Technical Report on Temperature Derating on API Flanges Under Combination of Loading

API TR 6AF1
SECOND EDITION, NOVEMBER 1998

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Exploration and Production Department

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FOREWORD

This Technical Report is under the jurisdiction of the API Subcommittee on Valves and Wellhead Equipment. The first edition was issued as an API Bulletin in 1991, was reaffirmed in 1997 with editorial changes, and was reissued as a Technical Report.

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Technical Report on Temperature Derating of API Flanges Under Combination of Loading

1 Scope

This report is a continuation to the report on the capabilities of flanges under combined loadings (PRAC 86-21)[2] which resulted in the publication of API Bulletin 6AF.[4] Included herein is an in-depth look into the effect of elevated temperatures on API flanges.

The results in this report are analytical and assume a temperature gradient across the flange as stated in this report. When the flange is insulated on the outside surface, the allowable loads will be higher.

Additional finite element models of five new flanges in API 6A, Sixteenth Edition, 1989, which were not in the 1986 Fifteenth Edition, used as a basis for the earlier work, were developed for the combined loading of bolt makeup, internal pressure, tension and bending moment. The API materials were then grouped into four material categories. A thermal analysis was performed (using all 63 axisymmetric finite element models of PRAC 86-21[2] and the 5 new models) to determine the temperature gradient and resulting thermal stresses at steady state for all four material types at design bore temperatures of 350°F and 650°F.

The post-processor program of PRAC 86-21[2] (calculating the maximum moment capacity for various levels of pressure and tension based on superposition) was partly modified to include thermal effects and produce separate rating curves on the same chart, based on the leak or loss of preload (on the ring joint) criterion and the stress criteria. The stress criteria used were of two types: a) ASME Section VIII, Division 2, allowable stress categories for the flange with the basic membrane stress allowable established by API, and b) allowable bolt stresses as established by API. The results of this post-processing are presented in plots of pressure vs. allowable moment for various tension levels. These new rating charts were developed at two elevated temperatures for all four material categories in Appendices A, B, C, and D respectively.

See Section 4 for details of the axisymmetric analysis and Section 5 for details of the load capacity calculations.

As in the previous report PRAC 86-21[2], this report does not address the actual gasket contact loads required to make a seal. This report utilizes the leak or loss of preload (on the ring joint) criterion as in Bull 6AF[4] (PRAC 86-21) and Bull 6AF2[5] (PRAC 88-21)[6] and not the leakage criteria in report PN 90-21.[7]

2 References

This Technical Report references the following research reports and publications:

1. *Temperature Derating of API Flanges Under Combinations of Loading,* PRAC 89-21, by Andreas T. Katsousnas, Joe R. Fowler, Stress Engineering Services, Inc., Report prepared for API, December 1989.

2. *Capabilities of API Flanges Under Combinations of Loading,* PRAC 86-21, by K. C. Walker, Joe R. Fowler, Stress Engineering Services, Inc., Report prepared for API, October 1987.

3. API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment,* Sixteenth Edition, October 1, 1989.

4. API Bulletin 6AF, *Capabilities of API integral Flanges Under Combination of Load,* First Edition, April 1, 1989.

5. API Bulletin 6AF2, *Capabilities of API Integral Flanges Under Combinations of Loading,* First Edition, January 1, 1993.

6. *Capabilities of API Integral Flanges Under Combinations of Loading,* PRAC 88-21, by G. A. Ghoneim, K. H. Haverty, Veritas Marine Services (USA), Inc., Report prepared for API, December 1990.

7. *Sealability of API R, RX, & BX Ring Gaskets,* PN 90-21, by Joe R. Fowler, Stress Engineering Services, Inc., Report prepared for API, January 1994.

8. ASME *Boiler and Pressure Vessel Code,* Section VIII.

9. ASME *Boiler and Pressure Vessel Code,* Section III.

10. ANSI B1.1, *Unified Standard Inch Screw Threads,* 1974.

11. Frank Kreith. *Principles of Heat Transfer,* Scranton, Pennsylvania, 1965.

3 Introduction to Rating Charts

3.1 INTRODUCTION AND SCOPE

The publication of the API Bulletin 6AF (resulting from PRAC 86-21) with load ratings corresponding to a combination of loadings provided an improved method of flange design as compared to traditional, more conservative methods, such as designing for pressure loads only. The previous work, on the determination of rating charts for API 6B and 6BX flanges, did not consider the effects of temperatures higher than 250°F. Determination of the effects of temperatures from 350°F–650°F, on four different flange and bolt material combinations, is the topic of this Technical Report. The effects of temperatures on load capacity are primarily in two areas. First, the yield strength—and thus allowable stresses—of the flange and bolt materials may change at these elevated temperatures. Second, thermal gradients across the flange and between the bolts and flange can cause thermal stresses, which must be considered when developing allowable loads.

Similar to the analysis done on the 69 previous flange geometries of API Bulletin 6AF, the five new flanges added to the new API 6A, Sixteenth Edition, were analyzed with four different load conditions: Makeup, Pressure, Tension, and Moment. The resulting capacity charts are presented in Appendix E. The six 30,000 psi 6BX flanges (not currently used) and the four 6B flanges (2,000 psi $3^5/_8$, $16^3/_4$, $21^1/_4$, 3,000 psi $13^5/_8$ which did not meet allowables when subject to makeup load case only) were excluded from the thermal analysis. The new 64 flange set was then subjected to thermal gradients. Two different bore temperatures were selected (350°F and 650°F) while the outside temperature was selected to be 32°F.

Heat transfer on the outside surface of the flange was modeled by a convection film with convection coefficient equal to ten Btu/hr ft^2 °F with an outside surface temperature of 32°F.

Bolt bending stresses were excluded from consideration despite being calculated in the previous study. Modeling of bolts and nuts is such that the bolt as a whole follows the deflected shape of the flange. The simplicity of this idealation does not exactly reflect the bending behavior of bolts. The modeling is sufficient, though, for axial bolt stress which was considered.

To simplify the results, the yield strength of bolts was derated as if the bolt temperature were the same as the corresponding bore temperature. This is a conservative assumption since the actual temperature of the bolt will always be lower than the bore temperature.

There are several limitations to this work which should be understood. First, no transverse shear or torsion effects were considered. Second, the results are for static loading only. No dynamic, fatigue, corrosion, or fretting phenomena were considered for this Technical Report.

Finally, these charts are not intended to replace a critical evaluation of any particular connection in an application where the charts show the flange to be marginal. The charts are intended to be used only as a general guideline for design. The conditions under which these flanges may leak have not been thoroughly defined. If the flanges are not made up to the bolt loads specified, the results will not be as predicted by the charts.

