2560

“Maximum Load” Casing Design

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Introduction

With increased drilling in areas where there are lost returns, abnormal formation pressures, and differential sticking problems, there is a great need for stronger, better designed casing. The attainable, optimum condition is to design casing to withstand these problem-imposed loads for the minimum cost.

To properly evaluate the loads imposed on different types of designs, each type should be considered separately. They are: (1) surface casing, (2) intermediate casing, (3) intermediate casing with a drilling liner, (4) drilling liners, and (5) production casing.

The loading for burst should be considered first, since burst will dictate the design for most of the string. Next, the collapse load should be evaluated and the string sections upgraded if necessary. Once the weights, grades and section lengths have been determined to satisfy burst and collapse loadings, the tension load can be evaluated. The tube can be upgraded as necessary, and the coupling types determined. The final step is a check on biaxial reductions in burst strength and collapse resistance caused by compression and tension loads, respectively. If these reductions show the strength of any part of the section to be less than the potential load, the section should again be upgraded.

By initially choosing the least expensive weights and grades of casing that will satisfy the burst loading, and upgrading only as called for by the prescribed sequence, the resulting design will be the most inexpensive possible that can fulfill the maximum loading requirements.

Design Procedure

The basic procedure applies, in its entirety, only to intermediate casing. The other types of design require variations that will be discussed later.

Burst

To evaluate the burst loading, the values of surface and bottom-hole burst limits must first be established. The surface burst pressure limit is arbitrary, and is generally set equal to the working pressure rating of the surface equipment used. (5,000 psi is used for illustrations.) The bottom-hole burst pressure can be calculated, and is equal to the predicted fracture gradient of the formation immediately below the casing shoe plus a safety factor. Since the value of fracture gradient is generally expressed in terms of mud weight, the recommended safety factor is 1.0 lb/gal. Thus the bottom-hole burst pressure, defined as the injection pressure, is equal to the fracture gradient expressed as mud weight plus the safety factor of 1.0 lb/gal, converted to pressure.

With the end points determined (surface and injection pressure), the maximum burst load line may now be constructed. Since the maximum load will occur when the end points are satisfied simultaneously, the loading will necessarily be provided by kick conditions. A characteristic of kick loading is the existence of two or more fluids in the borehole — the mud being drilled with at the time of the kick, and the influx fluid. Since we are dealing only with maximum loads,

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the fluids considered will be those with the heaviest mud weight projected for use below the casing string, and gas as the single influx fluid. The position of these fluids in the borehole is important (see Fig. 1). If the gas is considered to be on top, the load line will appear as the line labeled 1. If the positions are reversed so that mud is placed on top, the load line will be as illustrated by Line 2. It is evident by the amount of shaded area between the lines that the condition represented by Line 2 exerts the greater burst loading. Therefore the configuration indicating that the heaviest mud weight is at the top, gas is at the bottom, and the end points are satisfied simultaneously will constitute the maximum load line. Remaining to be determined is the length of the columns of mud and gas. By assuming a gradient for the gas (0.115 psi/ft), this may be accomplished by solving the following simultaneous equations.

$$x + y = D \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$\begin{aligned} p_s + xG_m + yG_g &= \text{Injection Pressure} \\ &= 0.052\,(\text{Fracture Gradient} \\ &\qquad + \text{S.F.})\,D \quad . \; . \; . \; . \; . \quad (2) \end{aligned}$$

where

x = length of mud column, ft
y = length of gas column, ft
D = setting depth of the casing, ft
p_s = surface pressure, psi
G_m = gradient of heaviest mud weight to be used, psi/ft
G_g = gradient of gas, assumed as 0.115 psi/ft
S.F. = safety factor, recommended as 1.0 lb/gal
0.052 = conversion factor (psi × gal/lb × ft)

and the fracture gradient is a calculated value in pounds per gallon.

With the simultaneous solution of the equations, the length of the respective columns of fluids becomes known, and the resulting load line is as illustrated in Fig. 2.

