 where MD = $\frac{n \cdot \Delta l}{2}$, then tortuosity added to inclination and azimuth for each survey will be:

$$
\begin{aligned}
\text{Tortuosity} &= T \cdot \sin\,(2\pi \cdot MD/\Delta l) \\
&= T \cdot \sin\,(2\pi \cdot \frac{n \cdot \Delta l}{2} \cdot \frac{1}{\Delta l} \\
&= T \cdot \sin\,(n \cdot \pi) \\
&= 0
\end{aligned}
$$

Total dogleg added to the original survey depends on the survey data, Amplitude T, and period length. The amplitude or tortuosity number (T) is the maximum possible degree added to or subtracted from inclination and azimuth.

It is recommended that Δl be chosen to do at least five times the interval between survey stations.

4. Program Installation

4.1 BEFORE INSTALLING

4.1.1 Check the Hardware and System Requirements

CSTRESS1 is written in Visual Basic®. It runs in either standard or enhanced mode of Microsoft Windows 3.1 or higher. The basic requirements are:

- Any IBM-compatible machine built on the 80386 processor or higher.
- Hard disk.
- Mouse.
- CGA, EGA, VGA, Hercules, or compatible display.
- MS-DOS version 3.1 or higher.
- Windows version 3.1 in standard or enhanced mode.
- An 80486 processor and VGA display is recommended.

For assistance with the installation or use of CSTRESS1 contact:

Lee Chu or Gefei Liu
Maurer Engineering Inc.
2916 West T.C. Jester Boulevard
Houston, Texas 77018-7098 U.S.A.
Telephone: (713) 683-8227 Fax: (713) 683-6418
Telex: 216556

4.1.2 Check the Program Disk

The program disk is a 3½ inch, 1.44 MB disk containing twenty files. These twenty files are as follows:

SETUPKIT.DL_	MDICHILD.VBX
VBRUN100.DL_	CMDIALOG.VBX
VER.DL_	CSGDB.DB
GSWDLL.DLL	CTDB.DB
GSW.EXE	CDRAG4.EXE
SETUP.EXE	TEST.CDR
SETUP1.EXE	TEST.WDI
SETUP.LST	TEST.SDI
GRAPH.VBX	TEST.CT4
GRID.VBX	TEST.CP4

We recommend that all .VBX and .DLL files, that have the potential to be used by other DEA-67 Windows applications, be installed in your Microsoft Windows\SYSTEM subdirectory. This applies to all the .VBXs and .DLLs included here. The CSTRESS1 executable (CSTRESS1.EXE) file should be placed in its own directory (default "C:\CSTRESS1"). All these procedures will be done by a simple setup command explained in Section 4.2.

In order to run CSTRESS1, the user must install all the files into the appropriate directory on the hard disk. Please see Section 4.2 to setup CSTRESS1.

It is recommended that the original diskette be kept as a backup, and that working diskettes be made from it.

4.1.3 Backup Disk

It is advisable to make several backup copies of the program disk and place each in a different storage location. This will minimize the probability of all disks developing operational problems at the same time.

The user can use the COPY or DISKCOPY command in DOS, or the COPY DISKETTE on the disk menu in the File Manager in Windows.

4.2 INSTALLING CSTRESS1

The following procedure will install CSTRESS1 from the floppy drive onto working subdirectories of the hard disk (i.e., copy from B: (or A:) drive onto C: drive subdirectory CSTRESS1 and WINDOWS\SYSTEM).

1. Start Windows by typing "WIN" <ENTER> at the DOS prompt.
2. Insert the program disk in drive B:\.
3. In the File Manager of Windows, choose [Run] from the [File] menu. Type B:\setup and press Enter.
4. Follow the on-screen instructions.

This is all the user needs to setup CSTRESS1. After setup, there will be a new Program Manager Group (DEA APPLICATION GROUP) which contains the C.T. icon for CSTRESS1 as shown in Figure 4-1.

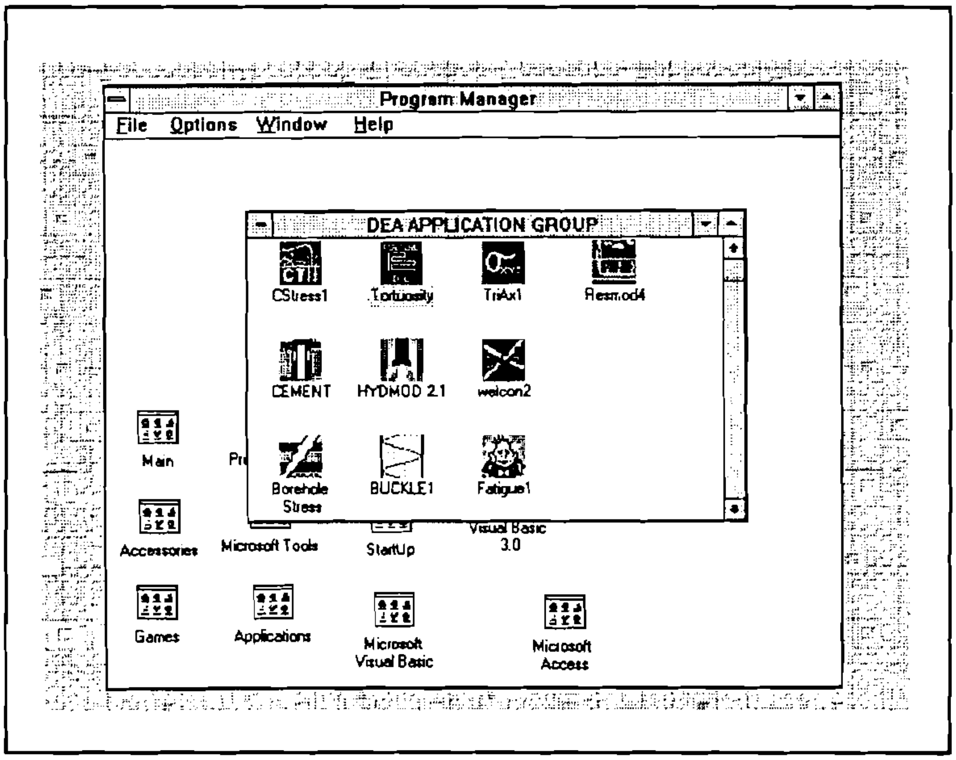


Figure 4-1. DEA APPLICATION GROUP and "CSTRESS1" Icon

4.3 STARTING CSTRESS1

4.3.1 Start CSTRESS1 from Group Window

To run CSTRESS1 from the GROUP Window, the user simply double-clicks the "CSTRESS1" icon, or when the icon is focused, press <ENTER>.

4.3.2 Use Command-Line Option from Windows

In the Program Manager, choose [Run] from the [File] menu. Then type C:\CSTRESS1\CSTRESS1.EXE <ENTER>.

4.4 ALTERNATIVE SETUP

If the SETUP procedure described before fails, follow these steps to install the program:

1. Create a subdirectory on drive C: C:\CSTRESS1.
2. Insert the source disk in drive B: (or A:).
3. Type: CD\CSTRESS1 <ENTER>.
4. At prompt C:\CSTRESS1, type:
   Copy B:\CSTRESS1.EXE <ENTER>
   Copy B:*.DB <ENTER>
   Copy B:\TEST.* <ENTER>.

5. Type: CD\WINDOWS <ENTER>.

6. At prompt C:\WINDOWS>, type:
   Copy B:\VBRUN100.DL_ VBRUN100.DLL <ENTER>.

7. Type: CD\WINDOWS\SYSTEM <ENTER>.

8. At prompt C:\WINDOWS\SYSTEM>, type:
   Copy B:*.DLL <ENTER>
   Copy B:*.VBX <ENTER>.
   Copy B:\GSW.EXE <ENTER>

9. Type: CD.. <ENTER> then key in "WIN" <ENTER> to start Windows 3.1 or later version.

10. Click menu "File" under "PROGRAM MANAGER," select item [New...] click on [PROGRAM GROUP] option, then [OK] button.

11. Key in "DEA APPLICATION GROUP" after label "Description:," then key in "DEAMEI" after "Group File:," then click on [OK] button. A GROUP Window with the caption of "DEA APPLICATION GROUP" appears.

12. Click on menu [File] again, Select [NEW...] click on "PROGRAM ITEM" option, then, [OK] button.

13. Key in "CSTRESS1" after label "Description," key in "C:\CSTRESS1\CSTRESS1.EXE" after label "COMMAND LINE," then click on [OK] button. The CSTRESS1 icon appears.

14. Double-click the icon to start the program.

5. Basic Operation of Microsoft Windows

CSTRESS1 runs in a Microsoft Windows environment. It is assumed that the user is familiar with Windows, and the user's computer is equipped with Windows 3.0 or later version.

Some elements and terminology of Windows are reviewed here:

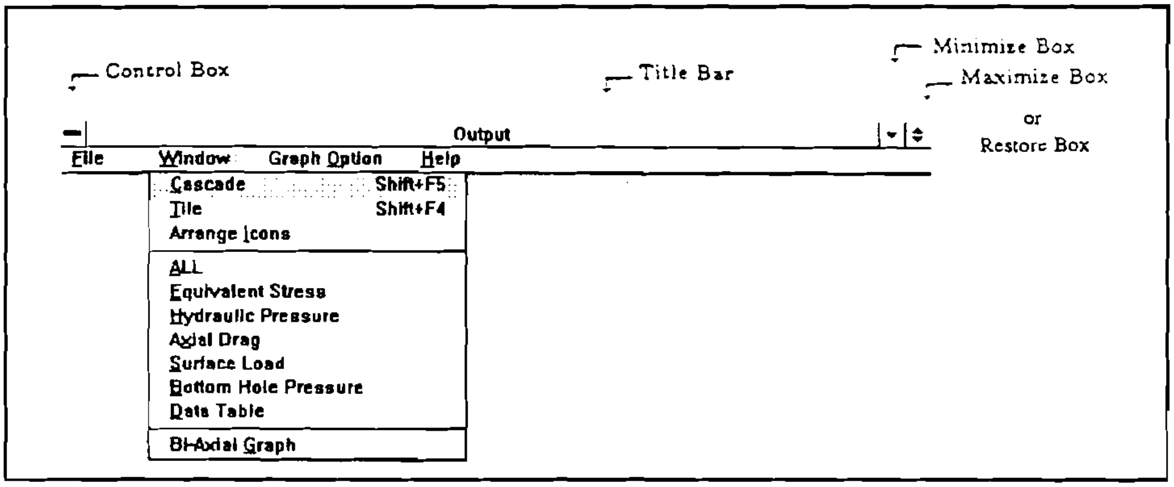


Figure 5-1. Title Bar in Window

5.1 THE TITLE BAR

The title bar serves two functions: one is to display the name of the current window and the other is to indicate which window is active. The active window is the one whose title bar is in color. (On monochrome monitors, the difference is shown by the intensity of the title bar). The user can make a window active by clicking anywhere within its border.

5.2 THE CONTROL BOXES

At the left side of the title bar is the control box. It has two functions. First, it can display the CONTROL menu, which enables the user to control the window size using the keyboard. Second, double-clicking the control box will end the current program.

During execution of CSTRESS1, the control boxes are not needed. The program will run according to its own flow chart.

5.3 MINIMIZE AND MAXIMIZE BOXES

At the right side of the title bar are the MINIMIZE and MAXIMIZE boxes. The box with the up arrow is the MAXIMIZE box. The box with the down arrow is the MINIMIZE box. If a window has already been maximized, the MAXIMIZE box changes to a RESTORE box with both up and down arrows, as shown in Figure 5-1.

- Clicking on the MINIMIZE box will reduce the window to the size of an icon. The window's name in the title bar appears below the icon. To restore a window from an icon, double-click on the icon.
- Clicking on the MAXIMIZE box will make the window take up the total working area.
- Clicking on the RESTORE box will make the window take up a portion of the total working area, which is determined by how the user manually sizes the window.

5.4 TEXT BOXES

TEXT boxes can display the information that the user enters. Sometimes there will be text already typed in for the user. The user can utilize arrow keys to edit the existing text. Figure 5-2 shows a typical text box.

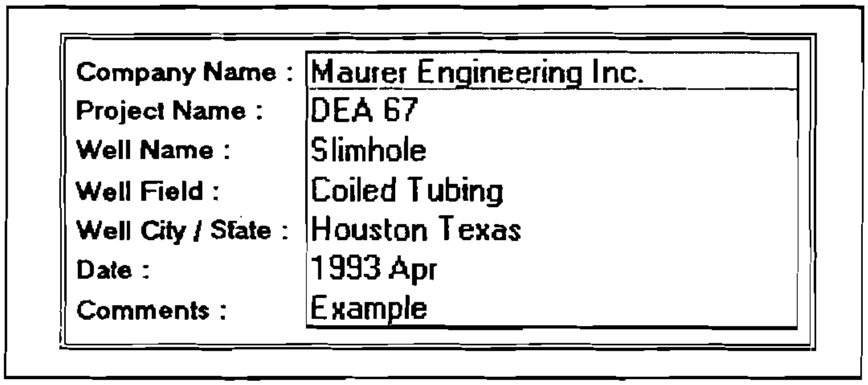


Figure 5-2. Text Box

5.5 CHECK BOXES

A CHECK box indicates whether a particular condition is on or off. When it is on, an X appears. When it is off, the box is empty. Figure 5-3 shows a typical check box.

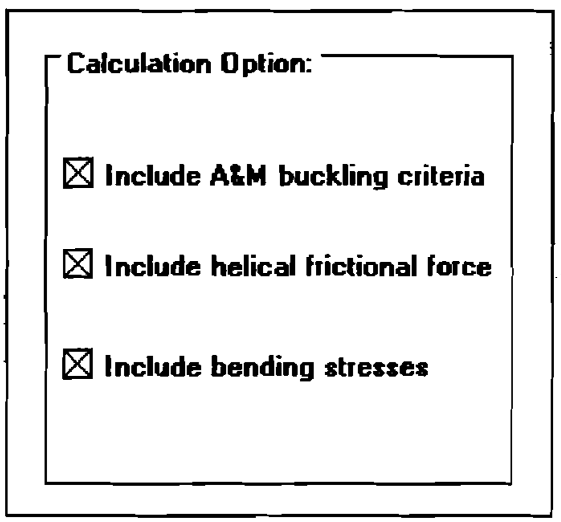


Figure 5-3. Check Box

5.6 OPTION BUTTONS

OPTION buttons are exclusive settings. Selecting an option immediately causes all other buttons in the group to be cleared. Figure 5-4 is a typical option box.