3.2 MATERIAL CATEGORIES

The material properties required for a thermal analysis are the thermal conductivity and specific heat. These properties are temperature-dependent. The material properties used in the thermal stress analysis (modulus of elasticity and coefficient of thermal expansion) are also temperature-dependent.

API materials were grouped into a total of four material categories. The grouping of materials considered, among others, the variations in the above material properties. Three different flange materials were combined with two different bolting materials as shown on Table 1. API minimum yield strengths were used for flanges; while derating at elevated temperatures was applied according to Table 1 (derated from ambient temperature yield at 72°F). The properties for both bolts and flanges, as well as the yield strength of bolts, were derated according to the ASME *Boiler and Pressure Vessel Code* (see Table 2).

3.3 FLANGE COMBINED LOAD CAPACITIES

The plotted results for the combined load capacity of each flange analyzed in this project are given in Appendices A, B, C, and D. The rating charts for each material category are presented in a separate Appendix. The results for each category are arranged in the same order as found in API 6A, first at 350°F and then at 650°F. The 6B flanges are first, followed by 6BX flanges. For each flange style the results are given in order of increasing diameter within each working pressure rating. (Thus, the $21^1/_4$" 2,000 psi 6B flange is before the $2^1/_{16}$" 3,000 psi 6B flange; and the 11" 5,000 psi 6B flange is before the $26^3/_4$" 2,000 psi 6BX flange.)

For the first two material categories (Appendices A and B) combined load ratings were determined for each flange with two different bolt makeup stresses. The first rating was determined for bolts made up to 52.5 ksi, and the second rating was done for a makeup stress of 40 ksi. The two plots are given on the same page to help evaluate the effect of a reduced preload on a flange's bending capacity. For each of the first two material categories, two separate sets of plots are provided at 350°F and at 650°F.

For the last two material categories (Appendices C and D) combined load ratings were determined for each flange with only one bolt makeup stress. The rating charts were determined for bolts made up to 42.5 ksi. Therefore, the charts for the two temperature ratings are provided in the same plot. Bolt makeup is taken as half the yield strength of the bolts.

To assist the user in better understanding the rating charts, a table of controlling criteria has been established (see Table 6). Each identification number corresponds to a separate stress condition. Also included in the table is ID=11, which denotes leak/loss of preload. The controlling capacity curve with ID=11 is shown in the rating charts with a continuous line. Therefore, only the identification of the controlling stress criteria will be shown in the rating charts.

When studying these results, one should keep in mind that for a particular flange the moment capacity based on leak/loss of preload criteria is assumed to not be affected by temperature variations; thus no difference exists between material categories or between temperatures within a material category. This assumption was made because, in general, the thermal boundary conditions chosen result in the flanged-joint preload increasing, due to temperature. This increase, if accounted for, would allow higher moments for the leak criterion. However, if

Table 1—List of Materials

	Material Category	Flange	Bolts	Derating Factors	
				350°F	650°F
A	Carbon and Low Alloy Steels	4130 CR-1/5 Mo	SA 193 B7 or SA 193 B7M Cr-1/5 Mo	0.85	0.75
B	Martensitic, Ferritic and Precipitation Hardening Stainless Steels	410SS 13 Cr	SA 193 B7 or SA 193 B7M Cr-1/5 Mo	0.85	0.75
C	Austenitic and Duplex Stainless Steels	Ferralium-255 S-32550	SA 453 Gr 660 (A286) 26Ni-15Cr-2Ti	0.80	0.73
D	Carbon and Low Alloy Steels	4130 Cr-1/5 Mo	SA 453 Cr 660 (A286) 26Ni-15Cr-2Ti	0.85	0.75

the thermal boundary conditions are not as severe, then accounting for thermal preload increase is unconservative.

On the other hand, leak/loss of preload is affected by bolt makeup. In addition, when primary loads (without makeup) control, the moment capacity—based on stress criteria—is the same for any material category with the same flange material (compare material categories A and D at equal temperatures). The latest observation (when primary loads control) is also true for flanges made up of different flange material but with the same yield strength derating factors (compare material categories A and B at equal temperatures). When reviewing the rating charts, note that the moment capacity range is kept the same as in API Bulletin 6AF so as to aid comparison between rating charts.

Material category A was dominated by bolt stresses (controlling condition ID=12), especially at 650°F. No significant capacity, if any, exists for 6BX flanges larger than 9" in size (5,000 psi and above) but the same is not true for 6B flanges. This is because the bolt allowable stress is exceeded by makeup plus thermal stress alone for several flanges. This is a direct result of lower bolt stresses on 6B flanges, as compared to 6BX flanges, due to temperature-loading. The variation is attributed to differences in geometry and the levels of maximum working pressure between the two types of flanges. However, the results for 2,000 psi and 3,000 psi of 6BX flange at 650°F require some further explanation. An increase in pressure (at low levels of bore pressure) results in higher moment capacity. Due to the geometry of these 6BX flanges and the majority of 6B flanges, pressure-loading results in some preload loss. The large diameter flanges rotate towards each other enough under load that bolt stresses due to pressure actually decrease. Therefore, with the preload-reducing, higher capacity is expected when bolt-stress criteria control. Also note that a total of six 6B flanges (one 2,000 psi, and one larger size, 3,000 psi) exhibit higher capacities at lower bolt makeup at 650°F. Thermal stresses, plus makeup, plus stresses control (ID=202) for higher bolt makeup; while pressure, tension, and moment control for 40 ksi makeup. At 650°F, the six smaller size 10,000 psi 6B flange rating charts level off at pressures close to the maximum working pressure. In all cases, the controlling condition is ID=1 for both slopes, meaning stresses control at section 1.1. No distinction is made between membrane and membrane-plus-bending controlling. It so happens that for these flanges, membrane and membrane-plus-bending control at different levels for the same section.

At 350°F, no significant differences exist between material categories A and B. At this temperature, the moment capacity based on stress criteria controls over leak/loss of preload criteria for several flanges. Flange stresses control at smaller size flanges (10,000 psi up to $7^1/_{16}$, 15,000 psi up to $4^1/_{16}$, 2,000 psi and 3,000 psi up to $4^1/_{16}$ and all 5,000 psi 6B flanges). Stress criteria control for larger flanges when the controlling stress criteria is the bolt stress criteria. At 650°F, 6BX flanges made up of material categories A and B behave differently. This is because of lower bolt stress of category B caused by the lower thermal conductivity of material B, hence higher moment capacity. When bolt stresses or thermal gradient do not control, the two materials have exactly the same capacity (almost all 6B flanges).

