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CASING STRING DESIGN MODEL (CASING2)

THEORY AND USER'S MANUAL

DEA 67
PHASE II

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Casing String Design Model
(CASING2)

Theory and User's Manual

DEA-67, PHASE II

Project to Develop and Evaluate Coiled-Tubing and Slim-Hole Technology

By

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CASING STRING DESIGN PROGRAM FOR WINDOWS

Theory and User's Manual

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Introduction

Users who do not wish to read the background material can go directly to Chapter 3 - Program Installation to install and then to Chapter 6 to run an example.

The Casing String Design Program for Windows, Casing2, has been developed jointly by Lone Star Steel Company and Maurer Engineering Inc. Casing2 is coded in Microsoft Visual Basic 3.0, and also incorporates Microsoft Access 2.0 database drivers and Seagate Software Crystal Reports 4.5. An IBM compatible computer with Microsoft Windows 3.0 or later is required.

MODEL DESCRIPTION

The Casing2 program calculates burst and collapse pressures and designs pipe based on least cost. The relevant depths are converted to vertical depths when a directional plan is specified. The input parameters will vary somewhat depending on the selection of string type. In general, the parameters against which the pipe is designed are based on maximum load of the casing (or tubing) "as set." Minimum design factors may be modified, and the performance properties of the pipe may be viewed in uniaxial, biaxial and/or triaxial formats. A variety of graphs and reports can be printed or exported to other Windows-based programs.

PROGRAM FEATURES

Casing2 is a sophisticated and user-friendly program with the following features:

1. Microsoft Windows applications
2. Supports both English and metric units
3. Includes an expandable database of some 3,700 tubular items from 1.050" to 48" in diameter in Microsoft Access (ver. 2.0) files
4. Tubular items in the database may be limited to a specified available quantity
5. Tubular items, grades and connection types may be added and may also be specified as being "available" for use or "not available"

6. "API" properties of pipe can be generated for any diameter, wall thickness and grade
7. Burst performance can be biaxially adjusted for tension and/or (high) temperature
8. Triaxial stress analysis can be performed for both burst and collapse
9. Collapse biaxial adjustment model can be selected
10. Internal burst gradients can be either directly input or calculated based on gas gravity using the real gas law
11. Tubular designs can be both computer generated or input by engineer
12. New wells are generally based on program defaults, which can be modified and saved
13. Well parameters can be saved and retrieved
14. Units of measurement can be selected, modified, and saved
15. Directional wells can be designed internally as two dimensional or can be input (or imported in SDI format) as three dimensional
16. A total of nine graphs can be viewed, printed or posted to the "clipboard"
17. Intermediate burst parameters can be input as "Maximum Load" with "mud over gas" or "gas over mud."

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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.

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Chapter 1

Theory of Casing / Tubing String Design

While many aspects of casing and tubing string design are subject to company preferences, basic concepts and specific options are presented here.

Designing downhole tubulars

As shown in Figure 1.1, the process for designing pipe on a “least cost” basis involves an iteration.

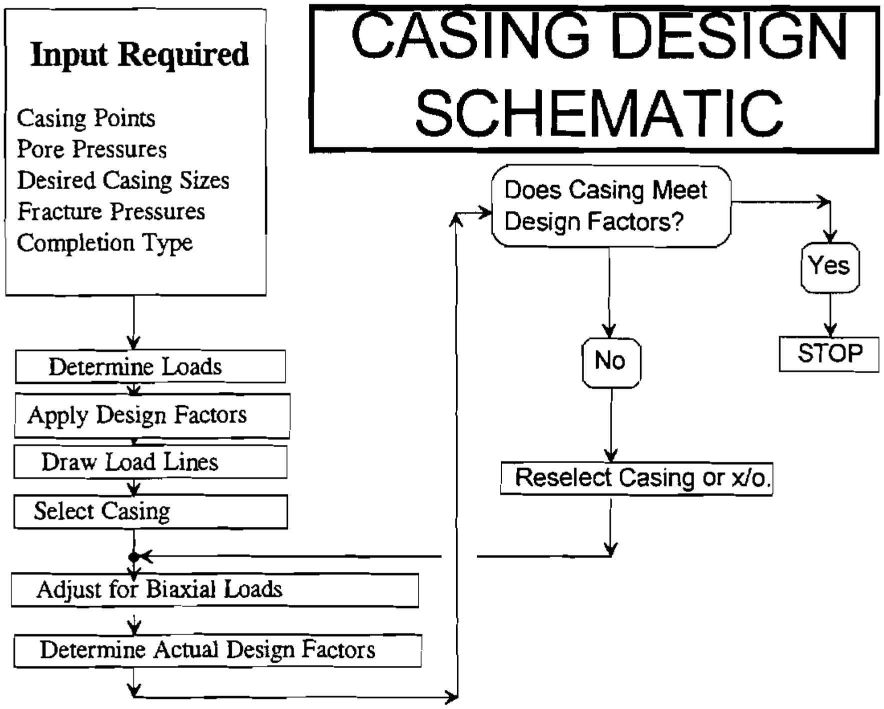


Figure 1.1 Casing (and tubing) should be selected after determination of the loads. As the loads vary, the performance properties (strengths) of the pipe also vary. Thus, pipe may have to be tried on a trial and error basis. This problem creates the utility of computer driven casing design programs.

The process of selecting pipe typically begins at the bottom of the string, where adjustments for the effect of tension on burst and collapse are typically not made, and proceeds to the surface. For offshore wells, it is typical for wells to have only one size, weight, grade and connection type (segment) for the string. In these cases, the effect of tension on burst and collapse can be checked throughout the string, but there is usually no need to go through an iterative process of selecting pipe based on least cost. For onshore wells, at least where logistics are adequate, a single string may have three or more segments. For these wells, cost is of significant interest, and by carefully selecting the pipe, substantial savings can be realized.

It is worth noting here that tubing design can be performed by Casing2. Tubing designs sometimes, however, incorporate tapered strings, and often need a buckling analysis, particularly for deep, high temperature wells. The tapered string design can be checked with the program, but cannot be internally designed. Buckling analysis is presently beyond the scope of Casing2. Finally, it should also be noted that the resulting tubing designs are not price rationalized to the same degree that casing designs are. These designs should be treated more as a guide, rather than a finished design.

Determining pipe loads

It is typical to address loads leading to pressures in terms of fluid densities (i.e., mud weight) and depth. For English units, the customary equation is

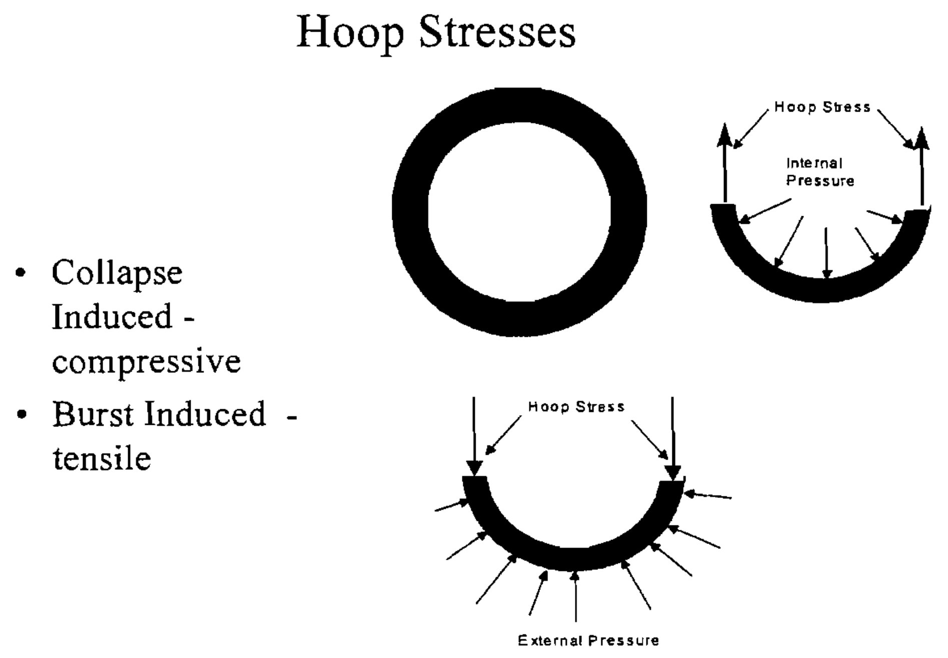
$$p = 0.052 * d * \rho_m$$

As a side note, the calculations in this program are made in English units regardless of the selected unit of measure. In lieu of the 0.052 conversion factor, a more precise conversion factor is used, 0.05194806.

Pressure loads are the differential pressure of external pressure, p_e, less internal pressure, p_i, for collapse, and vice versa for burst loads. Tension loads are often considered independently, though the effects of tension are often taken into account on collapse and (less frequently) on burst strength.

Determining pipe stresses

As with all solid objects, there are three principal stresses to which pipe is subject: axial (longitudinal), hoop (or tangential - Figure 1.2), and radial (Figure 1.3). The three stresses can be summarized in a von Mises analysis as shown in Figure 1.4



Hoop Stresses

- Collapse Induced - compressive
- Burst Induced - tensile

Figure 1.2. Hoop Stresses

Radial Stress

- Burst Loading or
- Collapse Loading

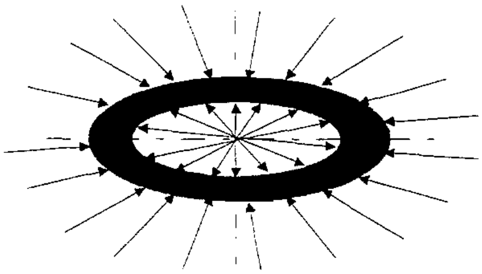


Figure 1.3. Radial Stress

Triaxial Stress Analysis

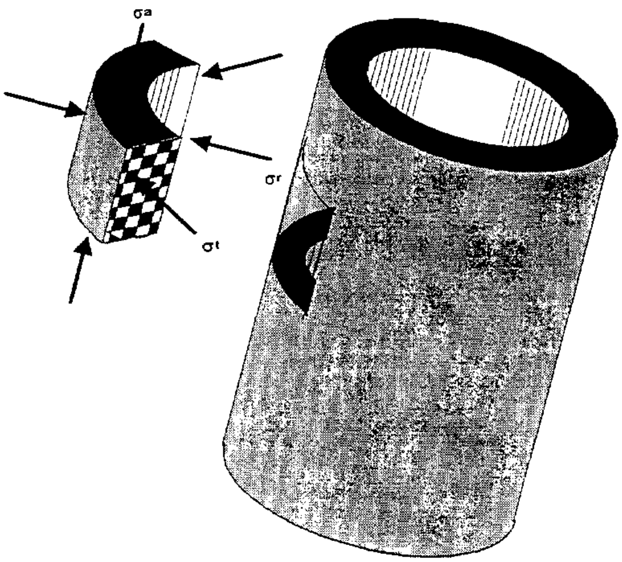


Figure 1.4. Triaxial Stress Analysis

Though the von Mises analysis is generally only used for heavier wall pipe, it can be performed for all pipe. Casing2 performs the analysis as a matter of course for the pipe, based on burst loading and, looking at the inside diameter, ID stress. The equations for the von Mises analysis are as follows:

von Mises Analysis

σ_{vm}, von Mises stress

σ_t, Tangential (hoop) stress

σ_r, Radial stress

σ_a, Axial stress

$$\sigma_{vm} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_a)^2 + (\sigma_a - \sigma_t)^2}$$

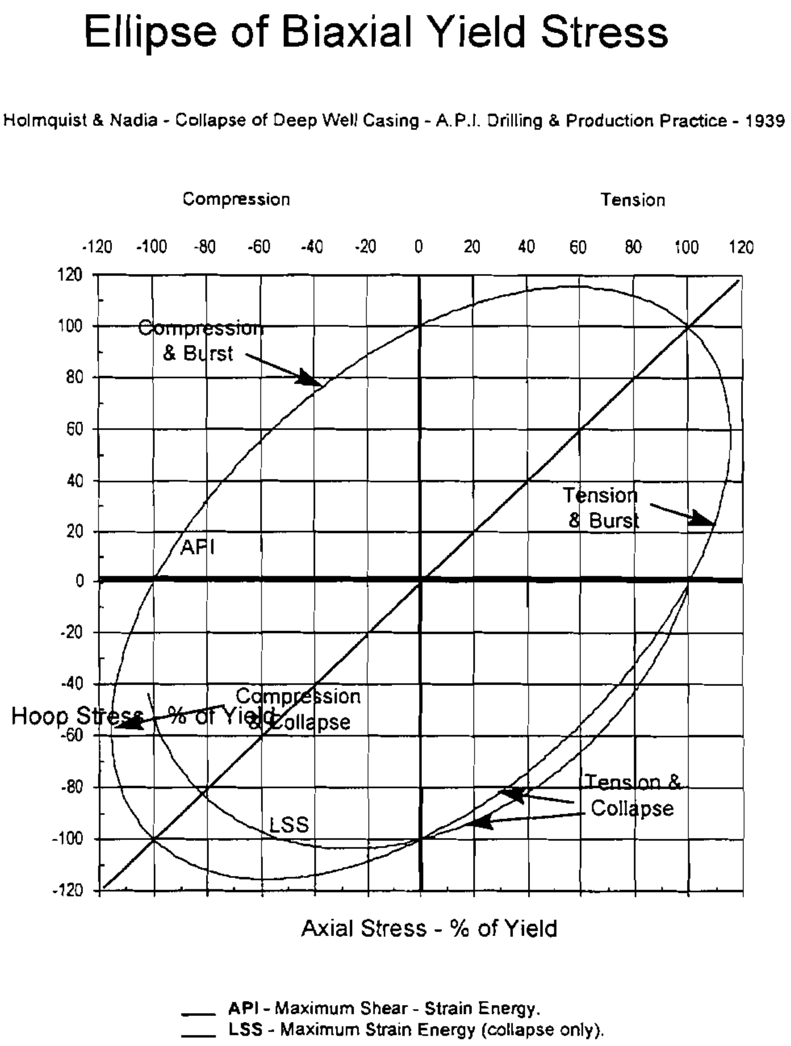
Where:

$$\sigma_t = \frac{ID^2_{max} \ast Pi - OD^2 \ast Pe}{OD^2 - ID^2_{max}} + \frac{ID^2_{max} \ast OD^2 \ast (Pi - Pe)}{D^2 \ast (OD^2 - ID^2_{max})}$$

$$\sigma_r = \frac{ID^2_{max} \ast Pi - OD^2 \ast Pe}{OD^2 - ID^2_{max}} - \frac{ID^2_{max} \ast OD^2 \ast (Pi - Pe)}{D^2 \ast (OD^2 - ID^2_{max})}$$

$$\sigma_a = \frac{L}{(OD^2 - ID^2_{max}) \ast \pi/4} \pm \frac{Dg \ast D \ast E}{137{,}510}$$

More typically, the effects of tension upon collapse and burst strength are analyzed and radial stress is ignored. This method of analysis is biaxial analysis, described in more detail below. The biaxial ellipse is as shown in Figure 1.5.


Ellipse of Biaxial Yield Stress

After Holmquist & Nadia - Collapse of Deep Well Casing - A.P.I. Drilling & Production Practice - 1939

Figure 1.5

Collapse design

Collapse loading is typically based on the setting mud weight, with the inside of the pipe assumed to be "evacuated." Variations in these assumptions depend on the type of string and the general practice for the area. Many times for offshore wells, the pipe is never assumed to be fully evacuated, except for production strings which may eventually be put on gas lift. For offshore protection strings, a sea water gradient is assumed to exist which will support the drilling mud to some level. That is, the pore pressure based on sea water at the setting depth of the pipe will support the mud density used to a level where the hydrostatic head of the mud equals the pore pressure.

One of the more difficult aspects of collapse design is the problem of using the proper mud weight when the hole was drilled with air. In these cases, as a minimum, the prevailing mud weight for the comparable geologic formation in the nearest area where mud is used as the drilling medium should be used.

When pipe is placed in tension, the rated collapse strength decreases. Normally, the collapse loading decreases at a faster rate than the collapse strength due to tension, and only the bottom of a pipe segment need be checked. For wells in which an internal gradient is considered on collapse, this may not be the case. There are at least three models which describe the biaxial effect of tension on collapse.

- Old API Maximum shear - strain energy theory - *API Drilling and Production Practice*, 1939 - Holmquist and Nadia. In this method, the collapse strength is adjusted by a factor determined by the equation:

$$p_{cradj} = [\{1 - 0.75 * (\sigma_a / \sigma_{yield})^2\}^{0.5} - 0.5 * (\sigma_a / \sigma_{yield})] * P_{co}$$

where $\sigma_a / \sigma_{yield}$ is, in a more familiar format,

axial tension / pipe body yield strength

and P_{co} is the original collapse strength rating.

- LSS - Maximum strain energy theory - *API Drilling and Production Practice*, 1940 - Wescott, Dunlop & Kemler. This method is similar to the method above, but adjusts the collapse strength using the equation:

$$p_{cradj} = [\{1 - 0.9324 * (\sigma_a / \sigma_{yield})^2\}^{0.5} - 0.26 * (\sigma_a / \sigma_{yield})] * P_{co}$$

- New API - Axial stress equivalent grade method - *API Drilling and Production Practice*, 1982 - Hencky von Mises. In this method, an equation is used to adjust the effective yield strength, which is then used in the API collapse equations (see Chapter 2) to determine the revised collapse strength.

$$\sigma_{yield\,adj} = [\{1 - 0.75 * (\sigma_a / \sigma_{yield})^2\}^{0.5} - 0.5 * (\sigma_a / \sigma_{yield})] * \sigma_{yield}$$

Figure 1.5 shows the biaxial ellipse (after Holmquist and Nadia), with an additional arc shown for the Wescott, Dunlop & Kemler theory. The API methods work well with API grades, because of the manner in which the collapse strength is obtained. For proprietary grades having special collapse ratings, either the Old API method or the LSS method should be used, unless equations for the collapse strength which utilize yield strength are available. In general, the beneficial effect of compression on collapse is ignored, and only the effect of tension is considered.

Two more theories on collapse should be mentioned. One is a variation on the effective collapse pressure given in API Bulletin 5C3. Rather than defining the effective pressure, p_e, as $p_o - p_i$, the effective pressure is:

$$p_e = p_o - [1 - 2 / (d_n / t)] * p_i$$

Just as collapse strength can be adjusted for the effects of axial tension, burst strength can be similarly adjusted. It is not done with the same regularity as the adjustment for collapse because, as shown in the biaxial ellipse, Figure 2.2, burst strength increases with axial tension – a non-conservative feature! There are also adjustments to tension which are made throughout the life of the well, such as the adjustments based on the temperature effect on steel. A more rigorous overview of the (production) pipe's anticipated temperature changes will show that the burst strength can be expected to increase or decrease after it is put into service. Shown is the equation for the effects of biaxial tension and dogleg severity on burst strength.

$$p_{badj} = p_b * F_{cor}$$

where

Stress, $\sigma = \sigma_z + \sigma_{bending}$,

$\sigma_{bending} = 218 * \alpha * d_p$ (for 40 foot lengths), and

$\sigma_z = F_a / A_p$

$F_{cor} = [1 - 0.75 * (\sigma / \gamma_{yield})^2]^{0.5}$

$F_{cor} = F_{cor} - \sigma / (2 * \gamma_{yield})$

It is thought that the detrimental effects of compression on burst strength are ignored in casing design. Perhaps this is because the pipe is in compression at depth, or perhaps because the pipe is often in cement at these places. Casing2 takes the approach of derating the pipe's burst strength in doglegs, but not in compression.

Finally, the effects of radial stress can be taken into account along with hoop and axial stresses, and the resulting triaxial stress for the collapse mode can be analyzed. Casing2 makes this analysis on the Triaxial Analysis page (under “Results”).

Burst design

Burst loading is dependent on the string type, primarily. Frequently, there will be an internal and external load. For production strings, the external load is sometimes ignored. In these cases, the burst pressure is greatest at bottom hole pressure (BHP) and smallest at top, the maximum anticipated surface pressure (MASP). More frequently, for production strings, the burst loading assumes a high tubing leak which acts upon the packer fluid, and which is backed up by the annular mud weight. Tubing strings should ignore the annular fluid. For any string with only one fluid density gradient (AGG) on the inside, the pressure load at any depth, d_x, is as follows:

$$p_{bx} = \text{MASP} + [\text{AGG} - (\rho_{me} * 0.052)] * d_x$$

The primary difficulty in the above equation is in determining the proper MASP. The related problem is to find the proper AGG. The problems are greatly simplified, of course, if field experience is available. For production strings, BHP is generally a function of the mud weight and depth.

$$\text{BHP} = 0.052 * \rho m * \text{TVD}$$

For wells which will be hydraulically fraced, the BHP for casing design will actually be the frac pressure, FP. The service company which will do the frac work can give the MASP, or surface treating pressure (in their vernacular). While on the topic of fracture pressure, injection pressure also deserves mention. Casing design is often based on injection pressure, which is basically fracture pressure plus a safety factor to insure the formation will fail. This is especially the case for protection strings. In Casing2, where the field calls for fracture pressure, one should incorporate whatever safety factor he thinks is appropriate, as there is no built-in safety factor. This injection pressure is as shown:

$$\text{Injection pressure} = d_c * (\rho_{Frac} + SF) * 0.052$$

AGG can be found from several places. Unless field experience dictates otherwise, it is typical to use a gas gradient for AGG. Many casing strings have been designed using a “standard” number, such as 0.15 or 0.12 psi per foot. For those with a more mathematical bent, the real gas law or ideal gas law can be used, as well as a popular empirically derived equation which has not yet found its way into the proper public domain. The ideal gas law assumes a compressibility (“z”) factor of 1.0, and is reasonable for most wells up to about 11,000 feet in depth. The oilfield equation shown below is a variation of the Weymouth equation, and is derived from the familiar $P\,V = n\,R\,T$.

$$\text{MASP} = \text{BHP} / e^{[(\gamma * \text{TVD}) / (53.30 * T)]}$$

where

γ = gas gravity (air = 1.0), and

T = average temperature in °R, or °F + 460.

Normally, usage of the real gas law is beyond the scope of casing string design practice. However, because Casing2 allows usage of this method, the equations used in the program are reviewed in the appendix. Of principal note here is the concept that the real gas law may be used to determine MASP.

For protection strings, the burst pressure is especially dependent on injection pressure. This is not the case for those unusual occasions when the pore pressure at the next setting depth is less than the pore pressure at the current depth. The schematic of this is as follows.

For typical situations where the next pore pressure minus the gas gradient to the shoe depth is greater than the pore pressure at the shoe, internal pressure at shoe depth for protection strings is the lessor of:

- Shoe fracture pressure
- Maximum formation pressure - gas gradient to the shoe

In any event, it is typical to use an external pressure equivalent to the pore pressure as a backup. Casing2 allows the choice of having either one or two internal fluid densities for burst. It is customary to incorporate only one fluid density unless the shoe fracture pressure is the relevant pressure at the shoe. Then, in a kick situation, the well may be shut in prior to all of the mud being expelled, and a gas over mud or mud over gas interface will result. In either case, the MASP will be less than it would be if only gas were in the hole. The methodology for this burst situation is succinctly described in “Maximum Load.” In brief, the maximum load design uses a simultaneous equation based on the two end points, MASP and FP, and the two fluid densities, ρ_m and ρ_g, to determine the mud gas interface, d_{mgi}. For the case of mud over gas, the equation is as follows.

$$\text{FP} = 0.052 * \rho_m * d_{mgi} + \text{AGG}\,(d_c - d_{mgi}) + \text{MASP}$$

Remember, when the next string will be a drilling liner, then the "next setting depth" and "next mud weight" is effectively the setting depth for the string after the drilling liner(s). This is because the protection string will be subjected to pressures from the open hole at depths below the drilling liner. Also, the proper fracture depth would be the shoe depth for the drilling liner.

Tension design

Tension may be considered at as either air weight (more conservative) or buoyed weight (less conservative.) When the effect of tension on burst is taken into account, however, it is not appropriate to use air weight, as that would tend to exaggerate the burst strength. There are two ways to determine buoyed weight. The simpler method is to find the buoyancy factor, based on mud weight, and to multiply the air weight by the buoyed weight. Casing2 uses the more mathematically rigorous method, which is to multiply the cross section area of the pipe by the external pressure. The former method is shown below.

$$W_e = W * (1 - \rho_m / 65.4)$$

The upper portion of the string will be in tension, and the lower portion will be in compression. The neutral point of the string is determined similarly:

$$d_{neutral} = d_c * (1 - \rho_m / 65.4)$$

Before leaving the discussion on tension, it is important to note that compression can be of great significance for surface and/or conductor strings, which have to support the weight of the subsequent strings and BOP. Casing2 does not have an automatic check of this value, and the engineer should make this check himself for deeper wells. If the casing design appears to be marginal in compression at the top of the surface string, then a prudent change would be to go up at least one weight of the casing size, and, if buttress is not used, to include buttress for the top 200 feet.

String types

In this program, the following string types may be selected. Depending on the type of string selected, the forms regarding basic conditions and burst parameters will vary. Some of the types are repeated, as alternative or contingency strings may be required for the same well.

1. Drive pipe
2. Conductor

3. Surface
4. Intermediate
5. Intermediate / production
6. Drilling liner
7. Production
8. Production / hydraulic fracture
9. Production liner
10. Tubing
11. Tieback
12. Scab liner
13. Surface (2)
14. Intermediate (2)
15. Drilling liner (2)
16. Production (alternative)
17. Tubing - hydraulic fracture
18. Tubing (2)
19. Tieback (2)
20. Tieback (3)

Design Factors

Minimum design factors are especially within the domain of company policy, while other aspects of tubular design may be left up to the engineer. For instance, some designs will incorporate an internal pressure gradient for collapse where others do not. Not all burst designs incorporate an external pressure gradient. Sometimes a design factor is intended to deal implicitly with casing wear. In other cases, the casing performance properties will be "pre-downgraded" for wear. Some companies use air weight where others use buoyed. Also, in directional wells, some use measured depth for tension, where others use vertical depth. At least as a guide, however, the following design factors are presented as "typical."

Collapse:	1.125	- protection strings
	1.0	- oil strings
	0.85	- below cement top
	1.125	- air drilled strings
Burst:	1.0	- when designed in uniaxial mode
	1.2	- when using the biaxial effect of tension
Tension	1.5	- for body yield strength
	1.8	- for connection strength based on ultimate yield
	1.6	- for connection strength based on yield
	1.2	- for compressive (static) loading

For tension, the amount of minimum overpull is important to know in some cases, but has little universal agreement other than for tubing strings.

Harsh Environments

Sour Service, H_2S

A primary obstacle to the successful drilling and completing of deep sour wells is sulfide stress cracking (SSC), a catastrophic mode of failure that affects high strength steels in environments containing moist hydrogen sulfide in varying amounts. While experts will disagree as to the actual mechanism of failure, SSC appears to be a form of hydrogen embrittlement which occurs when atomic hydrogen penetrates the surface of the metal through grain boundaries. As the hydrogen migrates through the metals, it recombines to form molecular hydrogen, which, due to its volume cannot escape the higher strength steels, and thus increases internal stresses to the point of crack initiation. While H_2S is normally associated with this problem, it need not necessarily be present. However, for SSC to occur, the following conditions must be met:

- moist H_2S must be present;

- the pH of the water (moisture) should be low enough (under 10) to permit the initial corrosion reaction to proceed;
- the metal must be susceptible to SSC at its environmental temperature; and
- the metal must be stressed in tension through internal and/or external forces.

The Texas Railroad Commission's Rule 36 controls what can be used in sour gas service in the State of Texas. Rule 36 makes reference to NACE Standard MR-01-75 which has become the most widely accepted standard for selecting materials in sour service. NACE defines the threshold partial pressure for sour gas environments as those in which the total pressure is at least 65 psia and the partial pressure for H_2S is at least 0.05 psia. Sour oil and multiphase systems are those in which the maximum gas:oil ratio is 5,000 SCF:bbl, the gas phase contains a maximum of 15% H_2S, the partial pressure of H_2S in the gas phases is a maximum of 10 psia, and the (operating) MASP is a maximum of 265 psia. Table 1 was prepared using NACE guidelines. As shown, the higher the temperature, the better the H_2S resistance of oilfield steels (with some maximum limitations).