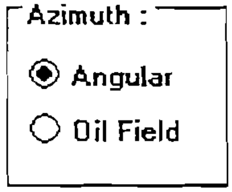


Figure 5-4. Option Buttons

5.7 COMMAND BUTTONS

A COMMAND button performs a task when the user chooses it, either by clicking the button or pressing a key. The most common command buttons are the **OK** and **Cancel** buttons found on almost every dialog box. In most cases, there is a button with a thick border—the default button which will be executed if you press <ENTER>. Figure 5-5 shows a typical command button:

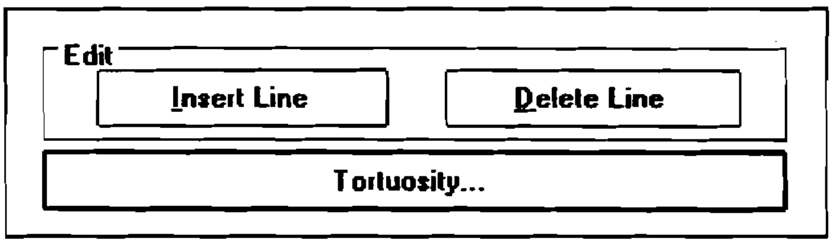


Figure 5-5. Command Buttons

5.8 LIST BOXES

A LIST box gives the user a list of options or items from which to choose. If the LIST box is too small to show all possible selections, a SCROLL box will appear on the right side of the box. The user makes a selection from a LIST box by clicking on it, or from the keyboard, highlighting the desired item with the arrow keys, and then pressing <ENTER>. Figure 5-6 is a typical list box.

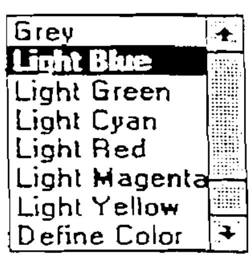


Figure 5-6. List Box

5.9 DROP-DOWN LIST BOXES

A DROP-DOWN LIST box is indicated by a small arrow in a box to the right of the option. The current setting is shown to the left of the arrow. When the user clicks on the small arrow, it drops to list all selections. A typical drop-down list box is shown in Figure 5-7.

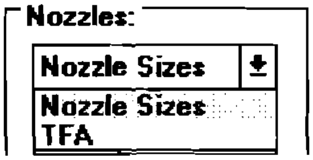


Figure 5-7. Drop-Down List Box

5.10 SCROLL BARS

SCROLL BARS are graphical tools for quickly navigating through a long line of items. There are two types of scroll bars: HORIZONTAL and VERTICAL SCROLL BARS.

The small box inside the bar is called the SCROLL BOX. The two arrows on the ends of the scroll bar are scroll buttons (Figure 5-8). Clicking the scroll buttons or moving the SCROLL BOX will change the portion of the information you are viewing.

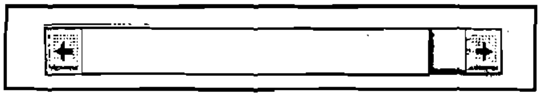


Figure 5-8. Scroll Bar

5.11 GRID

GRID displays a series of rows and columns (Figure 5-9). In case of a long list of items or a large amount of information, scroll bars will attach to the grid providing easy navigation.

	O.D.	I.D.	Wt in air	Density	Elastic	Yield
	[in]	[in]	[lb/ft]	[lb/ft3]	[psi]	[psi]
32	2.000	1.688	3.072	490.0	30000000	70000
33	2.000	1.624	3.638	490.0	30000000	70000
34	2.000	1.594	3.896	490.0	30000000	70000
35	2.380	2.157	2.638	490.0	30000000	70000
36	2.380	2.125	3.004	490.0	30000000	70000
37	2.380	2.107	3.207	490.0	30000000	70000
38	2.380	2.063	3.697	490.0	30000000	70000
39	2.380	1.999	4.391	490.0	30000000	70000
40	2.380	1.969	4.709	490.0	30000000	70000
41	2.880	2.625	3.671	490.0	30000000	70000

Figure 5-9. Grid

In the INPUT Window, grids are used to let the user input data. Some columns of grid only allow number input. Typing of an alphabetical character is prohibited by the program. The user can edit an entry by typing desired characters or pressing the <BACKSPACE> key to delete. In many grids, just like a spreadsheet, the user can insert and delete a row.

On the other side, grids are for presentation only in the OUTPUT Window. They do not allow editing.

The grid supports word-wrapped text presentation, resizeable columns and rows, etc. Even though the user can manually change the cell's column width or row height, we do not recommend this because all grids in CSTRESS1 are carefully designed to fit the length of the appropriate data string.

6. Running CSTRESS1

CSTRESS1 runs in Microsoft Windows environment. Windows' graphical user interface (GUI) and point-and-click environment gives the user the flexibility that is needed for today's software.

6.1 OVERVIEW

There are two major windows in CSTRESS1:

1. INPUT-CRITERIA Window
2. OUTPUT Window

Only one window can be shown on the screen at a time. The menu bar, control button, arrow keys, hot keys, etc., can be used to control the program's flow and the keyboard or mouse to input the data. Each major window contains several sub-pages or sub-windows to hold different groups of input and output information.

The menu bar selection is not always available in certain sub-pages or sub-windows. This type of design is to reduce the possibility of destroying the program in operation flow.

TABLE 6-1. Input Criteria Window Menu

FILE	MODEL	PAGE	RUN	CUSTOMER UTILITY	HELP
New Project	Pick up (Logging)	Next — F11	Start	Foreground Color	Assistance
Open Project	Slack off (Logging)	Previous — F12		Background Color	About
Save Project	Pick up (Drilling — Tripping)	First		Monochrome	
Save Project As...	Slack off (Drilling — Tripping)	Last		English	
New File	Drill			Metric	
Open File	Consider Hydraulic While Tripping			Wellbore	
Save File					
Save File As...					
Print ► Current Page					
All Pages					
Exit					

TABLE 6-2. Output Window Menu

FILE	WINDOW	GRAPH OPTION	HELP
Print Report/Graph Only	Cascade — Shift F5	Curve Option	Assistance
Print Project File	Tile — Shift F4	Image File Format ► Bitmap	About
		Metafile	
Print WDI and SDI File	Average Icons		
Print TDI and PDI File	All		
Copy Graph to Clipboard	Equivalent Stress		
Save Report Disk File	Hydraulic Pressure		
Back to Input	Axial Drag		
Exit	Surface Load		
	Bottom-Hole Pressure		
	Data Table		
	Bi-Axial Graph		

6.2 GETTING STARTED

Bring up Windows and select "DEA APPLICATION GROUP" as the active window, as shown in Figure 6-1.

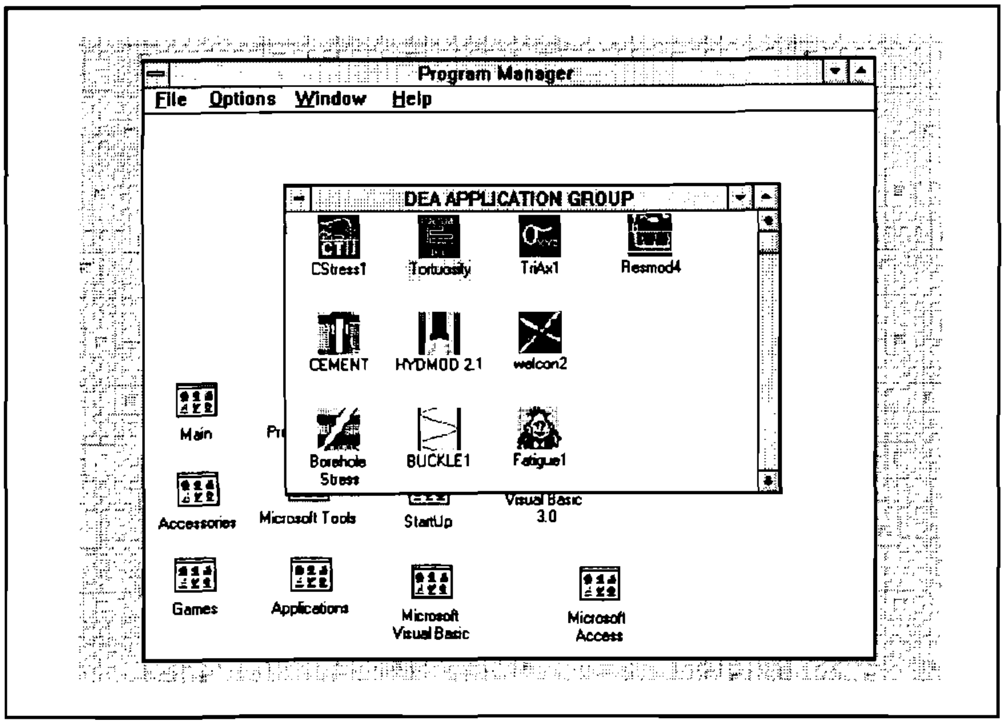


Figure 6-1. "DEA APPLICATION GROUP" and CSTRESS1 Icon

This window may contain more than one icon. Double-click on the CSTRESS1 icon, the INTRODUCTION window with two command buttons, "Exit" and "Continue" will be displayed on the screen.

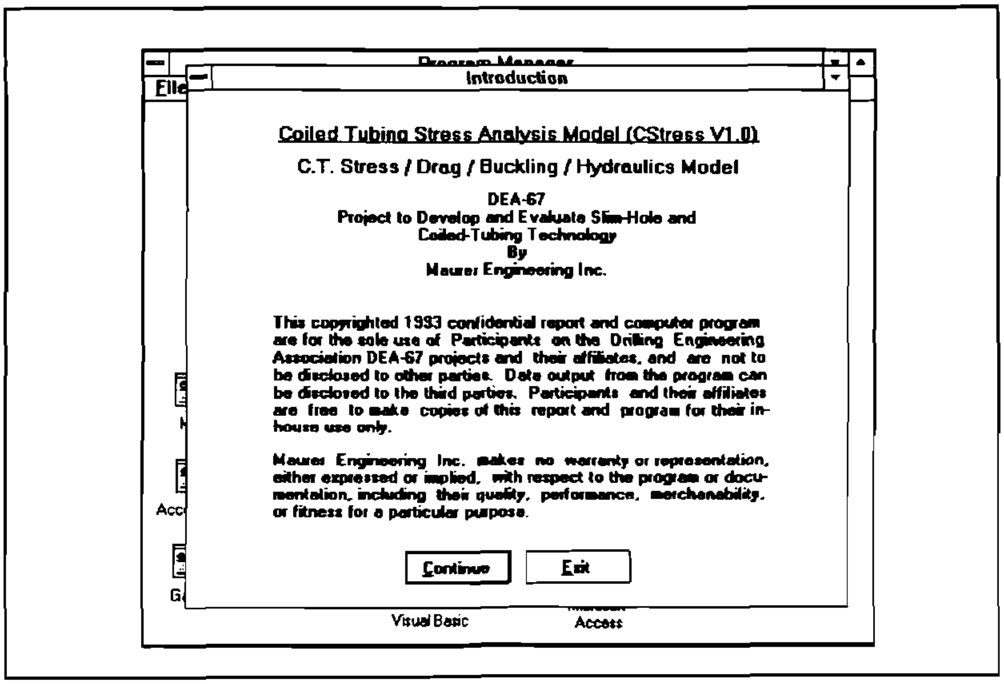


Figure 6-2. Introduction Window

Clicking "Exit" will terminate the program. The "Continue" button is the default command which means that the user can press the button by pressing <ENTER> or clicking the mouse. This will invoke and display the INPUT Window. Note that after the INTRODUCTORY Window appears, it takes a few seconds for the command buttons to be responsive; it is loading necessary files.

6.3 PULL-DOWN MENUS IN THE INPUT WINDOW

The CSTRESS1 menu system provides many tools that the user will utilize while running the application. As in other Windows applications, the user can pull-down a menu by clicking the menu name with the mouse, or by pressing the Alt key on the keyboard and then striking the first letter or the underscored letter of the menu name. Once a menu is displayed, the user selects a command by clicking the command name with the mouse or by highlighting the command name and pressing <ENTER>.

There are six menus in the INPUT Window: File menu, Model menu, Page menu, Run menu, Customer Utility menu, and the Help menu as shown in Figure 6-3.

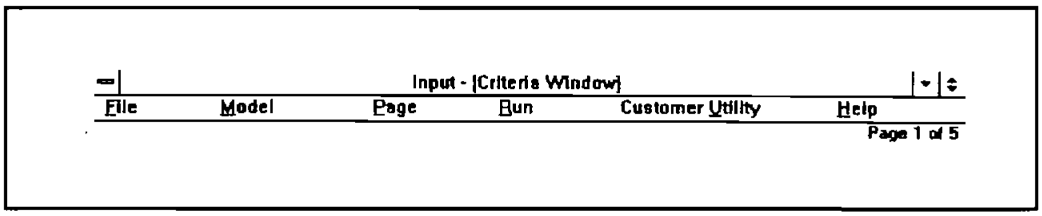


Figure 6-3. Input Window

The page number is shown on the right-hand side below the menu bar. These five pages are illustrated in detail in the next section. The Page, Run and Help menus are enabled for five pages. Model and Customer Utility menus are enabled only on the first page. However, the last item "Wellbore" under Customer Utility can be selected only on the fifth window page.

For the File menu, the four commands on project file ("New Project," "Open Project...," etc.) are enabled only on the first page while the four commands on file ("New File," "Open File..." etc.) are enabled only on pages 2 through 5 of the INPUT Window.

The File menu contains commands for creating, retrieving, saving and printing input data as displayed in Figure 6-4.