Material categories C and D generally exhibit higher capacity capabilities than categories A and B. The comparison between the two sets of categories is better accomplished through a comparison of material categories A and D since they have the same flange material. Comparing bolt makeup of 40 ksi and 42.5 ksi for A and D respectively, leak/loss of preload gives slightly higher capacity for material D (due to difference in bolt makeup). Material category D has higher capacity based on stress criteria, since bolt-stress criteria almost never control. This was not true for material A, which

Table 2—Derated Values of Material Properties

	Temperature	Carbon and Low Alloy Steels		Martensitic, Ferritic and Precipitation Hardening Stainless Steel		Austenitic and Duplex Stainless Steels[f]		Carbon and Low Alloy Steels[g]	
	°F	Flange	Bolts	Flange	Bolts	Flange	Bolts	Flange	Bolts
		60.0		60.0		60.0		60.0	
	70		80.0		80.0		85.0		85.0
			105.0		105.0				
		75.0		75.0		75.0		75.0	
		51.0		51.0		48.0		51.0	
Yield Strength[a] psi x 10^3	350[e]		70.7		70.7		81.8		81.8
			92.8		92.8				
		63.8		63.8		60.0		63.8	
		45.0		45.0		43.8		45.0	
	650[e]		63.1		63.1		80.6		80.6
			82.8		82.8				
		56.2		56.2		54.8		56.2	
Coefficients of Thermal Conductivity[b] BTU/hr ft^2 °F	70	24.2	24.2	15.2	24.2	7.8	7.5	24.2	7.5
	350	24.0	24.0	15.7	24.0	9.6	9.0	24.0	9.0
	650	22.3	22.3	15.9	22.3	11.5	10.4	22.3	10.4
Moduli of Elasticity[c] psi x 10^6	70	29.7	29.7	29.2	29.7	30.5	28.3	29.7	28.3
	350	28.2	28.2	27.6	28.2	29.0	26.8	28.2	26.8
	650	26.6	26.6	25.8	26.6	27.0	25.1	26.6	25.1
Coefficients of Thermal Expansion[d] in./in. x 10^{-6}/°F	70	5.73	5.73	5.98	5.73	6.10	8.24	5.73	8.24
	350	6.59	6.59	6.35	6.59	6.40	8.62	6.59	8.62
	650	7.40	7.40	6.57	7.40	6.75	9.00	7.40	9.00

Notes:
[a]API.
[b]ASME *Boiler and Pressure Vessel Code*, Sec. VIII, 1986, Table 1.
[c]ASME *Boiler and Pressure Vessel Code*, Sec. VIII, 1986 Table AMG-2.
[d]ASME *Boiler and Pressure Vessel Code*, Sec. VIII, 1986 Table AMG-1.
[e]API Proposed Change, Table G2.
[f]Cabot Corporation.
[g]ASME *Boiler and Pressure Vessel Code*, Sec. III, App., 1983.

was dominated by bolt stresses. This is evident, considering the difference in derated bolt yield strength allowables of 52.4 ksi for A and 66.9 ksi for D (0.83 factor also included). The A286 bolts do not derate as much as the SA193 B7 and SA193 B7M bolts at elevated temperatures. As noted previously, bolt temperatures were taken conservatively at 650°F rather than using their actual temperature. Using the actual temperatures would definitely improve the capacity capabilities of category A and B flanges.

3.4 USE OF RATING CHARTS

An explanation of the proper use of the plotted results in Appendices A, B, C and D is given below. Also, a procedure to use in evaluating a flange for a particular combination of loads is outlined to aid those who will be using these results. Figure 1 is reproduced from Appendix A for the $3^1/_{16}$" 10,000 psi 6BX flange at 350°F for reference in the discussion below.

The plotted results given in Appendices A, B, C and D show limiting load combinations of temperature, makeup, pressure, tension, and moment. The results are based on the stress criteria (shown with dashed lines) as well as leak criteria (shown with continuous lines) that controls at each load combination. Some curves have a "knee" in them, when the controlling criteria changes from a flange-stress limitation to a bolt-stress limitation, or even within the same flange-stress limitation. Thus, the minimum capacity of a flange can be derived, based on both leak control and stress control, if the