By referring to the graphical representation we can know the load acting to burst the casing at every increment of depth. A load resisting this burst, imposed by the fluid occupying the annular space behind the casing may also be calculated and applied. Because of the weight degradation of the fluid that is behind the casing and in contact with the formations (the backup fluid), it is to be assumed, in keeping with the maximum load concept, that backup is provided by a column of fluid equal in density to salt water (gradient = 0.465 psi/ft). By plotting this burst-resisting backup load, and subtracting it from the burst load line, the actual pressure load at each depth increment can be determined. This load is labeled "resultant burst load" in Fig. 3.

If a design factor is deemed necessary to allow for wear, it may be applied to the resultant burst load to obtain the design line. For illustrative purposes, a design factor of 1.1 is applied and the design line shown in Fig. 4 is created. If no design factor is necessary, the resultant burst load line becomes the design line.

Starting at either end of the design line, plot the published values of minimum yield for the least expensive weight and grade of casing that exceeds the design load. The section length is determined by intersection with the design line. The strength of the next applicable weight or grade can be plotted to intersection, and this procedure is repeated until the string is completely designed for burst.

If this procedure is rigidly adhered to, it is possible ultimately to have more sections than would be practical to handle in the field, particularly for offshore operations. For this reason, a compromise may be made between cost and practicality by restricting

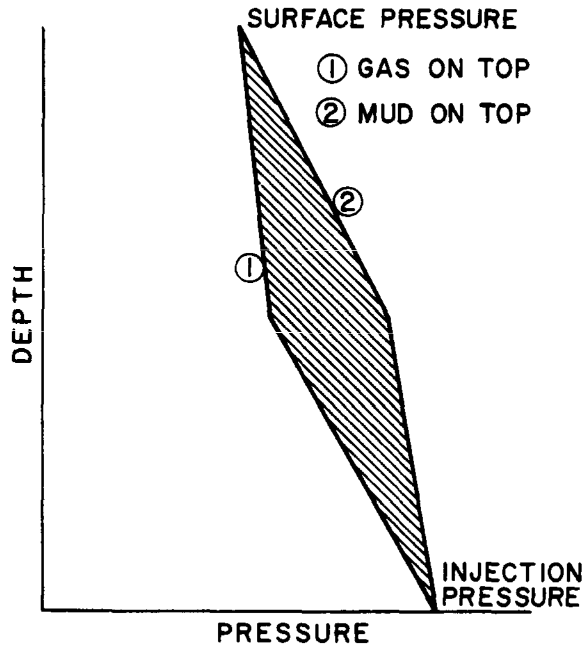

Fig. 1—Position of the load line relative to the positions of the fluids in the borehole.

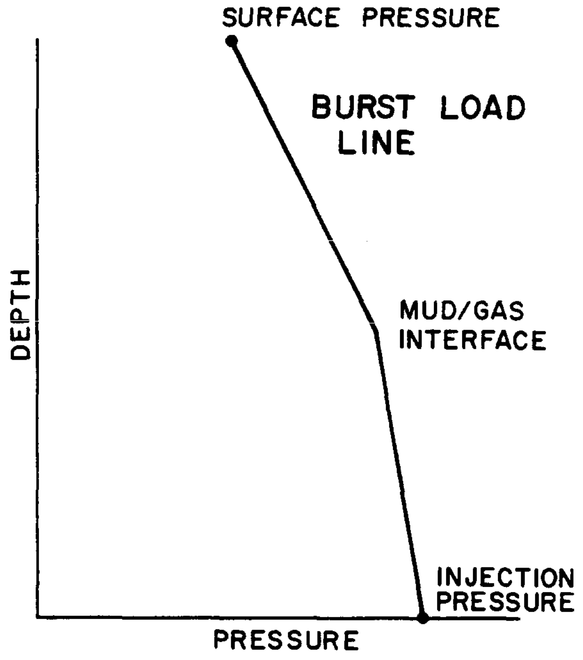

Fig. 2—Burst design.

the number of sections that would be allowed.

Upon completion of this phase, the designer will have the weights, grades and section lengths of the casing that will satisfy the burst loading. This tentative design is set aside pending evaluation of the collapse loading.