Table 1
Sour Service Guidelines (after NACE MR-01-75-92)

For All Temperatures	For 150° F or Greater	For 175° F or Greater	For 225° F or Greater
<u>Tubing and Casing</u> API Spec 5CT Grades H-40, J-55, K-55, L-80 (Type 1) Proprietary Grades per 3.2.3 (i.e. LS-65)	<u>Tubing and Casing</u> API Spec 5CT Grades N-80 (Q&T) and Grade C-95 Proprietary Q&T grades with 110 ksi or less maximum yield strength	<u>Tubing and Casing</u> API Spec 5CT Grades H-40 (w/σ_{yield} > 80 ksi), N-80, P-105 and P-110 Proprietary Q&T Grades to 140 ksi maximum yield strength (σ_{yield}).	API Spec 5CT Grade Q-125 with maximum yield strength of 150 ksi, quench and tempered, and based on a Cr-Mo alloy chemistry.
<u>Pipe</u> API Spec 5L Grades A & B and Grades X-42 through X-65 ASTM A-53 A 106 Grades A,B,C			

Sweet Corrosion, CO_2

Corrosion resulting from CO_2 is known as "sweet" corrosion or sometimes "weight-loss corrosion" and can occur in wells where the partial pressure of CO_2 is as low as 3 psi. Many factors affect this threshold pressure, however, which include temperature, pressure, amount of water and/or oil present, dissolved minerals in the water, produced fluid velocity, and production equipment. The resulting corrosion is usually distinctive in that it occurs as sharply defined pits on the surface. Methods used to control the effects of CO_2 attack include chemical inhibition, plastic or ceramic lining, and special steel alloys, such as 13 chrome. Unfortunately, unlike H_2S, the higher the temperature, the worse the corrosive problem.

Special problems arise when both CO_2 and H_2S coexist at high temperature. Metals exist that can handle these problems, but they tend to be expensive. Expert advice should be sought if in doubt about these situations.

Chlorides and Bromides

Produced fluids with a high chloride (bromide) content can create chloride stress cracking (CSC) at high temperatures. At temperatures above 250 °F, 13% chrome may be subject to pitting corrosion. High density completion fluids such as zinc bromide can also be a significant problem at elevated temperatures.

Salt Sections

Casing may collapse during the initial completion, or later in the productive life of the well due to plastic salt flow. Typical design parameters for known problem formations are to use 1.0 to 1.2 psi/ft equivalent fluid densities and 1.125 minimum design factors.

Casing Wear

Wear can occur in any well which has doglegs, whether the well is "directional" or "non-directional." Wear occurs primarily from the mechanical action of wireline or drill pipe tooljoints against the inside diameter of the casing in dogleg sections. It may be unpredictable without sufficient drift surveys. Wear adversely affects the burst and collapse performance of the casing in a non-linear fashion. Casing2 allows usage of downgraded tubular items, but has no internal mechanism for such calculations.

Chapter 2

Discussion of Oil Country Tubular Goods

A reasonable knowledge of oil country tubular goods will help make better string designs and will make life easier for the person responsible for procurement of pipe.

GRADES

API

API has developed specifications for the manufacture of oil country tubular goods (OCTG). In general, the specifications pertain to minimum and maximum strength levels, chemistry, hardness, toughness, elongation, size, minimum wall thickness, ovality, drift, NDT inspection, and the Quality Program implemented by the manufacturer. In many respects, particularly with regard to threading, the API specifications are very specific and detailed. Manufacturers may produce their tubulars to specifications more constrictive than API, but the API specifications must be met as a minimum. The general API requirements for OCTG are found in Bulletin 5CT, for line pipe in Bulletin 5L, and for drill pipe in Bulletin 5D.

Grade Yield (psi)	Min Yield (ksi)	Max Yield (ksi)	Min Tensile (%)	Max Hardness (HRc)	NACE Class	Mfg S/E	Pipe Class	Remarks
H-40	40	80	60		All	S,E	OCTG	
J-55	55	80	75		All	S,E	OCTG	
K-55	55	80	95		All	S,E	OCTG	
L-80	80	95	95	23	All	S,E	OCTG	
N-80	80	110	100		>150(Q)	S,E	OCTG	
C-90	90	105	100	25.4	All	S	OCTG	
C-95	95	110	105		>150	S,E	OCTG	
T-95	95	110	105	25.4	All	S	OCTG	
P-110	110	140	125		>175	S,E	OCTG	
Q-125	125	150	135		>225	S,E	OCTG	Type 1 for NACE

Grade B	35		60		All	S,E	line pipe	API 5L
X-42	42		60		All	S,E	line pipe	API5LX
X-46	46		63		All	S,E	line pipe	
X-52	52		66		All	S,E	line pipe	
X-56	56		71		All	S,E	line pipe	
X-60	50		75		All	S,E	line pipe	
X-65	65		77		All	S,E	line pipe	
X-70	70		82			S,E	line pipe	
X-80	80		90			S,E	line pipe	max tensile 120 ksi
Grade E	75	105	100		All*	S	drill pipe	NACE MR01-75
X-95	95	125	105		All	S	drill pipe	requires controlled
G-105	105	135	115		All	S	drill pipe	environment for
S-135	135	165	145		All	S	drill pipe	H2S
HCK-55	55	95	95	99HRb	All	S,E	OCTG	high collapse K-55
LS-65	65	85	85		All	S,E	OCTG	high toughness
HCL-80	80	95	95	22	All	S,E	OCTG	high collapse L-80
HCN-80	80	110	95		> 150	S,E	OCTG	high collapse N-80
RY-85	85	100	98		All	S,E	OCTG	restricted yield
S-95	95	125	110	31	>175	S,E	OCTG	high collapse
CYS-95	95	110	110	28	> 150	S,E	OCTG	restricted yield S95
HCP-110	110	140	125		> 175	S,E	OCTG	high collapse P110
HCQ-125	125	150	135		> 225	S,E	OCTG	"
135	135	160	145		N/A	S,E	OCTG	
140	140	165	150		N/A	S,E	OCTG	
160	160		170		N/A	S,E	OCTG	

- H-40 is the lowest strength casing and tubing grade in the OCTG specifications, with a minimum yield strength of 40,000 psi, and a minimum tensile strength of 60,000 psi. H-40 is a carbon type steel. The maximum yield strength of 80,000 psi assures suitability for use in hydrogen sulfide service (H_2S).

- **J-55** is both a tubing and casing grade and has a minimum yield strength of 55,000 psi and a minimum tensile strength of 75,000 psi. J-55 is a carbon type steel. As with H-40, the maximum yield strength of 80,000 psi assures suitability for use in H_2S.

- **K-55** is a casing grade only, with a minimum yield strength of 55,000 psi and a minimum tensile strength of 95,000 psi. K-55 is also classified as a carbon type steel. K-55 was developed after J-55 and has a higher tensile strength. In fact, the collapse and internal yield strengths of both grades are identical. But due to the higher tensile strength, K-55 has a casing joint strength that is approximately 10 percent higher than J-55. The API equations for joint strength for tubing includes only yield strength and excludes tensile strength, and hence, only J-55 is used for tubing. K-55 has a maximum yield strength of 80,000 psi, and is considered suitable for use in H_2S at all temperatures.

- L-80 is by far the most widely used high strength grade for H_2S service. The minimum yield strength is 80,000 psi, the minimum tensile strength is 95,000 psi, and the maximum yield strength is 95,000 psi. The method of manufacture can be either ERW or seamless, and the steel must be quench and tempered. L-80 is both a casing and tubing grade and was the first grade to have a maximum hardness requirement, Rockwell C-23.

- N-80, with a minimum yield strength of 80,000 psi and a minimum tensile strength of 100,000 psi, is the highest strength grade in Group 1. N-80 is classified as an alloy type steel. N-80 is not considered suitable for H_2S at all temperatures, due to its maximum yield strength of 110,000 psi. NACE rates N-80 for H_2S service at temperatures of 150°F and hotter if the steel is quench and tempered, and at temperatures of 175°F and hotter if the steel is normalized.

- C-90 was added to the API specifications in 1983. The grade has enjoyed increasing usage in recent years in critical high pressure wells containing H_2S. C-90 is both a casing and tubing grade. Minimum yield strength is 90,000 psi, and the minimum tensile strength is 100,000 psi. The maximum yield strength is restricted to 105,000 psi. The method of manufacture is specified as seamless with the chemistry an alloy steel (containing chromium and molybdenum) for added toughness. Maximum hardness is restricted to Rockwell C-25.4.

- C-95 is a casing grade only and was placed in the specifications after early successes with use of restricted yield strength for grade C-75 (discontinued by API). C-95 has a minimum yield strength of 95,000 psi and a maximum yield strength of 110,000 psi. Minimum tensile strength is 105,000 psi. The process of manufacture can be ERW or seamless, and the steel type is alloy. Despite the earlier successes with C-75 and its restricted yield strength, C-95 was found to be not suitable for H_2S at lower temperatures due to the higher strength levels permitted. API did not give C-95 a hardness limitation. In part due to the popularity of grades such as Lone Star Steel's S-95, very little C-95 is purchased today.

- T-95 is modeled after C-90, and solves the problems encountered with C-95 in H_2S. T-95 is both a casing and tubing grade. Minimum yield strength is 95,000 psi, and the minimum tensile strength is 105,000 psi. The maximum yield strength is restricted to 110,000 psi. The method of manufacture is specified as to 110,000 psi. The method of manufacture is specified as seamless with the chemistry an alloy steel. Maximum hardness is restricted to Rockwell C-25.4.

- **P-110** is a casing and tubing grade (since the discontinuation of the API tubing grade P-105). It has a minimum yield strength of 110,000 psi, a maximum yield strength of 140,000 psi, and a minimum tensile strength of 125,000 psi. The process of manufacture is both ERW and seamless for casing, and seamless for tubing. When P-110 was created, it was thought that this grade would handle all future deep drilling requirements. However, drilling depths and pressures continue to increase, and higher grades are now in regular use.

- **Q-125** is a grade used for casing in wells with very high pressures and for large OD casing with significant collapse forces. The grade was adopted by API in 1985, and is classed as Group 4. Q-125 has a yield strength range of 125,000 psi to 150,000 psi and a minimum tensile strength of 135,000 psi. The process of manufacture is both ERW and seamless for casing sizes. Q-125 was the first API grade to require impact tests to confirm steel toughness. NACE included what amounts to Q-125 Type 1 in its specification for H_2S service, but only at temperatures of 225°F and hotter.

- **V-150**, while not an API grade, is usually included in a discussion of API grades. The grade has a yield strength range of 150,000 psi to 180,000 psi, and a minimum tensile strength of 160,000 psi. It is not rated for H_2S service at any temperature. Commercially, it is very uncommon.

Proprietary grades

The following grades are manufactured by Lone Star Steel, using the ERW process of manufacture. Many of these grade names, however, have entered general usage, and may be procured in a seamless equivalent.

- **HCK-55**, formerly referred to as S-80, is a high collapse strength variation of K-55. The grade is produced in casing sizes from 8-5/8" to 13-3/8". In most cases, the collapse strength of HCK-55 is greater than the next heavier weight of K-55, and also of the same weight of N-80. The burst strength of HCK-55 matches that of K-55. HCK-55 is a carbon grade. As it meets API specifications for K-55, it is also suitable for use in H_2S.

- **LS-65** is a casing grade featuring high toughness and all temperature H_2S service. It has a yield strength range of 65,000 psi to 80,000 psi, and a minimum tensile strength of 85,000 psi. The burst and collapse performance exceed that of J-55 and K-55, and the joint strength exceeds that of J-55. The couplings are either L-80 or K-55, depending on the wall thickness of the pipe.

- **HCL-80**, formerly referred to as SS-95, was the first high strength casing developed for sour gas service. The A. O. Smith Company developed this grade some years before API adopted the C-75 and L-80 specifications. From its introduction, the grade has incorporated both restricted yield strength and hardness control, 80,000 psi to 95,000 psi and Rockwell C-22, respectively. The minimum tensile strength is 95,000 psi, the same as L-80. The grade also features all temperature H_2S service and high collapse performance. It is a quench and tempered product, and is available in sizes from 4-1/2" to 13-5/8" in diameter.

- **HCN-80** is a high collapse variation of API N-80, and is generally available in sizes 10-3/4" to 16". Smaller sizes may be available on request.

- **S-95** is a quench and tempered casing developed by the A. O. Smith Company. The grade was developed to provide a casing product having high collapse strength with an intermediate burst strength based on its longitudinal yield strength of 95,000 psi. The collapse performance exceeds heavier weights of N-80, and many identical weights of P-110. The pipe has a maximum yield strength of 125,000 psi and a minimum tensile strength of 110,000 psi. The maximum hardness is Rockwell C-31. With its yield strength range, the grade is rated by NACE for H_2S service at temperatures of 175°F and hotter. It is available in sizes from 4-1/2" to 16" in diameter.

- **CYS-95** is the controlled yield variation of S-95. It has a yield strength range of 95,000 psi to 110,000 psi, and is suitable for H_2S at temperatures of 150°F and hotter. The maximum hardness is Rockwell C-28.

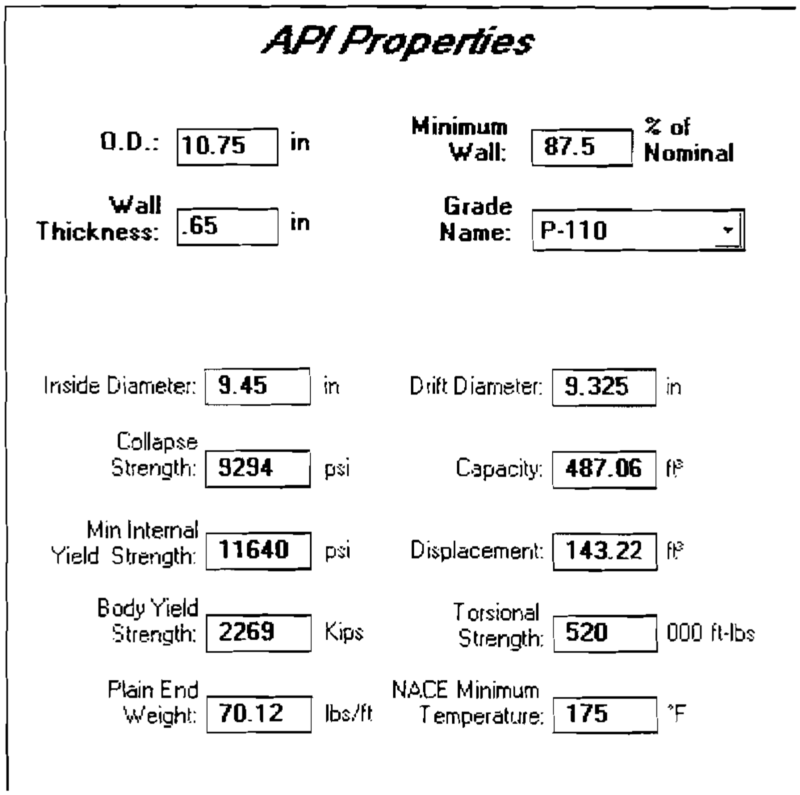
- **LS-110** is a quench and tempered casing grade with a minimum yield strength of 110,000 psi, a maximum yield strength of 140,000 psi, and a minimum tensile strength of 125,000 psi. It features a collapse strength equal to at least that of S-95, and is suitable for H_2S service at temperatures of 175°F and hotter.

- **HCP-110** is the high collapse strength variation of API P-110.

- **LS-125** is a quench and tempered casing grade with a minimum yield strength of 125,000 psi and a maximum yield strength of 140,000 psi (for pipe manufactured subsequent to 1988). The minimum tensile strength is 135,000 psi. The steel refining process for LS-125 imparts a degree of toughness not usually obtainable in casing of this strength level. The toughness not only assures good down hole performance, but eliminates any need for special handling prior to running in the well. The collapse performance is equal to at least that of S-95.
- **HCQ-125** is the high collapse strength variation of API Q-125.
- **LS-140** is suitable for use in deep high pressure wells where burst and joint strength are the primary design considerations. It has a minimum yield strength of 140,000 psi, a maximum yield strength of 165,000 psi and a minimum tensile strength of 150,000 psi. Like V-150, it is not rated for service in H_2S at any temperature. However, the refining of its steel process assures good toughness.

API PROPERTIES

The performance properties of pipe calculated in accordance with API equations may be determined by the *API Properties* screen. The screen is called up by selecting "View API Properties" from the pull down menu. The input information includes outside diameter, wall thickness, grade, and minimum remaining wall. In addition to strengths, plain end weight and capacities, the minimum temperature for H_2S service is shown. A temperature of "0" is given for all temperature H_2S grades.



API Properties

O.D.: 10.75 in

Minimum Wall: 87.5 % of Nominal

Wall Thickness: .65 in

Grade Name: P-110

Inside Diameter: 9.45 in

Drift Diameter: 9.325 in

Collapse Strength: 9294 psi

Capacity: 487.06 ft³

Min Internal Yield Strength: 11640 psi

Displacement: 143.22 ft³

Body Yield Strength: 2269 Kips

Torsional Strength: 520 000 ft-lbs

Plain End Weight: 70.12 lbs/ft

NACE Minimum Temperature: 175 °F

One of the primary minimum requirements of API is that the pipe have a wall thickness of no less than 87-1/2 percent of the nominal wall. This gives rise to the minimum internal yield pressure (often referred to as burst strength for short), which is calculated from the Barlow equation as follows:

$$p_b = 0.875 * (2 * \sigma_{yield} * t / d_p)$$

The 0.875 term in the above equation pertains to the minimum wall thickness allowed as a departure from nominal wall. If pipe is offered with a higher burst rating than the above equation notes, then either the minimum wall tolerance has been upgraded or the minimum yield strength has been raised. This equation and others related to performance properties of pipe are found in API Bulletin 5C3. The pipe body yield strength is simply the cross section area of the pipe body multiplied by the minimum yield strength:

$$P_y = \pi/4 * (d_p^2 - d^2)$$

The API equations for collapse strength vary depending upon the minimum yield strength of the pipe, σ_{yield}, and the diameter to thickness ratio, d_p/t. The equations are as follows:

- Yield strength collapse pressure formula

$p_{cr} = 2 * \sigma_{yield} * [d_p/t - 1 / (d_p/t)^2]$

- Plastic collapse pressure formula

  $p_{cr} = \sigma_{yield} * [(A/ d_p/t) - B] - C$

  where A, B, and C are coefficients based upon grade and the d_p/t ratio.

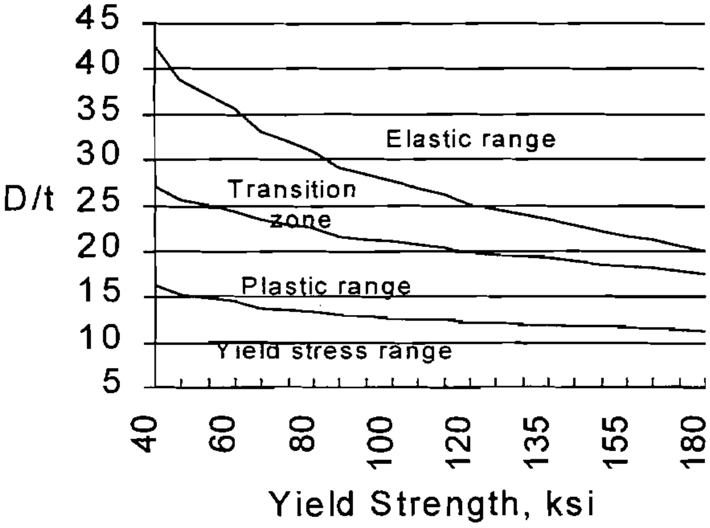
- Transition collapse pressure formula

  $p_{cr} = \sigma_{yield} * [(F/ d_p/t) - G]$

  where F and G are coefficients based upon grade and the d_p/t ratio.

- Elastic collapse pressure formula

  $p_{cr} = 46.95 * 10^6 / [(d_p/t) * \{(d_p/t) -1\}^2]$



While not a true von Mises equation, API does recognize the effect of both external and internal pressure on the strength of the pipe. Their equation has the purpose of modifying the effective collapse pressure, p_r, on the pipe, and is as follows:

$p_r = p_e - [1-2/(d_p/t)] * p_i$

The API equations for joint strength are more complex, as they are based upon actual or theoretical thread dimensions for the thread forms, the pipe diameter, wall thickness, yield and tensile strengths, and all of the same information for the couplings, for the threaded connections. In addition to Bulletin 5C3, Bulletin 5B1 will be needed for the values required by the equations. The equations relate in some fashion to a critical area of the connection, which may be in either the pin or the coupling. The API equation for round casing joint pullout (or jumpout) strength is as follows:

$$P_j = 0.95 * A_{jp} * L * [(0.74 * d_p^{-0.59} * \sigma_{tensile})/(0.5 * L + 0.14 * d_p) + \sigma_{yield} / (L + 0.14 * d_p)]$$

where:

P_j = minimum joint strength, pounds

A_{jp} = cross-sectional area of the pipe wall under the last perfect thread, in^2

= $\pi/4 * [(d_p - 0.1425)^2 - d^2]$ for 8 round threads

d_p = nominal outside diameter of the pipe, inches

L = engaged thread length, inches

= L_4 - M for nominal make-up, API Standard 5B

σ_{yield} = minimum yield strength of the pipe, psi

$\sigma_{tensile}$ = minimum ultimate tensile strength of the pipe, psi

Premium connections are generally presented with a critical cross section area value, to which either the tensile strength or the yield strength may be multiplied in order to find the joint strength rating. Typically, production casing and tubing uses the yield strength for this value and other casing strings incorporate the tensile strength for the joint strength rating.

Proprietary

Pipe manufacturers have modified the specifications for API pipe for many years in order to provide certain features to meet customer needs. These features are generally in the categories of high (or enhanced) strength, high collapse, lower cost, and corrosion resistance.

PIPE MANUFACTURE

ERW

ERW (or sometimes EW) pipe is made from the electric resistance weld (ERW) or electric induction weld (EIW) process. Flat steel sheet (or skelp) is fed through a series of rolls to form a tube, which is welded with a high-frequency AC current. At the point where electrical current heats the edges of the skelp, pressure rolls force the edges together, to form a bonded tube. Following welding, the pipe is further heat treated by seam annealing or full-body normalizing to modify the grain structure of the weld zone or entire tube body, respectively. ERW is made in OCTG grades from H-40 to V-150 with the exception of API C-90 and T-95.

SEAMLESS

Seamless pipe is made from either the plug pierce process or pierce mandrel process. In both cases, a pre-heated billet is forced through a set of rolls and over a piercer to form a tube hollow. This hollow is then fed through a set of rolls to lengthen the pipe and form the OD and wall thickness.

QUALITY

The performance properties of purchased pipe are determined by either API literature or by proprietary information. API has a quality program to which companies holding API licenses must comply. Any problems with this pipe are taken through the selling agent to the manufacturer. One of the caveats to this is that the pipe must have its identity which is traceable to the manufacturer. Otherwise, any problems will stop with the selling agent. This identity is known as the "heat number" for the pipe. As pipe is brought on location, if the heat number and manufacturer is recorded then any subsequent problems can be rectified much more quickly.

CONNECTIONS

API

Threading is the easiest and cheapest way to join two pieces of pipe together, at least in the size range commonly used as OCTG. For large OD pipe, OD > 20", squinch or snap connectors welded to the pipe ends are more efficient. Large OD pipe is heavy, hard to handle, hard to thread, and very difficult to make-up without crossthreading.

Threaded connections are basically designed to perform three distinct, supposedly mutually exclusive functions which are unfortunately destined to be interdependent to some degree. Ideally these functions are to be as independent as possible such that the failure of any one will not result in the failure of any other(s), i.e. no weak links.

Function 1) Act as a machine to draw the male and female elements of the connection together.

*Function 2)*In some manner effect a seal that is resistant to ID and OD pressure under various loadings.

*Function 3)*Mechanically lock the male and female elements together, preventing back-off or additional make-up, and maintaining the connection integrity under load.

This is the order in which these functions occur when a threaded connection is made-up. Obviously, the three functions are not as independent as would be desired since generally a connection will not seal or prevent back-off unless it is fully made-up. In connection designs where the sealing is performed by the threadform (which of course performs the other two functions) only, the three functions are quite closely linked. In these designs, the connection must be fully made-up (to torque or standoff) in order for it to hold pressure or be mechanically effective. This requires that the connection be power tight or it will leak, will back-off without restraint, or may separate prematurely under tension.

The API casing connections include 8 Round Short (ST&C or STC), 8 Round Long (LT&C or LTC), Buttress, (BTC) and Extreme-Line (X-Line or XL). All but the X-Line is readily available. The X-Line is a non-threaded and coupled connection with a swedged box and threads based on a variation of the buttress connection. The 8 round threads have stabbing and load flanks which have 60° angles and a rounded crest and trough. The buttress thread is somewhat more expensive than the 8 round, and has a 87° load flank and a 80° stab flank, with respect to the pipe axis. The buttress thread resists jumpout failure to a greater extent than 8 round, and performs better in deviated wells.

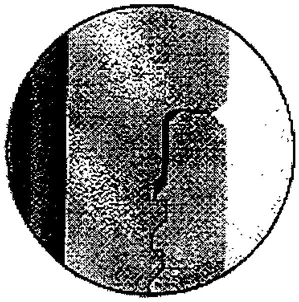
The API tubing connections include external upset (EUE), non upset (NUE) and integral joint connection (IUE). There is also a buttress connection for tubing, but it was not adopted as a standard by API. For NUE tubing, the thread pitch for 2-3/8" through 3-1/2" is 10 threads per inch, and for larger sizes and EUE tubing, the pitch is 8 threads per inch.

Proprietary

The primary difference between API and non-API connections is that non-API, or proprietary (premium), connections have been subjected to some degree of optimization whereby attempts are made to separate the three functions as much as possible. Ideally the optimization should permit a connection to provide sealing and mechanical integrity to yield in the tight position, and added security when power tight. When the specific aspects of a design are optimized, and each function can work on its own without interference from any other, the connection becomes a balanced system wherein all desirable characteristics (easy stabbing, fast make-up, pressure tight and strong at low make-up torques, easy break-out for tripping work strings, etc.) are maintained, and the undesirable traits (cross threading, large number of turns to power tight, seal or thread galling, high torques, susceptibility to handling damage, etc.) are eliminated.

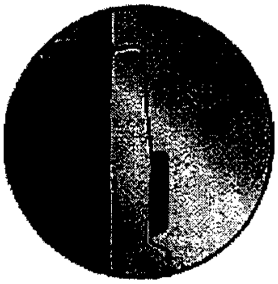
Proprietary connections are used when API connections are inadequate for the well operating conditions or for the expected conditions (expecting a kick). They are specifically designed to provide features that surpass API connection specifications, in particular:

- **Greater tensile and compressive strengths.** The connection is as strong as the pipe body up to yield, and in some cases is stronger than the pipe beyond the ultimate strength. Many connections have torque shoulders which lend themselves to higher imposed torque from rotation.



A torque shoulder

- **Better sealing capabilities.** Able to seal gas tight without the need for Teflon rings, special thread compounds, complicated torque / turn requirements, etc. under extreme operating conditions due to metal to metal seals.



Example of metal to metal seal and smooth bore inside diameter

- **Consistent make-up parameters.** Due to high precision machining, each connection is essentially a mirror image of the previous, thus will exhibit the same make-up characteristics to a specified torque without the need for counting turns or measuring standoff.

- **Burst and collapse equal to the pipe body.** Again, the connection is as strong as the pipe body, combined with tensile efficiency mentioned previously, allows the operator to design the string based on the properties of the pipe, knowing that the connection is not a weak link.

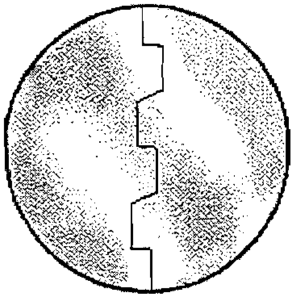
- **Smooth bore ID.** In high velocity flow this reduces turbulence, recirculant flow and erosion, as well as reducing friction losses, eliminating recesses to hang tools or tear swab cups.

- **Smooth or improved OD profile.** Collar or box end OD may be less than for API connections and may allow easier stripping through packing, plus will allow one size larger NU tubing to be run vs EU.

- **More balanced stress state.** Reduced hoop stress in box end (good in hostile environments) and due to lower contact stresses in threads, generally will allow repeated make and break with no connection wear or galling.

- **Generally faster make-up and break-out.** Specifically in tubing sizes due to coarser pitch (6 threads per inch, tpi, as opposed to 8 tpi) combined with a steeper taper or a two step results in 30% to 50% fewer turns from stabbed to power tight position.

- **Features to accommodate high allow (CRA).** Due to balanced stress, low contact stress and other factors, proprietary connections are suitable for use on CRA (corrosion resistant alloy, i.e. stainless) materials.



Example of reverse angle threads

GRANT PRIDECO, INC.