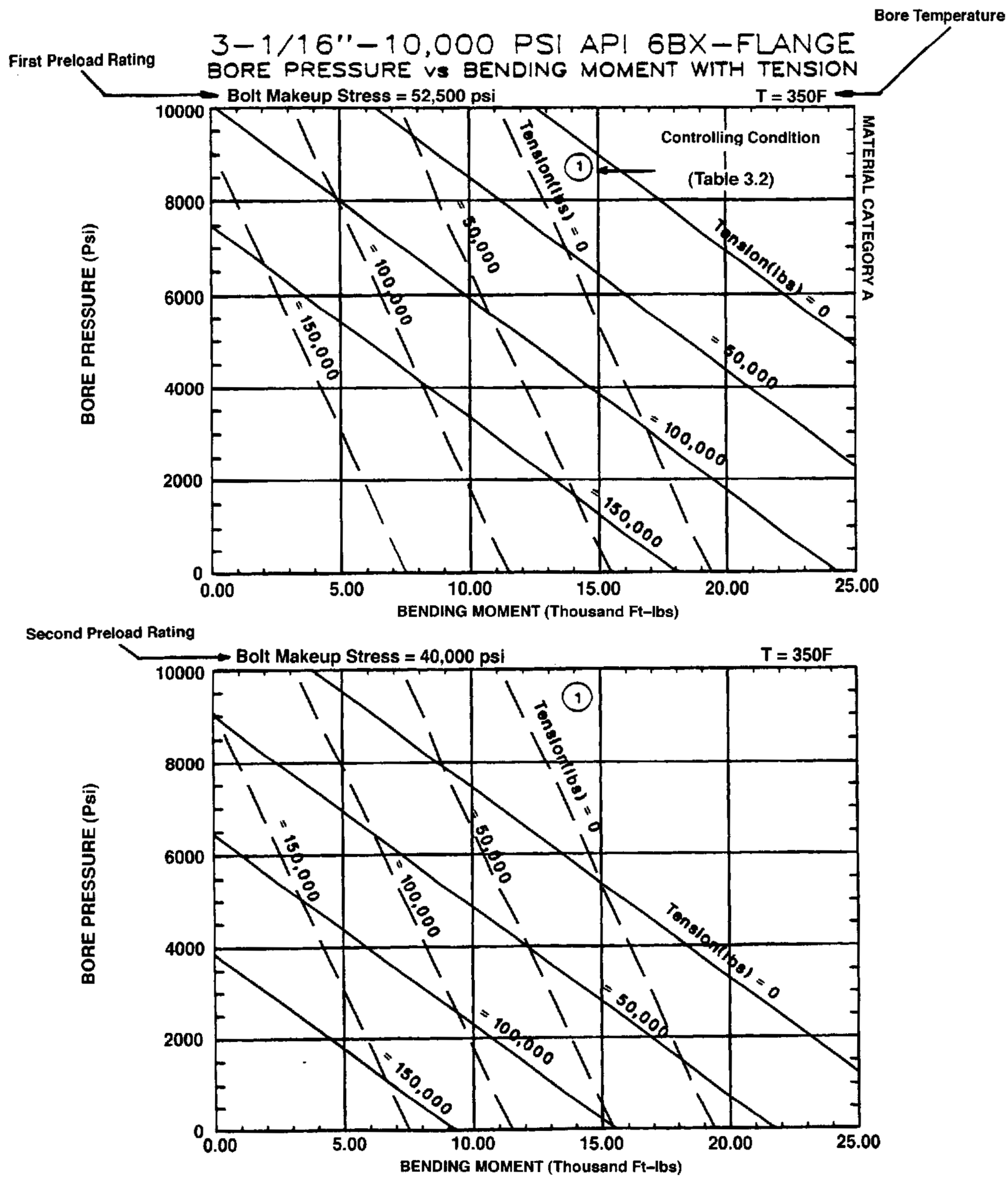


Figure 1—Typical Combined Load Capacity Results

user is concerned about leakage. Otherwise, the user can base his design only on stress criteria.

The steps outlined below are provided to simplify the use of the curves to evaluate a particular flange.

1. Establish magnitude of each load condition.
   a. Bolt makeup stress (52.5, 42.5 or 40 ksi).
   b. Pressure (psi).
   c. Tension (lb).
   d. Moment (ft-lb).
   e. Bore temperature (°F).

(Remember, the pressure load condition includes the tension due to the pressure end load, so if no other tensile loads are present, the Tension = 0 lb curve should be used.)

2. Determine appropriate material category.

3. Determine flange load capacity.
   a. Pick appropriate figure based on material, bore temperature, and makeup desired.
   b. Determine if leak/loss of preload is of concern. If not, ignore continuous line in figures. If leak/loss of preload is of concern, use minimum of continuous and dashed lines.
   c. Enter figure from left side with Pressure.
   d. Move to right to find required Moment.
   e. Intersection is point that defines Max Tension rating.
   f. Interpolate between lines to get Max Tension rating.

4. Evaluation
   a. If the Max Tension rating is greater than the required tension, the flange is satisfactory for the intended use based on the axisymmetric analysis.
   b. If the Max Tension rating is less than the required tension, the flange cannot carry the desired load combination, based on the axisymmetric analysis. The pressure, tension, or moment will have to be reduced, or in some cases, increasing the bolt makeup from 40 ksi to 52.5 ksi will help. If these changes are not acceptable, a more refined stress analysis will be required.

Example 1

Using the $3^{1}/_{16}$" 10,000 psi 6BX flange as an example, check the load rating for the following combination of loads:

a. Bolt Makeup Stress = 52.5 ksi.
b. Pressure = 10,000 psi.
c. Tension = 0 lb.
d. Moment = 5,000 ft-lb.
e. Temperature= 350°F.

Reading from Figure 2 and considering leak/loss of preload as well as stress criteria, the Max Tension rating for this Pressure/Moment combination is:

Max Tension rating = 61,000 lb
(same as previous report PRAC 86-21[2])

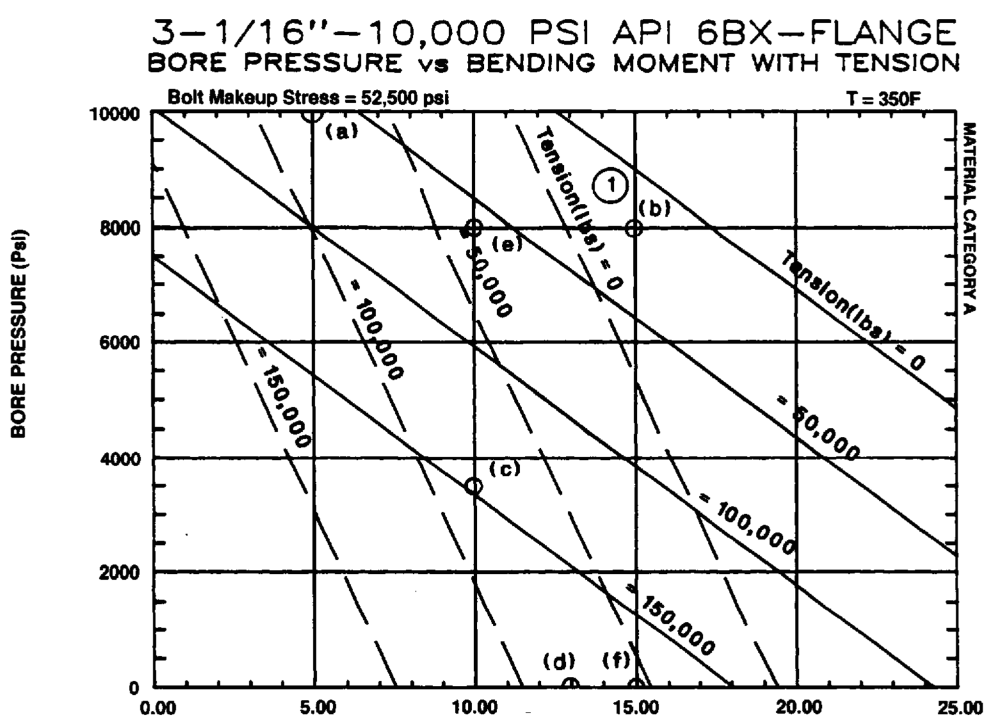


Figure 2—Load Capacity Results to Use with Example Problems

Since the required Tension is 0 lbs, the flange is okay.

Example 2

For the same flange, check the following combination:

a. Bolt Makeup Stress =52.5 ksi.
b. Pressure =8,000 psi.
c. Tension =80,000 lb.
d. Moment =15,000 ft-lb.
e. Temperature =350°F.