Collapse

The collapse load for intermediate casing is imposed by the fluid in the annular space, assumed to be the heaviest mud weight that it is expected the string will be run in. An ambiguity lies in the fact that in considering the burst loading, the density of the fluid behind the casing was taken as minimal (0.465 psi/ft salt water). If the precepts of maximum load are to be followed, however, no other assumption is valid (see Fig. 5).

The backup fluid for collapse considerations also adheres to the maximum load concept. The maximum collapse loading will occur when attendant with loss of circulation, the mud level inside the casing drops. At the intermediate casing shoe it is improbable that the hydrostatic pressure exerted by the reduced mud column would be less than that exerted by a full column of salt water. Experience with maximum loading design indicates that only the lower sections of the string will be affected by collapse considerations; therefore, using a full column of salt water as the backup fluid is valid.

By constructing the backup line and subtracting it from the load line, a resultant collapse load line may be defined (Fig. 6).

Application of a 1.1 design factor for collapse results in the collapse design line illustrated in Fig. 7. Should no design factor be applied, the resultant collapse load line becomes the collapse design line.

On the graphical representation of the collapse design line, the collapse resistances of the sections

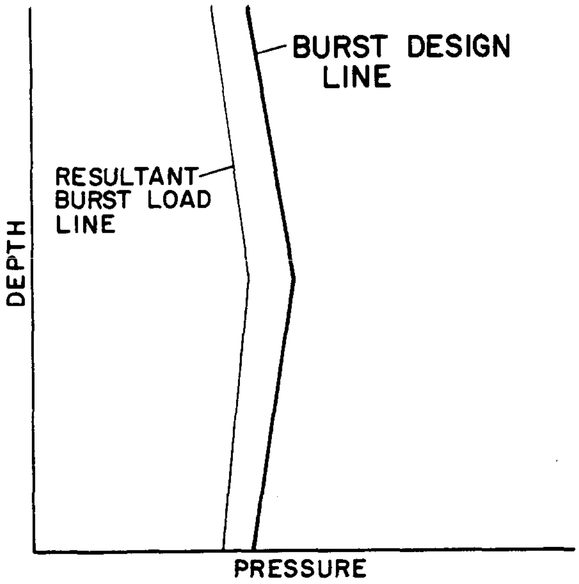

Fig. 4A—Burst design.

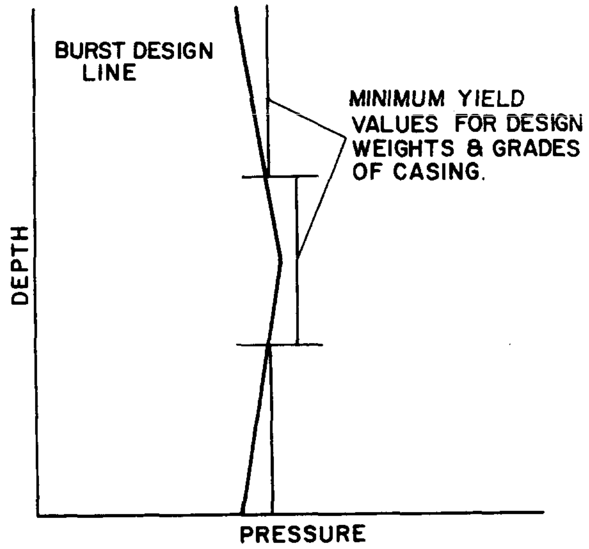

Fig. 4B—Burst design.

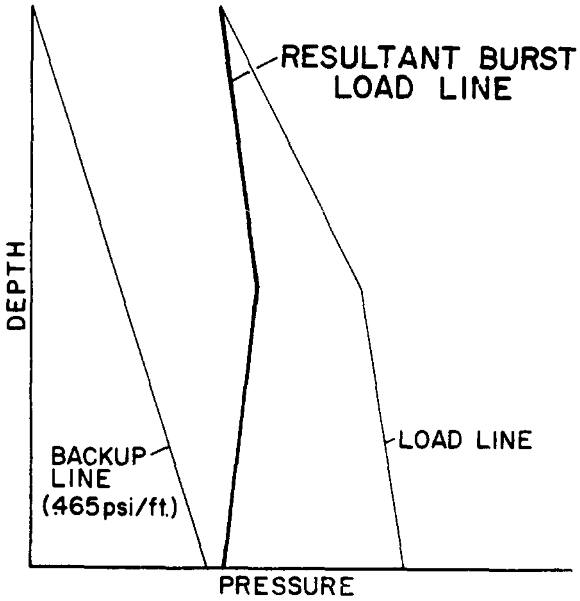

Fig. 3—Burst design.