Atlas Bradford and Enerpro (formerly Baker Tubular) products are available from Grant Prideco and authorized distributors. The Houston, Texas telephone and fax numbers are (713) 931-0040 and (713) 931-4525, respectively. Atlas Bradford products include ST-C, ST-P, IJ-3SS, FL-4S, ST-L, FL-21, ST-FI, TC-4S, ST-M, AB Modified, NS-CC, Spiraline, AB-TC, DSS, and IJ-4S. Enerpro products include HDL, Big HDL, NJO, Big NJO and RFC casing connectors, and RTS-8, RTS-8PR, RTS-6, and RTS-6PR tubing connectors.

HUNTING INTERLOCK

Hunting Interlock and Threadmasters products are available from Hunting Interlock and authorized distributors. Their Houston, Texas telephone and fax numbers are (713) 442-7382 and (713) 442-3993, respectively. The products include the following, furnished by courtesy of Hunting Interlock.

THREADMASTERS PRODUCT LINE
TUBING CONNECTIONS

Convertible 8rd. A low cost, high performance design. Converts 8rd to higher performance applications. Center ring provides a positive torque stop preventing additional downhole make-up under extreme torsional procedures, positional make-up, metal-to-metal axial seal and flush I.D. bore. SealLube™ provides a separate independent sealing system. Close tolerance coupling provides optimum thread seal and stress control. Connections are easily repaired at Hunting Interlock authorized API end finishers.

TKC 8rd. A low cost, high performance design. Converts 8rd to higher performance applications. Internal torque shoulder provides a positive positional make-up preventing additional downhole make-up under extreme torsional procedures, positional make-up, metal-to-metal axial seal and flush I.D. bore. Elastomeric secondary seals provides a separate independent sealing system. Close tolerance coupling provides optimum thread seal and stress control. Connections are easily repaired at Hunting Interlock authorized API end finishers.

FS-150. A rugged design specifically for non-upset tubulars. Center ring provides a positive positional make-up, metal-to-metal axial seal, flush I.D. bore and eliminates neck down of pins and belled couplings. Improves swabbing efficiency and extends life of swab cups. Non-upset design allows economical use of standard NU coupling stock. Low interference thread form, with true 90° load flank, allows free spinning make-up, reducing running time and achieving longer thread life. Turned coupling O.D. provides operating capabilities comparable to integral upset connection. Excellent for dual completions. Excellent for reclamation programs where tubes cannot be rethreaded to 8rd because of short upsets.

Convertible 4040-NU. A rugged design specifically for non-upset tubulars. Center ring provides a positive positional make-up, metal-to-metal axial seal, and flush I.D. bore. Improves swabbing efficiency and extends life of swab cups. Non-upset design allows economical use of standard NU coupling stock. Close tolerance couplings and pins, designed with 3° load flank for strength, provide optimum thread seal and stress control. Excellent for dual completions. Tensile efficiency approaches pipe body. SealLube™ provides a separate independent sealing system. Excellent for reclamation programs where tubes cannot berethreaded to 8rd because of short upset.

MMS 8rd. Economical connection for severe corrosive environments. Most API licensed facilities can thread accessories. Close tolerance coupling provides optimum thread seal and reduces stress. Teflon® center ring provides a "Superior Teflon® Sealing System" and "Soft" landing area to protect coated pins. SealLube™ provides a separate independent sealing system. MMS utilizes a positional make-up system and is a gas tight connection.

TS-8. Designed for internal plastic coating and downhole rotation. External torque shoulder provides positive precision make-up, allows for multiple trips, and prevents over penetration of Teflon® seal. Teflon® center ring provides a "Superior Teflon® Sealing System," "Soft" landing area to protect coated pins. Close tolerance coupling provides optimum thread seal and reduces stress. TS-8 is a gas tight connection.

THREADMASTERS PRODUCT LINE
CASING CONNECTIONS

Convertible Casing. Upgrades API Buttress and 8rd to low cost, high performance connections. Designed to extend performance in high angle/deviated horizontal wells. Close tolerance coupling controls induced make-up stress. Center ring provides increased torque resistance, improved pressure capability and positive torque stop. SealLube™ provides a separate independent sealing system.

TKC Casing. Upgrades API Buttress and 8rd to low cost, high performance connections. Designed to extend performance in high angle/deviated horizontal wells. Close tolerance coupling controls induced make-up stress and improves sealability. Internal torque shoulder provides increased torque resistance, improved pressure capability and positive torque stop.

FJ-150 Flush Joint. A low cost rugged connection. External flush design with internal flush bore. External torque shoulder, low interference thread (true 90 load flank), and energized axial metal to metal seal. Free spinning connection for quick make-up. High over torque resistance due to double torque stops.

SEAL-LOCK PRODUCT LINE TUBING CONNECTIONS

SEAL-LOCK® PC. Special Non-Upset T&C Connection for plastic coated pipe. Coatable pin end. "T" shaped PC ring. Hooked thread design maintains pin to box engagement and provides structural integrity under combined tension and bending loads. Conical metal-to-metal gas tight seal is rated at 100% of pipe body yield, and with its long low angle design and phonographic finish it remains effective after numerous trips.

TC NU-LOCK®. Special Upset T&C Connection. Internal and external shoulders give maximum protection from over-torque. The outside shoulder also provides a visual indicator for determining make-up. Optional plastic coated design is available with "T" shaped PC ring. Deep stabbing hooked thread design resists cross threading resulting in faster running times. Hooked thread design maintains pin to box engagement and provides structural integrity under combined tension and bending loads. Conical metal-to-metal gas tight seal is rated at 100% of pipe body yield, and with its long low angle design andphonographic finish, it remains effective after numerous trips.

I-J NU-LOCK®. Heavy duty integral connection for deep, high pressure wells. It features high joint strength, rugged internal and external torque shoulders and a gas tight metal-to-metal seal. Maximum resistance to overtorque is assured by having two 5° trapped shoulders that contact upon determine make-up. Also available as I-J NU-LOCK PC with an elastomeric ring and special "bullet" nose for pipe to be internally plastic coated and used in highly corrosive service.

LOCK-IT®-EIGHT. Non-upset connection provides superior performance while eliminating upsetting and normalizing costs associated with upset connections. Excellent for use in applications where pressure integrity and flow characteristics are the primary concerns. A low angle metal-to-metal seal with a specially machined phonograph finish minimizes galling and provides a gas tight seal that will equal pipe body internal yield strength. A standard minimum coupling O.D. reduces costs and provides added hole clearance allowing 2 7/8" tubing to be run inside 4 ½" casing while maintaining minimum tensile efficiency equal to pipe body yield strength. Coupling I.D.'s are machined to match the pipe I.D. to provide superior flow characteristics.

HD LOCK-IT™. Heavy duty, non-upset T&C connection provides superior performance while eliminating upsetting and normalizing costs associated with upset connections. Special hooked thread design incorporates a "chevron" feature on the load flank to alleviate thread hang-up during tripping. A low angle metal-to-metal seal with a specially machined phonograph finish minimizes galling and provides a gas tight seal that will withstand pipe body pressures. Seal location on flank side of pin allows for greater resistance to pin nose damage. Also available as HD LOCK-IT PR with an elastomeric seal ring for added protection against leaks.

SEAL-LOCK PRODUCT LINE CASING CONNECTIONS

SEAL-LOCK® HC. The time proven Seal-Lock design has been optimized to meet the requirements of the most critical well applications (4½" - 13 5/8"). Assembly and operational stresses have been set at the optimum levels for certified performance. SEAL-LOCK HC has been designed to meet or exceed pipe body burst ratings, formation collapse loads and provide superior tensile strength. Hooked threads for tensile strength mated with a trapped shoulder for high compressive loading give SEAL-LOCK HC superior bending and torque resistance necessary for highly deviated well designs. Thread jumpout is virtually eliminated under the most severe applications. A special phonograph finish on the metal-to-metal seal surface minimizes galling, holds lubricants, and helps sealing with no need for special plating procedures. Trapped internal torque shoulder provides a positive torque stop to lessen the chance of over torquing and guarantees a smooth bore through the pipe I.D. Low profile, parallel root and crest, hooked thread design provides smooth stabbing and virtually eliminates cross threading.

SEAL-LOCK® APEX. Designed for critical service (4½" - 13 5/8"). The unique combination of a metal-to-metal seal and a close-tolerance thread-seal provides pressure integrity for both internal and external pressure in moderate to heavy wall tubular applications. Exhaustive testing has produced reliable results on a variety of load combinations. These include: tension and compression with internal and external pressure, thermal cycling with pressure, tension to failure, compression to failure, internal and external pressure to failure. This testing has verified the design as structurally sound even under the most extreme load conditions. A special relief groove is machined in the coupling to eliminate problems associated with hydraulic dope entrapment. Trapped lubricant is minimized allowing the flank metal-to-metal seal to generate sufficient contact loads to remain leaktight at pressures exceeding pipe body burst. Positive torque shoulder stop improves compressive, torsional and leak resistance. The inside diameter of pin is profiled to match the J area of the coupling. This provides a smooth bore through the connection. A rugged hooked thread form provides excellent resistance against tensile loads, bending moments and external pressures under a variety of load combinations. The thread element geometry provides for easy stabbing, minimizing the chance of cross-threading while maximizing the chance of a quick, trouble-free run.

HW SEAL-LOCK®. An optimized design for the most critical applications (4½" - 10 3/4"). The connection will always equal or exceed pipe-body strength in tension, burst and collapse. The hooked thread form guarantees effective pin/box radial engagement and virtually eliminates thread jumpout failures on deep casing strings. The thread form root and crest surfaces are parallel to the pipe body axis, which provides smooth stabbing and virtually eliminates cross threading. Trapped internal shoulder provides a positive torque stop and guarantees a smooth bore through the pipe I.D. A special phonograph finish on the metal-to-metal seal surface holds lubricants, helps sealing and minimizes galling when multiple trips are required. The hooked thread form for tensile strength mated with a trapped shoulder for compressive loading gives HW SEAL-LOCK superior bending and torque resistance necessary for highly deviated well applications. Connections cut with an optional seal ring groove can be supplied with a PTFE pressure seal ring. The seal ring acts as a back-up seal in the event the metal-to-metal seal is damaged.

BIG "O" SEAL-LOCK®. Designed to withstand the toughest service conditions (13 5/8" - 24½"). Whether the application is a long string, bending or compression, BIG "O" SEAL-LOCK is engineered to solve well design problems. It is threaded directly on plain-end pipe with no welding or additional welding-related inspection procedures required. A low angle metal-to-metal seal with a special machined phonograph surface finish minimizes galling and provides a gas tight seal that equals pipe body yield strength. High tensile efficiency is achieved by incorporating a negative load flank thread. Hooked threads maintain pin-to-box engagement and provide structural integrity even under combined bending and tensile loads. A rugged 3-pitch thread form provides quick make-up. The negative five degree torque shoulder provides a solid torque stop. This shoulder provides a smooth bore ID to eliminate hang ups and connection damage during drilling operations.

SEAL-LOCK® BOSS. An excellent choice for horizontal applications where torsional, bending and compressive loads are the primary concerns (9 5/8" - 20"). The negative angle thread design provides an effective pin/box radial engagement while virtually eliminating thread jump-out failures. The coarse thread form stabs smoothly and reduces chances for cross threading. SEAL-LOCK BOSS development included extensive combined load gas testing. Even under extreme loads, the connection remained gas-tight. The controlled connection make-up allows pins to shoulder, providing a smooth bore I.D. and a positive torque stop. Tapered run out hooked thread form provides high tensile efficiencies, excellent make-and-break capabilities, and positive sealing. SEAL-LOCK BOSS utilizes API dimensional coupling stock for cost savings and market availability. A wide coupling face allows the use of standard shoulder type elevators for additional running cost savings. SEAL-LOCK BOSS is threaded directly on plain-end pipe. No welding or additional fabrication is required. SEAL-LOCK BOSS development included the latest in computer-aided design, strenuous physical testing, and stress analysis. The connection remains gas-tight when subjected to tensile loads and internal pressures that produce 100% VME pipe body stresses based on actual material yield strength.

SEAL-LOCK® HT. An excellent choice for horizontal applications where torsional, bending and compressive loads are the primary concerns (2 1/16" - 8 5/8"). The negative angle thread design provides an effective pin/box radial engagement while virtually eliminating thread jump-out failures. The controlled connection make-up allows pins to shoulder, providing a smooth bore I.D. and a positive torque stop. Tapered run out hooked thread form provides high tensile efficiencies, excellent make-and-break capabilities, and positive sealing. SEAL-LOCK HT utilizes API dimensional coupling stock for cost savings and market availability. A wide coupling face allows the use of standard shoulder type elevators for additional running cost savings. SEAL-LOCK HT is threaded directly on plain-end pipe.

FLUSH SEAL-LOCK®. Integral connection with a flush O.D. provides maximum clearance for slim hole applications (2 7/8" - 13 5/8"). The patented hooked thread form is optimized for pipe wall thickness and virtually eliminates thread jumpout failures. Additionally, the thread form resists pin/box disengagement under bending loads making it an excellent choice for horizontal applications. A flank metal-to-metal seal provides a pressure rating equal to the API minimum internal pressure rating for the pipe. Relief grooves machined in both the box and the pin help to eliminate problems associated with hydraulic dope entrapment. Pressure build-up from trapped lubricant is minimized so that sufficient contact loads are achieved at the flank metal-to-metal seal. External torque shoulder provides a visual make-up indicator and positive torque stop.

HYDRIL COMPANY

Hydril products are available from Hydril Company and their distributors. Their Houston, Texas telephone and fax numbers are (713) 449-2000 and (713) 985-3459, respectively. The following descriptions were furnished by courtesy of Hydril Company.

Hydril Tubing Connection Descriptions

- **Hydril CS, PH-6, and PH-4 Tubing** is recommended for work string, test string, and production tubing applications.

- **Hydril Series 500 Type 533 Tubing** is recommended for the most demanding production tubing and work string applications. An integral connection machined on internal/external upset ends, Type 533 provides pipe body strength combined with the sealing reliability of a metal seal. Type 533 is interchangeable with Type 563 and is available with the optional CB feature.

- **Hydril Series 500 Type 563 Tubing** is recommended for moderate to very heavy wall pipe for production tubing applications. Combining the structural characteristics of the dovetail Wedge Thread with the sealing reliability of a metal seal, Type 563 has been selected for use on carbon steel in sour environments and on stainless steels. It is also available with the optional CB feature.

- **Hydril Series 500 Type 503 Tubing** is offered on the lightest API tubing weights for production tubing and work string applications. Type 503 is an integral connection machined on long API external upset ends providing pipe body strength along with a metal seal.

- **Hydril Series 500 Type 501 Tubing** is offered on the lightest API tubing weights and has been used extensively for moderate depth workstring applications. Type 501 is an integral connection machined on API external upset ends providing pipe body strength at an economical price. Type 501 is interchangeable with Type 561.

- **Hydril Series 500 Type 561 Tubing** is offered on the lightest API tubing weights and recommended for moderate depth production tubing applications. Type 561 equipped with the CB feature has been used for plastic coated injection and production strings.

tubing applications. Type 561 equipped with the CB feature has been used for plastic coated injection and production strings.

- **Hydril Series 500 Type 511** in tubing sizes is recommended for repair string, scab liner, and horizontal applications. With this integral connection's overall structural capability combined with its pipe body OD, Type 511 has been selected for horizontal liners in re-entry wells, relatively long repair strings, and slim-hole liners.

Hydril Casing Connection Descriptions

- **Hydril SuPreme LX Casing** is recommended for high performance, medium to heavy wall production casing and tie-back strings. This integral connection combines a slim OD with tension and sealing reliability for multiple applications versatility. SuPreme LX has been selected for deep, high pressure liners, gas storage service, sour service tie-back strings, contingency drilling liners offshore, high pressure gas well production casing, intermediate casing, and high chromium liners.

- **Hydril Series 500 Type 563 Casing** is recommended for medium to heavy wall production casing, horizontal and extended reach applications, and geothermal and steam injection strings. This coupled connection provides the bending and torque strengths required for rotation in highly deviated wells. The Type 563 has been selected for sour service production casing strings, high strength primary casing in relief wells, high torque extended reach offshore wells, subsidence strings, and geothermal production strings.

- **Hydril Series 500 Type 521 Casing** has been used extensively in horizontal wells and for large diameter surface and intermediate casing strings. This integral connection with its combined bending and torque strengths has been used in long and medium radius horizontal and extended reach wells where it has been rotated comfortably during wash-down and cementing. Type 521 has also been used for large diameter surface and intermediate strings and is particularly suitable for slim-hole well designs.

- **Hydril Series 500 Type 511 Casing** is recommended for drilling liner, washover pipe, and horizontal liner applications. With good overall structural capability combined with a pipe body OD, Type 511 has been selected for horizontal liners in re-entry wells, relatively long repair strings, and slim-hole liners.

- **Hydril MAC-II Casing** is recommended for high performance, heavy wall production casing, intermediate casing, and tie-back strings. This integral connection, machined on Hydril formed and stress relieved ends, provides the combined tension and sealing capability required for deep, high pressure gas wells. MAC-II has been selected for long production and intermediate casing strings and gun barrel salt section strings.

- **Hydril Series 500 Type 533 Casing** is targeted for the structurally demanding horizontal and extended reach applications as well as geothermal and steam injection strings. This integral connection, machined on hot-forged upsets ends, provides the tension, compression, bending, and torque strengths desired for rotation in deep, highly deviated wells. With its 100% pipe body rated strength, Type 533 is also suited for long production casing and tie-back strings.

VAM

VAM products are available from VAM PTS, Sumitoma and Vallourec Companies and their distributors. The Houston, Texas telephone and fax numbers for VAM are (713) 821-5510 and (713) 821-7760, respectively. The products include New VAM, VAM Ace, and VAM FJL.

COMMERCIAL ASPECTS

API pipe is purchased according to the following format:

Size Weight Grade Joint type Range [mfg.] footage

For tubing sizes, the range is almost always II, which has a standard length of 31 feet, but may be from 25 to 34 feet. Casing sizes are almost always sold as range III, typically 42 feet, but varying from 34 feet to 48 feet. Some pipe may be obtained as range I for special purposes, which is from 16 to 25 feet. Seldom is the manufacturer or the method of manufacture required. The footage should include a make-up loss factor as well as any overage desired for the possible contingency of rigsite problems.

Other aspects which may form the requisition include the date and location required, the type of third party inspections desired, the type of thread protectors desired (i.e. hookable), minimum drift diameter (if special) and perhaps, suitable alternatives. In short, most sizes of J-55, K-55, L-80, N-80, S-95, P-110, and Q-125 have reasonably short lead times with the exception of some 5", 6-5/8", and 8-5/8" pipe over 32 lb/ft. Prices for the pipe can some 5", 6-5/8", and 8-5/8" pipe over 32 lb/ft. Prices for the pipe can decrease appreciably if the requirement(s) can be forecast sufficiently in advance for manufacture in volume. If the pipe required is of a special size and/or grade, there will be some minimum order volume associated with the order, typically given in number of tons (i.e., 200 tons of pipe).

Chapter 3

Program Installation

Without reading the additional information, the user can insert disk 1 into the computer and run "A:setup" to install.

BEFORE INSTALLING

Hardware and System Requirements

Casing2 is written in Visual Basic Version 3.0®. It runs in Microsoft Windows 3.1 or higher and Windows 95. The basic requirements are:

- Any IBM-compatible machine with 80386 processor or higher
- Hard disk with 6 MB free memory
- Mouse
- Windows 3.1 or higher or Windows 95
- An 80486 processor, VGA display, and a minimum of 4 MB of RAM is recommended

For assistance with the installation or use of CASING2 contact:

DR. XICHANG ZHANG

MAURER ENGINEERING, INC.

2916 WEST T.C. JESTER BOULEVARD

HOUSTON, TEXAS 77018-7098 USA

TELEPHONE: (713) 683-8227 FAX: (713) 683-6418

Program Disks

The program is contained on three 3-½ inch, 1.44 MB program disks containing 30 files. The disks contain the following files:

Disk 1

Casing2.Exe
GSW16.Exe
GSWdll16.dl_
SetG51.Exe
Setup.Exe
Setupkit.dll
Msajt200.dl_
Setup.1st
Sresults.rp_
LSSCSD.Ini
Vbrun300.dll
Commdlg.dl_
Ver.dl_

Disk 2

CMDialog.vb_
Crystal.vbx_
Gauge.vb_
Graphx.vb_
Gswag16.dl_
Lsshelp.hl_

Mdichild.vb_
MSABC200.dl_
OCTGwin.MD_
Threed.vb_
Spin.vb_
SSData1.vb_
SSData2.vb_
SSData3.vb_
Vbdb300.dl_
Uxddisk.dl_
Uxfdvc.dl_
Uxfxtext.dl_
Uxwordw.dl_

Disk 3

Crpe.dl_
Msajt16.dl_
Pdbjet.dl_
Pdctjet.dl_
Pdirjet.dl_

Uxfxls.dl_

The files with the underscore on the third character of the file extensions are compressed. The setup program will expand these compressed files and copy them to the user's hard disk. The extensions .DL_, .VB_, and .HL_ will become .DLL, .VBX, and .HLP.

All VBX and DLL files have the potential to be used by other Maurer Engineering DEA Windows applications installed in your Windows\System subdirectory. This applies to all the .VBXs and .DLLs included here. The Casing2 executable (Casing2.Exe) file should be placed in its own directory (default C:\CASING2). Please note, however, that potential software conflicts may arise from usage of different product releases of the same VBX or DLL program. If this is of any concern, and if space permits, all files may be kept in the subdirectory containing Casing2.Exe.

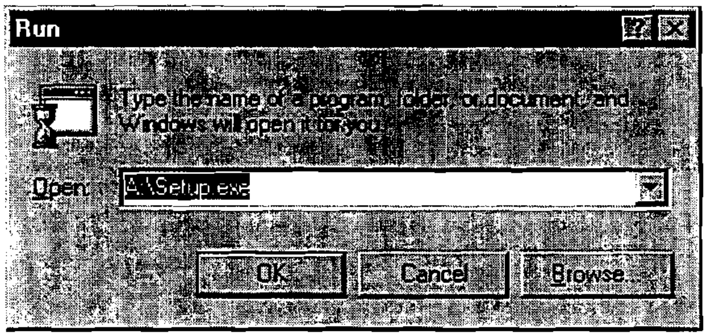
In order to run Casing2, the user must install all the files into the appropriate directory on the hard disk.

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

INSTALLING CASING2

The following procedure will install Casing2 from the floppy drive onto working subdirectories of the hard disk (i.e. copy from A: drive onto C: drive subdirectory CASING2.

1. Start Windows 3.x (Windows 95 already started) by typing "WIN" <ENTER> at the DOS prompt.
2. Insert program disk 1 in drive A:\.
3. In the File Manager of Windows 3.x, choose [RUN] from the [FILE] menu. Type A:\setup and press <ENTER>. For Windows 95 based systems, choose [Run] from the [Start] button, and A:\SETUP, as shown.



Type the name of a program, folder, or document, and Windows will open it for you.

Open: A:\Setup.exe

4. Follow the on-screen instructions, placing diskettes 2 and 3 in the A drive as required.
5. Note that the file LSSCSD.INI also goes into the Casing2 directory. This file gives the address for database, report and help files. If these files are subsequently moved, then the LSSCSD.INI file should be modified using Notepad to reflect the changes.

STARTING CASING2

To run CASING2 from the GROUP window, the user simply double-clicks the "CASING2" icon, or when the icon is focused, press <ENTER>.

As an alternative, in the Program Manager of Windows 3.x, choose [Run] from the [File] menu. Then type C:\Casing\Casing2.exe <ENTER>. Similarly, in Windows 95, click "Start", "Run", and type C:\Casing\Casing2.exe and click "OK."

Chapter 4

Running Casing2

The "fast start" as well as the detailed instructions for running Casing2 are in Chapter 4.

Fast Start

The sequence for a fast start is as follows:

1. Under "*File - New*" name the well such as "My Well."
2. Select the appropriate string type from the drop down menu.
3. Enter the measured setting depth of the string on the upper right.
4. The *Basic Parameters* window should now be open. Enter the mud weight.
5. Change the internal gas gradient or enter a new surface pressure if required.
6. If the well is directional, go to *Parameters - Environment - Directional* and enter the well information as needed.
7. Now go to *View Results* to get the computer generated design.
8. Look at the "Summary" on this window by clicking on "Summary," and click on Print, if one is desired.
9. To exit, go to "*File - Exit*," saving the design if desired. It will be saved under the name given it in step 1.

The Menu

The Windows style pull down menu consists of the following options: "File Edit View Select Parameters Results Help." The sub-elements of the menu contain various options as depicted in the following figures.

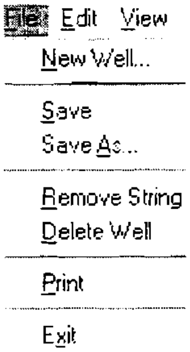


Figure 4.1

Figures 4.1 through 4.8 show the sequence of the menu. Figure 4.1, *File* allows a new well to be selected, allows the option to *save* a string (and well), to *save* a string *as* another well, to *remove* a string from a well, to *delete* a well (including its strings), to *print* results, and to *Exit* the program. It should be noted that there are two sets of data for each well (three sets for directional wells). The first set contains general information about the well, as well as the proper units of measurement. If the Microsoft software program Access Version 2.0 is available, the data can be viewed and modified in the table, "tblWellMast." The second data set contains specific information for each string for a well. It is named "tblWellDet." Again, by using Access, the table can be viewed or deleted, but the temptation to change any of the information in this file should be resisted, as much of the information is interdependent. Appendix 3 gives the detailed information contained in these tables. The third set contains the directional information for the well, and is named "tblSDI."

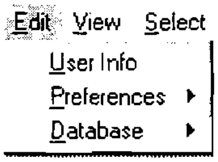


Figure 4.2

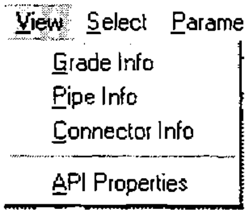


Figure 4.3

The second major menu heading is "*Edit*," shown in Figure 4.2. *Edit* allows options to change the general well information under *User Info*, to modify default values and units of measurement under *Preferences*, and to add (and subsequently edit) tubular grades, connections and pipe items in the *Database*.

The third major menu heading, "*View*," shown in Figure 4.3, shows *Grade*, *Connector*, and *Pipe* information, and also enables the engineer to calculate *API properties* (with the exception of joint strength) for any size, wall thickness, and grade.

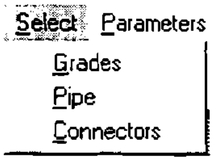


Figure 4.4

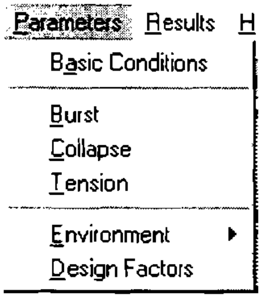


Figure 4.5

The next major menu heading, "*Select*," shown in Figure 4.4 allows the engineer to make selections of *Grades*, *Connectors* and *Pipe*. These selections are saved to the database. The principal menu heading under which design information is specified is *Parameters*, Figure 4.5. The first sub-menu, *Basic Conditions*, includes information primarily related to burst, but also includes "mud weight" which pertains to collapse as well. In order, the next sub-menu items include *Burst*, *Collapse*, *Tension*, *Environment*, and *Design Factors*. *Design Factors* differs from the similar page under *Edit* in that these factors override the factors specified in *Edit* as applicable. Some of the factors under *Edit* are not repeated, such as biaxial load model. All of the items under *Edit*, however, are intended to provide default values to the rest of the program.

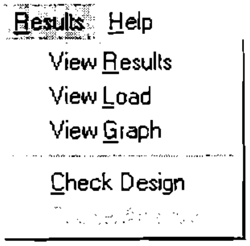


Figure 4.6

Figure 4.6 is the menu heading for *Results*, which calculates the (*View*) *Loads* for the given parameters, and either calculates the (*View*) *Results*, which is the computer generated casing design, or *Checks* the *Design* as specified by the engineer. *View Graph* shows the suite of graphs pertaining to the design and well which may then be printed or copied to the Windows "clipboard." Finally, a sensitivity analysis may be performed on the design, once initiated, with the *Triaxial Analysis*.

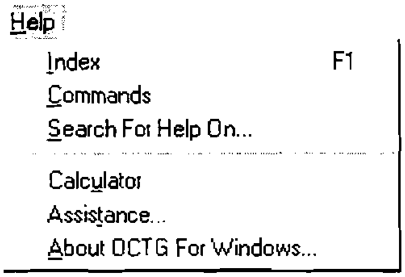


Figure 4.7

The last menu heading is "*Help*," shown in Figure 4.7. In addition to the Windows style "Help" items, *Index*, *Commands*, and *Search for help on*, one can pull up a scientific

Calculator, read about *Assistance* (typically the last resort but also the place to go to report "bugs"), and lastly, read *About OCTG for Windows.*

Having gone through the major menu headings, the following will give a quick "walk through" the sub-menu headings. Currently, there are only three, two under *Edit* and one under *Parameters*. As shown in Figures 4.8 and 4.9, the sub-menus under *Edit* include options for *Preferences* and *Database*. The Preferences menu include *Miscellaneous Defaults*, *Default Design Factors*, and *Units* of measure. These items, and *User Info*, are stored in the Well - Master data table as described in Appendix 3.