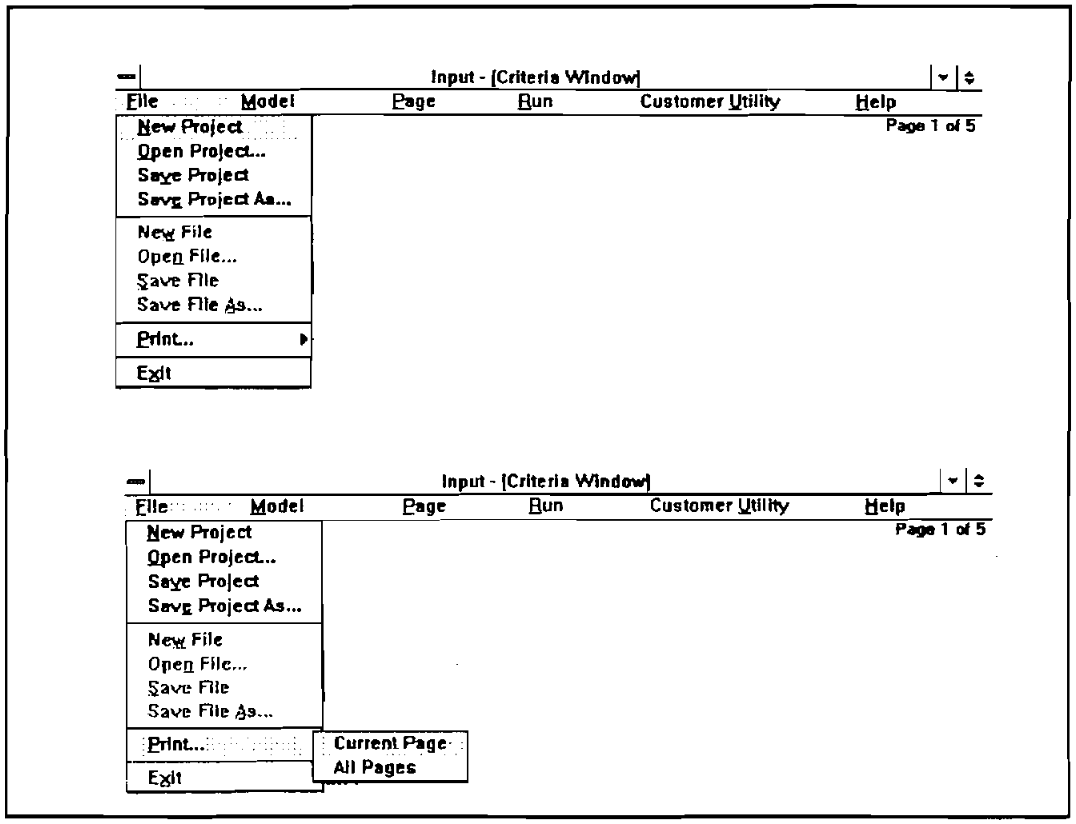


Figure 6-4. File Menu

When the user starts CSTRESS1, it automatically opens a new project (by default: Project1.CDR) and a set of input data files, namely, Project1.WDI, Project1.SDI, Project1.CT4 Project1.CP4, all in the current subdirectory. The reason for using the project file is for quick, future retrieval of a set of input data. The user can open an existing project file without opening each individual (.WDI, .SDI, CT4, .CP4) file. The project file, which is a collection of the paths and file names of all input data files, will do the rest of the retrieving work for the user.

However, although the listing in the CRITERIA Window (Page 1) represents files, CSTRESS1 does not automatically create files on the disk when the user starts CSTRESS1. The same is true with "New Project." Only when the user chooses one of the Save commands from the File menu does CSTRESS1 actually save something to disk.

1. "New Project" command clears every input data file and displays a set of null input data files with default names in the CRITERIA Window.

2. "Open Project..." command opens a dialog box which enables the user to explore the file system for input files with extension name ".CDR."

3. "Save Project" command replaces the previous version of each of the input data file in the project with the modified one. Note that the project file (.CDR) does not contain any input data. It is simply a list of all the input data files in the project. That list is updated every time the user saves the project.

4. "Save Project As..." command opens a dialog box. The user can specify the drive, directory, and the name of the project file.

5. "New File" command clears every entry box associated with the current page, (i.e., one of WDI, SDI, CT4, CP4 files).

6. "Open File..." command opens a dialog box which enables the user to explore the file system for input files with extension name which is determined by the current page the user is in. For example, in page 2, the user clicks the Open File...; the pattern for the file list box in the dialog box will be ".WDI."

7. "Save File" command replaces the previous version of the input data file.

8. "Save File As..." command enables the user to save a file under a new name the user specifies while also retaining the original file. The new file will be associated with the project file when the user saves the project.

9. "Print" command allows the user to print the input data of the current page or all pages.

10. "Exit" command terminates the current application. CSTRESS1 will prompt the user to save the files, if they are not saved.

The files that make up a project do not have to be in one directory on the hard drive, since the project records the detailed path information on each input file. A single file such as an SDI file can be part of more than one project. However, if the user renames or deletes a file outside of the CSTRESS1 application and then runs CSTRESS1 and tries to open the file, CSTRESS1 displays an error message to warn the user that a file is missing.

The Model menu contains commands for five different coiled-tubing operations as displayed in Figure 6-5.

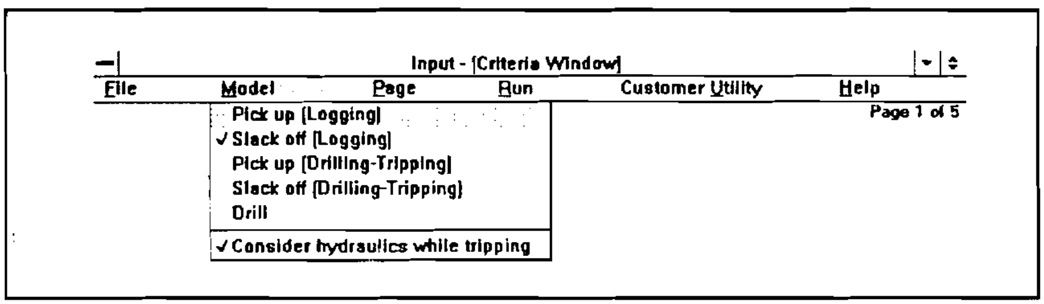


Figure 6-5.

1. "Pick Up (Logging)" operation allows pick up of the coiled-tubing string with the logging tool connected at the end.

2. "Slack Off (Logging)" operation allows the coiled-tubing string to be run into the well with the logging tool.

3. "Pick Up (Drilling—Tripping)" operation allows pulling the coiled-tubing string together with the bottom-hole assembly out of the well.

4. "Slack Off (Drilling—Tripping)" operation allows slack off of the coiled-tubing string with BHA.

5. "Drill" operation simulates the drilling operation.

6. "Consider Hydraulics While Tripping" tells the program to calculate only the hydrostatic pressure or to calculate surge and swab pressures (pick-up, slack-off operations) and circulating pressure (drilling operations). The check mark has to be at the front of this command or it will only calculate hydrostatic pressure.

The Page menu contains commands for browsing and navigating through the five pages as displayed in Figure 6-6.

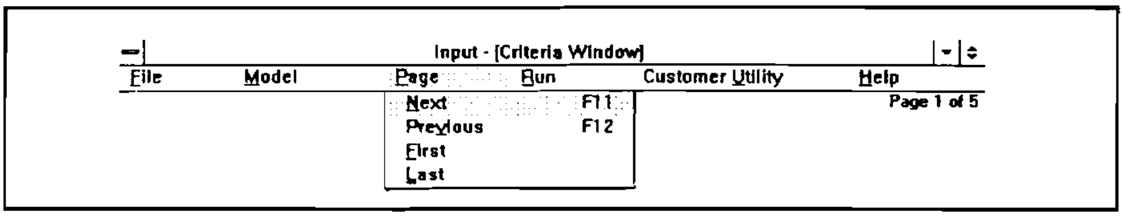


Figure 6-6. Page Menu

1. "Next" command leaves the current page and goes to the next page. Before doing so, the program will first check the validation of the input data in the current page and asks if the user wants to correct the invalid data entry. Then it will prompt the user to save the current file if it has not been saved.
2. "Previous" command functions the same as "Next" command, but in the opposite direction.
3. "First Page" command leaves the current page and goes to the CRITERIA Window. It will check the input data and prompts the user to save the file if the file on the current page is not saved.
4. "Last Page" command leaves the current page and goes to the PARAMETER DATA INPUT Window. It will check the input data and prompts the user to save the file if the file on the current page is not saved.

Usually, if all data are matched and consistent, the user will have no problem leaving one page for another. However, in some cases, the program will prompt a warning message even though each individual data page is good. One possibility is that an existing file is opened on the first page (Criteria page), and the user moves to the last page without going through the preceding pages. The program has no knowledge of the validation of the data in preceding files. In this case, going through the preceding pages will help clear the confusion.

The Run menu contains the command that the user chooses when ready to start calculation. The "Start" command does just that. The user can start the calculation from any page. The program will check the validation of all data.

The Customer Utility menu contains the command that enables the user to select the color, unit, and wellbore schematic.

Figure 6-7 shows this menu.

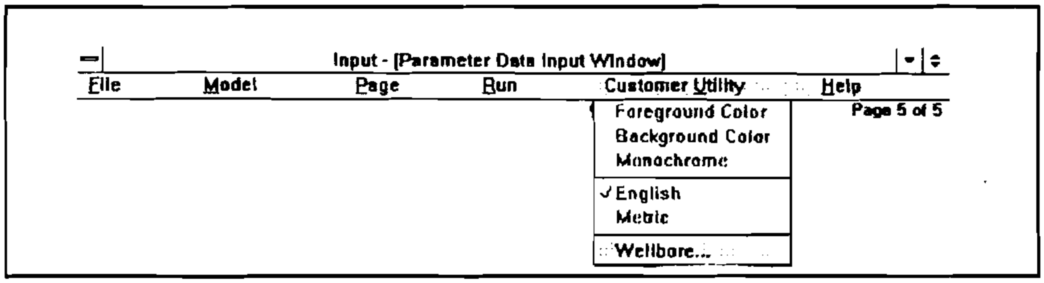


Figure 6-7. Customer Utility Menu

1. "Background Color" command opens the "Color" dialog box, which will let the user select the desired background color.
2. "Foreground Color" command opens the "Color" dialog box, which will let the user select the desired foreground color.
3. "Monochrome" command allows the CSTRESS1 program to run with a monochrome monitor.
4. "English" and "metric" menu allows the user to select the desired unit.
5. "Wellbore" command shows the wellbore schematic.

The Help menu gives the user information about the assistance and computer systems.

Figure 6-8 shows this menu.

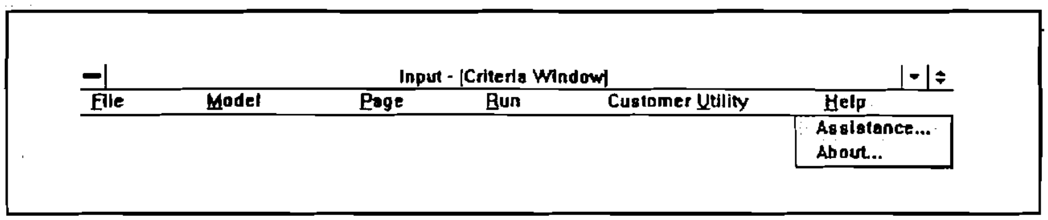


Figure 6-8. Help Menu

1. "Assistance..." command opens the "Assistance" dialog box, which displays MEI's address, phone number, and other applicable information.
2. "About..." command opens the "About" dialog box, which gives the user instant reference information about CSTRESS1 and current computer system information.

6.4 THE INPUT WINDOW

In the INPUT Window, there are five pages according to different input data files. These five pages are:

1. CRITERIA Window
2. WELL DATA INPUT Window (WDI)
3. SURVEY DATA INPUT Window (SDI)
4. TUBULAR DATA INPUT Window (TDI)
5. PARAMETER DATA INPUT Window (PDI)

When the user leaves each page, except the first page, the program automatically checks for input errors on that page.

6.4.1 Page 1: Criteria Window

Figure 6-9 shows a typical CRITERIA Window. The paths and names of input data, their saved status (Saved or Not), CT operating model, hydraulics consideration, and the unit system currently in use is displayed on this page.

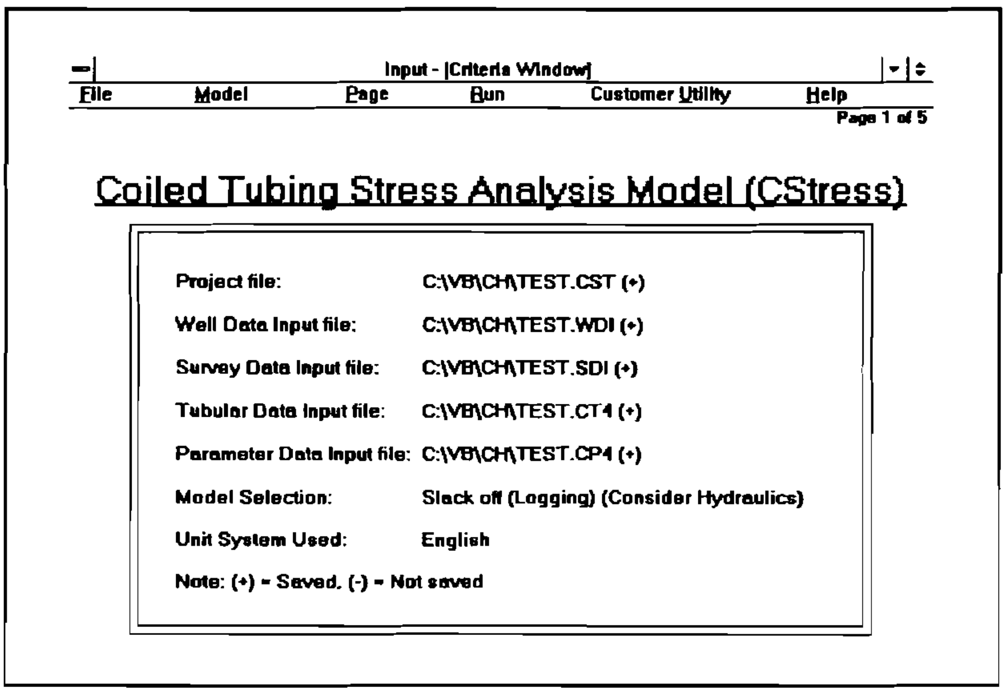


Figure 6-9. Criteria Window

6.4.2 Page 2: Well Data Input (WDI)

Figure 6-10 shows a typical WELL DATA INPUT Window.