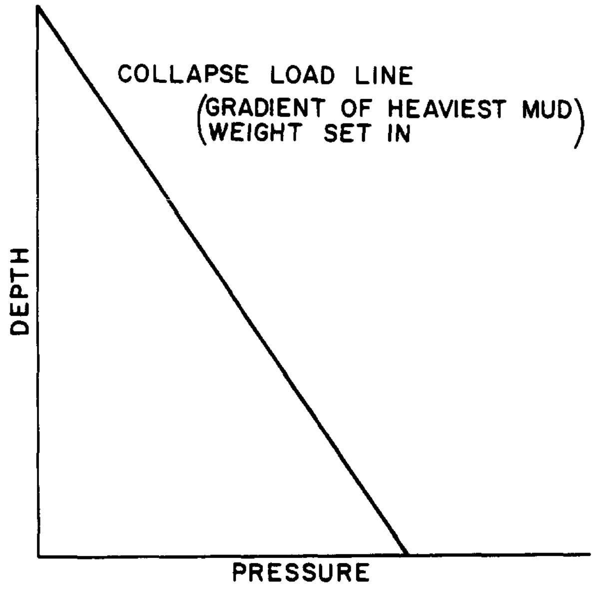

Fig. 5—Collapse design.

dictated by burst considerations should now be plotted and checked. Should the collapse resistances fall below the collapse design line, the section should be upgraded for collapse. When the checking and necessary upgrading are completed, the result is a design for weights, grades, and section lengths that satisfies the burst and collapse maximum loads.

Tension

Knowing the weights, grades, and section lengths based on burst and collapse design, the tension load (both positive and negative) can be evaluated.

Buoyancy has been omitted in some casing designs in the past for various reasons. Because of the way in which the buoyant force is applied to a casing string, burst and collapse resistances are altered by the effect of biaxial stresses. For this reason buoyancy cannot be overlooked in a maximum load design. The effect of buoyancy is commonly thought to be the reduction in the weight of the string when it is run in liquid as compared with the weight when it is run in air. However, no allowance is made for the way the buoyant force is applied to the casing. The buoyancy, or reduction in string weight, as noted on the surface is actually the result of forces acting on all the exposed horizontally oriented areas of the casing string. The forces are equal to the hydrostatic pressure at each depth times the number of exposed areas, and are defined as negative if acting upward. The areas referred to are the tube end areas, the shoulders at points of changing casing weights, and, to a small degree, the shoulders on collars.

Fig. 8 shows the forces acting at each exposed area of a casing string, with the resultant loading indicated as negative tension (compression). (The forces acting on the areas of collar shoulders are for practical purposes negligible in casing design.)

The reduction in hook load at the surface is the same as that determined either by using the "buoyancy factor" method, or by calculating the weight of the displaced liquid of known density and subtracting it from the dry weight. However, the tension loadings differ greatly.

Once the magnitude and location of the forces are determined, the tension load line may be constructed graphically (Fig. 9). It is noteworthy that more than one section of the casing string may be loaded in compression.