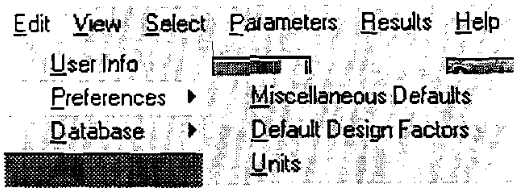


Figure 4.8 (*Edit - Preferences* sub-menu)

The database sub-menu allows additions and changes (to those additions) in the data tables of *Grades*, *Pipe* and *Connectors*.

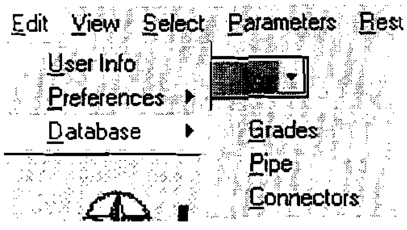


Figure 4.9 (*Edit - Database* sub-menu)

The last sub-menu item is *Environment*, Figure 4.10, which appears under the *Parameters* menu heading. *General* allows options pertaining to sour service, minimum section length, and offshore drilling conditions. *Directional Well* allows options related to designing a two dimensional well or importing or creating a three dimensional well in the Maurer Engineering "SDI" file format, and *Real Gases* includes a routine to calculate the average gas density in a well using a calculated "z" factor.

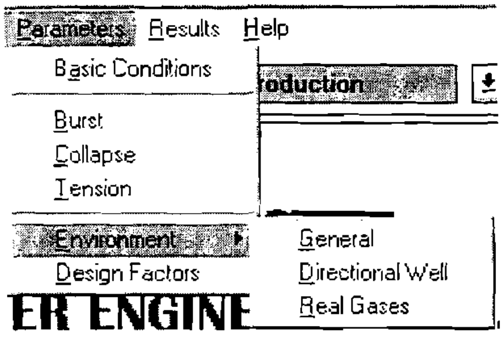


Figure 4.10 (*Parameters - Environment* submenu)

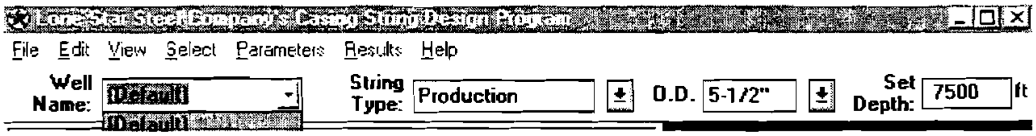
Window Descriptions

General

In the "form" windows, a "field" or "cell" colored yellow implies that the field is for informational purposes only, and cannot be changed or edited. Similarly, a field that is light blue is one that can be changed or edited. Occasionally, there may be a white field or cell in a grid which is editable. On the "View" windows, the white cells are not editable.

MAIN

The main window provides the most basic information of a well and string type - its name, the type of string, the size of pipe, and the measured setting depth of the string. This is shown in Figure 4.11. Also, it should be noted that *Well Name*, *String Type*, and *O.D.* (pipe diameter) are to be entered from the drop down list box. *Well name* can, alternatively, be typed in. Every time a new diameter is entered, a "query" is made on the pipe for that size range in the Access database. Additional sizes which fit in the size range are automatically entered. For example, a 9-5/8" query includes (at this writing), 9.625", 9.75", 9.875", and 10.000" pipe.

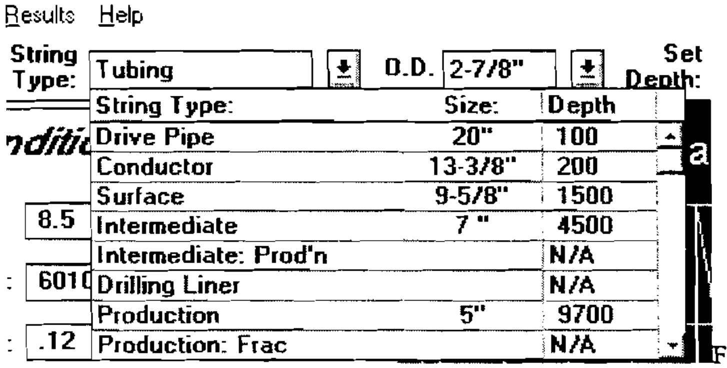


Well Name: (Default)
String Type: Production
O.D. 5-1/2"
Set Depth: 7500 ft

Figure 4.11

STRING TYPE

The string type is selected from a "drop down list box." Figure 4.12 shows such a box, with entries made for string types which have already been designed for the well. In this example, the drive pipe, conductor, surface, intermediate, and production strings have already been designed. The strings which are not a part of the well, or which have not yet been designed for the well are given a "N/A" in the *Depth* column. Additional strings can be seen by "scrolling" up or down with the right hand "slide bar."



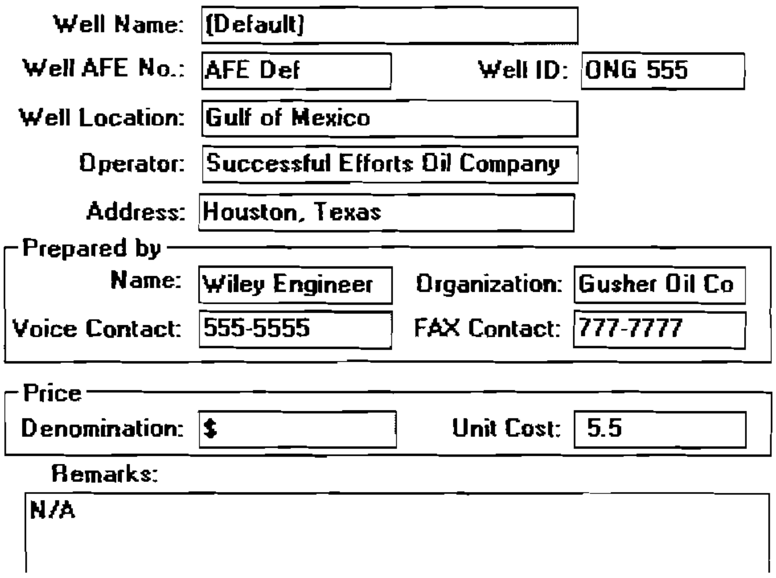
String Type: Tubing
O.D. 2-7/8"

String Type:	Size:	Depth
Drive Pipe	20"	100
Conductor	13-3/8"	200
Surface	9-5/8"	1500
Intermediate	7 "	4500
Intermediate: Prod'n		N/A
Drilling Liner		N/A
Production	5"	9700
Production: Frac		N/A

Figure 4.12

EDIT - USER INFORMATION

Figure 4.13 depicts the Edit - User Information window. Two comments need to be made about this window. One is that the database tables do not accept blanks, and "N/A" is the default value for anything that is intended to be left blank. It will appear on the printout, in such event, as a blank. Similarly, if no cost denomination is entered, then no costs will appear on the printout. Otherwise, this field can be used in any denomination, and the associated field, "Unit Cost" can then be adjusted for any denomination. At this writing, the baseline cost in U.S. dollars ($US) for this field is about 5.75.



Well Name: (Default)
Well AFE No.: AFE Def
Well ID: ONG 555
Well Location: Gulf of Mexico
Operator: Successful Efforts Oil Company
Address: Houston, Texas

Prepared by
Name: Wiley Engineer
Organization: Gusher Oil Co
Voice Contact: 555-5555
FAX Contact: 777-7777

Price
Denomination: $
Unit Cost: 5.5

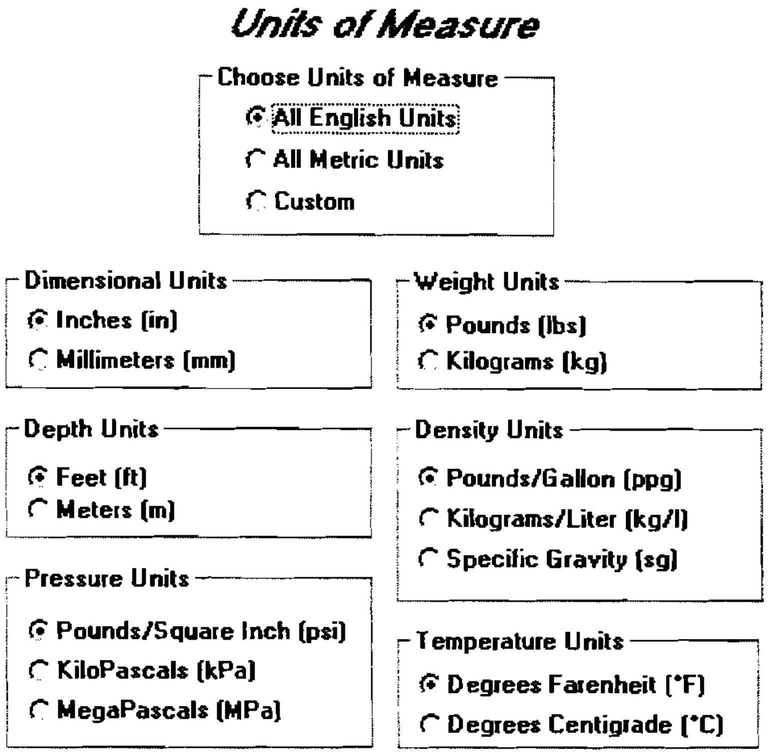
Remarks:
N/A

Figure 4.13

Another note which should be emphasized about *User Information*, *Edit Units*, *Edit Miscellaneous Program Defaults*, and *Edit Design Factors*, is that the information entered on this window can be saved under the well name, *Default*, which will avoid the need to enter this information for every new well.

EDIT - UNITS

Figure 4.14 depicts the *Units* window under *Edit - Preferences*. The only aspect of Casing2 that can depart from these entries is the SDI window, which also offers units such as "oilfield units." These units will be used for the entirety of any given well, but may be changed for another well name.



Units of Measure

Choose Units of Measure
- ● All English Units
- ○ All Metric Units
- ○ Custom

Dimensional Units
- ● Inches (in)
- ○ Millimeters (mm)

Weight Units
- ● Pounds (lbs)
- ○ Kilograms (kg)

Depth Units
- ● Feet (ft)
- ○ Meters (m)

Density Units
- ● Pounds/Gallon (ppg)
- ○ Kilograms/Liter (kg/l)
- ○ Specific Gravity (sg)

Pressure Units
- ● Pounds/Square Inch (psi)
- ○ KiloPascals (kPa)
- ○ MegaPascals (MPa)

Temperature Units
- ● Degrees Farenheit (°F)
- ○ Degrees Centigrade (°C)

Figure 4.14

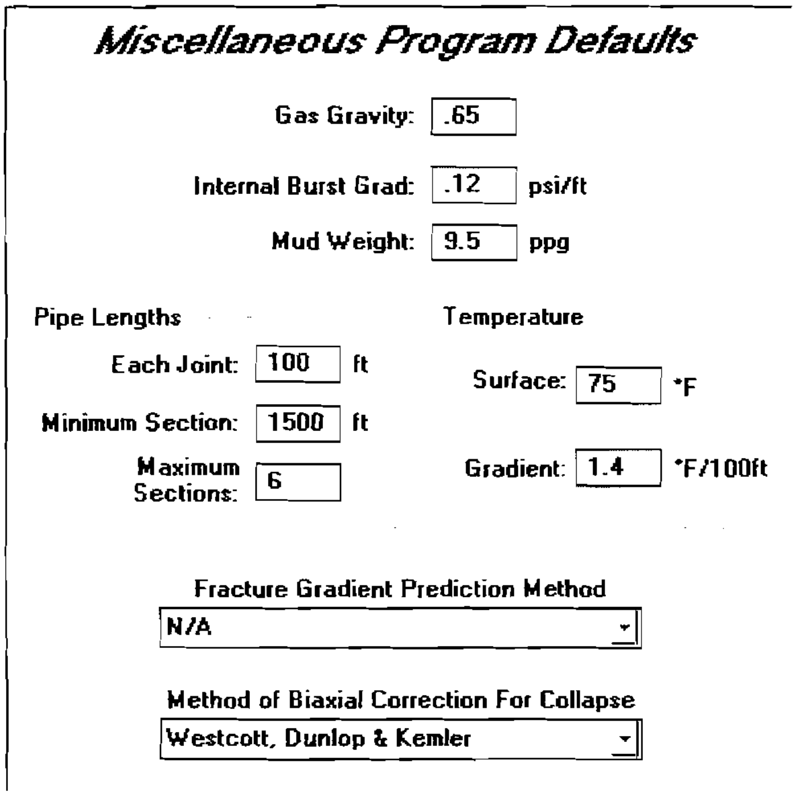
EDIT - MISC DEFAULTS

Figure 4.15 shows the *Miscellaneous Defaults* window under *Edit - Preferences*. The significance of "Each joint" is that the number of array points in the calculation will be based on this value. The default value is 100 feet. If program speed seems to be a problem, then this value might be changed to 250 feet to speed things along, with some loss in resolution of the parameters. Please note that items such as liner tops, mudline depths, and maximum - load depths which are not multiples of the joint length will be investigated only at the array points. The solutions for liner strings will have an "artificial top" which is rounded to the nearest array point.

The minimum section length is the minimum length that any one size, weight, grade, and joint type of pipe should be for the string.

The "method for biaxial correction" pertains to collapse. The options include: a) none; b) Holmquist & Nadia (the old API method); c) current API - with modifications for proprietary high collapse; d) Westcott, Dunlop & Kemler (Lone Star Steel); and e) current API with modifications for net collapse with internal gradients. These options are discussed in Chapter 1, Theory.

The "fracture gradient prediction method" is only intended as a *rough* guide, and the resulting value is not automatically used in any calculations. The choices for the fracture gradient prediction include: a) none; b) Eaton; c) M. Traugott - soft rock; d) M. Traugott - soft rock corrected for water depth; and e) M. Traugott - hard rock. These are explained in Appendix 5.



Miscellaneous Program Defaults

Gas Gravity: .65

Internal Burst Grad: .12 psi/ft

Mud Weight: 9.5 ppg

Pipe Lengths

Each Joint: 100 ft

Minimum Section: 1500 ft

Maximum Sections: 6

Temperature

Surface: 75 °F

Gradient: 1.4 °F/100ft

Fracture Gradient Prediction Method: N/A

Method of Biaxial Correction For Collapse: Westcott, Dunlop & Kemler

Figure 4.15

EDIT - DESIGN FACTORS

Figure 4.16 shows the *Program Design Factors* under the *Edit - Preferences* menu heading. "Other API" connections include EUE, X-Line, Buttress for tubing, and other API names.

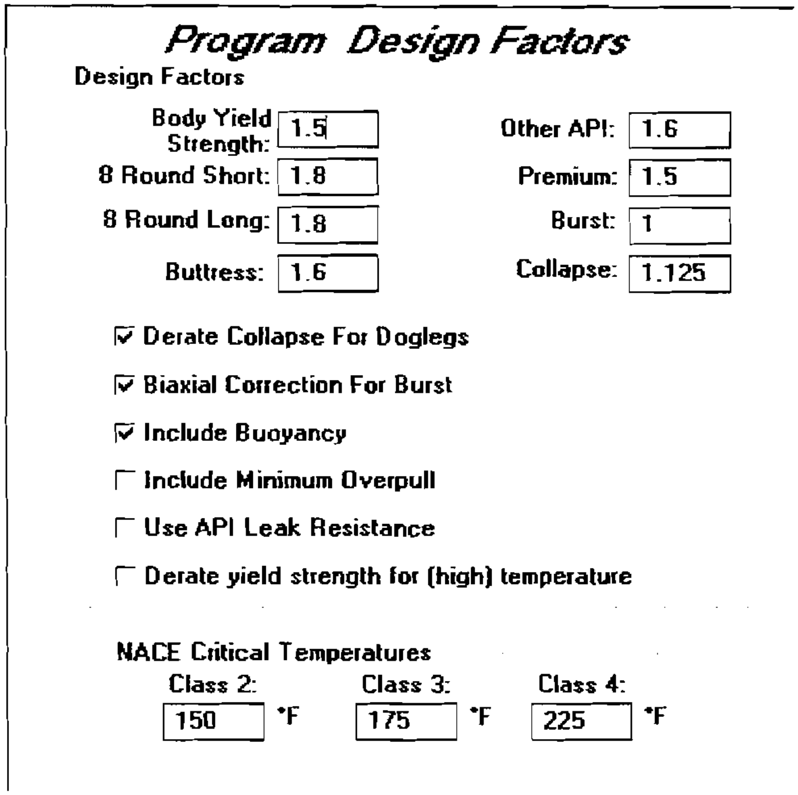
"Use API leak resistance" will change the minimum internal yield ratings for API connections to their maximum values as allowed by the API leak resistance formula, where applicable. These values are tabulated in the back of the Lone Star Steel Technical Data book, for one reference.

The check box for "Biaxial correction for burst" pertains to whether the burst strength for the design is based on uniaxial or biaxial methodology. This will probably be a "company" design philosophy.

The check box for "Derate collapse for doglegs" is one which does not have general agreement. If checked, then the maximum stress on the pipe in a dogleg is multiplied by the cross-section area to obtain an axial force value, which is then added on to the axial tension, and the pipe's strength is then revised accordingly.

The high temperature yield strength downgrading check box is used to lower body yield strength and "burst" strength linearly with temperature. In this program, the yield strength ranges from 100% at 100°F to 85% at 450°F, but the actual downgrading does not commence until the temperature reaches 225°F. In this way, when the box is checked, the strength is unaffected until the temperature gets moderately hot.

Finally, the NACE threshold temperature values may be modified, if desired. Some companies may wish, for instance, to be more conservative than the NACE values, which are 150°F, 175°F, and 225°F. Also, in certain circumstances for the drilling mode, assumptions may be rationalized with respect to minimum pH and minimum temperature thresholds.



Program Design Factors

Design Factors

Body Yield Strength: 1.5

8 Round Short: 1.8

8 Round Long: 1.8

Buttress: 1.6

Other API: 1.6

Premium: 1.5

Burst: 1

Collapse: 1.125

☑ Derate Collapse For Doglegs

☑ Biaxial Correction For Burst

☑ Include Buoyancy

☐ Include Minimum Overpull

☐ Use API Leak Resistance

☐ Derate yield strength for (high) temperature

NACE Critical Temperatures

Class 2: 150 °F

Class 3: 175 °F

Class 4: 225 °F

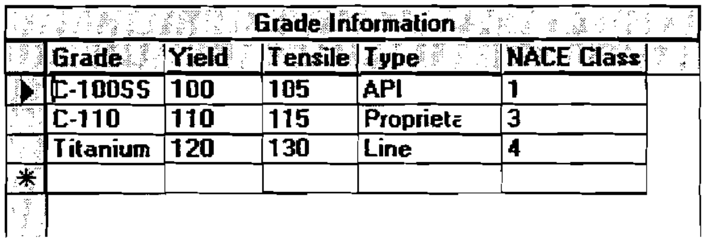
Figure 4.16

EDIT - GRADE

Figures 4.17 through 4.19 are for adding and editing grade, pipe, and connection information, respectively. The values should be entered as English units. Care should be taken not to enter a grade, especially, or connection which already exists by the same name in the database. The unique "keys" for pipe are OD, wall, grade and connection. Finally, it must be mentioned that not all of the items in the databases can be edited. Most are not editable. Should it become apparent that some item of connection, grade or pipe needs to be modified that is not in the list of items on the window, then the item should be modified from Access Version 2.0 within its respective table.

Grade information includes the grade name, yield strength, ultimate tensile strength, general type, NACE class, availability, and cost factor. The NACE class is "1" for all temperature H_2S service, "2" for H_2S service above 150°F, "3" for service above 175°F, "4" for service above 225°F, and "5" for no rating. Yield and tensile strengths should be entered in thousands of psi. The types include "API," "proprietary," "line pipe," and "drill pipe."

Edit Grade Database



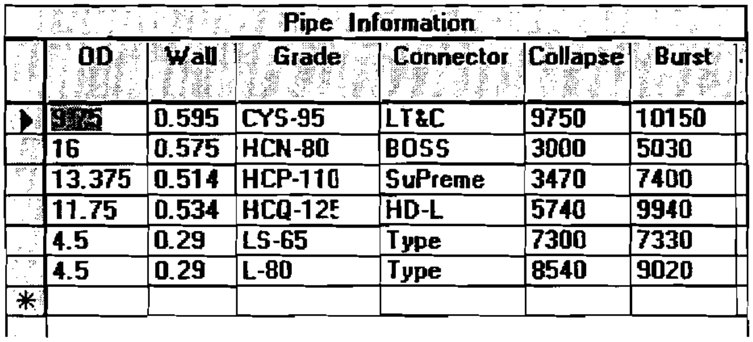
Grade Information

Grade	Yield	Tensile	Type	NACE Class
C-100SS	100	105	API	1
C-110	110	115	Propriet	3
Titanium	120	130	Line	4

Figure 4.17

EDIT - PIPE

The pipe information should be entered with English units of measurement. "Drop - down" list boxes furnish the list of grades and connections. To get the drop-down box for grades, click on the applicable grade "cell", and the list will drop down for selection after clicking on the down arrow. If the desired grade or connection is not on the list (double check "View - Grade" or "View - Connection" to be sure), then it may be added to the respective database. "Duplicates" of pipe items are not allowed by the Access database. If it becomes necessary to modify an item that is already part of the database, then it should be modified from within Access, not Casing2. Pipe information includes OD, wall thickness, grade, connection, collapse rating, minimum internal yield (burst) rating, joint strength - in pounds, drift diameter, cost factor, box diameter, inventory, and maximum torque in foot pounds (this can be either make-up torque or torsion strength.) A zero can be entered for any cell for which the information is not known.

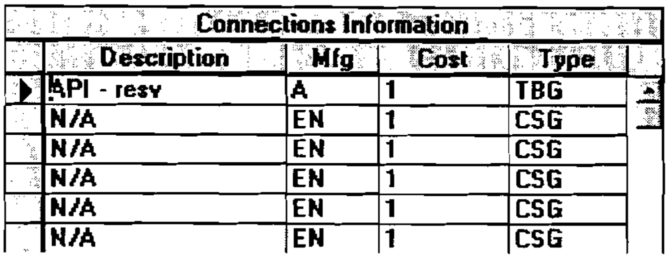


Pipe Information

OD	Wall	Grade	Connector	Collapse	Burst
9.625	0.595	CYS-95	LT&C	9750	10150
16	0.575	HCN-80	BOSS	3000	5030
13.375	0.514	HCP-110	SuPreme	3470	7400
11.75	0.534	HCQ-125	HD-L	5740	9940
4.5	0.29	LS-65	Type	7300	7330
4.5	0.29	L-80	Type	8540	9020

Figure 4.18

Unlike the "View" and the "Select" windows for pipe, any OD size can be entered on the "Edit" pipe window. The sequence is not important. The pipe cost factor should be commensurate with similar items for the same size, weight and grade, to the degree possible. The joint strength for premium connections is often unknown. Typically the *critical area* is given for the connection, and it is customary to multiply this value by the yield strength for tubing, and by the ultimate tensile strength for casing.



Connections Information

	Description	Mfg	Cost	Type
▶	API - resv	A	1	TBG
	N/A	EN	1	CSG
	N/A	EN	1	CSG
	N/A	EN	1	CSG
	N/A	EN	1	CSG
	N/A	EN	1	CSG

Figure 4.19

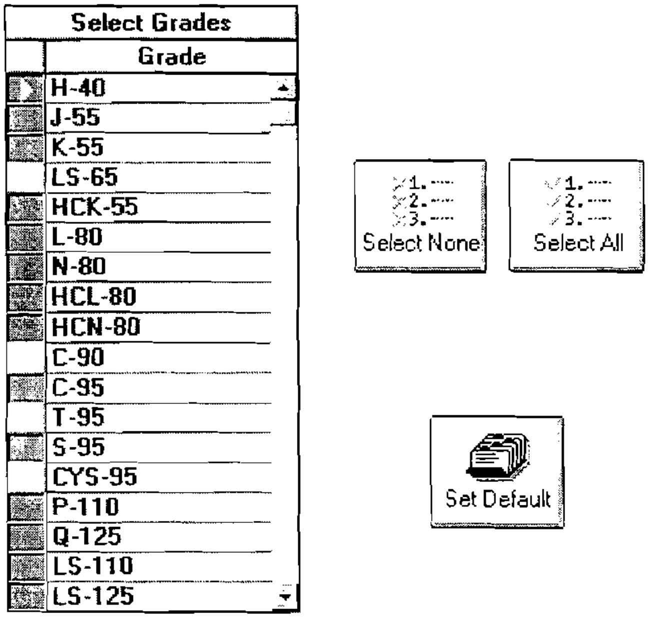
EDIT - CONNECTOR

The connector "mfg" should relate to the abbreviation for the manufacturer as depicted in the connector table in OCTGWin.MDB. The "Cost" is not presently used by Casing2, and should be left as the default. Connections from the same manufacturer should be kept within its grouping, if at all possible.

SELECT - GRADE

It may be useful to select certain grades as being available for design. When the grade is selected, the item is highlighted. If no grades are selected, then the program will not be able to design pipe for a well. However, the "Check Design" function of the program will still be operable. The "Set Default" button saves the information from this window to the database. The *Select Grade* window is seen in Figure 4.20.

Pipe, grades and connections that are saved to the database are saved independently of the well that is being examined. There is no direct correlation between any one well and the selection or inventory feature of these three elements of pipe.



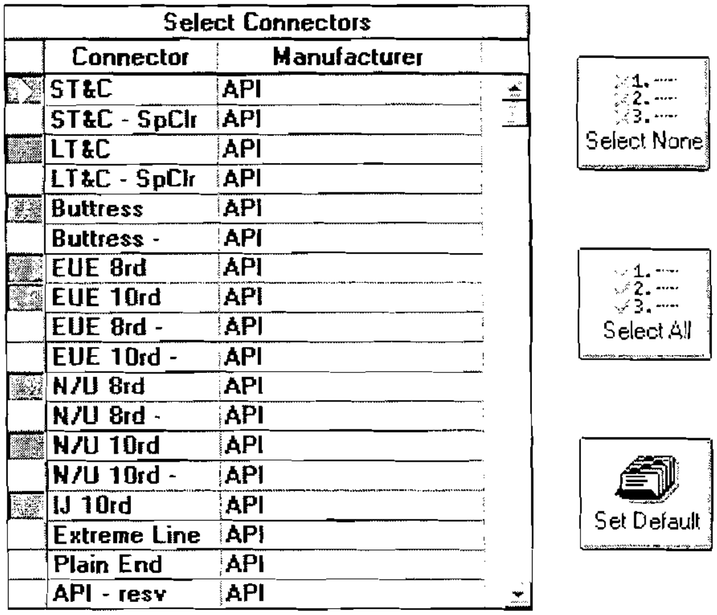
Select Grades

	Grade
▨	H-40
▨	J-55
▨	K-55
	LS-65
▨	HCK-55
▨	L-80
▨	N-80
▨	HCL-80
▨	HCN-80
	C-90
▨	C-95
	T-95
▨	S-95
	CYS-95
▨	P-110
▨	Q-125
▨	LS-110
▨	LS-125

Figure 4.20

SELECT - CONNECTOR

The purpose of the window to select connectors is similar to the window to select grades. Occasionally reasons exist to select or to ignore certain connections. For example, in tubing design, if the API connections should exclude non-upset or buttress (a pseudo-API connection for tubing sizes) then these items should be de-selected. This window is shown if Figure 4.21.