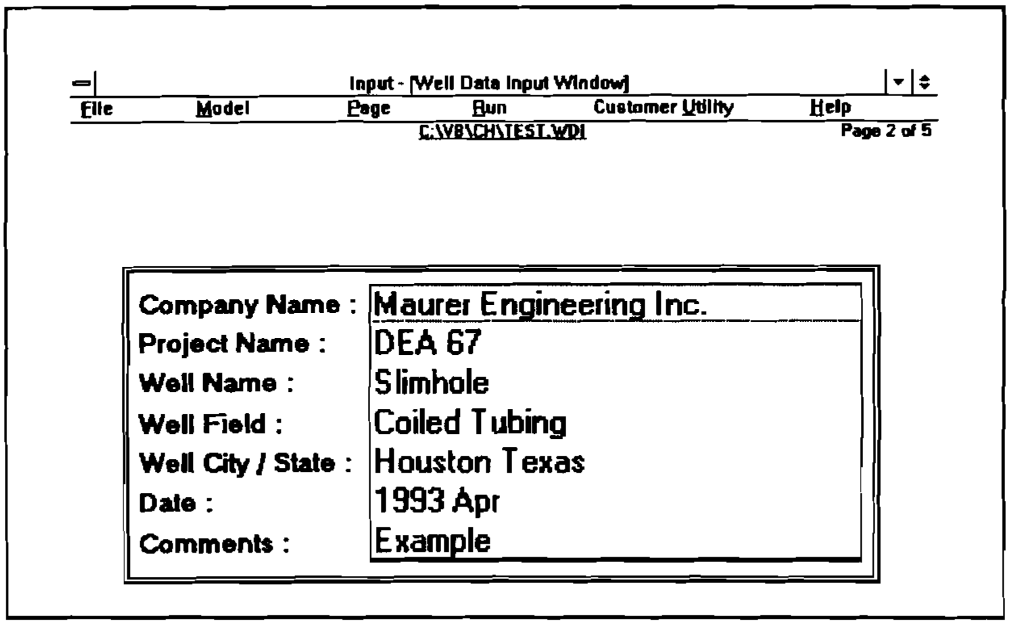


Figure 6-10. Well Data Input Window

The user is asked to input a series of strings representing the company name, project names, well location, data, and comments. They are optional and need not be completed. They will not be used in calculation or in the file name specification.

The strings must be less than 30 characters in length.

6.4.3 Page 3: Survey Data Input (SDI)

Figure 6-11 shows a typical SURVEY DATA INPUT Window.

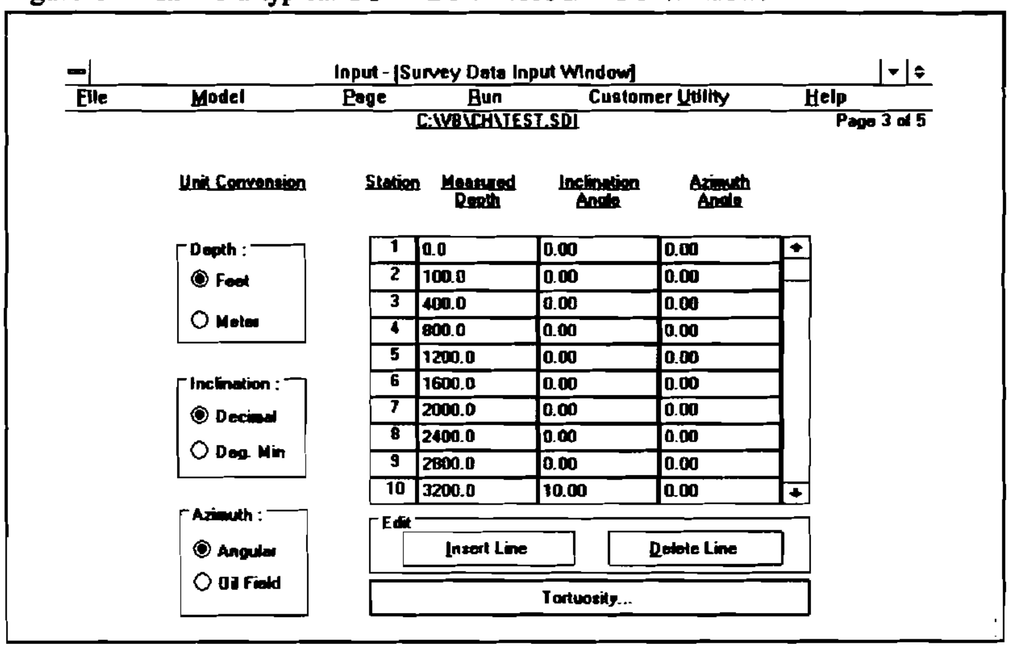


Figure 6-11. Survey Data Input Window

The user can input up to 400 survey data points. The measured depth, inclination angle and azimuth angle each have two unit options, independent of the application unit system the user selected for the application.

When the cursor is in the text box, press the ← or → key to move the cursor inside the box to edit. Pressing the ↑ or ↓ key will move the cursor to the above or the lower box. If the user wants to move the cursor to the right or left box, hold down the Ctrl key and press → or ←. Of course, the user can use the mouse or press the tab key to locate the cursor.

The SDI files used in CSTRESS1 are compatible with any SDI files in other DEA software applications developed by MEI.

The tortuosity command button lets the user torture the smooth survey data, so that the doglegs add to the original survey. See Section 6.8 for details.

6.4.4 Page 4: Tubular Data Input (TDI)

Figure 6-12 shows a TUBULAR DATA INPUT Window.

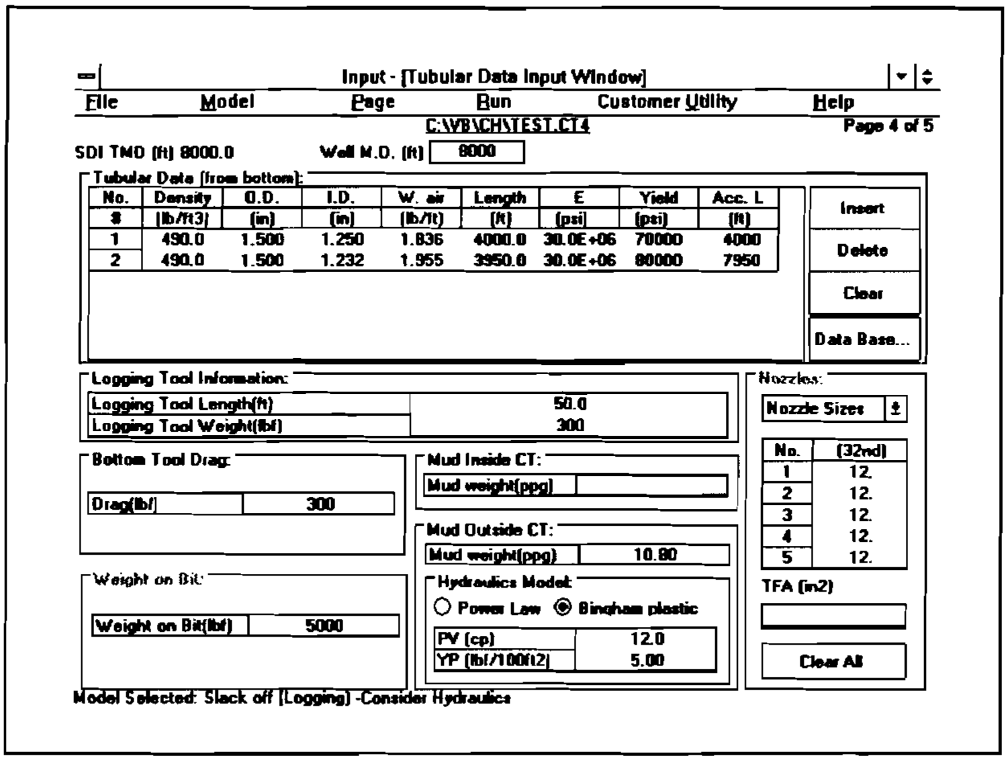


Figure 6-12. Tubular Data Input Window

The spreadsheet-like Tubular Data table is similar to the SDI file input, but TDI uses grids instead of text boxes which are used in SDI.

Depending on which model has been selected, the user can input only a fraction of the data window. The TDI Window groups the same type of input data and places them into frames. For example, if the user selects the slack off (logging) model, the nozzle and weight-on-bit information is not needed on the screen. The title color of the non-essential frame group becomes gray shading. The user cannot access these data.

BHA and CT string data are input into the Tubular Data table. The Tubular Data table input starts from bottom tool (BHA) to the surface. While the user edits the section length, the program continues to track the accumulative length of the CT string and BHA, then displays the accumulative length (i.e., Well MD) in the upper center of the screen. When the user selects the logging model, the logging tool length with the CT string length and/or BHA length becomes the Well MD.

At the top right-hand corner of the TDI Window, the program displays the SDI TMD which is the total survey measured depth input in the previous SDI Window. The Well MD must be smaller than or equal to the SDI TMD.

Sometimes when the user switches from one unit system to another, the previously compatible data may become unmatched due to the rounding off of the data during the conversion operation. Mostly this happens on measured depth in the SDI file and bit depth in the TDI file. Remember that the unit for measured depth in the SDI file may be different from the one in the application unit system.

If the user clicks the Database command button, the program opens the disk database file. The default file name is CDDB.DB.

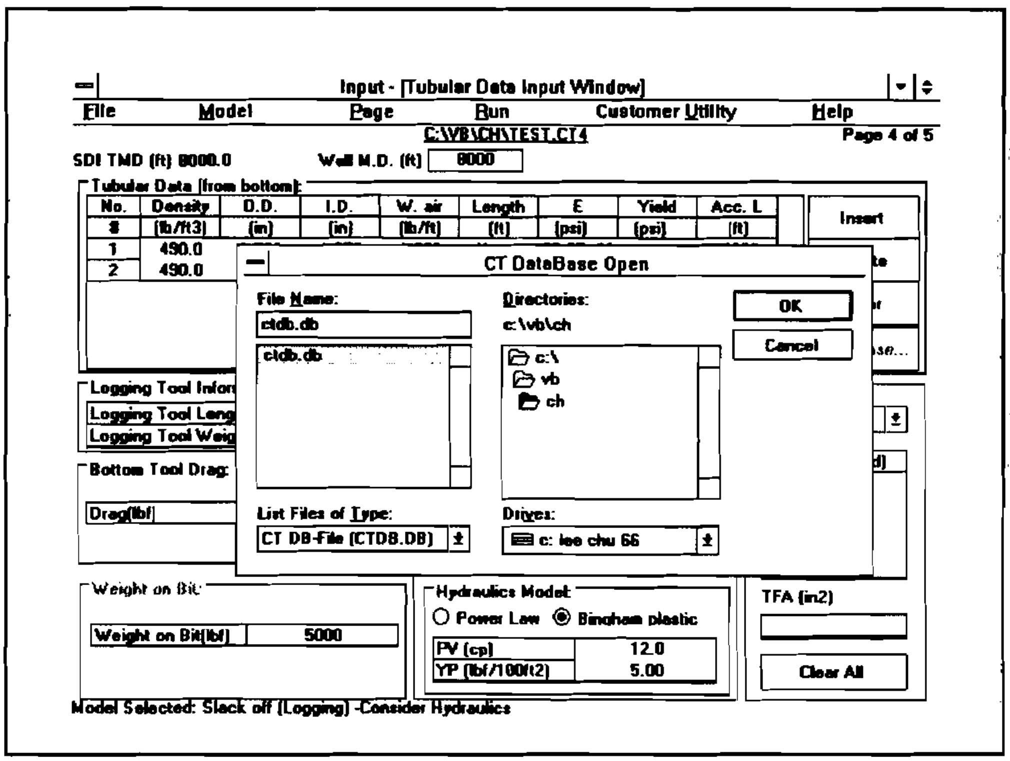


Figure 6-13. Open CT Database File

Click the OK button, the coiled-tubing database shows on the screen. The user can edit the data and save the changed data on the disk file. After finding the data, click the OK button, this will copy the data to the TDI table.

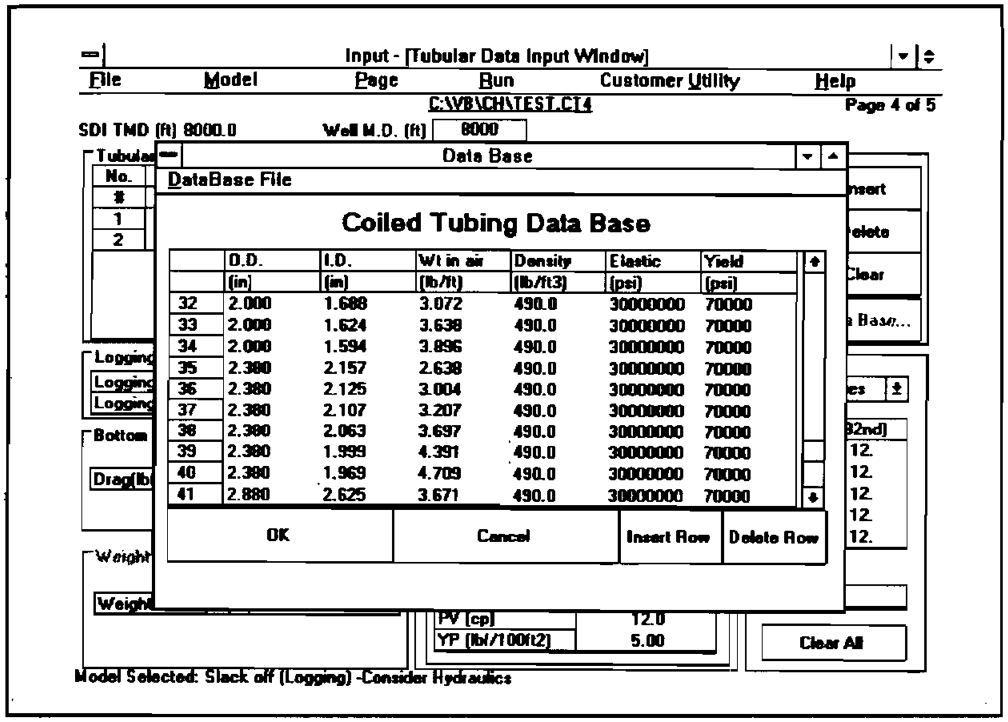


Figure 6-14. Coiled-Tubing Database

The PDI Window also provides the casing database (Figure 6-15).