Reading from Figure 15, the Max Tension rating for this Pressure/Moment combination is:

Max Tension rating = 0 lb

Since the required Tension is 80,000 lb, the flange is not adequate for this application. Possible lower combinations for this example were recommended in PRAC 86-21.[2] Because of reduced capacity at 350°F, the maximum tension that can be carried (for Pressure = 0 psi) is:

Max Tension rating = 55,000 lb

Therefore, the moment applied on the flange has to be reduced at least to 13,000 ft-lb to be able to carry 80,000 lb tension.

Example 3

Reconsider the above flange with the applied moment equal to 10,000 ft-lb. Possible lower combinations to satisfy the tension or the pressure are:

a. Reduced Tension:

P = 8,000 psi, T = 33,000 lb, M = 10,000 ft-lb

b. Reduced Pressure:

P = 3,600 psi, T = 80,000 lb, M = 10,000 ft-lb

4 Axisymmetric Finite Element Analysis

4.1 INTRODUCTION

The task of providing rating charts of conservative pressure vs. moment with tension for each API flange has been reduced to a standard analysis procedure which was developed based on work done in the past by Stress Engineering Services. The same finite element geometry models used in PRAC 86-21[2] have been used here. The flanges were grouped into nine different geometry groups, each with its own standardized finite element mesh (element and node numbering).

Similarly to the analysis done on the 69 previous flange geometries of API Bulletin 6AF[4], the five new flanges added in API 6A, Sixteenth Edition[3] were then analyzed with four different load conditions: Makeup, Pressure, Tension, and Moment. The resulting capacity charts are presented in Appendix E. The six 30,000 psi-6BX flanges (not currently used) and the four 6B flanges (2,000 psi $3^5/_8$, $16^3/_4$, $21^1/_4$, 3,000 psi $13^5/_8$ did not meet allowables when subjected to makeup load case only) were excluded from the thermal analysis.

The new 64 flange set was then subjected to thermal gradients. Two different bore temperatures were selected (350°F and 650°F) while the outside temperature was selected to be 32°F. Four different material combinations were selected. They were comprised of three flange and two bolting materials.

The effect of thermal gradients on the load capacity of the complete 64 flange set was then studied. The resulting stresses were linearized at several cross sections for each load step. Also, the reaction load at the gasket and the axial stresses in the bolts were tabulated.

A post processor was written for PRAC 89-21[1] to automate this data reduction, and was used herein with no significant modification. The thermal analysis results were then combined with the results of the previous study, PRAC 89-21, using linear superposition to determine a maximum moment rating for each possible combination of pressure and tension. The resulting data were plotted to aid in their use.

The second post-processing/plotting program, written to do the many repetitive calculations required, was modified and used. The details and assumption in the finite element analysis are detailed in this section. Section 5 has details of the stress criteria, stress linearization, and load rating calculations.

4.2 FINITE ELEMENT MODELING

The ANSYS Finite Element Program was used for all the axisymmetric analysis. The flange geometry was modeled with the STIF42 element for the makeup, pressure, and tension load cases. The STIF25 element was used for the bending solution. These are both isoparametric, quadrilateral elements with an axisymmetric stiffness formulation. The STIF25 element provides an option to apply harmonically varying loads around the circumference of the pipe (which is how a bending load is best represented). The bolt was modeled with the STIF3 element. This is a uniaxial element with axial and bending capabilities defined by the area and moment of inertia.

The thermal model conversion was done by changing the STIF42 element type to a STIF55 element. The STIF55 element is also an isoparametric quadrilateral element, with a single temperature degree of freedom at each node. Also, the beam element for the bolt was changed to a conducting bar (STIF32). Convection links (STIF34) between the flange and bolts were used to model the heat transfer of the air gap between them. In contrast to PRAC 89-21[1], a convection film was used to model the heat transfer at the outside surface of the flange. The thermal analysis was run to determine the steady-state temperature distribution through the flange. Once the temperature distribution was established, the results were input to the thermal stress analysis model (STIF42, STIF3) to calculate the resulting thermal state of stress.

The surface stresses calculated by the finite element method will depend on both the size of the stress raiser (hub/flange radius for example) and the size of the finite element mesh. The finite element mesh for each model was fine enough to predict the membrane and bending stresses required for comparison to stress-allowables. Typical meshes are shown in Figure 3. No attempt was made to predict peak stresses that would be used for a fatigue analysis. (Fatigue analysis is beyond the scope of API Spec 6A.) The proposed mesh was verified, in PRAC 86-21[2], to be sufficiently fine to correctly predict membrane and bending stresses.

The model was extended from the hub at least $2.5\sqrt{Rt}$ to prevent the end conditions from affecting the results in the flange, where R is the mean radius of the hub and t is the thickness.