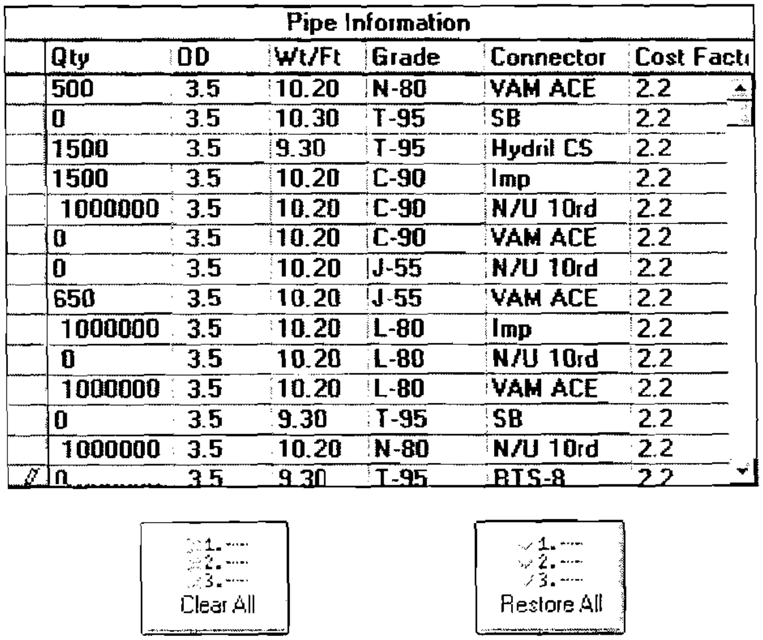
Select Connectors

	Connector	Manufacturer
▨	ST&C	API
	ST&C - SpClr	API
▨	LT&C	API
	LT&C - SpClr	API
▨	Buttress	API
	Buttress -	API
▨	EUE 8rd	API
▨	EUE 10rd	API
	EUE 8rd -	API
	EUE 10rd -	API
▨	N/U 8rd	API
	N/U 8rd -	API
▨	N/U 10rd	API
	N/U 10rd -	API
▨	IJ 10rd	API
	Extreme Line	API
	Plain End	API
	API - resv	API

Figure 4.21

SELECT - PIPE

The *Select Pipe* window has a more significant function than merely to select or not select pipe. Actual footages of pipe can be entered which would correspond to inventories on hand that one wishes to use, if possible. The default value for pipe that is selected is 1,000,000 ft. For pipe that is non-selected, the default value is 0 ft. The range of pipe to be selected from on this window corresponds to the size (range) selected on the list box of the main window. This window is shown in Figure 4.22.



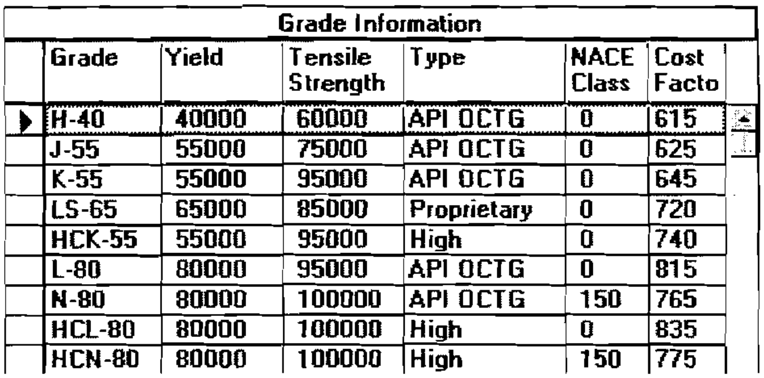
Pipe Information

Qty	OD	Wt/Ft	Grade	Connector	Cost Fact
500	3.5	10.20	N-80	VAM ACE	2.2
0	3.5	10.30	T-95	SB	2.2
1500	3.5	9.30	T-95	Hydril CS	2.2
1500	3.5	10.20	C-90	Imp	2.2
1000000	3.5	10.20	C-90	N/U 10rd	2.2
0	3.5	10.20	C-90	VAM ACE	2.2
0	3.5	10.20	J-55	N/U 10rd	2.2
650	3.5	10.20	J-55	VAM ACE	2.2
1000000	3.5	10.20	L-80	Imp	2.2
0	3.5	10.20	L-80	N/U 10rd	2.2
1000000	3.5	10.20	L-80	VAM ACE	2.2
0	3.5	9.30	T-95	SB	2.2
1000000	3.5	10.20	N-80	N/U 10rd	2.2
0	3.5	9.30	T-95	BTS-8	2.2

Figure 4.22

VIEW - GRADE INFO

The *View* windows are simply for "FYI" purposes. They are basically a convenient way of looking at information in the database - grades, connections and pipe, at least for the size range selected. The grade window shows the grade's name, yield strength, ultimate tensile strength, general type, NACE class (for H_2S service), cost factor and availability. The *Grade Information* window is shown in Figure 4.23.



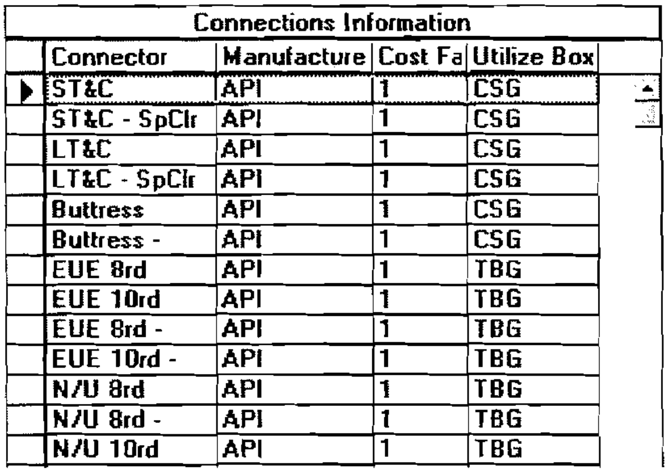
Grade Information

	Grade	Yield	Tensile Strength	Type	NACE Class	Cost Facto
▶	H-40	40000	60000	API OCTG	0	615
	J-55	55000	75000	API OCTG	0	625
	K-55	55000	95000	API OCTG	0	645
	LS-65	65000	85000	Proprietary	0	720
	HCK-55	55000	95000	High	0	740
	L-80	80000	95000	API OCTG	0	815
	N-80	80000	100000	API OCTG	150	765
	HCL-80	80000	100000	High	0	835
	HCN-80	80000	100000	High	150	775

Figure 4.23

VIEW - CONNECTION INFO

The connection information contains the name, the abbreviated manufacturer, the cost factor (most of these are presently unity), the classification as to casing, tubing, both casing and tubing, and drill pipe, the availability, and the full manufacturer's name. This window is shown in Figure 4.24.



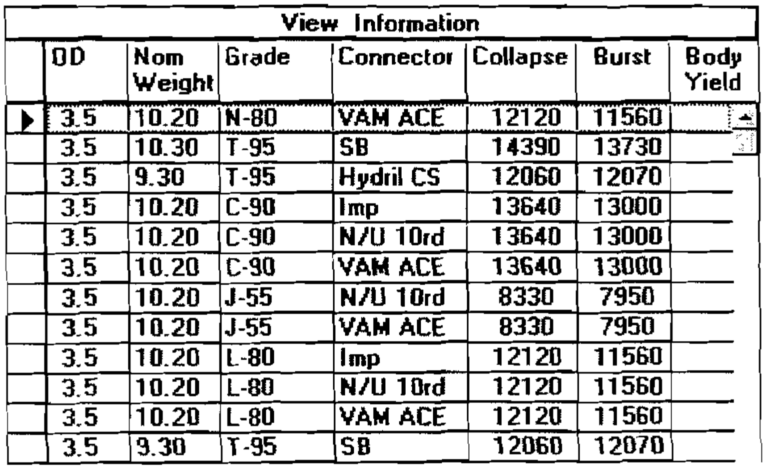
Connections Information

	Connector	Manufacture	Cost Fa	Utilize Box
▶	ST&C	API	1	CSG
	ST&C - SpClr	API	1	CSG
	LT&C	API	1	CSG
	LT&C - SpClr	API	1	CSG
	Buttress	API	1	CSG
	Buttress -	API	1	CSG
	EUE 8rd	API	1	TBG
	EUE 10rd	API	1	TBG
	EUE 8rd -	API	1	TBG
	EUE 10rd -	API	1	TBG
	N/U 8rd	API	1	TBG
	N/U 8rd -	API	1	TBG
	N/U 10rd	API	1	TBG

Figure 4.24

VIEW - PIPE INFO

The pipe information window, shown in Figure 4.25, is limited to pipe within the OD size range selected on the main window. The information includes OD, nominal weight, grade, connection, collapse, minimum internal yield ("burst"), body yield and joint tensile strength, drift diameter, wall thickness, box OD, cost factor, inventory, and torque strength (or maximum make-up torque).



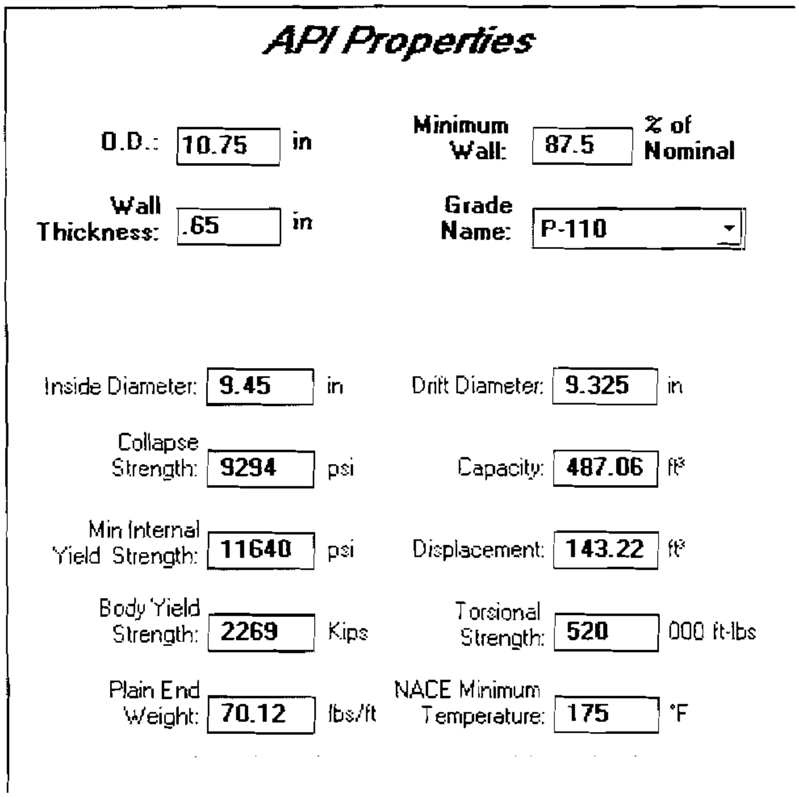
View Information

	OD	Nom Weight	Grade	Connector	Collapse	Burst	Body Yield
▶	3.5	10.20	N-80	VAM ACE	12120	11560	
	3.5	10.30	T-95	SB	14390	13730	
	3.5	9.30	T-95	Hydril CS	12060	12070	
	3.5	10.20	C-90	Imp	13640	13000	
	3.5	10.20	C-90	N/U 10rd	13640	13000	
	3.5	10.20	C-90	VAM ACE	13640	13000	
	3.5	10.20	J-55	N/U 10rd	8330	7950	
	3.5	10.20	J-55	VAM ACE	8330	7950	
	3.5	10.20	L-80	Imp	12120	11560	
	3.5	10.20	L-80	N/U 10rd	12120	11560	
	3.5	10.20	L-80	VAM ACE	12120	11560	
	3.5	9.30	T-95	SB	12060	12070	

Figure 4.25

VIEW - API PROPERTIES

The window for API properties, shown in Figure 4.26, is intended to be a reference guide for possible new pipe items for the database. It can also be used to show the downgraded burst rating for pipe that has been worn, that is for pipe which has a minimum wall thickness less than the standard API minimum of 87.5 percent. The inputs are OD, wall, minimum wall, and grade, which is taken from a drop-down list box. OD and wall may be entered in metric or English units. The results, as shown below, include inside diameter, collapse strength (by API equations), the minimum internal yield strength ("burst"), body yield strength, plain end weight, drift diameter, capacity, displacement, pipe body torsional strength, and NACE class (for H_2S service.)



API Properties

O.D.: 10.75 in

Minimum Wall: 87.5 % of Nominal

Wall Thickness: .65 in

Grade Name: P-110

Inside Diameter: 9.45 in

Drift Diameter: 9.325 in

Collapse Strength: 9294 psi

Capacity: 487.06 ft³

Min Internal Yield Strength: 11640 psi

Displacement: 143.22 ft³

Body Yield Strength: 2269 Kips

Torsional Strength: 520 000 ft-lbs

Plain End Weight: 70.12 lbs/ft

NACE Minimum Temperature: 175 °F

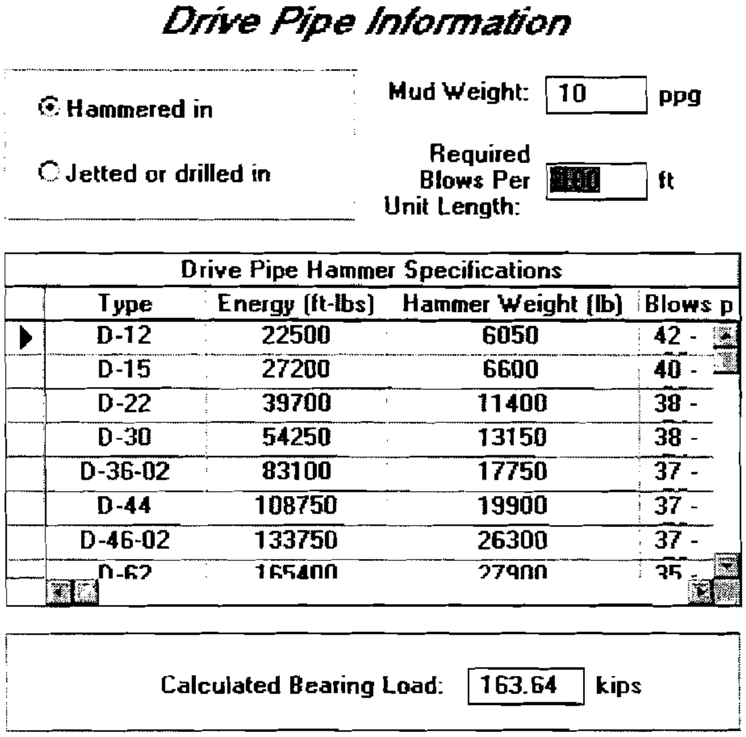
Figure 4.26

PARAMETERS - BASIC CONDITIONS

There are four different windows for basic conditions which will be encountered in Casing2, but only one for any one type of string. In an effort to minimize confusion, certain fields are presented for intermediate strings which are not presented for production strings, and vice-versa. The groupings by string are: drive pipe; tubing - frac, production - frac, alternate production, and production liner; conductor, production, surface (2), and tubing; and finally, surface, intermediate strings, drilling and scab liners, and tiebacks. One of the common fields for all basic conditions forms is the fluid density, or mud weight. The graph for these forms contains collapse load, burst load, and collapse load without backup and burst load without backup if different from their respective resultant loads.

BASIC CONDITIONS - DRIVE PIPE

The first type of window for basic conditions is that for drive pipes. For this window, mud weight is primarily just a formality. There are two "radio" buttons for selection of pipe that is hammered in or jetted or cemented into place after drilling. The drive pipe information is given from information made available by Franks Casing Crews, headquartered in Lafayette, Louisiana. The inputs for this is blows per foot (or unit length) and drive pipe type, which is selected by clicking on the desired row. The resulting answer is (dynamic) bearing load, which is a conservative estimate of the available bearing load after the hammering has terminated. The static bearing load can be as high as five times the dynamic bearing load. Normally, either area experience or a soil survey made by civil engineers are required to determine the static load. If the pipe is to be jetted or drilled in, then the hammer information and bearing load are not relevant.



Drive Pipe Information

● Hammered in

○ Jetted or drilled in

Mud Weight: 10 ppg

Required Blows Per Unit Length: [illegible] ft

Drive Pipe Hammer Specifications			
Type	Energy (ft-lbs)	Hammer Weight (lb)	Blows p
D-12	22500	6050	42 -
D-15	27200	6600	40 -
D-22	39700	11400	38 -
D-30	54250	13150	38 -
D-36-02	83100	17750	37 -
D-44	108750	19900	37 -
D-46-02	133750	26300	37 -
D-62	165400	27900	35 -

Calculated Bearing Load: 163.64 kips

Figure 4.28

BASIC CONDITIONS - PROTECTION STRINGS

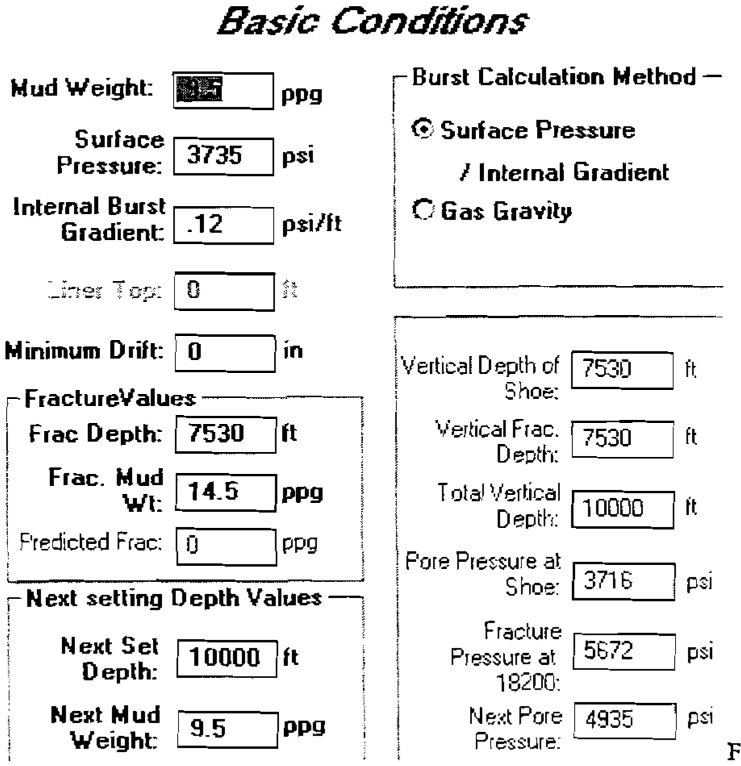
For intermediate strings, the basic conditions window contains many fields, all of which pertain to burst pressures with the exception of mud weight which also applies to collapse load and (optionally) buoyancy for tension. The field for *Minimum drift diameter* is also optional, and the default value is "0" or none. Although it is not obvious from Figure 4.29, the lower right portion of the window contains certain calculated fields which pertain to the inputs.

The surface pressure is based on the greater of the pore pressure at the shoe depth, or the lessor of the pressure at the shoe depth resulting from the next pore pressure minus the hydrostatic pressure of the gas from the next depth to the shoe depth, or the fracture pressure minus (if the fracture depth is below the shoe depth) the hydrostatic pressure of the gas from the fracture depth to the shoe depth. The shoe depth is input on the main window on the right-hand side, as a measured depth. The inputs on the basic conditions window for depths are also in measured depths. The corresponding depths are calculated.

If the string is a drilling or scab liner, then the liner top should be entered in measured depth. Casing2 will actually generate a design which "rounds off" the top of the liner to the nearest *pipe length*, as defined above in *Miscellaneous Program Defaults*.

Fracture values are not visible for the tieback strings, as they are not applicable. If, however, a tieback string is to be part of a hydraulic frac treatment, then the next mud weight should reflect the equivalent mud density of the fracture pressure for the depth of the lowest perforation. Otherwise *fracture depth* should be the measured depth of the weakest point below the shoe. *Fracture mud weight* should be the equivalent mud weight, EMW, of the injection pressure, which is typically ½ ppg above the actual fracture pressure EMW. This allows for a "cushion" of safety for potential underground "blowouts." For intermediate strings where one or two drilling liners will follow, then the *fracture depth* will be the depth of the lowest drilling liner, and the *next setting depth* will be the depth for the string following that liner. *Predicted frac value*, incidentally, is a calculated field which is based on the method selected on the window, *Edit - Miscellaneous program defaults*. It is not incorporated automatically into any other calculations.

The radio buttons for "*Burst Calculation Method*" determine whether the maximum anticipated surface pressure, MASP, is determined by entering a value *for Surface pressure* (MASP) or *Internal Burst Gradient*, or by the real gas law and gas gravity, which is input on the window, "*Parameters - Environment - Real Gas.*" When either the *surface pressure* or the *internal burst gradient* is changed on this window, the calculation method reverts to the top button. For these cases, the two values are inter-related. If *surface pressure* is changed, then *internal gradient* is "back-calculated", and vice-versa.



Basic Conditions

Mud Weight: 9.5 ppg
Surface Pressure: 3735 psi
Internal Burst Gradient: .12 psi/ft
Liner Top: 0 ft
Minimum Drift: 0 in

FractureValues
Frac Depth: 7530 ft
Frac. Mud Wt: 14.5 ppg
Predicted Frac: 0 ppg

Next setting Depth Values
Next Set Depth: 10000 ft
Next Mud Weight: 9.5 ppg

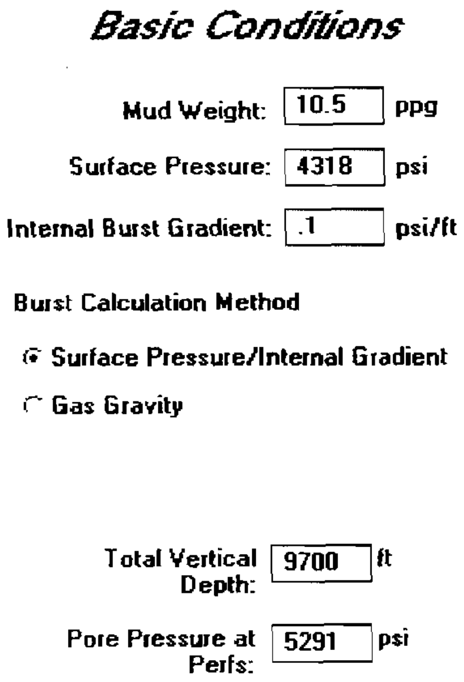
Burst Calculation Method
● Surface Pressure / Internal Gradient
○ Gas Gravity

Vertical Depth of Shoe: 7530 ft
Vertical Frac. Depth: 7530 ft
Total Vertical Depth: 10000 ft
Pore Pressure at Shoe: 3716 psi
Fracture Pressure at 18200: 5672 psi
Next Pore Pressure: 4935 psi

Figure 4.29

BASIC CONDITIONS - CONDUCTOR, PRODUCTION, AND TUBING STRINGS

For production and conductor strings, the basic conditions window is much less daunting than for intermediate strings. The fields at the bottom are calculated values. The shoe depth is, again, on the right hand side of the main window, above the graph. This field is for measured depth. *Mud weight* pertains to both burst and collapse loads, and, optionally, buoyancy. The *surface pressure* and *internal burst gradient* are fields that are inter-related. In other words, if the surface pressure is changed, the internal burst gradient is subsequently back-calculated, based on the BHP resulting from the mud weight multiplied by the vertical set depth, and by the coefficient, 0.052 (approx.) If the radio button for "Gas gravity" is clicked, then the internal burst gradient is based on the real gas law, and the gas gravity, as shown on the window, *Parameters - Environment - Real Gas.*



Basic Conditions

Mud Weight: 10.5 ppg

Surface Pressure: 4318 psi

Internal Burst Gradient: .1 psi/ft

Burst Calculation Method

● Surface Pressure/Internal Gradient

○ Gas Gravity

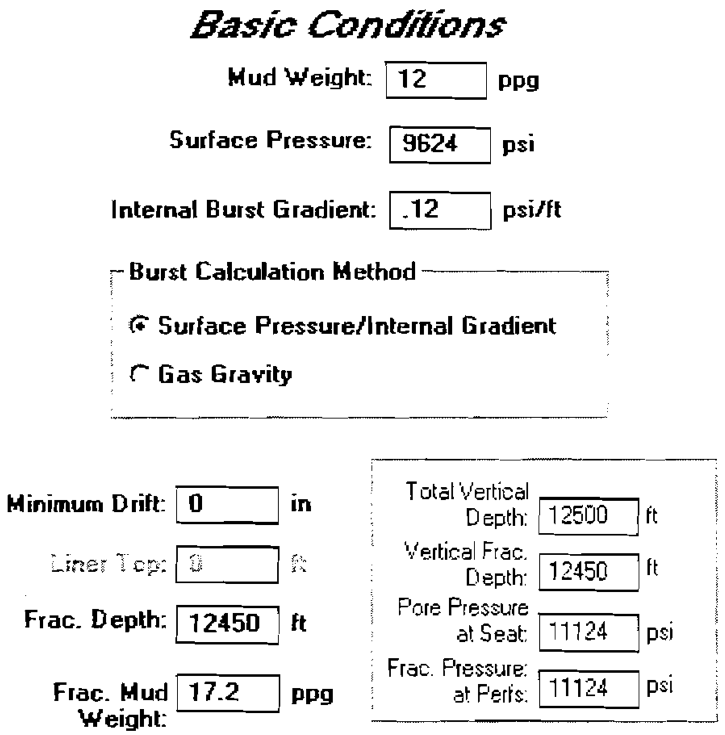
Total Vertical Depth: 9700 ft

Pore Pressure at Perfs: 5291 psi

Figure 4.30

BASIC CONDITIONS - PRODUCTION-FRAC

For the strings which will or could involve hydraulic fracture treatments, the input fields are expanded from the normal production string to include minimum drift (with a default value of "0"), liner top (for production liners), fracture depth (measured) and fracture equivalent mud weight, EMW. The mud weight at the top relates, in this case, only to collapse, as the fracture mud weight is almost assuredly greater than the mud weight that the pipe is to be set in. The other fields are typical for the other *Basic Condition* windows and include the radio button options for method of calculation of surface pressure, and the "either-or" input fields for surface pressure and internal burst gradient. The remaining fields are calculated values for vertical setting and completion depths, and pore and fracture pressures.



Basic Conditions

Mud Weight: 12 ppg

Surface Pressure: 9624 psi

Internal Burst Gradient: .12 psi/ft

Burst Calculation Method

● Surface Pressure/Internal Gradient

○ Gas Gravity

Minimum Drift: 0 in

Liner Top: 0 ft

Frac. Depth: 12450 ft

Frac. Mud Weight: 17.2 ppg

Total Vertical Depth: 12500 ft

Vertical Frac. Depth: 12450 ft

Pore Pressure at Seat: 11124 psi

Frac. Pressure at Perfs: 11124 psi

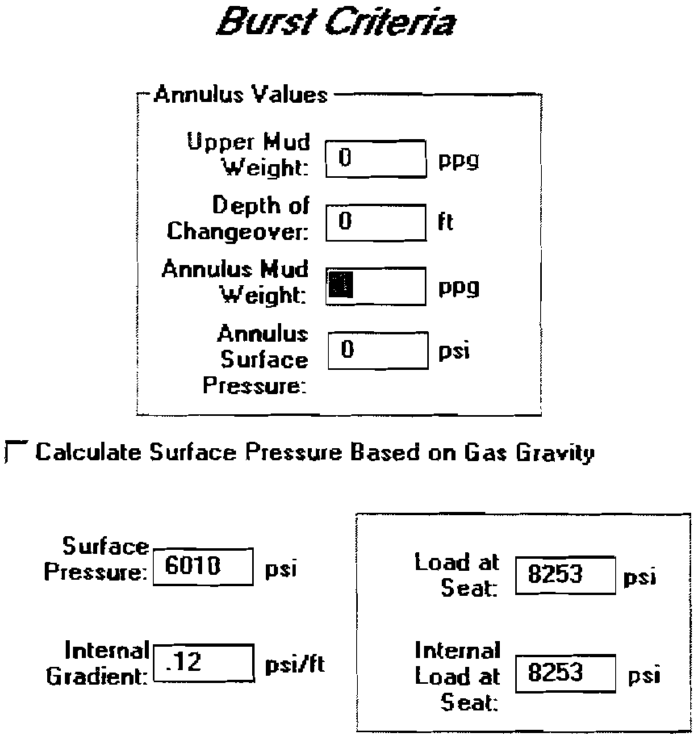
Figure 4.31

PARAMETERS - BURST

Similar to the "Basic Conditions" windows, the burst windows are tailored to the type of string that is being set. In general, BHP and MASP are established in the Basic Conditions forms, but MASP can be modified in the Burst window. In addition, up to two annulus (or "backup") mud densities can be specified, packer fluid conditions can be set up for strings which will become production strings, and for intermediate strings, a "mud-gas" interface can be specified. The graph for these forms pertains to the internal and external burst conditions, the resultant of these loads, and the minimum design line, if the minimum design factor is other than 1.0.

BURST - SIMPLE CRITERIA

Figure 4.32 discusses the facets of the simplest "Burst Criteria" window. This window is used for tubing, conductor and surface strings. *Depth of Changeover* should be entered as a vertical depth. When it has a value greater than "0", then *Upper Mud Weight* becomes activated. Some of the fields on the window are "repeats" from the "Basic Condition" window, namely, *Surface Pressure*, *Internal Gradient*, and the "check box" for gas gravity (real gas law.) *Load at Seat* is the resultant load of internal minus external burst pressure, and *Internal Load at Seat* is, of course, internal pressure only.