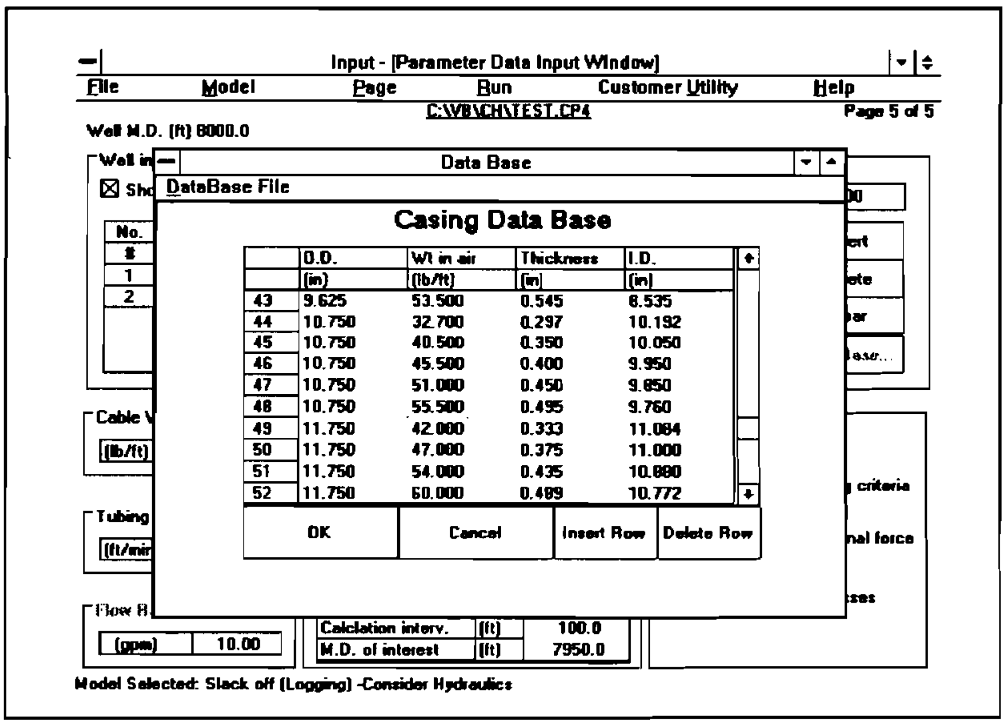


Figure 6-15. Casing Database

The default database file is CSGDB.DB

6.4.5 Page 5: Parameter Data Input (PDI)

Figure 6-16 shows a typical PARAMETER DATA INPUT Window.

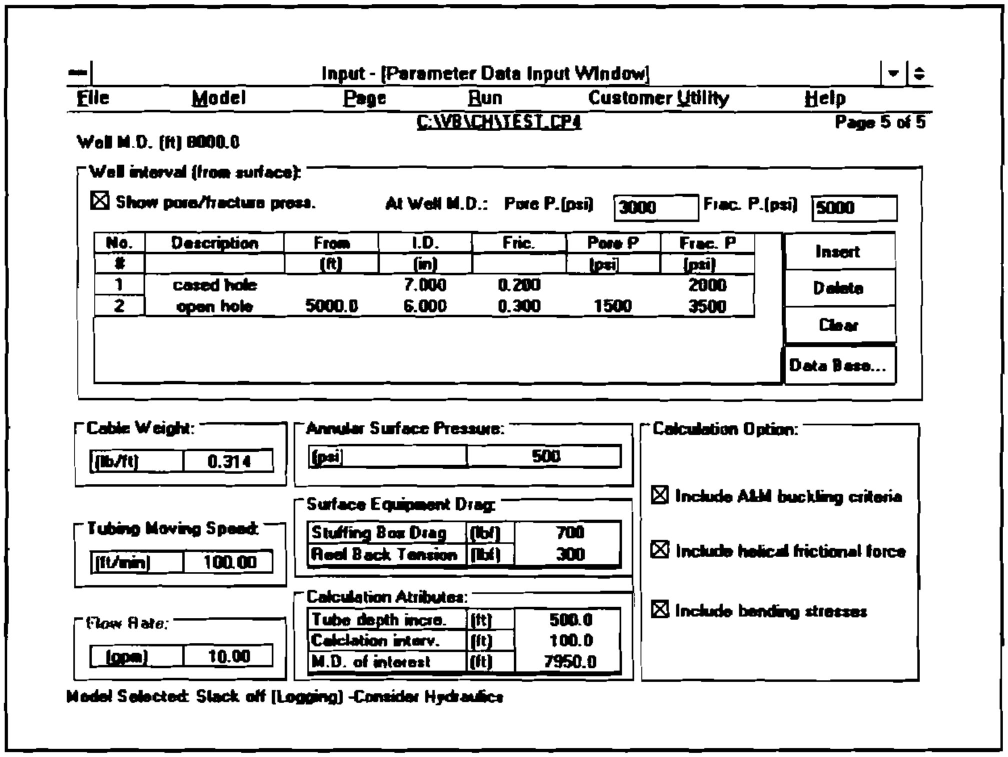


Figure 6-16. Parameter Data Input Window

In PDI the user finds the same input styles as in TDI, the data are grouped by frames. Some of these frames can only be accessed with certain operating model selection.

Well interval input sections are from surface down. When the check box is left empty in the "show pore/fracture pressure," the program does not consider pore/fracture pressures.

In the calculation option frame, there are three options that will affect the results of the calculations. The formulas for these calculations are discussed in Chapter 2 "Theory and Equations."

Pull-down the Customer Utility menu, select the wellbore option and the wellbore schematic will be displayed on the screen (Figure 6-17).

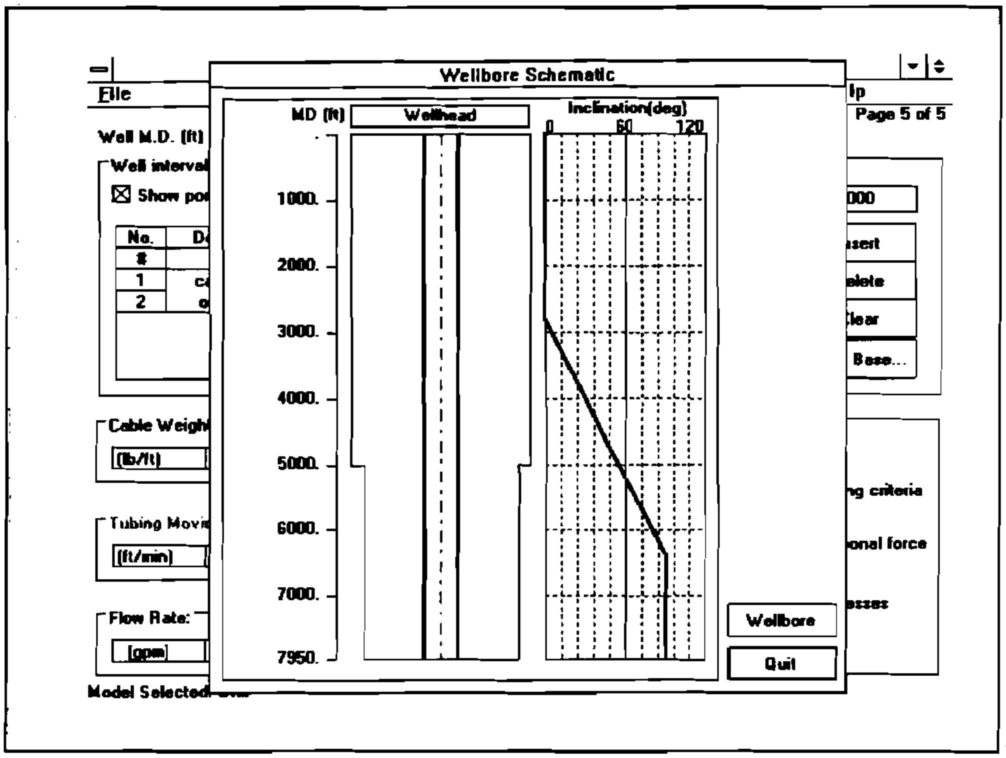


Figure 6-17. Wellbore Schematic

The wellbore graph is only available on the PDI screen page.

6.5 SAVE INDIVIDUAL FILES

The user can save WDI, SDI, TDI, and PDI files individually. While the PDI page is on the screen pull-down the File menu, the user can open/save the PDI file to a diskette. It is the same as managing other input pages.

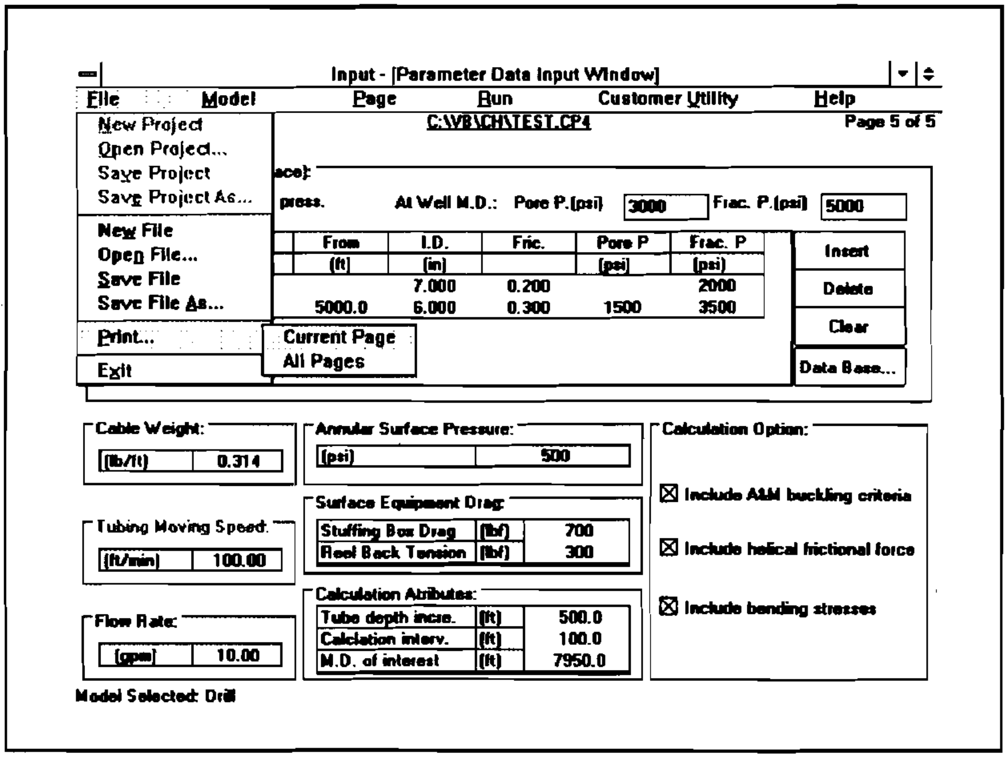


Figure 6-18. Manipulating with PDI File

6.6 RUN

After examining all input files, select operation model and check the calculation options, then click Run and Start to onset the calculation. There is an alerting window that displays on the screen while the program is calculating.

6.7 OUTPUT WINDOW

When the calculation is finished, the program unloads the INPUT Window and displays the OUTPUT Window.

"Child" windows are employed to display text reports, graphs for various calculation results. A "child" window is a window confined to its "parent" window - the OUTPUT window. "Child" windows can be displayed independently. The user can manipulate them just as normal windows: move, resize, close, etc. The arrangement commands in the Window Menu (Cascade, Tile, Arrange Icons) have the same functions as those of the Program Manager of Windows itself.

There are six "child" windows within the OUTPUT Window. These windows display on the screen in the file format automatically. They are:

1. Equivalent Stress (static) — graph
2. Hydraulic Pressure (static) — graph
3. Axial Drag (static) — graph
4. Surface Load (dynamic) — graph
5. BHP (dynamic) — graph
6. CSTRESS Data Report — table

Use the mouse to click any of the "child" windows, then the "child" window becomes activated and the title bar background color changes. Only one "child" window can be activated at a time. The CSTRESS Data Report Window will show data for the graph in the active "child" window.

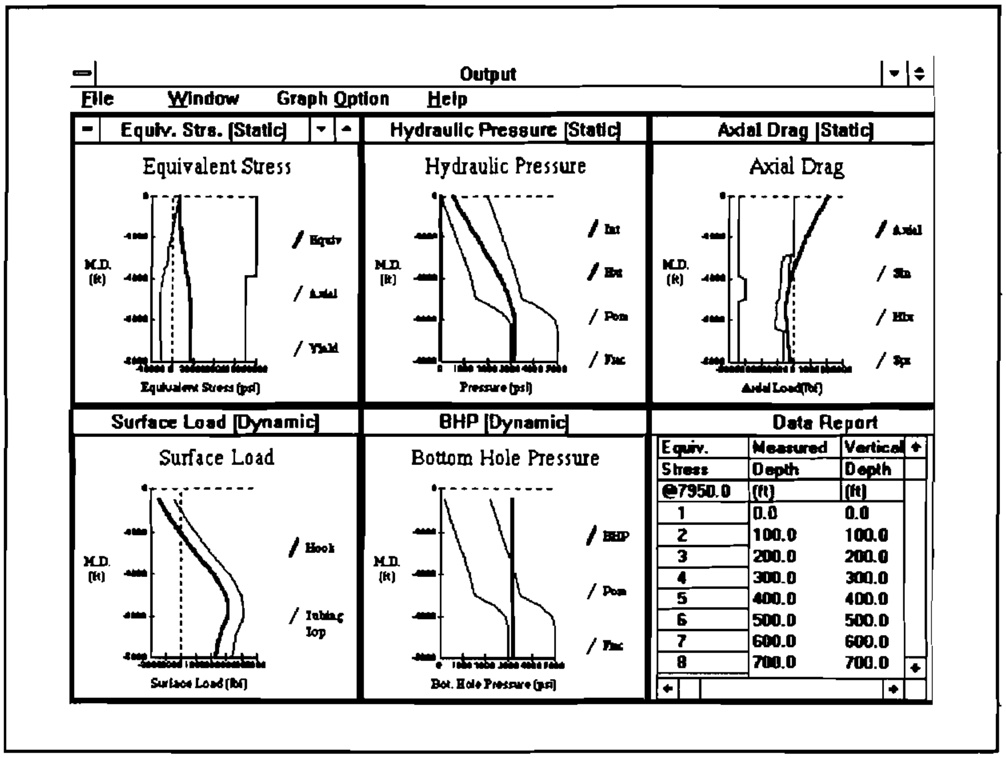


Figure 6-19. Output "Child" Window

6.7.1 Print Results

To send results to the printer: 1) activate the desired "child" window, 2) pull-down the File menu, and 3) click "Print Report/Graph Only."