To obtain a design line for tension, it is recommended that a design factor be used with a conditional minimum overpull value included. The recom-

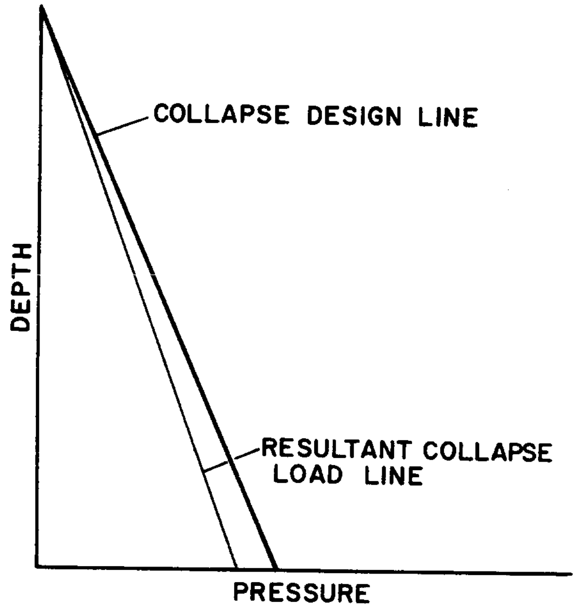

Fig. 7A—Collapse design.

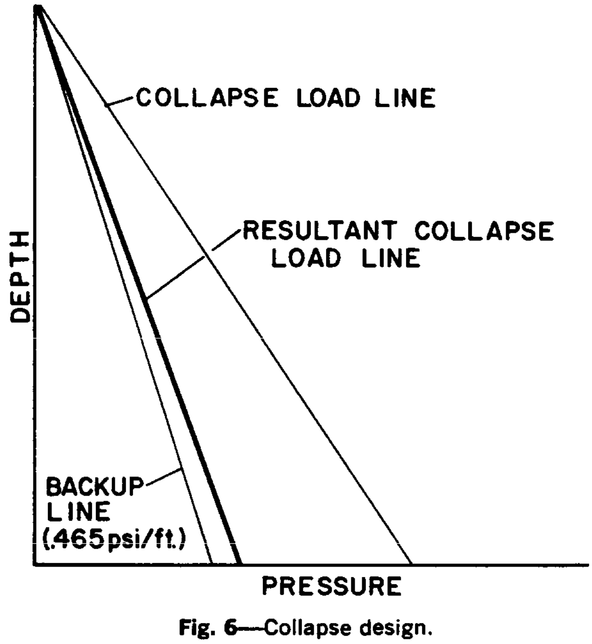

Fig. 6—Collapse design.

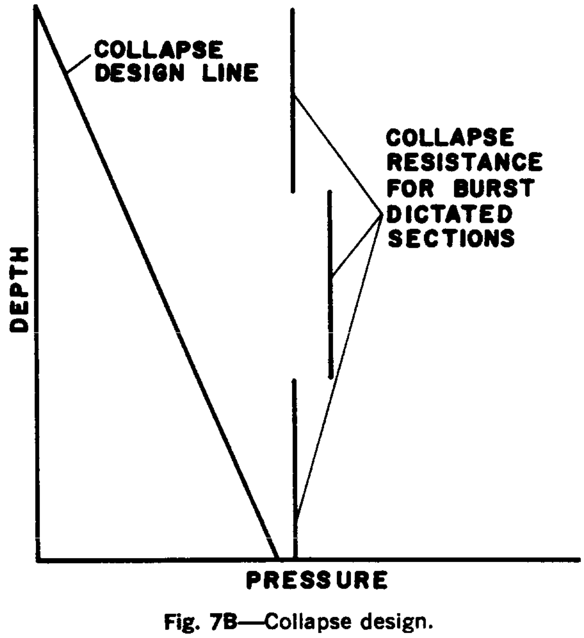

Fig. 7B—Collapse design.

mended values for the safety factors are 1.6 for the design factor or 50,000 lb of overpull, whichever is greater. This is a compromise with the Goins *et al.* "Marginal Loading" concept,[2] and allows for safely pulling on stuck casing to some definite predetermined value (50,000 lb in this case).

The graphical representation of this combination of design factors is shown in Fig. 10, and is labeled the "tension design line".

With few exceptions, the weakest part of a joint of casing in tension is the coupling; therefore, the tension design line is used primarily to determine the type of coupling to be used. The least expensive coupling strengths that satisfy the design can be plotted, and the proper couplings determined (Fig. 11).