Burst Criteria

Annulus Values

Upper Mud Weight: 0 ppg

Depth of Changeover: 0 ft

Annulus Mud Weight: ppg

Annulus Surface Pressure: 0 psi

☐ Calculate Surface Pressure Based on Gas Gravity

Surface Pressure: 6010 psi

Internal Gradient: .12 psi/ft

Load at Seat: 8253 psi

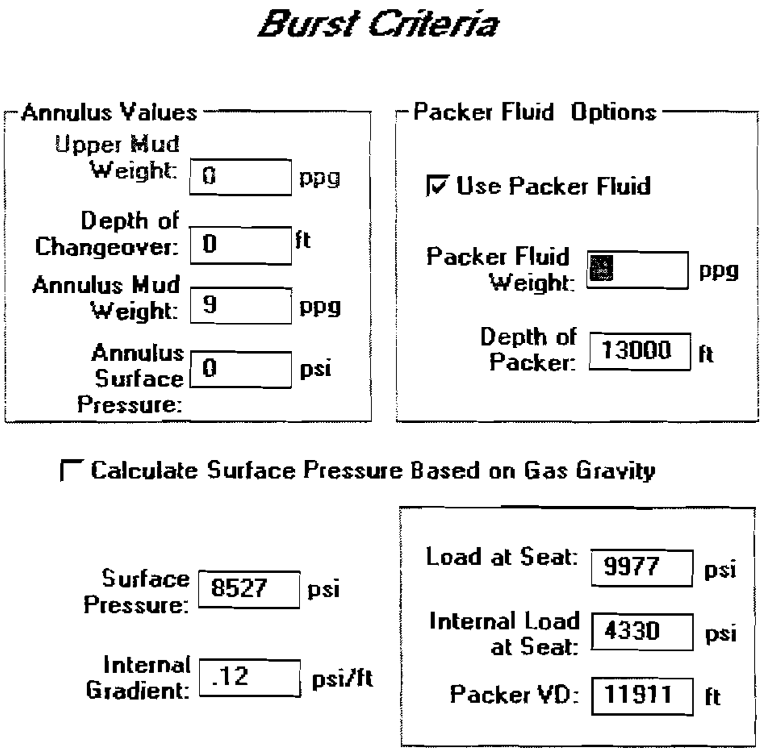
Internal Load at Seat: 8253 psi

Figure 4.32

BURST - PRODUCTION

The production string version of the burst window contains options for packer fluid, annular backup, and, as in *Basic Conditions*, options for internal gradient and MASP. Depth for annular backup should be entered as vertical depth, and depth for the packer (if any) should be entered as measured. The purpose for the packer fluid option is to allow for burst situations where a "high" tubing leak will occur, which will then create a burst load where the MASP acts upon the packer fluid to provide the internal burst pressure load. Note that if no packer depth is specified, the default value is "0", and the packer option will have no effect. In Figure 4.33, the density of the packer fluid exactly offsets the density of the annular backup, and the net burst load is then the MASP for the entire length of the string.

The other fields on the window are as shown on Figure 4.33. The values *Load at Seat*, *Internal Load at Seat*, and *Packer VD* or vertical depth are calculated values which can not be modified directly. If the "check box" for *Calculate Surface Pressure Based on Gas Gravity* is checked, then the surface pressure and internal pressure gradient will be based on the current gas gravity and the real gas law, as shown on the "Parameters - Environment - Real Gas" window. After checking this box, any new modifications to the surface pressure or to the internal gas gradient will negate the real gas law value.



Burst Criteria

Annulus Values

Upper Mud Weight: 0 ppg

Depth of Changeover: 0 ft

Annulus Mud Weight: 9 ppg

Annulus Surface Pressure: 0 psi

Packer Fluid Options

☑ Use Packer Fluid

Packer Fluid Weight: ppg

Depth of Packer: 13000 ft

☐ Calculate Surface Pressure Based on Gas Gravity

Surface Pressure: 8527 psi

Internal Gradient: .12 psi/ft

Load at Seat: 9977 psi

Internal Load at Seat: 4330 psi

Packer VD: 11911 ft

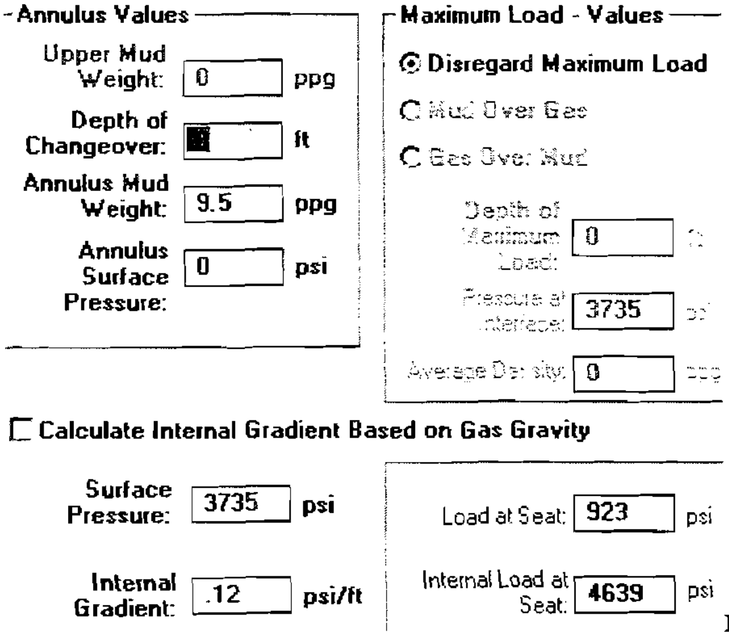
Figure 4.33

BURST - PROTECTION STRINGS

Figure 4.34 depicts the "Burst Criteria" window for various protection strings. All depths should be entered as vertical depths. When "Maximum Load" is disregarded, the program uses only one fluid density for the internal burst load. The other two options are for "kick" situations. When either of these are selected, the interface can be established either by modifying the *Depth of Maximum Load* or *Surface Pressure*. The balance of the parameters needed for solution of the mud-gas interface are established on the "Basic Conditions" window. These include *next mud weight*, *fracture* (injection) *depth*, *fracture mud weight*, and other parameters needed to establish that the fracture zone is a critical condition as compared to the next depth and pore pressure.

The other fields include options for up to two annular backup densities, an applied annular surface pressure, fields for modification of surface pressure (MASP) and internal gas gradient. The purpose of the "check box" is to utilize the real gas law for determination of internal gas gradient. The field for changing the gas gravity is on the window, "Parameters - Environment - Real Gas." The calculated fields for *Load at Seat* and *Internal Load at Seat* cannot be directly modified.

Burst Criteria



Annulus Values

Upper Mud Weight: 0 ppg

Depth of Changeover: ft

Annulus Mud Weight: 9.5 ppg

Annulus Surface Pressure: 0 psi

Maximum Load - Values

● Disregard Maximum Load

○ Mud Over Gas

○ Gas Over Mud

Depth of Maximum Load: 0 ft

Pressure at Interface: 3735 psi

Average Density: 0 ppg

☐ Calculate Internal Gradient Based on Gas Gravity

Surface Pressure: 3735 psi

Internal Gradient: .12 psi/ft

Load at Seat: 923 psi

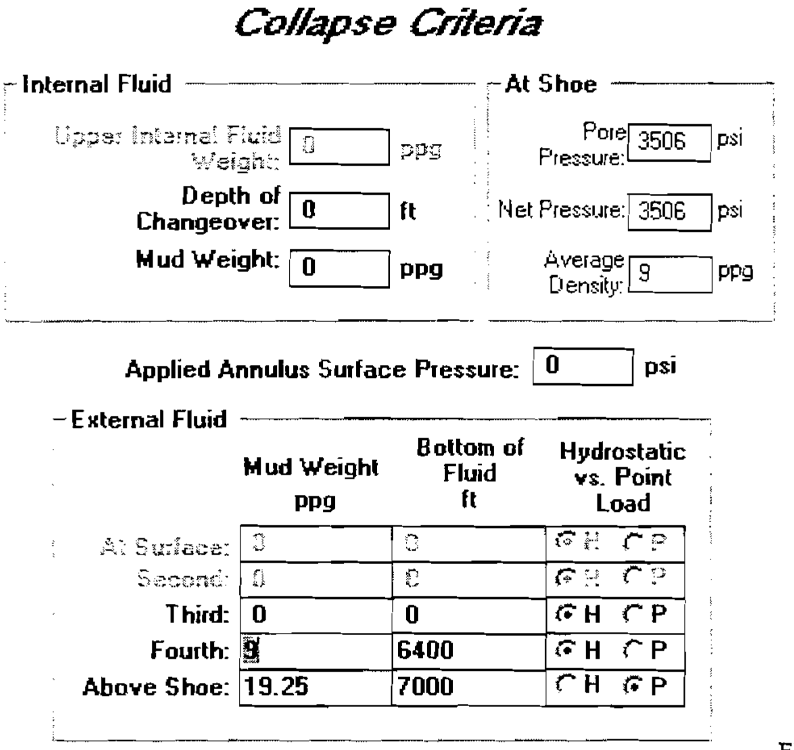
Internal Load at Seat: 4639 psi

Figure 4.34

PARAMETERS - COLLAPSE

Collapse load modifications can be made on the window, "Collapse Criteria" as seen in Figure 4.35. All depths on this window should be entered as vertical depths. Up to two internal fluids can be specified. The lowest field in the *Internal Fluid* frame is for the internal mud density, or for the lower internal mud density is two internal fluids are being utilized. The frame *At Shoe* just to the right, contains calculated values including *Pore Pressure* (mud weight x TVD x 0.052), *Net Pressure*, and *Average Density* (net pressure / TVD / 0.052). A surface pressure acting on the annulus of the string can be specified in the field in the middle of the window.

The lower section, titled *External Fluid*, allows up to five additional external fluid densities to be entered. These may be characterized as either hydrostatic loads (H) or plastic loads (P). If the load is entered as plastic, then the hydrostatic load below the plastic load continues to be calculated based on the hydrostatic load(s). Also, as discussed in the tension criteria, the buoyancy force will be calculated based on the hydrostatic load(s). The densities should be entered on the window from bottom to top, which matches the placement of the fluids on the string. If the information is filled in on this window, and then the setting depth of the string is changed to a shallower depth, then the depths inserted on this window will be reduced, if they are deeper than the new set depth. In the figure, a plastic (salt) load is applied from 7,000 feet to 6,400 feet. Above 6,400 feet, the loading reverts back to the normal mud density, 9 ppg.



Collapse Criteria

Internal Fluid

Upper Internal Fluid Weight: 0 ppg

Depth of Changeover: 0 ft

Mud Weight: 0 ppg

At Shoe

Pore Pressure: 3506 psi

Net Pressure: 3506 psi

Average Density: 9 ppg

Applied Annulus Surface Pressure: 0 psi

External Fluid

	Mud Weight ppg	Bottom of Fluid ft	Hydrostatic vs. Point Load
At Surface:	0	0	● H ○ P
Second:	0	0	● H ○ P
Third:	0	0	● H ○ P
Fourth:	9	6400	● H ○ P
Above Shoe:	19.25	7000	○ H ● P

Figure 4.35

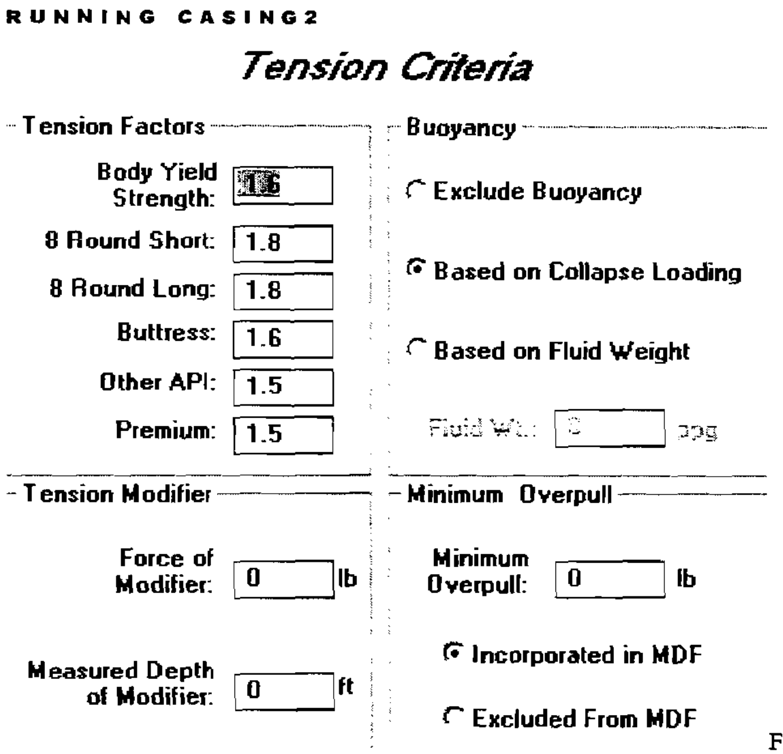
PARAMETERS

· TENSION

The *Tension Criteria* window, shown in Figure 4.36, combines tension design factors and other relevant information. These tension design factors are repeated on the *Design Factor* window, just as a matter of convenience. Note that the *Premium* design factor does not differentiate between joint strengths based on yield vs ultimate tensile strength. The options for buoyancy include (1) air weight, (2) *Based on Collapse Loading* (hydrostatic densities only), and (3) *Based on Fluid Weight*, which includes a field for the specified fluid density. As discussed earlier, the buoyancy is based on a pressure/area method rather than a buoyancy factor approach.

The field *Force of Modifier*, allows extraneous compressive or tensile loads to be inserted. An example would be a tensile force applied above the cement top. A minus sign (-) would make the force compressive. The depth should be entered as a measured depth.

Minimum overpull is another form of a minimum design criteria. If the option is made to have the overpull *incorporated in MDF*, then the minimum design criteria is actually the overpull multiplied by the *body yield strength* minimum design factor. If option *Excluded from MDF* is selected, then the *minimum overpull* is the actual criteria.



RUNNING CASING2

Tension Criteria

Tension Factors

Body Yield Strength: 1.6

8 Round Short: 1.8

8 Round Long: 1.8

Buttress: 1.6

Other API: 1.5

Premium: 1.5

Buoyancy

○ Exclude Buoyancy

● Based on Collapse Loading

○ Based on Fluid Weight

Fluid Wt.: 0 ppg

Tension Modifier

Force of Modifier: 0 lb

Measured Depth of Modifier: 0 ft

Minimum Overpull

Minimum Overpull: 0 lb

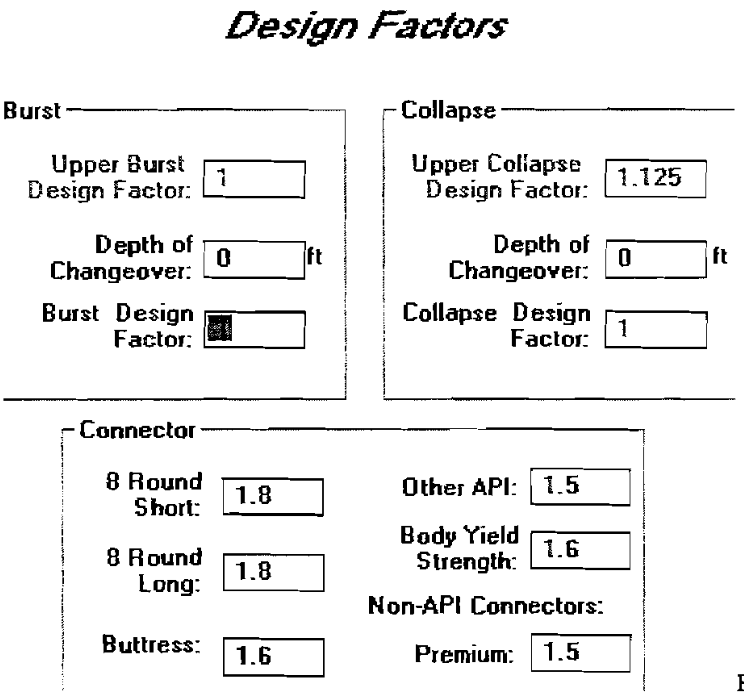
● Incorporated in MDF

○ Excluded From MDF

Figure 4.36

PARAMETERS - DESIGN FACTORS

Figure 4.37 depicts the Minimum Design Factors (MDF) window. The MDF window includes the burst, collapse, and tension criteria. Up to two design factors can be used for burst and collapse. The changeover depth should be entered as a vertical depth. If the depth is "0," then the upper design factor serves no purpose, and is, in fact, not enabled on the window. These design factors "override" the design factors entered on the "Edit - Preferences - Default Design Factors" window, but apply only to the well and string which is being analyzed.



Upper Burst Design Factor: 1
Depth of Changeover: 0 ft
Burst Design Factor:

Upper Collapse Design Factor: 1.125
Depth of Changeover: 0 ft
Collapse Design Factor: 1

8 Round Short: 1.8
8 Round Long: 1.8
Buttress: 1.6
Other API: 1.5
Body Yield Strength: 1.6
Premium: 1.5

Figure 4.37

PARAMETERS - ENVIRONMENT

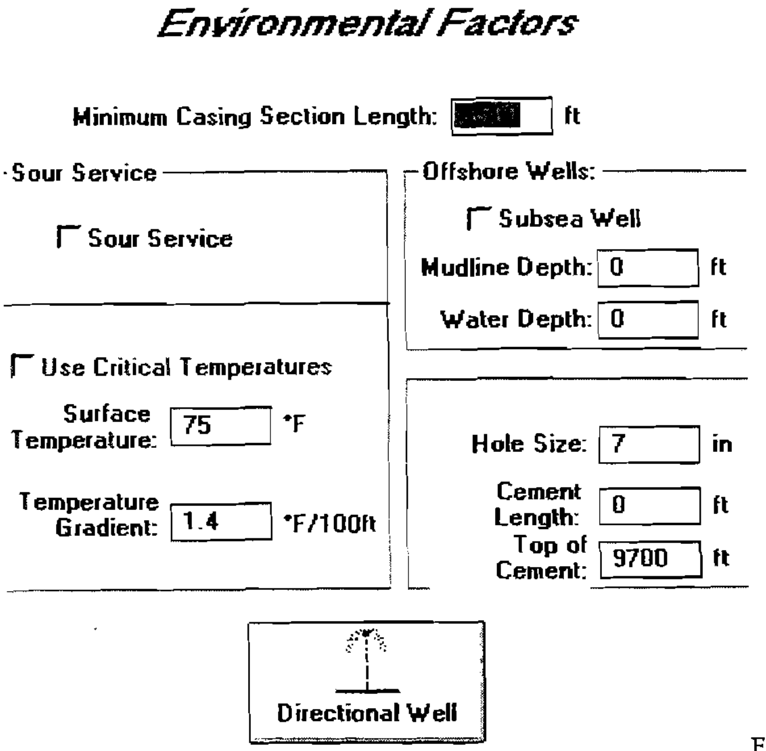
Several aspects of wells that are related to the loads and design factors, but in an indirect manner, have been combined into a section called "Environment." In general, these features include directional information, corrosion information, wellbore information, temperature, and "real" gas information.

ENVIRONMENT - GENERAL

The window shown in Figure 4.38 contains a variety of miscellaneous elements of designs under the heading "Parameters - Environment - General." Most of the fields deserve an explanation. *Minimum Casing Section Length* overrides the minimum section length entered on the field on the "Edit - Preferences - Miscellaneous Defaults" window. The check box *Sour Service* pertains to whether the well contains H_2S which will impact the string being designed. If checked, then another check box becomes active, *Use Critical Temperatures*. This box will determine whether lower cost, high-strength tubulars can be utilized at or above the respective threshold temperatures. The fields for surface temperature and temperature gradient affect, in addition to the *Critical Temperature* concept for H_2S, the real gas law and the derating of tubular yield strength, both of which are options which can be selected elsewhere in the program.

The check box for *subsea well* will determine whether strings are designed to surface (depth = 0) or to the mudline depth. Both *mudline depth* and *water depth* can be given values without *subsea well* being "checked." Water depth has no effect on the program.

Hole size is a field which does affect the pipe which will be selected for a given string. If the size is the same nominal size as the pipe (or smaller), then the field is ignored altogether. If the field is larger however, then the program will not select pipe which has a box diameter within 1/8" of the hole size. The box must be at least 0.128" smaller than the hole. Cement top and length have no current function in the program, but are included for the sake of completeness of the wellbore schematic. The button *Directional Well* leads to the options for a directional well plan.



Environmental Factors

Minimum Casing Section Length: [illegible] ft

Sour Service

☐ Sour Service

☐ Use Critical Temperatures

Surface Temperature: 75 °F

Temperature Gradient: 1.4 °F/100ft

Offshore Wells:

☐ Subsea Well

Mudline Depth: 0 ft

Water Depth: 0 ft

Hole Size: 7 in

Cement Length: 0 ft

Top of Cement: 9700 ft

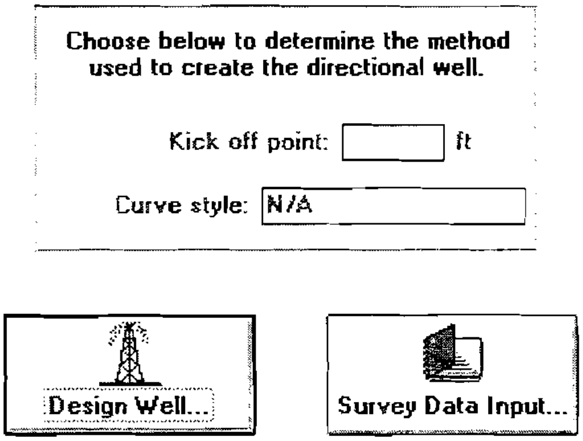
Figure 4.38

ENVIRONMENT - DIRECTIONAL WELL

Figure 4.39 shows a simple window which basically furnishes a convenient way to get to the 2-dimensional design window (*Design Well*) or to the *Survey Data Input* (SDI) window. The SDI window is used for wells which have a complex geometry, or which have an existing tabulation of survey points.

The two fields *Kick off point* and *Curve style* become activated after a directional plan has been established. They can then be modified as desired.

Directional Well Calculation Method


Choose below to determine the method used to create the directional well.

Kick off point: ft

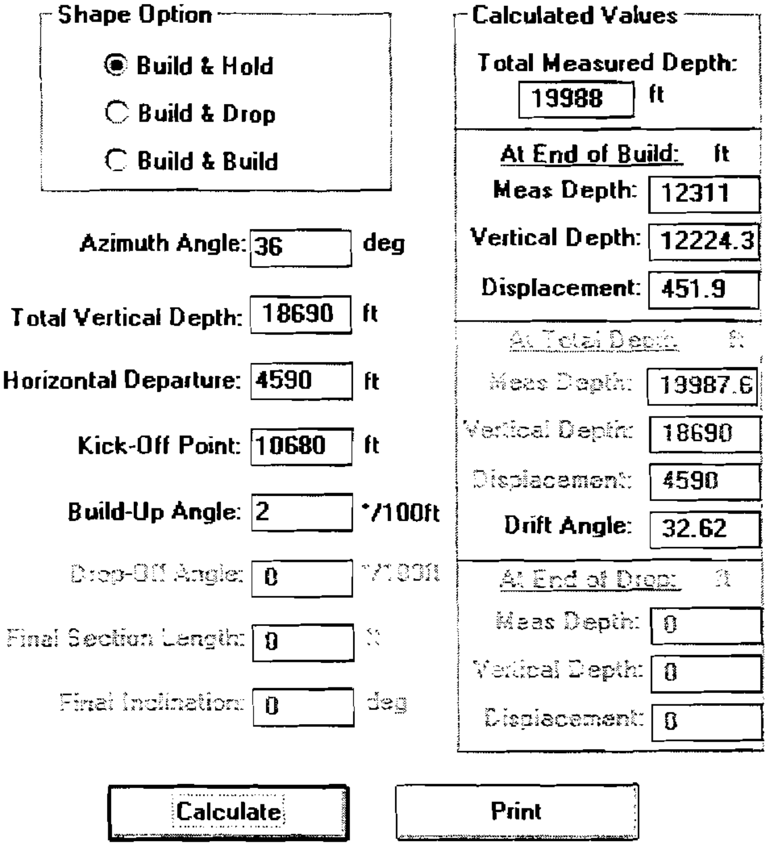
Curve style: N/A

Figure 4.39

DIRECTIONAL WELL - 2 DIMENSIONAL GEOMETRY

The window for 2-dimensional geometry is shown in Figure 4.40. The fields on the right half of the window contain calculated values. Only those fields pertaining to the Shape Option are "enabled." The *Shape Option* frame contains the three basic options for the wells, *Build and Hold*, *Build* (Hold) *and Drop*, and *Build* (Hold) *and Build*. The last option is primarily for high angle or horizontal wells, and the first two are for conventional plans. Azimuth is optional. The field, *Total Vertical Depth*, and all of the remaining fields relate to the well plan at total depth, and not to any shallower string. Put differently, once the well is planned, this window need not be revisited. After the parameters are properly entered, the results will be calculated by "clicking" on the button, *Calculate*. To accept the results and exit the window, the button, *Generate Survey Data* (SDI) should be "clicked." *Cancel* also provides a means to exit the window.

Once a well has generated the SDI information, modifications can be made either from the SDI window or from the 2-dimensional window, if a significant change has been made in the plan. To change back to a vertical well, the SDI fields can be "zeroed" out.



Shape Option
- ● Build & Hold
- ○ Build & Drop
- ○ Build & Build

Azimuth Angle: 36 deg

Total Vertical Depth: 18690 ft

Horizontal Departure: 4590 ft

Kick-Off Point: 10680 ft

Build-Up Angle: 2 °/100ft

Drop-Off Angle: 0 °/100ft

Final Section Length: 0 ft

Final Inclination: 0 deg

Calculated Values

Total Measured Depth: 19988 ft

At End of Build: ft
Meas Depth: 12311
Vertical Depth: 12224.3
Displacement: 451.9

At Total Depth: ft
Meas Depth: 19987.6
Vertical Depth: 18690
Displacement: 4590
Drift Angle: 32.62

At End of Drop: ft
Meas Depth: 0
Vertical Depth: 0
Displacement: 0

Figure 4.40

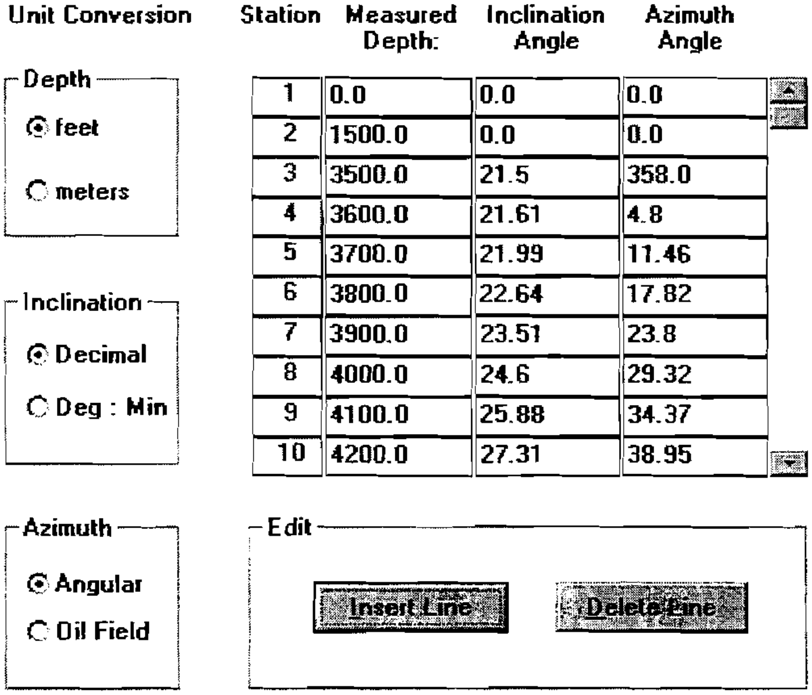
DIRECTIONAL WELL - SDI

Figure 4.41 shows the SDI window, a survey data window. Up to 400 survey data points can be input. The survey data table has four columns which include: *Station Number*, *Measured Depth, Inclination*, and *Azimuth*. The edit grid allows direct input of data. To select the cell in the grid for data entry, the mouse indicator should be moved to the cell and the mouse button should then be "clicked." Alternatively, the arrow keys, ←, ↑, →, and ↓, can be used to maneuver once the cursor is within the grid.

Pressing the key <Enter>can also change the column and row. If the selected cell is at the last row and last column of the grid, pressing the key <Enter> will add a new row at the end of the grid, and the cursor will go to the first cell of this row.

The buttons *Insert*, *Delete*, and *Append* edit the whole row of the grid. Clicking the *Append* button will add a last row at the bottom of the grid, and clicking the *Delete* button will delete the row of the current selected cell. There is a prompt before deleting a row to avoid any accidental action.