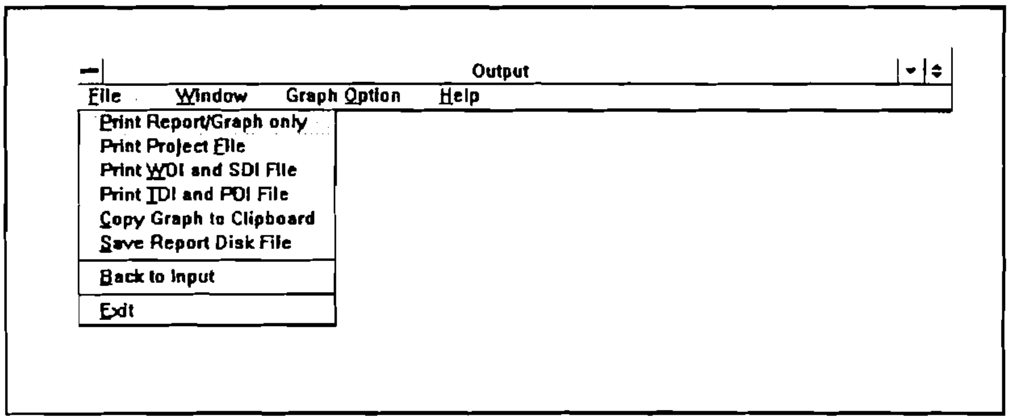


Figure 6-20. Pull-Down File Menu

The user can print the input data by selecting "Print Project File," "Print WDI and SDI File," and "Print TDI and PDI File." If "Save Report Disk File," is selected, the data in the CSTRESS Data Report "child" window with/without TDI and PDI data will save to diskette.

Copying the active graph to the clipboard can put the graph image to clipboard, and this graph image can be retrieved by certain window graphic programs, such as Window-Paintbrush.

6.7.2 Manipulating the Output Graph

Under Graph Options — Image File Format pull-down menu there are two types of graphic file formats: Bitmap and Metafile.

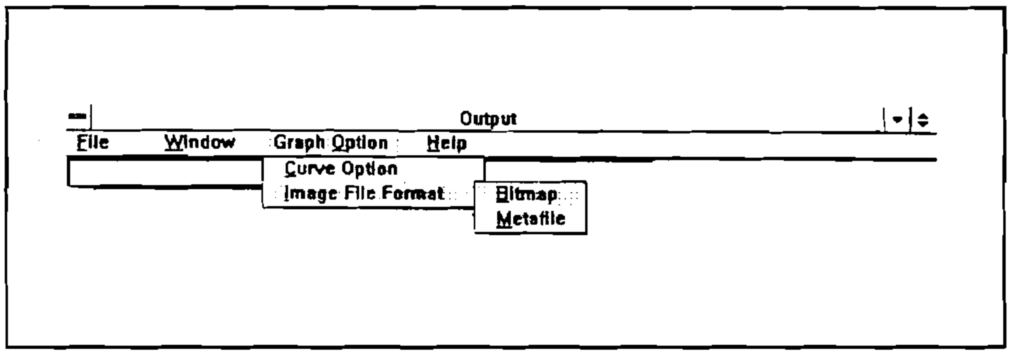


Figure 6-21. Graphic Image File Format Selection

One difference between Bitmap and Metafile is that Metafile is resizeable. After selecting Metafile and copy graph image to clipboard, open Windows Utility: Clipboard Viewer and change the size of the Viewer window. Graph size proportions itself to the window size.

To enlarge the size of the graph in the OUTPUT Window:

1. Activate the sub-window by clicking any where inside the window (the title bar of active sub-window is in color).

2. When the mouse cursor is moved to the boundary of the sub-windows, the cursor becomes a double arrow (Figure 6-22).
3. Hold left button of mouse, then drag the boundary to the size you want.
4. For a full-screen graph, click the maximize box in the top-right corner of the sub-window.

NOTE: It is important to change the size of the graph on the screen because the size of the printed graph depends on the size of the graph on the screen.

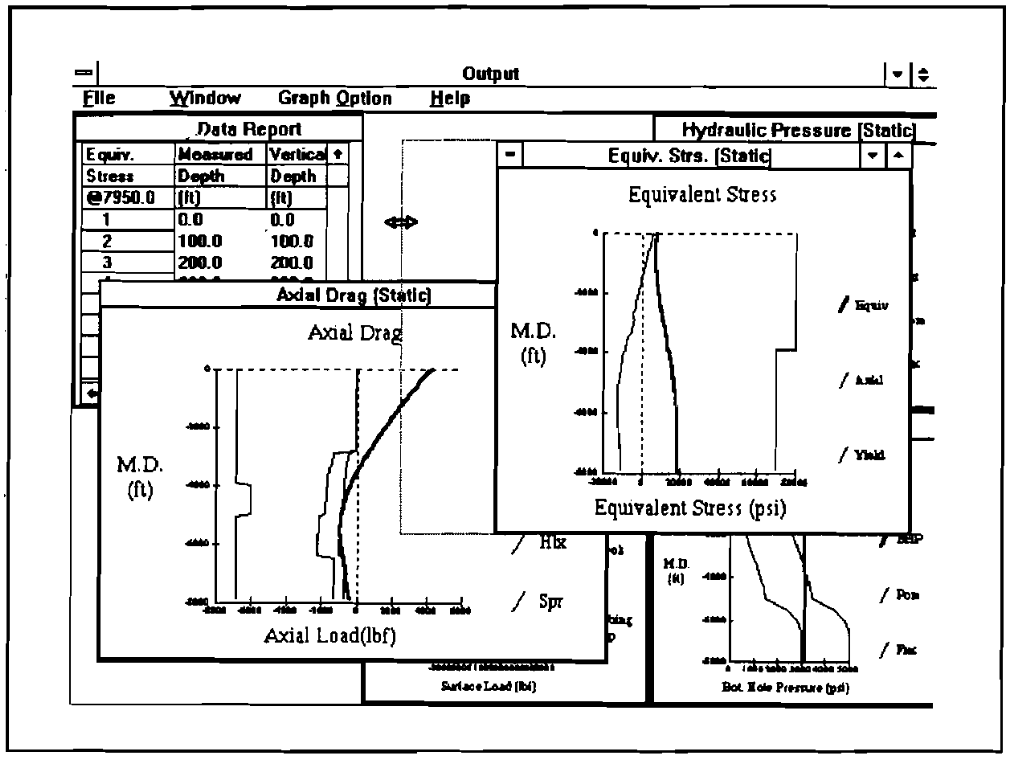


Figure 6-22. Change Graph Size

If the user selects Window — Cascade from the pull-down menu, the "child" window (only the visible "child" window) in the OUTPUT Window becomes CASCADE.

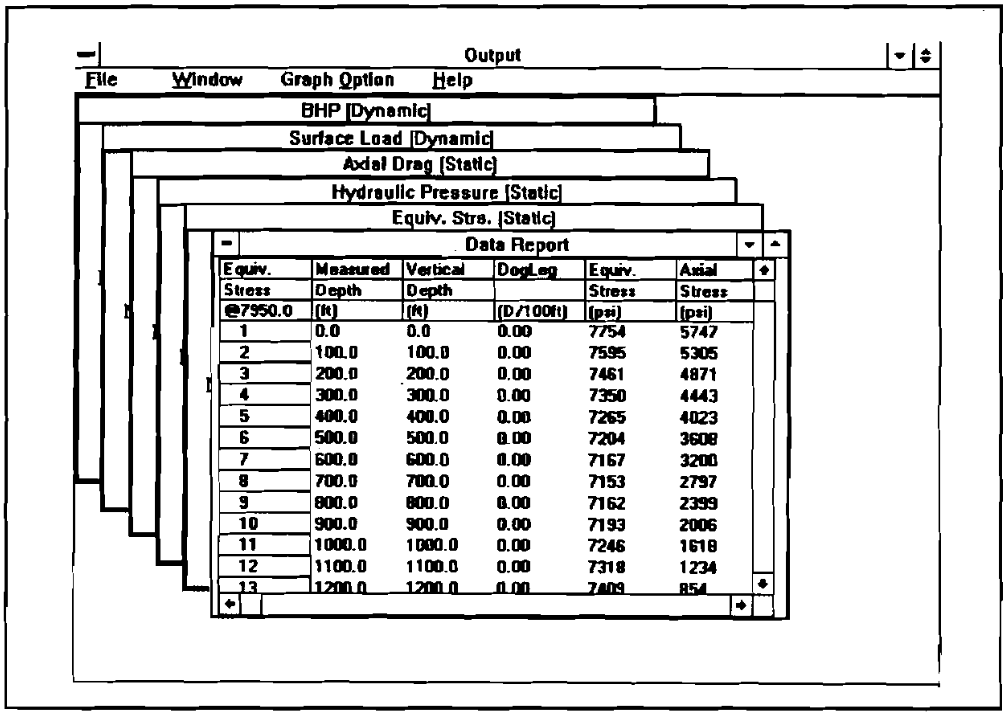


Figure 6-23. "Child" Window CASCADE

6.7.3 Select Output Graph Curves

When the calculation is finished, all output graphs with whole set curves will display on screen. Not every curve is important to the user, so the program provides the option of presenting the desired curve on the graph. Select Graph Option — Curve Option pull-down menu, CSTRESS's Graphic Curve setting will display on the screen.

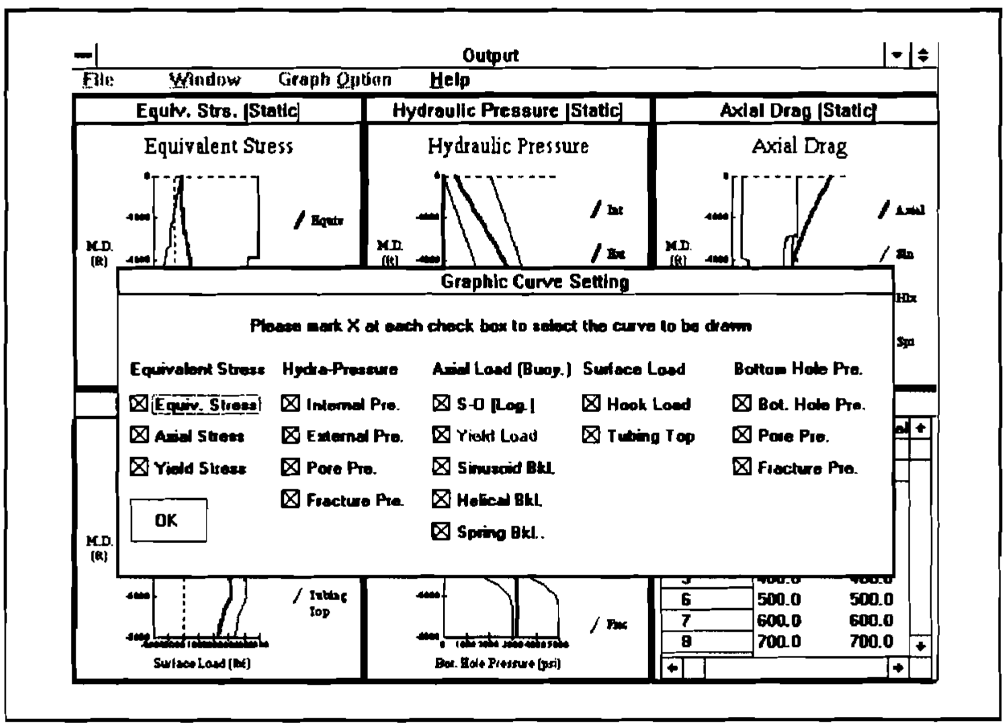


Figure 6-24. Graph Option — Curve Option Pull-Down Menu

Choose the desired curve by clicking the mouse at each check box (mark an x in each box), then click the OK button and the program redraws each graph.

6.7.4 Bi-Axial Graph

To examine the bi-axial and API stress for each coiled-tubing section, pull-down the window menu and select Bi-Axial Graph. The Bi-Axial stress graph displays on the screen.

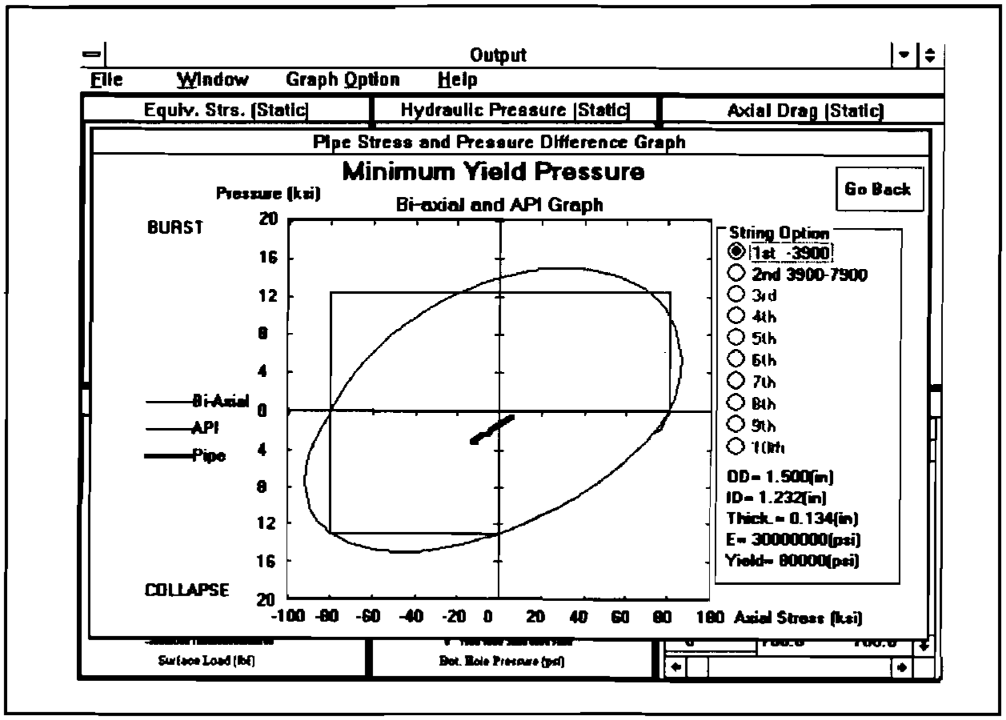


Figure 6-25. Bi-Axial API Stress

Depending on TDI input, the right-hand side of the program lets the user examine each input CT string section. ***NOTE: the TDI input program allows up to fifteen strings but only allows ten strings in this window.*** The numbers printed to the right of the string order number is the measure depth range of each section and shows string information at the bottom.