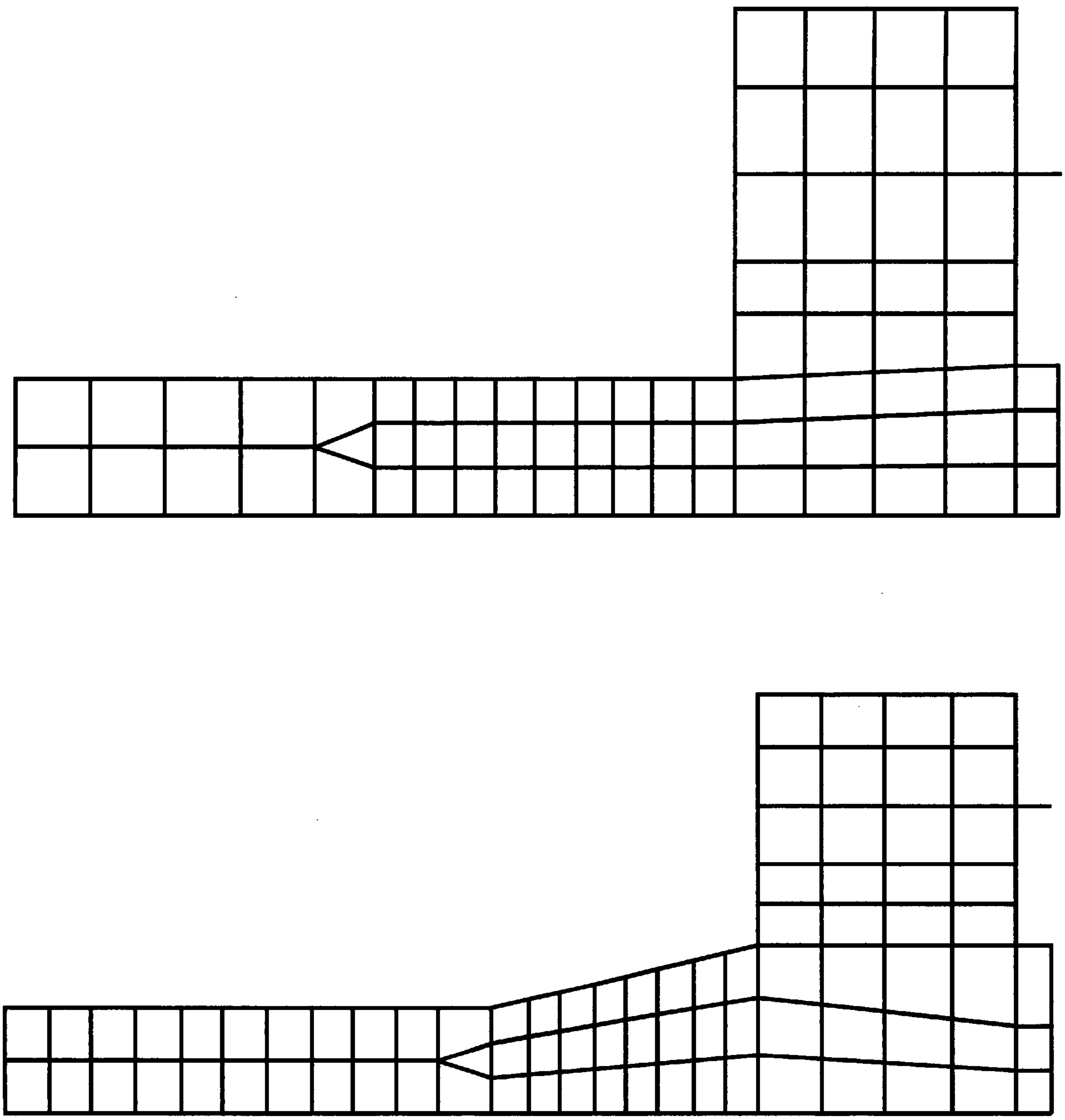


Figure 3—Typical Finite Element Meshes

4.3 ASSUMPTIONS

The assumptions and limitations of the methods used in the finite element modeling are presented here. For consideration of bolt makeup, internal pressure, tension, and bending moment material properties were assumed to be "typical" values for steel:

Elastic Modulus = 29,000,000 psi

Poisson's Ratio = 0.3

For the thermal analysis, actual material characteristics were implemented, a complete list of which appears in 4.4.

The geometry of the 6B flanges was defined using the integral flange dimensions without a taper from the "X" dimension on the hub. All flanges used the maximum raised face thickness. This is conservative, since using a smaller thickness will increase the bending stress. The ring groove was neglected to simplify the modeling. See PRAC 86-21[2] for the comparison of results with and without the groove included.

The bolt preload was reacted entirely through the ring gasket. This is correct for 6B flanges with R and RX gaskets where there is a standoff between the flange faces after makeup. The 6BX flanges are designed to preload on the raised face with no standoff. However, there have been reported cases of 6BX flanges not coming face-to-face due to strain-hardening in stainless steel gaskets. This assumption is conservative since it increases the moment arm between the preload forces, thereby increasing the resulting flange stresses. Also, this is the only reasonable way to model the boundary condition and still get linear solutions for each load step that can be used for superposition of results. The bolt preload was assumed to be made up to half the bolt yield strength.

The reaction point for the gasket load was set at the O.D. of the ring groove. It might be argued that a more reasonable location would be at the center of the gasket. However, a trade-off was made to correctly apply the pressure load out to the O.D. of the groove. It was considered more important to get the pressure-loading correct since the difference in the two diameters made only a small difference in the length of the moment arm between the bolts and gasket. The maximum diameter was used for the flange bore.

The diameters used to calculate the area and moment of inertia for the beam elements in the model were calculated from the tensile stress area given by ANSI B1.1-1974,[10] Appendices C and D. The bolt sizes used were based on Appendix D of Specification 6A, Sixteenth Edition, to calculate the recommended flange-bolt tension and makeup torque.

The reduced stiffness of the flange around the bolt holes was accounted for by reducing the modulus of the material used for elements in that region. The modulus was reduced by the percent of material removed by the bolt holes. This varied from flange to flange, but on the average it was approximately 70% of the elastic modulus given above.

Heat transfer on the outside surface of the flange was modeled by a convection film with a convection coefficient equal to 10 Btu/hr ft^2 °F with an outside surface temperature of 32°F. To establish if this value is conservative for all flanges, a lower value (1 Btu/hr ft^2 °F) was applied to the flange with largest O.D.; in this case, 10,000 psi 135/8 6BX flange. The results shown in Appendix F indicate that 10 Btu/hr ft^2 °F is indeed a conservative value. The use of 10 Btu/hr ft^2 °F is considered conservative since wind speeds in excess of 50 mph are required to achieve it for flange temperatures of 350°F and 650°F. Figure 4 shows the convection coefficient of air blowing across a 1-ft diameter cylinder as a function of the wind speed. The following empirical equation (refer to *Principles of Heat Transfer*[4]) used was:

$$\frac{\bar{h}_c D_o}{k_f} = C\left(\frac{V_\infty D_o}{\gamma_f}\right)^n,$$

where

$\frac{\bar{h}_c D_o}{k_f}$ = the average Nusselt number,

$\frac{V_\infty D_o}{\gamma_f}$ = the Reynolds number,

$\bar{h}_c$ = the average surface conductance,

D_o = the outside diameter,

V_∞ = the free-stream velocity,

k_f = the thermal conductivity,

γ_f = the kinematic viscosity.

Both C and n are empirical constants. Therefore, the use of 32°F on the outside surface of the flange is justified since some moisture would be present in order to reach a convection coefficient of 10 with a reasonably low wind speed. A 0°F air temperature would not have moisture. In PRAC 89-21[1], with analysis to 250°F, the outside flange temperature was set to 32°F, representing conditions in a cold, driving rain with an effective external convection coefficient of several thousands. For this case of cold, driving rain, the resulting thermal stresses with 350°F and 650°F bore temperatures were set to 32°F. Thus, an attempt was made to define a thermal boundary condition which is reasonably conservative but not exceedingly so.

Bolt-bending stresses were excluded from consideration despite having been calculated in PRAC 89-21[1]. Modeling of bolts and nuts is such that the bolt as a whole follows the deflected shape of the flange. The simplicity of this idealization does not exactly reflect the bending behavior of bolts. The modeling is sufficient, though, for axial bolt stresses which were considered.