To edit the data in a selected cell requires the use of keys of the alpha and numeric keyboard(s). Pressing a key will add a character to the end of the cell entry and the "Delete" key deletes the last character. Only the last character can be edited. If a character in the middle needs to be edited, all of the characters should be deleted following the character, and then be retyped. In the grid column *Measured Depth*, only numerals and the dot (decimal) key "." are allowed.



Depth
● feet
○ meters

Inclination
● Decimal
○ Deg : Min

Azimuth
● Angular
○ Oil Field

Station	Measured Depth:	Inclination Angle	Azimuth Angle
1	0.0	0.0	0.0
2	1500.0	0.0	0.0
3	3500.0	21.5	358.0
4	3600.0	21.61	4.8
5	3700.0	21.99	11.46
6	3800.0	22.64	17.82
7	3900.0	23.51	23.8
8	4000.0	24.6	29.32
9	4100.0	25.88	34.37
10	4200.0	27.31	38.95

Figure 4.41

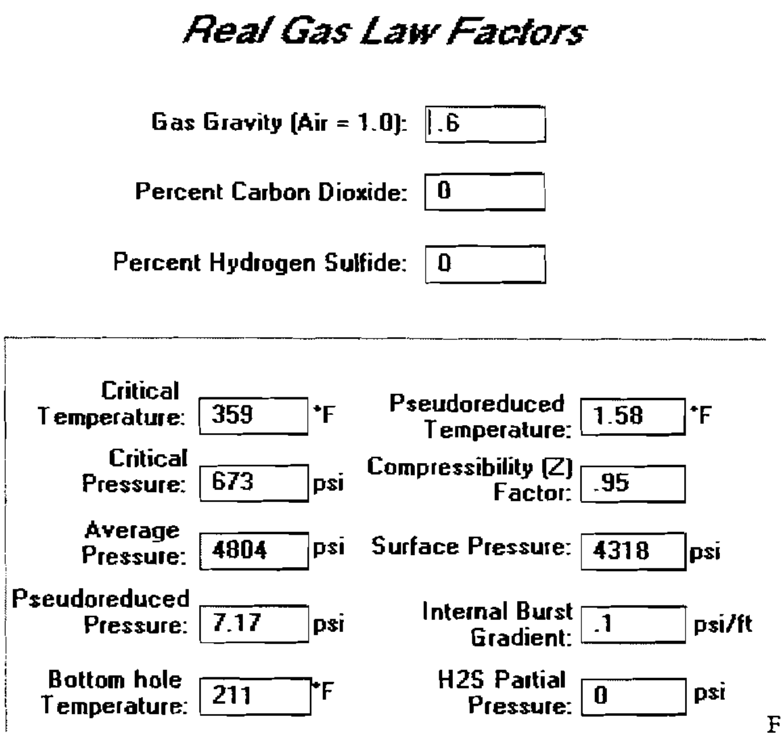
The measured depth, inclination angle, and azimuth angle each have two unit or format options. The unit of measured depth is independent of the application system of units (metric or English) the user selects for the application. The default is the same as the unit for the rest of Casing2. The default format for inclination and azimuth is "Decimal" and "Angular," respectively. Units can be changed any time while editing, and will not affect the system of units selected in Casing2.

To revert to a vertical well after the SDI file has been created for a well, delete all but the first and last row, change the inclination and azimuth values to "0" on the second row, and make the measured depth value on the second row a large number (i.e., 50,000).

After the 2-dimensional window is executed in Casing2, an SDI file for the well is established. The SDI files used in Casing2 are compatible with any SDI files in other DEA software applications developed by MEI.

ENVIRONMENT - REAL GASES

The window for parameters relating to real gas law is shown in Figure 4.42. The input fields include *gas gravity*, *percent carbon dioxide* (CO_2), and *percent hydrogen sulfide* (H_2S). The lower fields contain calculated values. Temperature changes can be made on the "Parameters - Environment - General" window.



Real Gas Law Factors

Gas Gravity (Air = 1.0): .6

Percent Carbon Dioxide: 0

Percent Hydrogen Sulfide: 0

Critical Temperature: 359 °F

Pseudoreduced Temperature: 1.58 °F

Critical Pressure: 673 psi

Compressibility (Z) Factor: .95

Average Pressure: 4804 psi

Surface Pressure: 4318 psi

Pseudoreduced Pressure: 7.17 psi

Internal Burst Gradient: .1 psi/ft

Bottom hole Temperature: 211 °F

H2S Partial Pressure: 0 psi

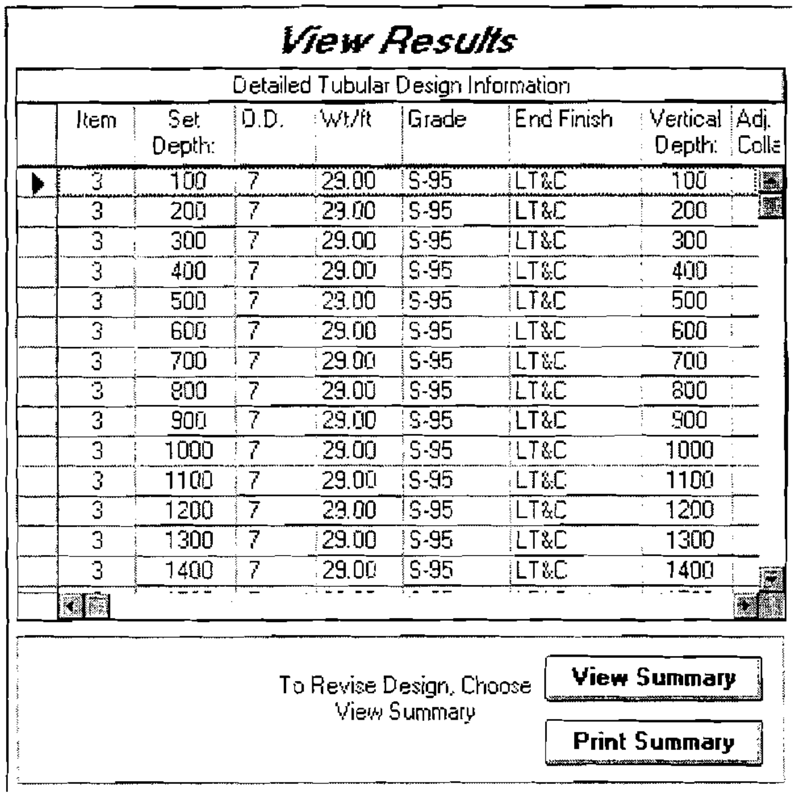
Figure 4.42

VIEW -

In general, the *View* menu options furnish "grids" which characterize the well design. The primary exception is the triaxial window, which only becomes enabled after a well is designed. The well string can either be designed by the program (*View Results*) or by direct input of the pipe (*Check Design*). Several of the "grids" contain information which can only be seen by "scrolling" either down or across. If a column contains only a blank where values should exist, then the width of the column should be increased, which can be done by "dragging" the line separating the column from the one to its right.

VIEW - RESULTS

Figure 4.43 shows the *View Results* window. This is the program - generated tubular string. The options available after this window is reached include printing the design, viewing the summary, and deleting certain items in the string. The latter option can be made by viewing the summary, highlighting a row by clicking on it with the mouse, and then by clicking on the *Delete* button. The string results can then be recalculated.


View Results

Detailed Tubular Design Information

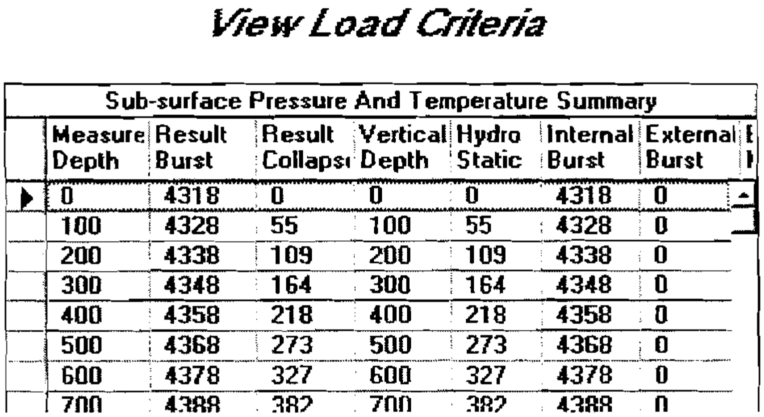
Item	Set Depth:	O.D.	Wt/ft	Grade	End Finish	Vertical Depth:	Adj. Coll
3	100	7	29.00	S-95	LT&C	100	
3	200	7	29.00	S-95	LT&C	200	
3	300	7	29.00	S-95	LT&C	300	
3	400	7	29.00	S-95	LT&C	400	
3	500	7	29.00	S-95	LT&C	500	
3	600	7	29.00	S-95	LT&C	600	
3	700	7	29.00	S-95	LT&C	700	
3	800	7	29.00	S-95	LT&C	800	
3	900	7	29.00	S-95	LT&C	900	
3	1000	7	29.00	S-95	LT&C	1000	
3	1100	7	29.00	S-95	LT&C	1100	
3	1200	7	29.00	S-95	LT&C	1200	
3	1300	7	29.00	S-95	LT&C	1300	
3	1400	7	29.00	S-95	LT&C	1400	

To Revise Design, Choose View Summary

Figure 4.43

VIEW - LOADS

The loads can be reviewed in the *View Load Criteria* window, as shown in Figure 4.44. This information is also sent to the Access database.


View Load Criteria

Sub-surface Pressure And Temperature Summary

Measure Depth	Result Burst	Result Collaps	Vertical Depth	Hydro Static	Internal Burst	External Burst
0	4318	0	0	0	4318	0
100	4328	55	100	55	4328	0
200	4338	109	200	109	4338	0
300	4348	164	300	164	4348	0
400	4358	218	400	218	4358	0
500	4368	273	500	273	4368	0
600	4378	327	600	327	4378	0
700	4388	382	700	382	4388	0

Figure 4.44

VIEW - GRAPHS

As seen in Figure 4.45, nine graphic windows are generated by Casing2 which can be printed or copied to the clipboard for use in other Windows based programs. By selecting View - Graphs from the menu after completing the *Check Design* window, the windows will contain figures pertinent to that design.

The figures include: Burst Pressure vs. Vertical Depth, Collapse Pressure vs. Vertical Depth, Burst and Collapse Pressure vs. Vertical Depth, Finished Design vs. Vertical Depth, Tension in Pipe vs. Vertical Depth, Horizontal Departure vs. Vertical Depth, Triaxial Analysis, Casing (wellbore) Schematic, and String Schematic. The triaxial analysis results are for the case of burst loads on the inside diameter of the pipe.

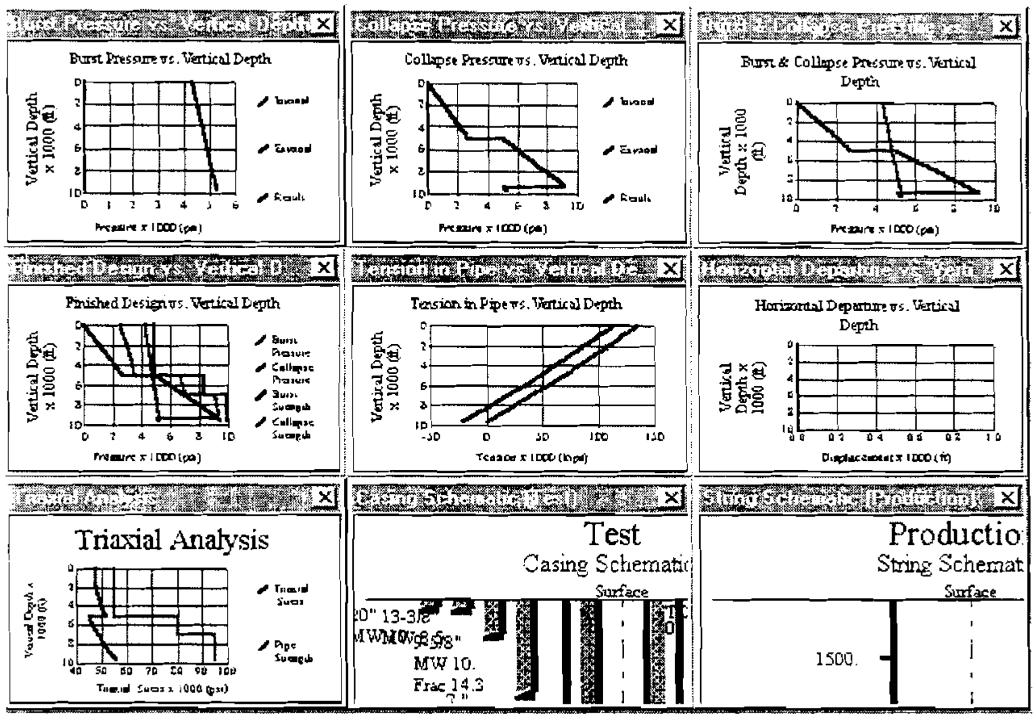
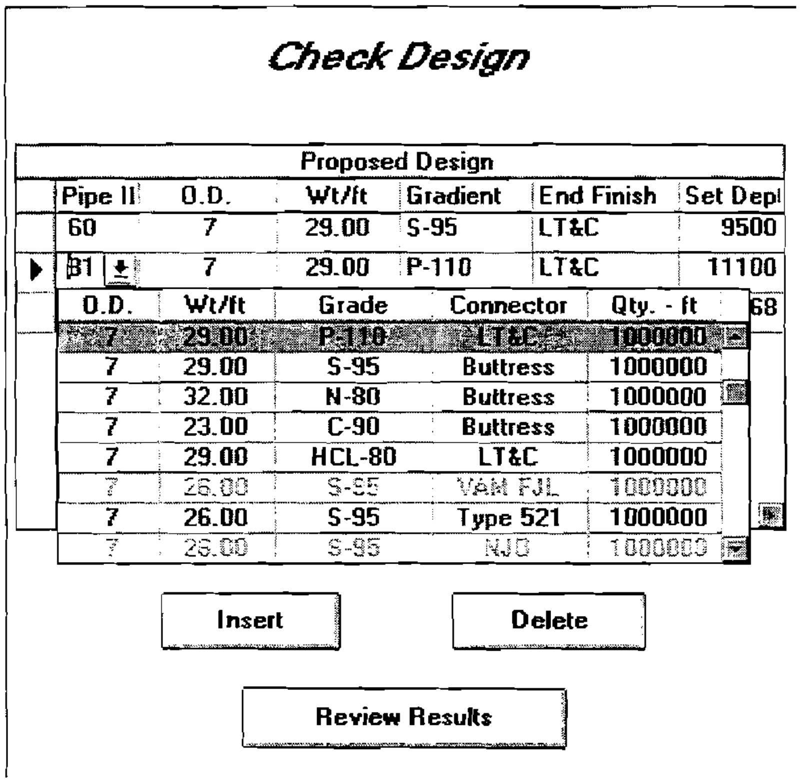


Figure 4.45

VIEW - CHECK DESIGN

As seen in Figure 4.46, *Check Design* is the window which allows user input of the pipe string. The pipe is input from top to bottom. As shown in the figure, a "drop - down" box will appear for the *Pipe I.D.* as well as for the *Set Depth*. Only pipe items which are currently in the database and which were included in the "query" for the string can be selected. The bold pipe items are those items which (1) have an inventory quantity, (2) have grades which are "available," and (3) have connections which are "available." *Review Results* should be "clicked" before attempting to go to the "View - Graphs" window for this string.



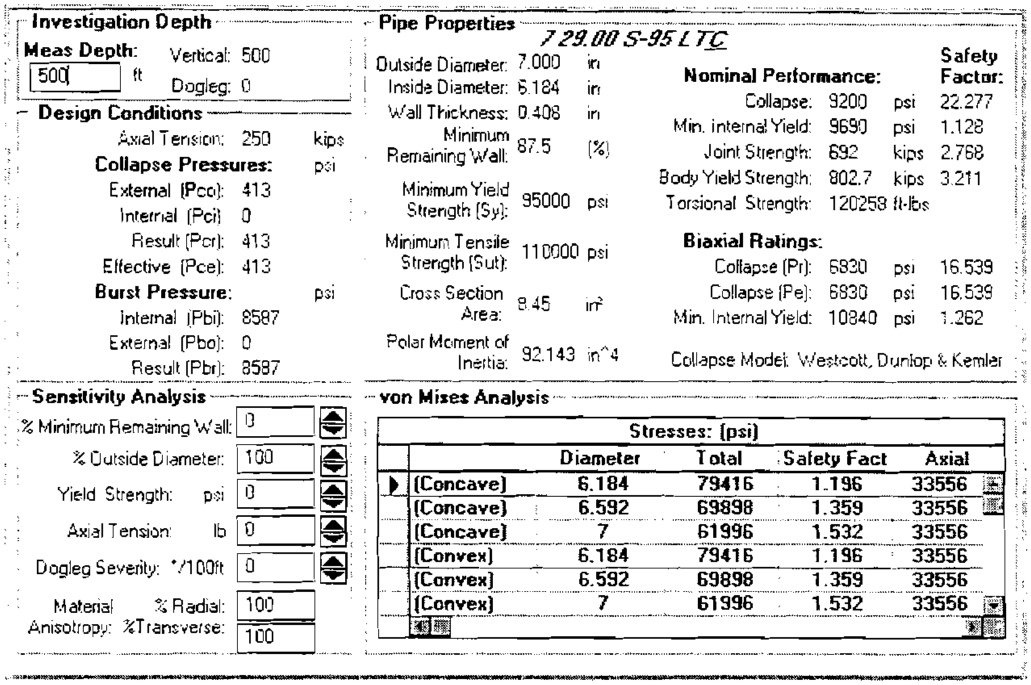
Proposed Design					
Pipe II	O.D.	Wt/ft	Gradient	End Finish	Set Depi
60	7	29.00	S-95	LT&C	9500
▶ B1	7	29.00	P-110	LT&C	11100
					68

O.D.	Wt/ft	Grade	Connector	Qty. - ft
7	29.00	P-110	LT&C	1000000
7	29.00	S-95	Buttress	1000000
7	32.00	N-80	Buttress	1000000
7	23.00	C-90	Buttress	1000000
7	29.00	HCL-80	LT&C	1000000
7	26.00	S-95	VAM FJL	1000000
7	26.00	S-95	Type 521	1000000
7	26.00	S-95	NJO	1000000

Figure 4.46

VIEW - TRIAXIAL ANALYSIS

Figure 4.47 provides a view of the *View - Triaxial Analysis* window. The purpose of this window is to enable a sensitivity analysis of the string just designed to be made. The input fields include measured depth and the fields ("spinners") under *Sensitivity Analysis*. The grid in the *von Mises Analysis* frame contain a breakdown of the stresses for the inside diameter case, the mid-wall case, and the outside diameter case. For burst, both the convex and the concave cases are shown, which will be different only when the pipe is in a dogleg at the depth of investigation.



Investigation Depth

Meas Depth: 500 ft

Vertical: 500

Dogleg: 0

Design Conditions

Axial Tension: 250 kips

Collapse Pressures: psi

External (Pco): 413

Internal (Pci) 0

Result (Pcr): 413

Effective (Pce): 413

Burst Pressure: psi

Internal (Pbi): 8587

External (Pbo): 0

Result (Pbr): 8587

Pipe Properties

7 29.00 S-95 LTC

Outside Diameter: 7.000 in

Inside Diameter: 6.184 in

Wall Thickness: 0.408 in

Minimum Remaining Wall: 87.5 (%)

Minimum Yield Strength (Sy): 95000 psi

Minimum Tensile Strength (Sut): 110000 psi

Cross Section Area: 8.45 in²

Polar Moment of Inertia: 92.143 in^4

Nominal Performance:			**Safety Factor:**
Collapse:	9200	psi	22.277
Min. internal Yield:	9690	psi	1.128
Joint Strength:	692	kips	2.768
Body Yield Strength:	802.7	kips	3.211
Torsional Strength:	120258	ft-lbs	
Biaxial Ratings:			
Collapse (Pr):	6830	psi	16.539
Collapse (Pe):	6830	psi	16.539
Min. Internal Yield:	10840	psi	1.262

Collapse Model: Westcott, Dunlop & Kemler

Sensitivity Analysis

% Minimum Remaining Wall: 0

% Outside Diameter: 100

Yield Strength: psi 0

Axial Tension: lb 0

Dogleg Severity: °/100ft 0

Material Anisotropy: % Radial: 100

%Transverse: 100

von Mises Analysis

	Stresses: (psi)			
	Diameter	Total	Safety Fact	Axial
(Concave)	6.184	79416	1.196	33556
(Concave)	6.592	69898	1.359	33556
(Concave)	7	61996	1.532	33556
(Convex)	6.184	79416	1.196	33556
(Convex)	6.592	69898	1.359	33556
(Convex)	7	61996	1.532	33556

Figure 4.47

The fields for further analysis include:

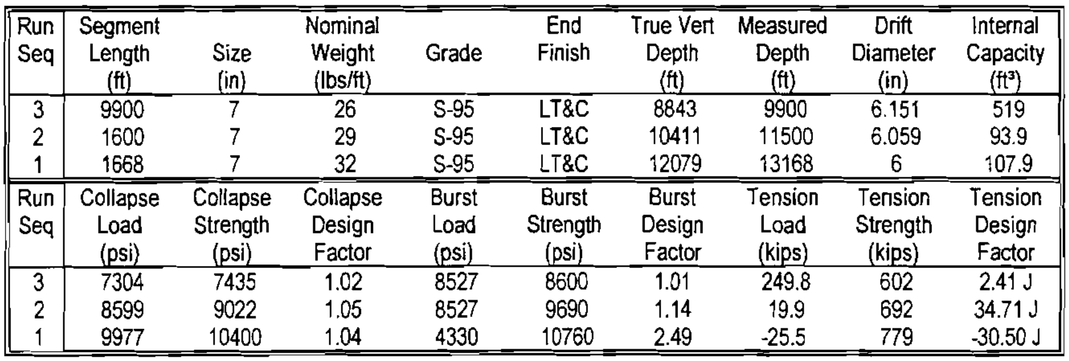
- Percent minimum remaining wall (i.e., for wear analysis)
- Percent outside diameter
- Yield strength
- Axial tension
- Dogleg severity
- Material anisotropy (i.e., typically for certain CRA materials.)

The response to changes in the above are reflected in the grid and in the calculated values for pipe properties.

THE REPORT

As seen in Figure 4.48, the central portion of the report contains a table summarizing the casing or tubing design. The full report is shown in Appendix 4. The *Run Sequence* is as the sequence will be on the rig. The order is inverted to show the pipe from top to bottom.

On the upper portion, if a cost is to be generated as found in "Edit - User Information," then the last column will show the cost rather than the *Internal Capacity* as seen below.



Run Seq	Segment Length (ft)	Size (in)	Nominal Weight (lbs/ft)	Grade	End Finish	True Vert Depth (ft)	Measured Depth (ft)	Drift Diameter (in)	Internal Capacity (ft³)
3	9900	7	26	S-95	LT&C	8843	9900	6.151	519
2	1600	7	29	S-95	LT&C	10411	11500	6.059	93.9
1	1668	7	32	S-95	LT&C	12079	13168	6	107.9

Run Seq	Collapse Load (psi)	Collapse Strength (psi)	Collapse Design Factor	Burst Load (psi)	Burst Strength (psi)	Burst Design Factor	Tension Load (kips)	Tension Strength (kips)	Tension Design Factor
3	7304	7435	1.02	8527	8600	1.01	249.8	602	2.41 J
2	8599	9022	1.05	8527	9690	1.14	19.9	692	34.71 J
1	9977	10400	1.04	4330	10760	2.49	-25.5	779	-30.50 J

Figure 4.48

On the lower portion, the three general load types are shown: collapse, burst, and tension. For each of these loads, the rated pipe strengths and the respective design factors are also shown. The collapse load will be the bottom load, which will *almost* always be the most severe case. The exception to this could be a plastic load. The burst load will be the most severe case, which will usually be found at the top or at the bottom of the segment. The tension load will be either the buoyed weight or the air weight, which is selected in the "Edit - Preferences - Program Design Factors" window. The tension strength will either be the joint strength ("J") or the body yield strength ("B"), and the respective design factor will be shown in the last column with the "J" or "B" noted. The worst case determines which will be used.

In addition to the printout of the full report, this portion of the report can be exported to many types of formats. The "suitcase" at the bottom of the report screen serves as the "export" button. Appendix 4 contains more information on this feature.

NOMENCLATURE

A	**Area**
A_i	**inner pipe area enclosed by ID**
A_{jp}	**steel area under last perfect thread**
A_o	**outer pipe area enclosed by OD**
A_p	**steel area in pipe body**
A_s	**steel cross-sectional area**
A_{sc}	**steel area in coupling**
AGG	**average gas gravity**
d	**ID of pipe**
d_b	**ID at critical section of joint box**
d_{c1}	**diameter at root of coupling thread at end of pipe in power-tight position**
d_{c2}	**OD of coupling**
d_n	**nominal pipe diameter**
d_{j1}	**nominal joint ID of made-up connection**
d_{j2}	**nominal joint OD of made-up connection**
d_1	**smaller diameter of annulus**
d_2	**larger diameter of annulus**
D	**depth**
D_c	**depth of casing**
D_i	**depth of injection (fracture)**
D_{lc}	**depth of lost-circulation**
D_m	**depth of mud surface**
E	**Young's modulus of elasticity**
E_f	**Young's modulus for the formation**
F	**force**
F_a	**axial force**
F_{ab}	**equivalent axial force caused by bending**
F_{bu}	**force tending to cause buckling**
F_{fr}	**frictional force**
F_s	**stability force**
F_{sc}	**side force at coupling**
F_{ten}	**tensional force**
F_w	**wall force**
g_p	**pore pressure gradient expressed as equivalent mud density**
γ	**gravity, i.e. air = 1.0 for gas**
h	**thickness**
I	**moment of inertia**
K	**square root of 1 over EI**
L	**length**
L_j	**joint length**
L_t	**length of engaged threads**
M	**bending moment**
M_c	**bending moment at coupling**
MASP	**max. anticipated surface pressure**
p	**pressure**

p_{br}	burst pressure rating
p_{cr}	collapse pressure rating
P	pipe strength rating
P_y	pipe body yield strength
P_j	pipe joint strength rating
p_e	external pressure
p_i	internal pressure
r	radius
Δr	radial clearance of annulus
r_i	inner radius
r_o	outer radius
t	thickness
T	temperature
w	weight per foot
W	weight
α	dogleg severity, °F/100 ft
T	temperature coefficient of expansion
Δ	change
ε	strain
ε_r	radial strain
ε_t	tangential strain
ε_z	axial strain
θ	angle
μ	Poisson's ratio
μ_f	Poisson's ratio for the formation
ρ	density
ρ_g	gas density
ρ_m	mud density
ρ_s	steel density
σ	stress
σ_r	radial stress
σ_s	nominal steel strength
σ_t	tangential stress
σ_{ult}	ultimate (tensile) strength
σ_{yield}	yield strength
σ_z	axial stress

SUBSCRIPTS

e (or r)	effective
max	maximum
m	measured
v	vertical
1,2,3	sections 1, 2, 3

SI METRIC CONVERSION FACTORS

°F	(°F -32) / 1.8	= °C
ft	* .3048	= m
in	* 2.54	= cm
lbf	* 4.448 222	= N

lbf/ft	* 1.355 818 E-03	= kJ
lbm/gal	* 1.198 264 E+02	= kg/m³
psi	* 6.894 757	= kPa
psi/ft	* 22.620 59	= kPa/m

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Appendix 1

DETERMINATION OF MASP USING REAL GAS LAW

The primary distinction between the ideal gas law and the real gas law is that the ideal gas law assumes a compressibility factor, "z," of 1.0. In fact, the "z" factor is dependent on gas gravity, composition, temperature and pressure. It is a non-linear function and so, will have different values from top to bottom. Since the objective in Casing2 is basically to find the maximum anticipated surface pressure (MASP) and average gas gravity (AGG), the assumption is made that the "z" factor is both constant and the average of temperature and pressure throughout the string. Two more important assumptions are that the nitrogen content is null and the gasses are "miscellaneous," as opposed to "condensate." Even with those assumptions, an iterative procedure is required to find the "z" factor.

In brief, the following variable inputs are used:

- vertical depth - either for the shoe depth for production strings and conductor strings, or for the next setting depth as input on the basic parameters form.
- mud weight - or the next mud weight, as above
- surface temperature and temperature gradient - found on the "environment" form next to the H_2S, and
- gas gravity (air = 1.0), percent H_2S and percent CO_2 (on the "real gas" form). Gas gravity should be in the range from 0.56 to 1.71, H_2S should be from 0 to 80 molar percent, and CO_2 should be from 0 to 100 molar percent.

In basic sequence, the following values are calculated.

Bottom hole temperature and average (static) temperature are based on surface temperature and temperature gradient, which is assumed to be a constant.