Although the program shows triaxial stress calculation results on the Equivalent Stress (static) graph and in the CSTRESS Data Report, the biaxial stress criteria is still required here to draw the ellipse. The upper part of the ellipse is based on zero outside pressure and the lower part of the ellipse is based on zero inside pressure. The pressure data used to draw the inherited pressure-stress curve for each pipe section, are the difference between inside and outside pressure. If the inside pressure is greater than the outside pressure, the program uses the pressure difference to check the pipe in burst consideration. If the inside pressure is less than the outside pressure, the program uses the pressure difference to check the pipe in collapse consideration. For example, if the outside pressure is 4000 psi and the inside pressure is 1500 psi, the program uses 3000 psi (= 4000 - 1000) outside pressure and zero inside pressure to draw the pipe curve and the user can examine the biaxial and API stress in collapse. In Figure 6-24, the curve of the pipe is inside the curve of the biaxial and API which implies the pipe inherited stress is less than the yield stress.

6.7.5 Pump Equipment

The tubing pressure data shown in the graph and output report are for coiled tubing that is inside the wellbore (i.e., below the BOP). For coiled-tubing operation, the mud pump is connected to the reel. Certain lengths of coiled tubing remain on the reel. When mud is pumped through the coiled tubing remaining on the reel, there is extra pressure loss on this section of the tubing. To calculate pressure loss and find the required output pressure and horsepower of the pump, pull-down the window menu and select PUMP EQUIPMENT. The PUMP EQUIPMENT Window displays on the screen.

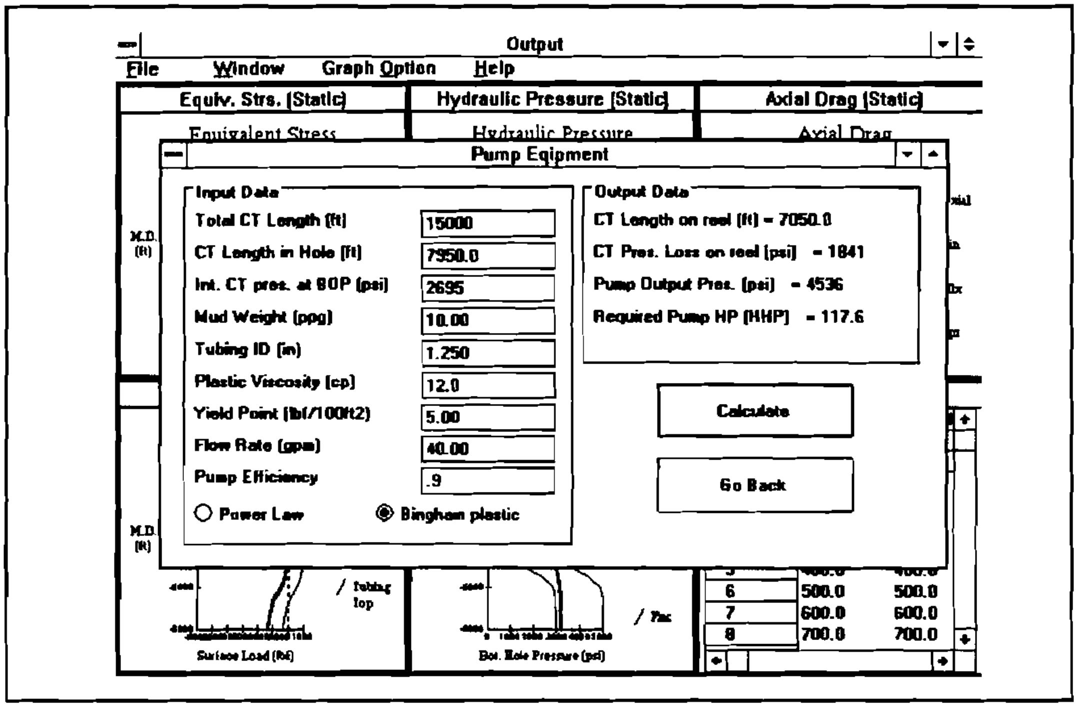


Figure 6-26. Pump Equipment Window

Most input data for the PUMP EQUIPMENT Window comes from previous input and output data. The user can edit any of the input data. After the input data are satisfied, click the calculate button and the output data is shown on the screen. Click the go back button and the PUMP EQUIPMENT Window is closed.

6.7.6 Exit Output Window

To leave the OUTPUT Window, pull-down the File menu, select "Back to Input." This takes the user back to the INPUT Window to edit input data, select "Exit." This exits the program and goes back to MS Windows.

6.8 USING TORTUOSITY

When the Survey Data Input (SDI) page is loaded into the INPUT Window and the survey data has been created, click the tortuosity command button and the TORTUOSITY Window displays on the screen.

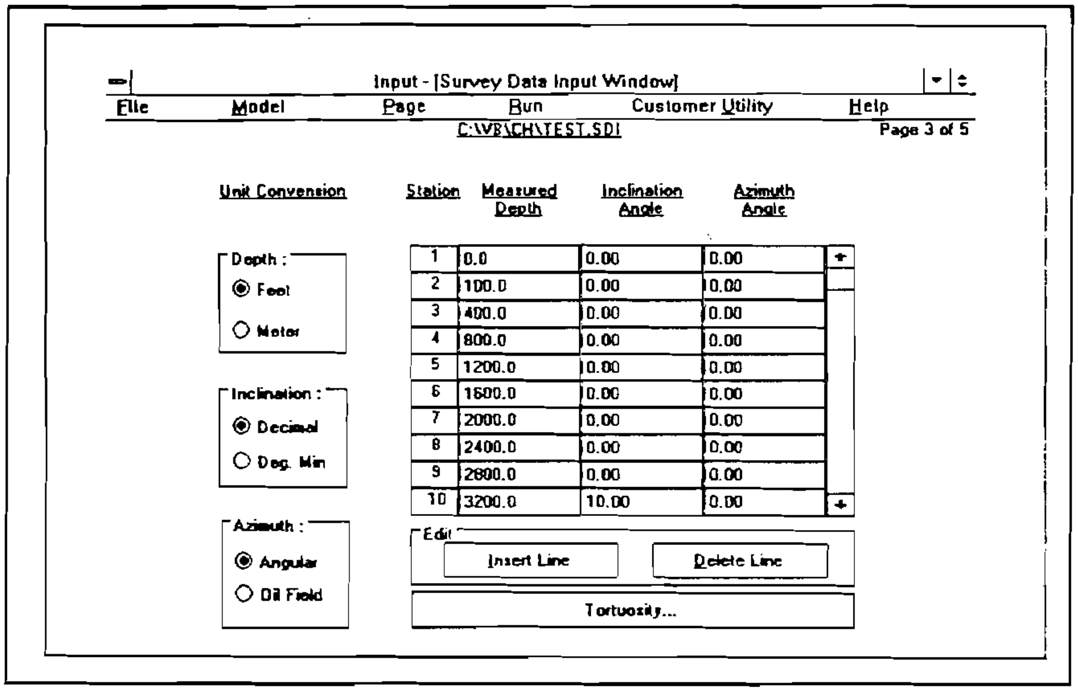


Figure 6-27. Tortuosity Command Button

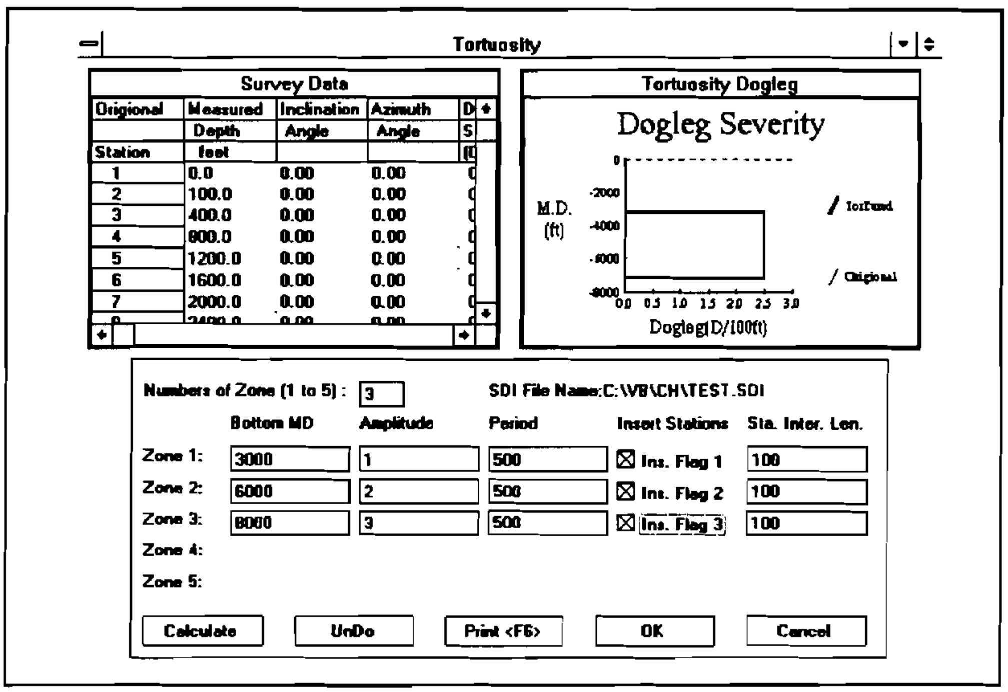


Figure 6-28. Tortuosity Window

At the top of the TORTUOSITY Window, there are two "child" windows: 1) Survey Data Table and 2) Tortuosity Dogleg Graph. At the bottom of the TORTUOSITY Window is the data input area.

The survey can be divided into as many as five zones (for example: surface to KOP, first build section, first tangent section, second build section, and second tangent section). Each survey zone may then be given a different amplitude for its distributed tortuosity. The bottom measured depth is always equal to the maximum survey depth. The period data is the length of one sine wave cycle. The user can input the desired tortuosity cycle. Sometime the survey data density is low and the user can click insert stations and the program inserts more stations between the two original survey stations. The default insert station interval length is 100 ft.

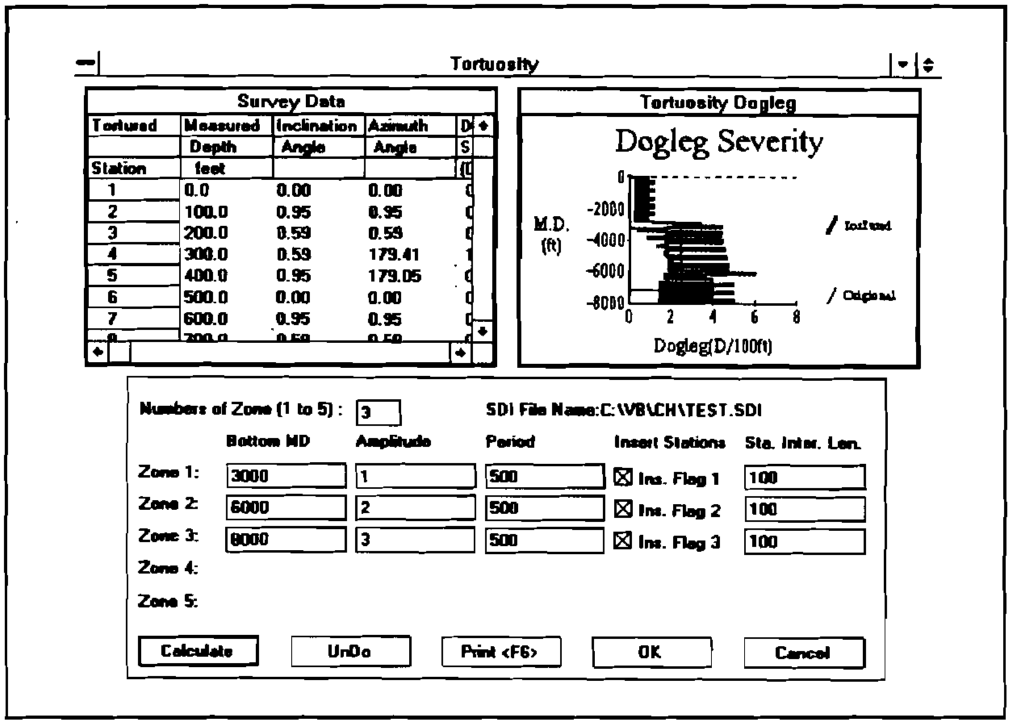
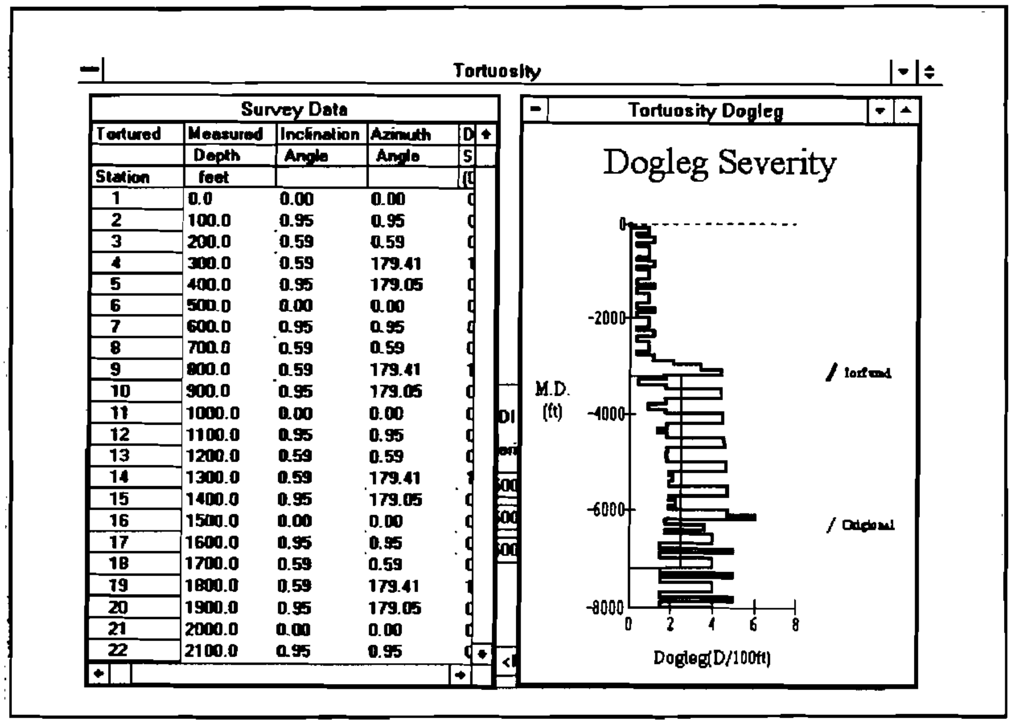


Figure 6-29. Tortured Survey

There are five command buttons at the bottom:

1. Calculate — tortures the original wellpath, and both the survey data table and dogleg severity graph shows the tortured survey.
2. Un-Do — resets the data to the original survey data.
3. Print <F6> — prints the active window. If a table or graph is displayed on the screen and the print command button cannot be seen, press the <F6> function key to execute the print command.
4. OK — copies the tortured survey data to the SDI file in the SDI Input screen.
5. Cancel — leaves the TORTUOSITY Window without any changes in the SDI data.