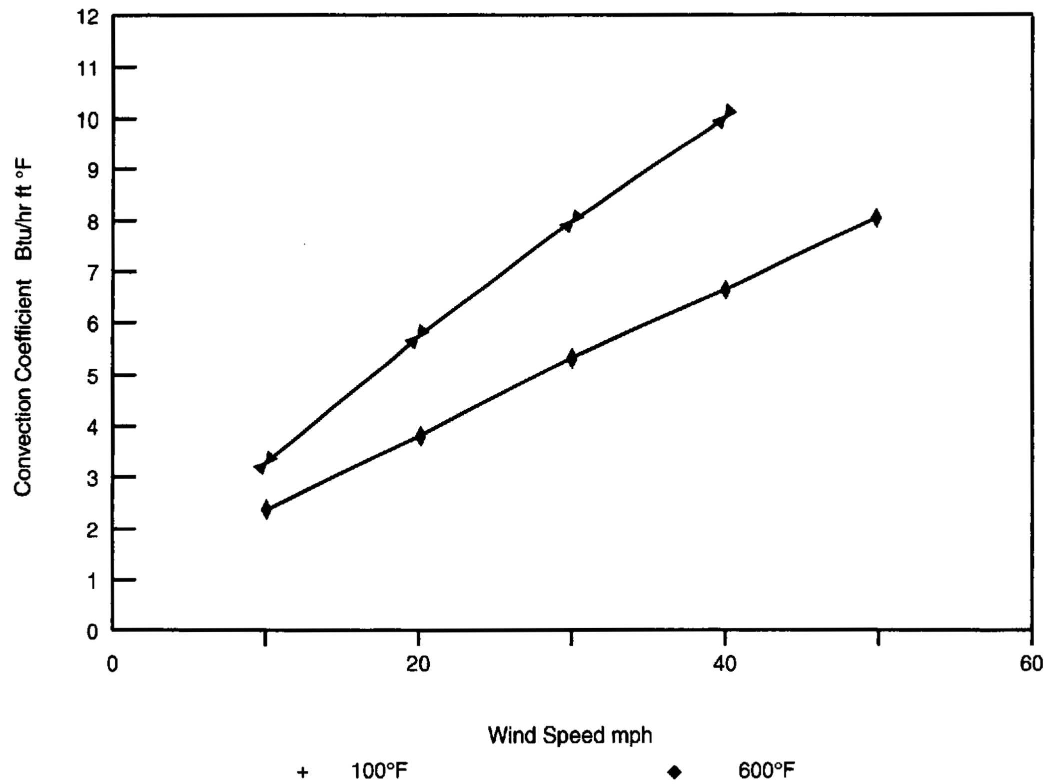


Figure 4—Convection Coefficients for Air Blowing Across a 1-Ft Diameter Cylinder as a Function of Wind Speed and Temperature

To simplify the results, the yield strength of bolts was derated as if the bolt temperature was the same as the corresponding bore temperature. This is a conservative assumption, since the actual temperature of the bolt will always be lower than the bore temperature.

4.4 MATERIAL CATEGORIES

The material properties required for a thermal analysis are the thermal conductivity and specific heat. These properties are temperature dependent. The material properties used in the thermal stress analysis (modulus of elasticity and coefficient of thermal expansion) are also temperature dependent.

API materials were grouped into a total of four material categories. The grouping of materials considered among others the variations in the above material properties. Three different flange materials were combined with two different bolting materials as shown on Table 3. API minimum yield strengths were used for flanges, while derating at elevated temperatures was applied according to Table 3 (derated from ambient temperature yield strength at 72°F). As mentioned in 4.3, bolts were derated as if their temperatures were the same as the bore temperatures. The properties for both bolts and flanges, as well as the yield strength of bolts, were derated according to the ASME *Pressure Boiler and Pressure Code* (see Table 4). The material derating data of Table 3 was provided by the chairman of API 6A Subcommittee Task Group on Design and Materials.

A material category containing Inconel 718 as flange material was excluded from the analysis due to the variability of the yield strength, attainable by specific heat treatments, corresponding to this material.

4.5 LOAD CASES

In the PRAC 86-21[2] four different unit load cases were run for each flange geometry. An additional thermal load case was considered in this study, and was repeated for two bore temperature conditions. Each thermal load case consists of two parts, the thermal analysis and the thermal stress analysis. The applied loads and boundary conditions used for each load case are fully detailed here. In all five load cases, the flange was restrained axially at the gasket to model the change in the gasket load due to that load case. In the makeup load case, a force condition was used on the end of the bolt. In the other cases, symmetry boundary conditions were used on the end of the bolt. This models the flange bolted to an identical flange. Details of each load case are shown in Figures 5, 6, and 7.

Table 3—List of Materials

	Material Category	Flange	Bolts	Derating Factors 350°F	Derating Factors 650°F
A	Carbon and Low Alloy Steels	4130 CR-1/5Mo	SA 193 B7 or SA 193 B7M Cr-1/5Mo	0.85	0.75
B	Martensitic, Ferritic and Precipitation Hardening Stainless Steels	410SS 13 Cr	SA 193 B7 or SA 193 B7M Cr-1/5Mo	0.85	0.75
C	Austenitic and Duplex Stainless Steels	Ferralium-255 S-32550	SA 453 Gr 660 (A286) 26Ni-15Cr-2Ti	0.80	0.73
D	Carbon and Low Alloy Steels	4130 Cr-1/5Mo	SA 453 Cr 660 (A286) 26Ni-15Cr-2Ti	0.85	0.75

Table 4—Derated Values of Material Properties

	Temperature °F	Carbon and Low Alloy Steels Flange	Carbon and Low Alloy Steels Bolts	Martensitic, Ferritic and Precipitation Hardening Stainless Steel Flange	Martensitic, Ferritic and Precipitation Hardening Stainless Steel Bolts	Austenitic and Duplex Stainless Steels[f] Flange	Austenitic and Duplex Stainless Steels[f] Bolts	Carbon and Low Alloy Steels[g] Flange	Carbon and Low Alloy Steels[g] Bolts
		60.0		60.0		60.0		60.0	
	70		80.0		80.0		85.0		85.0
			105.0		105.0				
		75.0		75.0		75.0		75.0	
		51.0		51.0		48.0		51.0	
Yield Strength[a]	350[e]		70.7		70.7		81.8		81.8
psi x 10^3			92.8		92.8				
		63.8		63.8		60.0		63.8	
		45.0		45.0		43.8		45.0	
	650[e]		63.1		63.1		80.6		80.6
			82.8		82.8				
		56.2		56.2		54.8		56.2	
Coefficients of	70	24.2	24.2	15.2	24.2	7.8	7.5	24.2	7.5
Thermal Conductivity[b]	350	24.0	24.0	15.7	24.0	9.6	9.0	24.0	9.0
BTU/hr ft °F	650	22.3	22.3	15.9	22.3	11.5	10.4	22.3	10.4
	70	29.7	29.7	29.2	29.7	30.5	28.3	29.7	28.3
Moduli of Elasticity[c] psi x 10^6	350	28.2	28.2	27.6	28.2	29.0	26.8	28.2	26.8
	650	26.6	26.6	25.8	26.6	27.0	25.1	26.6	25.1
Coefficients of Thermal	70	5.73	5.73	5.98	5.73	6.10	8.24	5.73	8.24
Expansion[d]	350	6.59	6.59	6.35	6.59	6.40	8.62	6.59	8.62
in./in. x 10^{-6}/°F	650	7.40	7.40	6.57	7.40	6.75	9.00	7.40	9.00