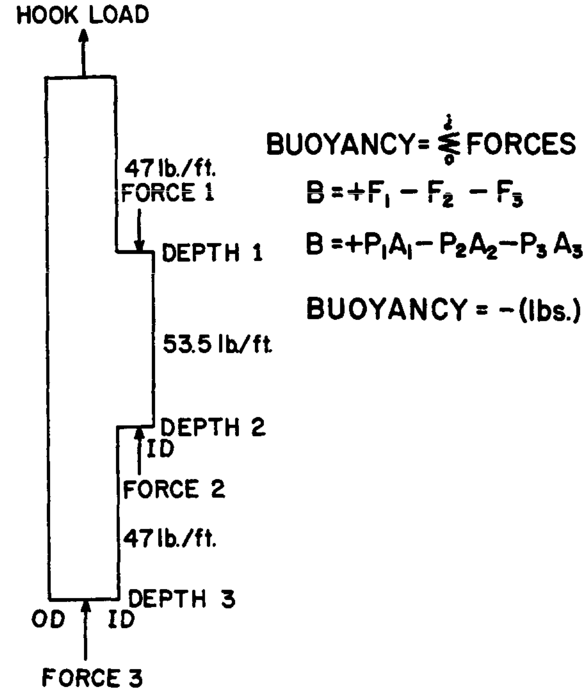

Fig. 8—Effect of buoyancy.

At this point the entire string is designed for burst, collapse and tension, and the weights, grades, section lengths, and coupling types are known. Remaining to be checked is the reduction in burst resistance and collapse resistance caused by biaxial loading.

The tension load line, which shows tension loading vs depth, is used to evaluate the effect of biaxial loading (Fig. 9). By noting the magnitude of plus (tension) or minus (compression) loads at the top and bottom of each section, the strength reductions can be calculated using the Holmquist and Nadai[3] ellipse. With the reduced values known at the end of each section, a new strength line can be constructed by connecting the end points with a straight line. Should the reduced values indicate an underdesign, the section should be upgraded.

Variations of Procedure

As previously mentioned, only the intermediate casing design follows the outlined procedure in its entirety. The following are variations that are used for the other four types of casing design.

Surface Casing Design

Burst

Because of the relatively low injection pressures associated with surface casing, a surface pressure limit can be disregarded. In designing for burst, the injection pressure at the casing shoe is determined and a column of gas back to the surface is assumed (Fig. 12). Thus, rather than a set limit, the pressure at the surface will be equal to the injection pressure less the hydrostatic pressure of a column of gas (0.115 psi/ft). The procedure for determining section, weight, and grade of surface casing is the same as that used for determining them for intermediate casing.

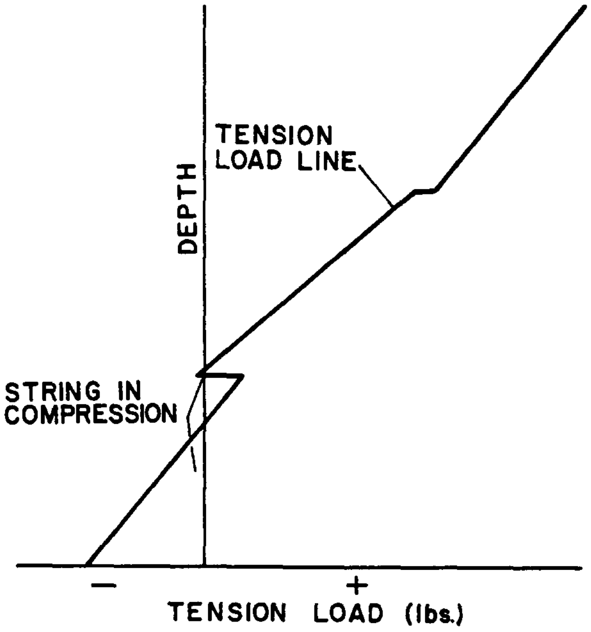

Fig. 9—Tension design.