Below, the specific gravity of the gas is denoted Gas γ_{HC} which is a modification of γ for CO_2 and H_2S content, if any. Please note that the following equations and inputs incorporate English units, i.e. psi, °F, feet, and ρ_m in pounds per gallon.

$$\text{Gas } \gamma_{hc} = (\gamma - 1.5195 * \%CO_2 - 1.1765 * \%H_2S) / (1 - \%CO_2 - \%H_2S)$$

$$T_{cHC} = 168 + 325 * \text{Gas } \gamma_{hc} - 12.5 * \text{Gas } \gamma_{hc}^2$$

$$p_{cHC} = 677 + 15 * \text{Gas } \gamma_{hc} - 37.5 * \text{Gas } \gamma_{hc}^2$$

From the above intermediate calculations, critical temperature, T_c and critical pressure, p_c are calculated.

$$T_c = (1 - \%CO_2 - \%H_2S) * T_{cHC} + (547.6 * \%CO_2 + 672.4 * \%H_2S)$$

$$p_c = (1 - \%CO_2 - \%H_2S) * p_{cHC} + (1071 * \%CO_2 + 1306 * \%H_2S)$$

The Wichert-Aziz correction, C_{WA}, is used if H_2S is present.

$$F_{CO2H2S} = (\%CO_2 + \%H_2S)$$

$$C_{WA} = 120 * (F_{CO2H2S}^{0.9} - F_{CO2H2S}^{1.6}) + 15 * (\%H_2S^{0.5} - \%H_2S^4)$$

Finally, T_c and p_c are then corrected for H_2S content.

$$p_c = p_c * (T_c - C_{WA}) / [T_c + C_{WA} * \%H_2S * (1 - \%H_2S)] \qquad \text{(critical pressure)}$$

$$T_c = T_c - C_{WA} \qquad \text{(critical temperature)}$$

With these values, pseudoreduced temperature, T_{avg}, and pressure, p_{avg}, are calculated using average temperature and (estimated) average pressure.

$$T_{avg} = [\text{surface temperature} + (\text{temperature gradient} * \text{vertical depth} / 100)] / 2$$

$$T_R = (T_{avg} + 460) / T_c \qquad \text{(in degrees Rankin)}$$

$$p_{avg} = d * (\rho_m * 0.052 - .12)$$

$$p_R = (15 + p_{avg}) / P_c$$

Obviously, p_R is only a guess at this point. The "z" factor is determined iteratively as the following "DO" loop describes.

```
NewMASP = BHP - (TVD * AGG)

Do

MASP = NewMASP

$p_{avg}$ = (BHP + MASP) / 2

$p_R$ = ($p_{avg}$ + 15) / $p_c$                    (pseudoreduced pressure)
```

Check to make sure that p_R is between 0 and 30 and use the following terms.

```
  $A = .06423$                                $B = .5353 * T_R - .6123$
  $C = .3151 * T_R - 1.0467 - (.5783 / T_R^2)$      $D = T_R$
  $E = .6816 / T_R^2$                            $F = .6845$
$G = .27 * p_R$
$D_{r1}$ = pseudoreduced density = $D_r$
  $D_r = (.27 * p_R) / T_R$                          ( initial guess )
  Do the following 12 times                    ( an arbitrary number )
$D_2 = D_r^2$                                  $D_3 = D_r^3$
$D_4 = D_r^4$                                  $D_5 = D_r^5$
$D_6 = D_r^6$
$p_1 = (A*D_6) + (B*D_3) + (C*D_2) + (D*D_r) + (E*D_3) * (1 + F*D_2) * e^(-F*D_2) - G$
$D_P = (6*A*D_5) + (3*B*D_2) + (2*C*D_r) + D + (E*D_2) * (3 + F*D_2 * (3 - 2*F*D_2)) * e^(-F*D_2)$
$D_{r1} = D_r - (p_1 / D_P)$
If $D_{r1} <= 0$ Then $D_1 = .5 * D_r$
If $D_{r1} >= 2.2$ Then $D_{r1} = D_r + .9 * (2.2 - D_r)$
If $Abs(D_r - D_1) < .00001$ Then stop this sequence
$D_r = D_{r1}$
Go back and do this again, until it has been done 12 times
$z = .27 * p_R / (D_{r1} * T_R)$
$z_{Exp} = 1 / e^{0.01875 * Gas \gamma_{hc} * TVD / [z * (460 + T_{avg})]}$
NewMASP! = BHP! * $Z_{Exp}$
Loop Until Absolute (MASP - NewMASP) < 10
```

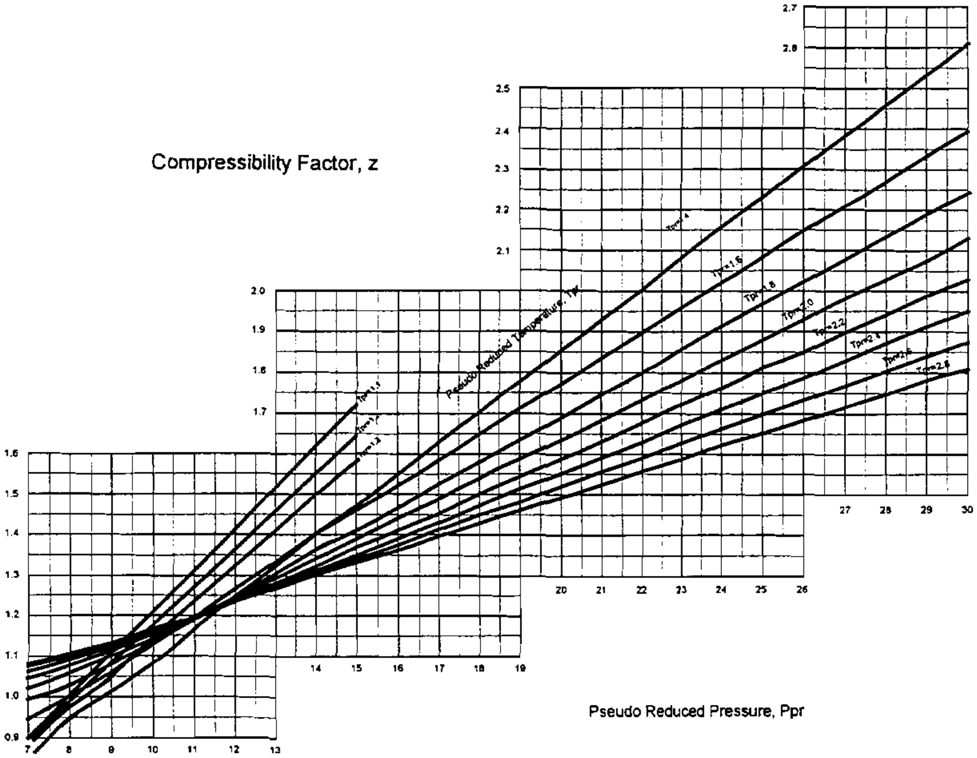
This is the end of the loop, and as shown, the "z" factor is considered to be close enough when the surface pressure iterations are within 10 psi.

Surface pressure = NewMASP

AGG = (BHP - NewMASP) / TVD

p_{avg} = (BHP + NewMASP) / 2

Below, the compressibility factor chart is shown, as used in the back of Lone Star Steel Company's Technical Data book. A reference for the ideal gas law chart can also be found there.

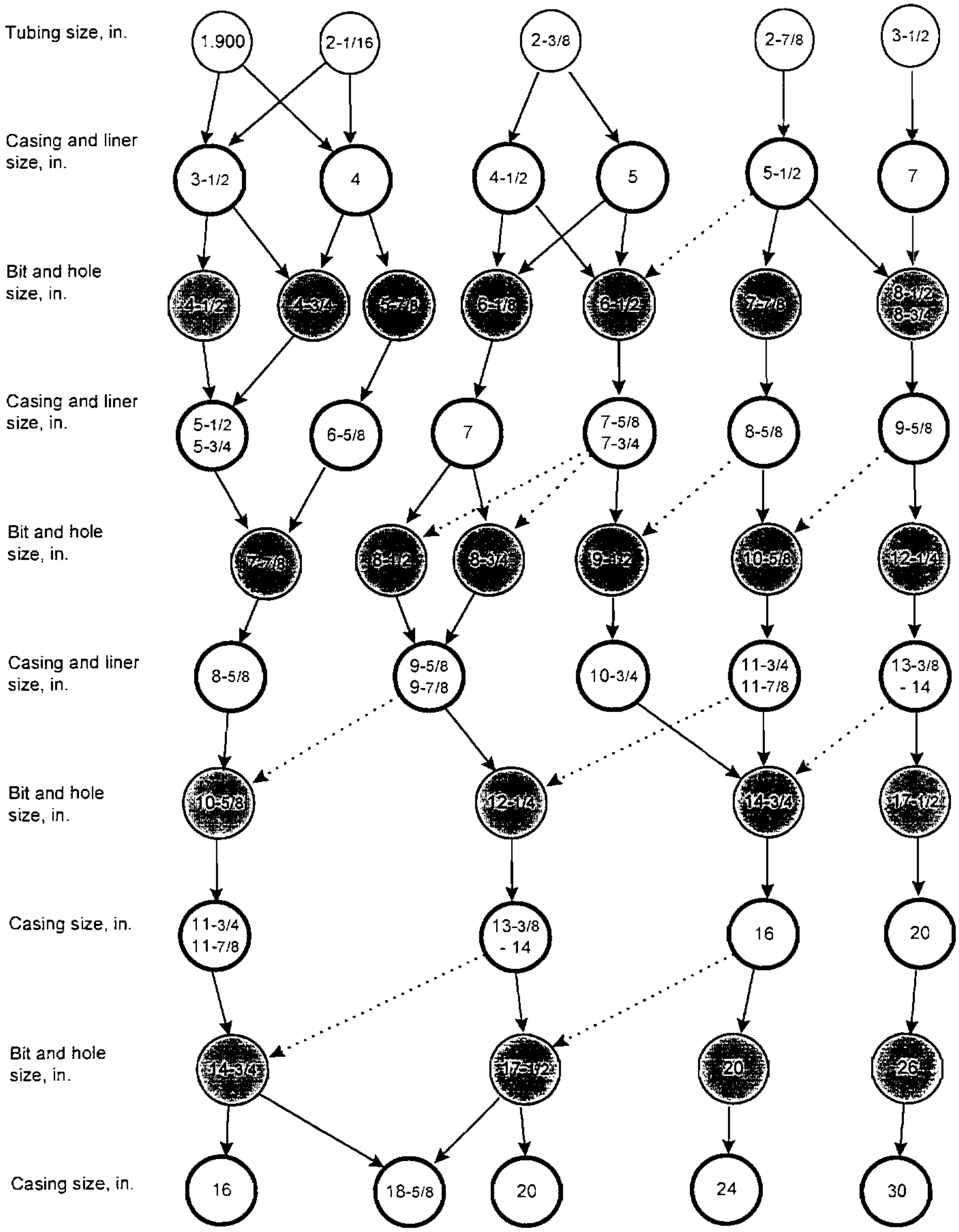


In the above figure, a "z" factor of 1.78 is found for a pseudo reduced pressure of 21.7 and a pseudo reduced temperature of 1.80. For a 17,800 foot well with a gas gravity of 0.65, a ST of 74°F, a BHT of 323°F and a BHP of 15643 psi, the MASP is calculated to be 13,073 psi.

Appendix 2

CASING AND HOLE SIZES

The figure shown depicts typical tubing, casing and hole sizes. Some of the holes may require under-reaming, especially for the benefit of a better cement job. Also, some of the casing combinations may dictate that nonthreaded and coupled pipe be used. In the figure, dotted lines represent situations as above, where special casing connections must be used. The bit and hole sizes are typical for tricone rotary bits, and variations may exist, particularly for PDC bits.


Tubing size, in.
1.900
2-1/16
2-3/8
2-7/8
3-1/2
Casing and liner size, in.
3-1/2
4
4-1/2
5
5-1/2
7
Bit and hole size, in.
4-1/2
4-3/4
5-7/8
6-1/8
6-1/2
7-7/8
8-1/2
8-3/4
Casing and liner size, in.
5-1/2
5-3/4
6-5/8
7
7-5/8
7-3/4
8-5/8
9-5/8
Bit and hole size, in.
7-7/8
8-1/2
8-3/4
9-1/2
10-5/8
12-1/4
Casing and liner size, in.
8-5/8
9-5/8
9-7/8
10-3/4
11-3/4
11-7/8
13-3/8
- 14
Bit and hole size, in.
10-5/8
12-1/4
14-3/4
17-1/2
Casing size, in.
11-3/4
11-7/8
13-3/8
- 14
16
20
Bit and hole size, in.
14-3/4
17-1/2
20
26
Casing size, in.
16
18-5/8
20
24
30

Appendix 3

DATABASE INFORMATION

As discussed in the text, the data sets are contained in the Microsoft Access Version 2.0 file, OCTGWIN.MDB. It contains tables, queries, a form, and reports that pertain to the program. The tables are the primary data that should be of interest to the Casing2 user. These include:

• tblWellMast	the "master" file for a well
• tblWellDet	the details for any one string, associated with one well
• tblConnection	the catalog of end connections
• tblGrade	the catalog of grades, including line pipe and drill pipe
• tblPipe	the catalog of pipe
• tblResDet	the details of results for a well solution
• tblResMast	the master information of results for a well solution
• tblLoads	the complete array of loads and results for a well solution
• tblSDI	the directional information for a well

The contents of tblWellMast are as follows:

ID (a counter)
Az unit flag
Well location
Pressure units
Diameter units
Well name
Inclination unit flag
Well ID
Weight units
Pressure gradient units
SDI key AFE no.
Address Operator
RemarksDepth units
Density units
Temperature units

- Torque units
- Volume units
- Cross section area units
- Tonnage units
- Temperature gradient units
- Dogleg units
- Volume gradient units
- Collapse design factor
- Burst design factor
- Premium DF
- Body yield strength design factor
- API 8 Round Short DF
- Buttress DF
- 8 Rd Long DF
- Other API joint strength DF
- De-rate collapse - doglegs
- Burst - biaxial
- Pipe length
- Surface temperature
- Temperature gradient
- Mud weight
- Internal gradient
- Collapse biaxial model
- Fracture gradient model
- Include buoy.
- Minimum overpull
- NACE critical temp. 1
- NACE critical temp. 2
- Mudline depth
- Water depth
- NACE critical temp. 3
- API leak resistance
- subsea completion
- Engineer
- Cost denominator (inflation index)
- Cost unit (i.e. "$")
- Engineer's organization
- Requestor's organization (org)
- Engineer's fax
- Engineer's phone
- Requestor's phone
- Requestor's fax
- Requestor of design
- Triaxial design factor
- Compression DF
- Maximum sections
- Temperature correction
- Kick off point
- Curve style

The contents of tblWellDet can (and do) override the contents from tblWellMast as applicable. They include the following:

- Well ID (master ID)
- String type
- Measured depth
- Vertical depth
- Next vertical depth
- Measured frac depth
- Pipe OD index
- Pipe OD
- Fracture mud weight
- Fracture depth
- Packer depth
- Mud weight
- Internal burst gradient
- Minimum drift
- Liner top
- Frac pressure
- Fracture equivalent mud weight
- Surface pressure
- Burst method
- Pore pressure
- Next pore pressure
- Next mud weight
- Upper mud wt
- Lower mud wt

Annular burst pressure
Annular burst mud weight xover
Reservoir BHP
BHP
Maximum load depth
Interface pressure
Packer fluid flag
Packer fluid density
Maximum load flag
Maximum load option
Collapse external mud weight 1-6
Collapse crossover depth 1-6
External point load 1-6
Annular collapse pressure
Upper internal fluid weight
Lower internal fluid weight
Internal fluid weight xover depth
Upper burst design factor
Lower burst design factor
Burst design factor crossover depth
Upper collapse design factor
Lower collapse design factor
Collapse design factor xover depth
API 8rd ST&C design factor
API 8rd LT&C design factor
Buttress design factor
Premium joint design factor
Body yield design factor
Directional well code
Minimum section length
Surface temperature
Temperature gradient
Use critical temperatures for H_2S
Sour service
Hole size
Cement top
Gas gravity
Average pressure
%CO_2
%H_2S
Gas critical pressure
Gas critical temperature
Pressure gradient
z factor
Pseudo-reduced temperature
Pseudo-reduced pressure
Minimum overpull
Fluid weight
Axial load modifying force
Depth of axial load
Neutral point
Buoyancy
HydMDF inclusion
Hydraulic pressure 0-5
Hydraulic mud gradient 1-7
Inspections 0-11
Triaxial design factor

The solution table, tblSolution, and the results tables, tblResultMast and tblResultDet, contain information relevant to only one well and one string type. This information can be accessed directly after Casing2 is closed, and the fields will contain information pertinent only to the last string for which a "print" was called for. The contents of tblResultMast are as follows:

Well ID (matches master)
String type (no. & name)
BH Temperature
Average temperature
Minimum drift diameter
ID (counter)
Length units
Diameter units
Pressure units
Temperature units
Area units
Density units
Pressure gradient units
Weight units
Ton units

Volume units
Torque units
Problem text
Kick off point
Build up angle
Departure
Drop off point
Temperature gradient units
Gyration units
Total cost
Dogleg & angle units
Hold angle
Azimuth
Volume gradient units
Program remarks
Curve type
Max. dogleg
Drop off angle
Inclination

The contents of tblResultDet are as follows:

Sequence
Well ID
Heading 1-10
Field 1-20

The contents of tblConnector are arranged in sequence as to manufacturer. When connections are added, to the extent possible, the sequence should be maintained. The field, "Type," is used to indicate casing ("CSG") or tubing("TBG") or , sometimes, both. The fields are as follows:

ID (assoc. with tblPipe)
Cost
Mfg. abbr.
Type
User
Manufacturer
End finish description
Available

A couple of notes should be made regarding tblGrade. One is that the *NACE* field contains a number which indicates its status with NACE for H_2S service. These numbers are: 1) all temperature; 2) temperatures hotter than 150°F; 3) temperatures hotter than 175°F; 4) temperatures hotter than 225°F; and 5) no rating for H_2S. The *Type* field indicates the general type of tubular. Its abbreviations are: 1)API OCTG; 2) proprietary OCTG; 3) obsolete OCTG; 4) drill pipe; 5) line pipe; and 6) high-collapse OCTG . The contents of tblGrade are as follows:

ID (assoc. with tblPipe)
Type
User
Poisson's ratio
Yield strength
Grade description
Available
Density
NACE
Tensile strength
Young's modulus

The pipe for Casing2 is called up from the following table, tblPipe, based on an OD range. There will be some overlap between casing and tubing sizes. The distinction pertains mostly to the connection, but sometimes to the wall thickness as well. There is also usually a big cost difference. For this reason, when connection items are added to the database it is important, to the extent possible, to make the notation regarding casing or tubing type. "Inventory" in the following list is a number which can limit the availability of a particular tubular item. Grade ID and Connection ID are integer numbers which relate to the *grade* and *connector* tables. Finally, please note that before a new item is added to tblPipe, the necessary *grade* and *connector* items should be valid.

- Outside diameter
- Wall thickness
- Weight / foot
- Grade ID
- Connection ID
- Joint strength
- Collapse strength
- Box OD
- Minimum internal yield strength
- Drift diameter
- Cost
- Inventory
- Torque (strength or nominal)
- User added

The contents of tblSDI are as follows:

- SDI Key (Well ID no.)
- SDI Number
- Azimuth
- Inclination
- Measured depth

Presently, tblSolution exists as a repository for detailed load and strength information which can be exported to spreadsheets for whatever purpose. The contents of tblSolution are as follows:

- Array ID (a counter)
- Measured depth
- Vertical depth
- Air weight
- Pipe segment number
- Buoyed weight
- Triaxial stress
- Dogleg severity
- Adjusted collapse strength
- Adjusted burst strength
- Internal burst p
- Annular burst p
- External collapse pressure
- Internal collapse pressure
- Collapse DL
- Burst DL
- Horizontal departure
- Temperature

For some users, a good purpose may be found for entering the database through Access Version 2.0, rather than through the program, Casing2. At least two cautions must be mentioned regarding this. One is that the pipe table contains cost information which is relative to each other. New items entered should be "priced" at a level commensurate with comparable items, not merely with the current market price. Secondly, newer versions of Access will come along which will be able to open OCTGWin.MDB. The file must, however, be saved in its original version, as otherwise Casing2 and its report(s) may not be able to read the data.

Appendix 4

REPORT INFORMATION

The report for Casing2 was created using Crystal Report Version 4.5. Crystal Reports is a creation of Crystal, a Seagate Software Company. The sales and information number for Crystal is (604) 681-3435. Additional reports can be made, which use information saved to any of the tables described in Appendix 3. The report can also be exported, as discussed herein.

The Report

The report is designed to give the overview of details regarding the input parameters as well as the string design with its associated design loads, strengths and safety factors. Many items of the report are "blanked out" when they do not impact on the design. As an example, if the upper design factor for burst is the same as the lower burst design factor or the crossover depth for this value is at the surface, then both the upper burst design factor and the crossover depth are not visible.

Export Specific Requirements

Most of the export options export the central portion of the report only, as shown below. Other options enable the entire report to be exported.

Seq.	Length (ft)	Size (in)	Weight (lb/ft)	Grade	End Finish	True Vert Depth (ft)	Measured Depth (ft)	Drift (in)	Cost ($)
1	7500	9.625	43.50	N-80	LT&C	3500	7584	8.625	86501

Seq.	Collapse Load (psi)	Collapse Strength (psi)	Collapse Design Factor	Burst Load (psi)	Min Int Yield (psi)	Burst Design Factor	Tension Load (kips)	Tension Strength (kips)	Tension Design Factor
1	1758	3808	2.17	1776	6330	3.56	152.2	825	5.42 J

If you wish to export the report(s), you must have files from the following list appropriate to the export option:

Format DLLs

UXFCR.DLL	Crystal Reports Format (16 bit)
UXFDIF.DLL	DIF format
UXFDOC.DLL	Word for DOS and Word Perfect format
WORDDOS.XTD	Only required if exporting to Word for DOS
WPERFECT.XTD	Only required if exporting to Word Perfect
UXFQP.DLL	Quattro Pro
UXFREC.DLL	Record format
UXFRTF.DLL	Rich Text Format
UXFSEPV.DLL	Comma Separated Values Format
UXFTEXT.DLL	Text format
UXFWKS.DLL	Lotus 1-2-3 format
UXFWORDW.DLL	Word for windows format
UXFXLS.DLL	Excel format

DESTINATION DLLS

UXDDISK.DLL	Disk file destination
UXDMAPI.DLL	MAPI format (Microsoft mail)
UXDVIM.DLL	VIM format (cc: MAIL, Lotus Notes, WordPerfect Office, etc.

If you need any of the above files or would like information on foreign language runtime file requirements, please contact Maurer Engineering Inc. or Lone Star Steel Company.

Shown below is the full text of a report. It was exported to "Word for Windows," and imported using the "Insert - Object - Microsoft Word Document." If a report is desired which summarizes the strings for the entire well, it would be easiest to import the set of individual string report "summaries" into one document. A unique file name should be used for each report exported.

The large space beneath the summary table is normal, and is a feature of the software used to generate the report. The remarks which follow the summary are a combination of program generated remarks and remarks entered on the window, *Edit - User Information*.

Well name:	**OCS-G-3800 Well A-11**
Operator:	**Oil & Gas Company**
String type:	Production
Location:	Gulf of Mexico - Eugene Island Blk 361

Design parameters:

Collapse

Mud weight:	15.9 ppg
Design is based on evacuated pipe	

Burst

Max anticipated surface pressure:	8,527 psi
Internal gradient:	0.120 psi/ft
Calculated BHP	9,977 psi
Annular mud density:	9.00 ppg
Packer fluid details:	
Fluid density:	9.000 ppg
Packer depth:	13,000 ft

Minimum design factors:

Collapse:

Design factor	1.000

Burst:

Design factor	1.00

Tension:

8 Round STC:	1.80 (J)
8 Round LTC:	1.80 (J)
Buttress:	1.60 (J)
Premium:	1.50 (J)
Body yield:	1.60 (B)

Tension is based on buoyed weight.

Neutral point:	10,436 ft

Environment:

H_2S considered?	No
Surface temperature:	75°F
Bottom hole temperature:	244°F
Temperature gradient:	1.40°F/100 ft
Minimum section length:	1,500 ft
Water depth:	105 ft
Directional Info -	Build & Hold
Kick-off point	0 ft
Departure at shoe:	3,839 ft
Maximum dogleg:	2.5°/100 ft
Inclination at shoe:	0°

Run Seq	Segment Length (ft)	Size (in)	Nominal Weight (lbs/ft)	Grade	End Finish	True Vert Depth (ft)	Measured Depth (ft)	Drift Diameter (in)	Internal Capacity (ft^3)
3	9900	7	26	S-95	LT&C	8843	9900	6.151	519
2	1600	7	29	S-95	LT&C	10411	11500	6.059	93.9
1	1668	7	32	S-95	LT&C	12079	13168	6	107.9

Run Seq	Collapse Load (psi)	Collapse Strength (psi)	Collapse Design Factor	Burst Load (psi)	Burst Strength (psi)	Burst Design Factor	Tension Load (kips)	Tension Strength (kips)	Tension Design Factor
3	7304	7435	1.02	8527	8600	1.01	249.8	602	2.41 J
2	8599	9022	1.05	8527	9690	1.14	19.9	692	34.71 J
1	9977	10400	1.04	4330	10760	2.49	-25.5	779	-30.50 J

Prepared by:	Good Engineer Oil & Gas Company	Phone: BR 548 FAX: BR 549	Date: September 27, 1996 Houston, Texas

Remarks:

Collapse is based on a vertical depth of 12079 ft, a mud weight of 15.9 ppg The casing is considered to be evacuated for collapse purposes.

Collapse strength is based on the Westcott, Dunlop & Kemler method of biaxial correction for tension.

Burst strength is not adjusted for tension.

Collapse strength is (biaxially) derated for doglegs in directional wells by multiplying the tensile stress by the cross section area to calculate a tensile load which is added to the axial load.

Engineering responsibility for use of this design will be that of the purchaser.

Appendix 5

FRAC GRADIENT PREDICTION

While not an integral design feature of Casing2, fracture gradient prediction is available for protection strings. Such predictions are fraught with potential problems, and should include many things beyond the scope of this program, such as log information and formation dip. Nonetheless, four prediction methods are offered. All of the methods have this in common: they are based on the stated fracture depth, d_f (which may be deeper than the shoe depth), and on the stated mud weight, that is the mud weight, ρ_m specified at the shoe. Again, the predicted value is not incorporated at all in pressure load calculations and the fracture gradient, ρ_{fg} (in ppg equivalent) must be entered by the designer. The equations for the methods are as follows:

Variable Overburden Gradient (psi/ft), VOBG

Poisson's ratio, γ

Depth of mudline, d_m

Water depth, d_w

Air gap, KB - d_w, AG

Eaton's method (the extension pressure. ...the initiation pressure is higher.)

D = fracture depth, d_f, in 1,000s of feet

$$VOBG = 0.84753 + 0.01494\,D - 0.0006\,D^2 + 1.199E\text{-}5\,D^3$$

$$\gamma = 0.23743 + 0.05945\,D - 0.00668\,D^2 + 0.00035\,D^3 - 6.71E\text{-}6\,D^4$$

$$\rho_{fg} = (VOBG - .052 * \rho_m) * \gamma / (1 - \gamma) + 0.052 * \rho_m + 100 / d_f$$

M. Traugott's method for soft rock

$p_{sw} = 8.7\text{ ppg} * 0.052 * d_w$ sea water pressure

$$VOBG = [p_{sw} + (\rho_m + 0.008 * (d - d_m)^{0.6} * (d - d_m) * 0.052] / (d * 0.052)$$

$$\gamma = 0.39 * (d - d_m)^{0.33}$$

$$\rho_{fg} = \gamma * (VOBG - \rho_m) + \rho_m$$

M. Traugott's method for soft rock, revised for water depth

$p_{sw} = 8.7\ \text{ppg} * 0.052 * d_w$ sea water pressure

$$VOBG = [p_{sw} + (\rho_m + 0.008 * (d + d_w - d_m)^{0.6} * (d + d_w - d_m) * 0.052] / (d * 0.052)$$

$$\gamma = 0.39 * [(d + d_w - d_m) / 2]^{0.33}$$

$$\rho_{fg} = \gamma * (VOBG - \rho_m) + \rho_m$$

M. Traugott's method for hard rock (assuming no sea water pressure or water depth)

$$VOBG = \rho_m + 0.008 * d^{0.6}$$

$$\gamma = 0.35$$

$$\rho_{fg} = \gamma * (VOBG - \rho_m) + \rho_m$$

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