Both tables and graphs can be enlarged.



Tortured Station	Measured Depth feet	Inclination Angle	Azimuth Angle
1	0.0	0.00	0.00
2	100.0	0.95	0.95
3	200.0	0.59	0.59
4	300.0	0.59	179.41
5	400.0	0.95	179.05
6	500.0	0.00	0.00
7	600.0	0.95	0.95
8	700.0	0.59	0.59
9	800.0	0.59	179.41
10	900.0	0.95	179.05
11	1000.0	0.00	0.00
12	1100.0	0.95	0.95
13	1200.0	0.59	0.59
14	1300.0	0.59	179.41
15	1400.0	0.95	179.05
16	1500.0	0.00	0.00
17	1600.0	0.95	0.95
18	1700.0	0.59	0.59
19	1800.0	0.59	179.41
20	1900.0	0.95	179.05
21	2000.0	0.00	0.00
22	2100.0	0.95	0.95

Figure 6-30. Tortured Survey Data and Dogleg Graph

6.9 CSTRESS HELP AND DIALOG BOXES

There are five types of dialog boxes associated with menus: Assistance dialog box, About dialog box, File Open dialog box, File Save dialog box, and Color dialog box.

6.9.1 Help — Assistance...

When the user selects the "Assistance..." command from the Help menu in both INPUT and OUTPUT Windows, the following dialog box appears (Figure 6-31):

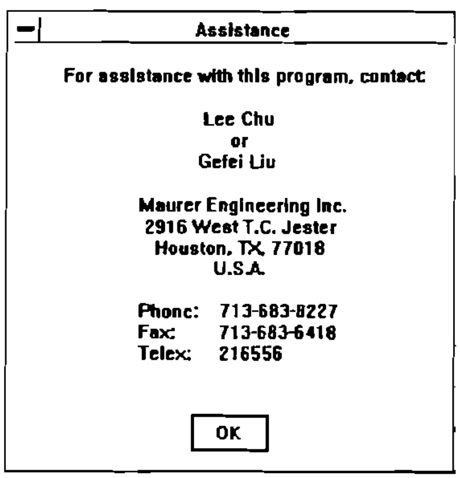


Figure 6-31. Help — Assistance Dialog Box

6.9.2 Help — About...

When the user selects the "About..." command from the Help menu in both INPUT and OUTPUT Windows, the following dialog box appears (Figure 6-32):

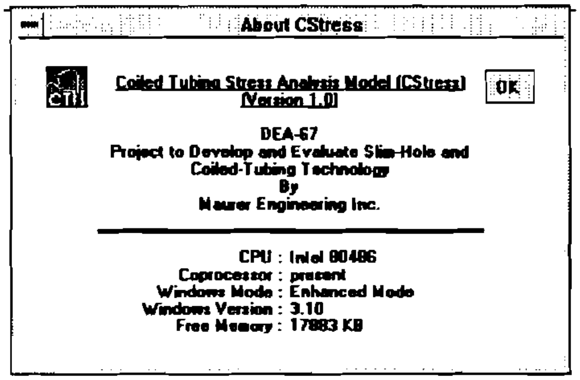


Figure 6-32. Help — About Dialog Box

6.9.3 Open Project and Data File

When the user selects the "Open Project" or "Open File" from the File menu in the INPUT Window, the following Open dialog box appears (Figure 6-33):

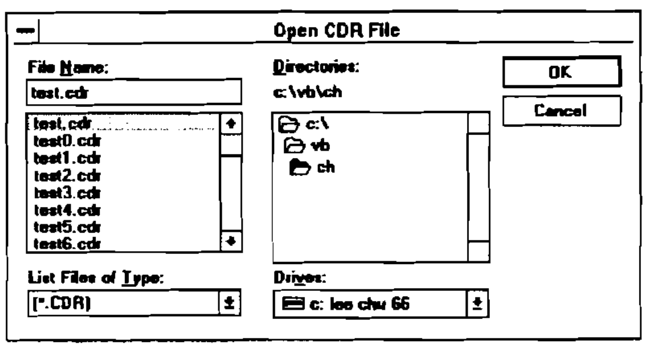


Figure 6-33. "Open Project" Dialog Box

This dialog box enables the user to search the file system for the desired files with the extension ".CDR." The extension name (.CDR, .WDI, .SDI, .CT4, .CP4, .DB, etc.) is chosen automatically by the program to determine the type of file that will be opened in the different windows.

The user can move between sections of the dialog box by simply clicking on the desired section. Alternatively, the user can press the <TAB> key from keyboard until the focus moves to the desired section.

There are four list boxes: the drive list box, the directory list box, the file list box, and type list box. Their functions are described below. There is one text box and two command buttons: OK and CANCEL.

1. **The Drive List Box**

   On the lower right corner is the drop-down drive list box. In its normal state, it displays the current drive. When the user clicks the arrow at the right of the drive list box, it drops to list all valid drives. The user can activate a new drive by single-clicking the desired one.

2. **The Directory List Box**

   The directory list box displays the hierarchy of paths of the current drive. The current directory appears as a shaded, open-file folder; directions above it in the hierarchy appear as a nonshaded open-file folder, and those immediately beneath the current directory are closed-file folders. The user can change the directory by double-clicking the selected one. Note that in the directory list box, a single click only selects (highlights) the item; a double click is required for the command to be performed.

3. **The File List Box**

   The file list box displays the files in the current directory. The file names shown are those specified by their extension name "CDR." A single mouse click on an item makes it appear in the "File Name" text box. If the user chooses OK at this time, the data file is retrieved and all data related to the current calculation mode are displayed in appropriate entries. Double-clicking the selected file has the same effect as above.

   When the user selects a new drive, the directory list box is updated, which then causes the file list box contents to be updated. When a new directory is selected, the file list box is updated, but the drive remains the same.

   The path specification label always represents the current path information.

4. **The Type List Box**

   This list box is set by the program. The user cannot change it. It specifies the type of files that are to be displayed in the file list box. In this "Open Project.." dialog box, the type of file is "*.CDR."

5. **"File Name" Text Box**

   The application should also do the following when the user enters text in the "File Name" text box and then presses <ENTER>.

   - If a drive letter is entered, the drive, directory, and file list boxes should be updated.
   - If a directory path is entered (for example, "\CSTRESS"), the directory list box and the file list box should be updated accordingly.
   - If the name of an existing file (with extension name ".CDR") is entered, the dialog will be completed and the files will be retrieved.

6. **Command Buttons**

If the existing file name is shown in the text box, pressing OK will complete the dialog and the data file will be retrieved and displayed.

If the CANCEL button is pressed, the dialog is cancelled and no information is made available to the application.

6.9.4 Save Project — Data File

When the user selects "Save Project As" or "Save File As" commands form the File menu in the INPUT and OUTPUT Windows, the following dialog box appears (Figure 6-34):

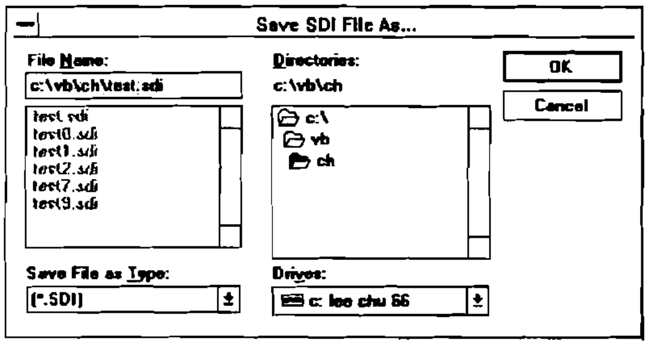


Figure 6-34. "Save File" Dialog Box

This dialog box is almost identical to the "Open Project" dialog box in appearance; however, the filter in the type list box is different. Depending on the file the user is manipulating, the filter in the type list box will be a ".CDR," ".WDI," ".SDI," ".CD4," or ".DB," etc., extension.

6.9.5 Color

When the user selects one of the commands on color from the Customer Utility menu in the INPUT Window, the following dialog box appears.

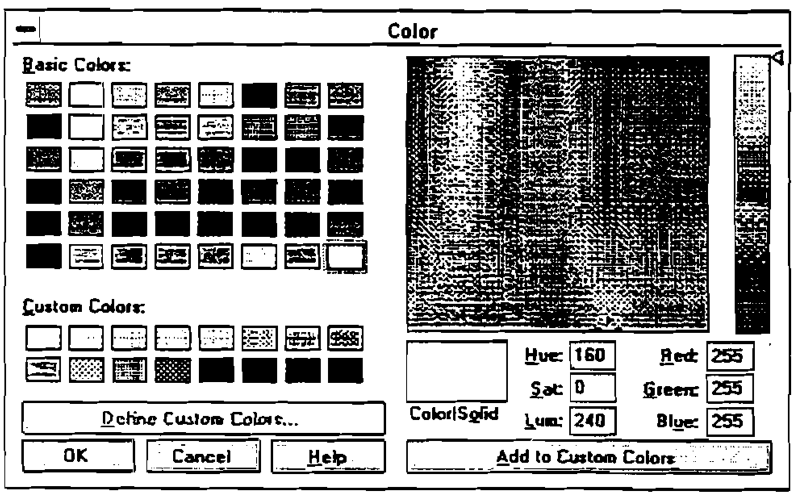


Figure 6-35. Color Dialog Box

The Color dialog allows the user to select a color from a palette or to create and select up to sixteen custom colors.

6.10 CSTRESS ERROR HANDLING

When input data on a page are outside the appropriate range of values and the user tries to leave the page, the CSTRESS error checking routines will locate the error. The application will then display an error message explaining why the data are not acceptable. The user can ignore the error message and leave the page even though the data on the page do not make sense. This enables the user to edit and view different input pages without having to complete one before going to another.

The user can start calculation from any page. If any invalid data are found at this time, the application will display an error message and force the use to go to the page with invalid data for editing.

When an error message appears, click OK or press <ENTER> to return to the associated page in the INPUT Window.

6.11 QUICK START

Use the following procedure to get started with the CSTRESS1 program.

Install:

1. Start Windows (3.0 or later version).
2. Insert Disk into drive A:.
3. In the File Manager, choose Run from the File menu.
4. Type **A:setup** and press Enter.
5. Follow on-screen instructions. (Please use the default subdirectory).

Run:

6. Double-click the CSTRESS1 icon.
7. In the first window (INTRODUCTORY Window), click "Continue" after it becomes responsive.
8. In the INPUT Window, choose "Open Project..." from the File menu.
9. From the "Open CDR File" dialog box, click the drive C: in the drive list box, double-click the "CSTRESS" subdirectory, click the "TEST.CDR" in the file list box, and then click OK.
10. Click "Next" from the Page menu to view other pages of input data (WDI, SDI, TDI, PDI).
11. Click the "Start" from the Run menu. After calculation the OUTPUT Window is loaded.
12. In the OUTPUT Window that follows, select the text report or interested graph windows under the "Window" and "Graph" options of the menu to view the output.
13. To print the text report or graph, make the corresponding "child" window active, select "Print Report/Graph Only" from the File menu.
14. Choose "Back to Input" from File menu to return to the INPUT Window or choose "Exit" to terminate the application.

7. References

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10. Spotts, M.F., *"Design of Machine Elements,"* Prentice-Hall, Inc., Englewood Cliffs, N.J.

11. Wahl, A.M., 1963: "*Mechanical Springs*," 2nd Ed., McGraw-Hill Book Company, New York.

12. Wu, Jiang and Juvkam-Wold, Hans C., 1993: "Preventing Helical Buckling of Pipes in Extended Reach and Horizontal Wells," Energy-Sources Conference & Exhibition, January 31—February 4.

13. Wu, Jiang and Juvkam-Wold, Hans C., 1993: "Frictional Drag Analysis for Helically Buckled Pipes in Extended Reach and Horizontal Wells," Energy-Sources Conference & Exhibition, January 31—February 4.

14. API Bulletin, 5C3, 1989: "Formulas and Calculations For Casing, Tubing, Drill Pipe and Line Pipe Properties."

8. BUG Report or Enhancement Suggestion Form

Name: ______________________ Company: ______________________

Address: ______________________ City: ______________ State: ________

Phone No.: ______________________ Fax No.: ______________ Date: ________

☐ Bug\Problem Report ☐ Enhancement Suggestion

Program Name and Version Number: ______________________________________

____

Bug\Problem Description or Enhancement Suggestion: ______________________

____

____

____

____

Regarding the Bug Report, please answer the following questions:

<u>Computer System</u> Brand: ______________

Chip: ☐ 286 ☐ 386 ☐ 486 ☐ Pentium

Type: ☐ Desktop ☐ Laptop ☐ Notebook ☐ Other

<u>RAM</u>: ________MB <u>Speed</u>: ________ MHz

<u>Math-Coprocessor Present</u>: ☐ Yes ☐ No ☐ Unknown

Printer Type: ______________________ (for printing error only)

Plotter: ______________________ (for plotting error only)

Within Network System: ☐ Yes ☐ No Type: ______________

Video Type: ☐ EGA ☐ VGA ☐ SVGA ☐ Mono ☐ LCD

Video Card Ram: ______________ (video problem only)

<u>Operating System</u>

MS-DOS Version No.: __________ MS-Windows Version No.:__________(for Windows applications)

OS2 ______________________ MS-Windows NT Version No.: __________

Other ______________________

<u>BUG Detecting Data</u>

☐ Will be mailed on diskette ☐ Will be faxed ☐ Attached ☐ None

Other Comments: ____

____

____

____

Please send or fax to:

Lee Chu
MAURER ENGINEERING INC.
2916 West T.C. Jester
Houston, TX 77018-7098
Ph.: 713/683-8227 • Fax: 713/683-6418