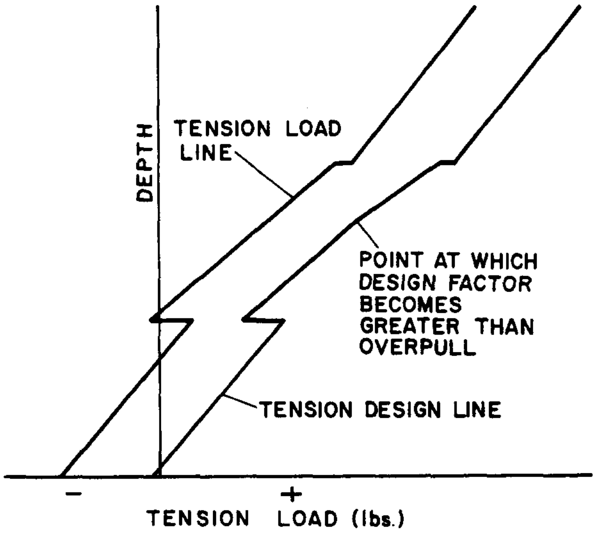

Fig. 10—Tension design.

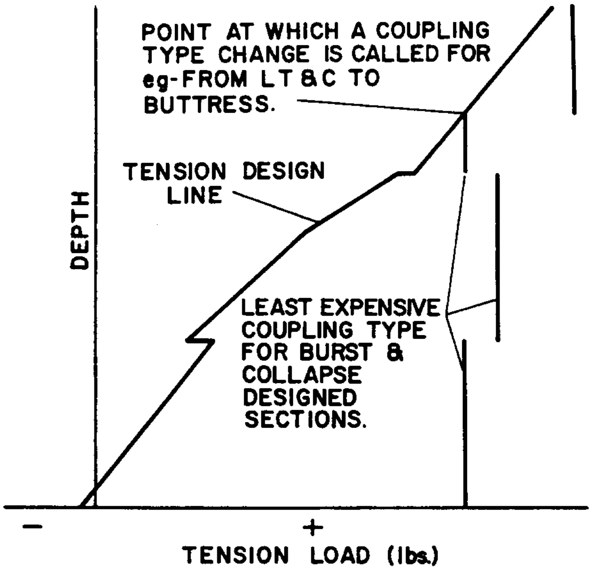

Fig. 11—Tension design.

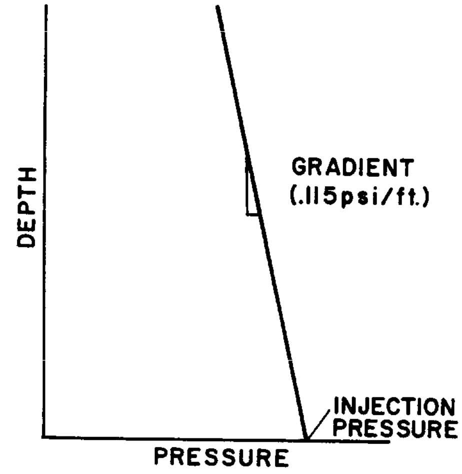

Fig. 12—Surface casing burst design.

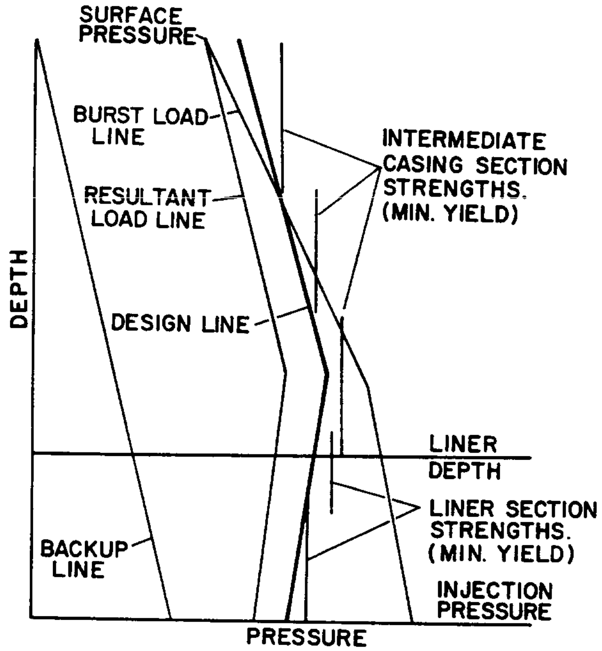

Fig. 13—Intermediate casing and drilling liner burst design.

Collapse

Because of the possibility that lost returns will allow the fluid level to fall below the surface casing shoe, no backup load is applied to collapse loading. The load line with a design factor applied becomes the design line. The design line for the burst-dictated sections is checked the same way for surface casings as it is for intermediate casing.

The tension and biaxial reduction calculations are as outlined previously.

Intermediate Casing and Liner

Burst

If a drilling liner is to be included in the drilling of a well, the design of the intermediate casing string is altered slightly.

Since the injection pressure and heaviest mud weight will be greater below the liner, these values are used to design the intermediate string as well as the liner. The procedure for evaluation remains the same. A surface pressure limit is decided upon. The injection pressure at the liner shoe is calculated, and the load line developed just as in the intermediate string design. The backup fluid is salt water, and the resultant loading is defined as before. A design factor can be applied to the resultant load to obtain the design line. This design line is used to design both the intermediate casing and the liner for burst (Fig. 13).

Collapse, tension and biaxial loading remain the same as previously discussed.

Production Casing

Burst

The burst design for production casing involves several assumptions that warrant discussion. One of the assumptions is that the density of the packer fluid is

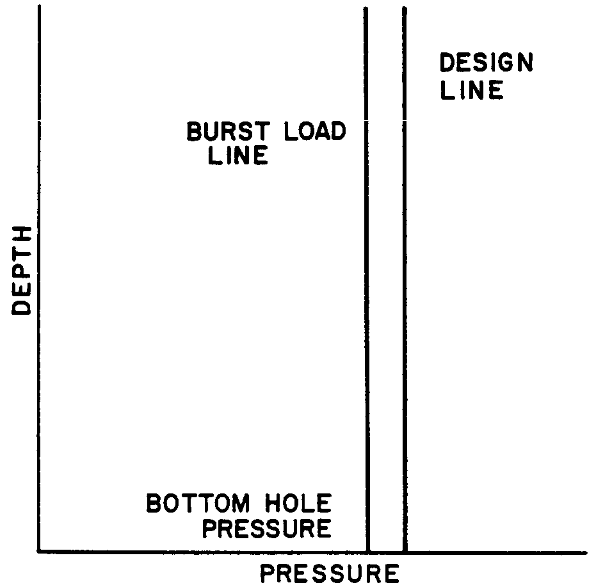

Fig. 14—Production casing burst design.

equal to the weight of the mud in the annular space behind the casing (the mud the string was run in). This is not strictly in keeping with maximum loading considerations and makes a good case for using lightweight packer fluids. The result of this assumption is that the effects of the load and of the backup fluids cancel each other, and at this point the casing has no burst load or backup.

The second assumption is that there is a tubing leak near the surface, with the result that surface tubing pressure is introduced as a burst load over the entire length of the production casing. The surface tubing pressure used for this calculation can be predicted either from offset data, measured pressures from tests, or by log interpretation.

As may have been noted, the fracture gradient and the injection pressure are not used to design production casing.

A design factor is applied to the load line, resulting in a design line (Fig. 14), and the design for burst can proceed as previously discussed.

Collapse

Owing to the possibility of tubing leaks, artificial lift, and plugged perforations, the collapse design for production casing incorporates no consideration for backup fluid. The string is designed dry inside. The collapse load is supplied by the hydrostatic pressure of the heaviest mud weight the string is to be run in, and the design factor is applied directly to this load. The resulting design line is used as in the other types of design to check and upgrade the burst design as necessary. The tension and biaxial reductions are evaluated as previously outlined.

Summary

Although this method of designing casing is presented in a general manner, it should be recognized that the considerations and assumptions applied are based on Gulf Coast conditions. Other areas should be evaluated for specific needs before "maximum load" techniques are applied.

In the procedure outlined, no consideration is given to designing casing for buckling loads caused by deviated holes. This is a special design problem that is well covered in the existing literature.

Acknowledgment

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