Notes:
[a]API.
[b]ASME *Boiler and Pressure Vessel Code*, Sec. VIII, 1986, Table 1.
[c]ASME *Boiler and Pressure Vessel Code*, Sec. VIII, 1986 Table AMG-2.
[d]ASME *Boiler and Pressure Vessel Code*, Sec. VIII, 1986 Table AMG-1.
[e]API Proposed Change, Table G2.
[f]Cabot Corporation.
[g]ASME *Boiler and Pressure Vessel Code*, Sec. III, App., 1983.

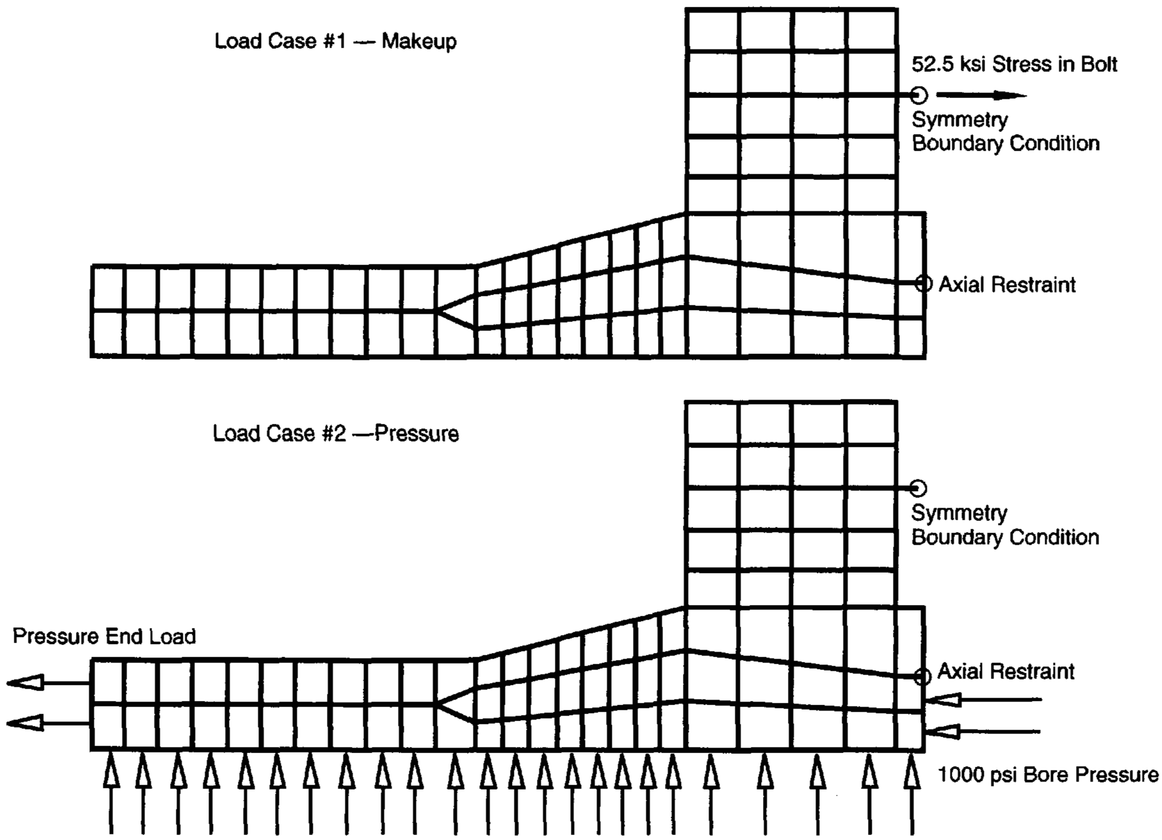


Figure 5—Load Conditions for Makeup and Pressure

The first load case was makeup of the bolts to 52.5 ksi. For this solution, the required bolt force was applied to the end of the bolt. The preload force was reacted with the displacement boundary condition at the ring groove.

The second load case was an internal pressure of 1000 psi applied along the bore and out to the ring gasket O.D.

Note: No makeup loads were included in this load case.

Note: The pressure end load is included in this load step as tension on the end of the flange.

The third load case was axial tension with no makeup. The tension was input as a 10,000 psi axial stress on the end of the flange.

The fourth load case was a bending moment with no makeup. The bending moment was input with nodal forces to give a 10,000 psi stress at the extreme fiber on the end of the flange.

Finally, the fifth was a thermal load case performed in the current study. Two different cases were run with bore temperature at 350°F and at 650°F. In both cases the outside temperature was considered to be 32°F. A convection coefficient equal to 10 Btu/hr ft^2 °F was used on the outside surface while no coefficient was used on the inside surface. The thermal distribution resulting from the thermal analysis was used in the stress analysis to calculate the induced stresses.

4.6 ANALYSIS RESULTS

Each finite element analysis gives displacement and reaction forces at the nodes in addition to the element stresses for each load step. Those are covered in PRAC 86-21.[2] The results from each pair of thermal and stress analysis solutions are the nodal temperatures, displacements and element stresses. Because of the volume of output due to the large number of models, material categories and two temperatures (a total of 1024 solution steps resulting in 396 plots) these results are not provided in this report. Stress and thermal results for the 7$^1/_{16}$" 10,000 psi 6BX and 2$^1/_{16}$" 2,000 psi 6B flanges are given here to show "typical" flange stress intensity of a 6BX flange for each load step are shown in Figures 8 and 9, while Figure 10 shows thermal contours and thermal stress contours. The corresponding contour plots for the typical 6B flange are shown in Figures 11 through 13. The binary results on FILE04 (Thermal analysis) and FILE12 (thermal stress analysis) were saved for later post-processing as detailed in Section 5. Also, all output and results files have been saved on magnetic tape for archival purposes.

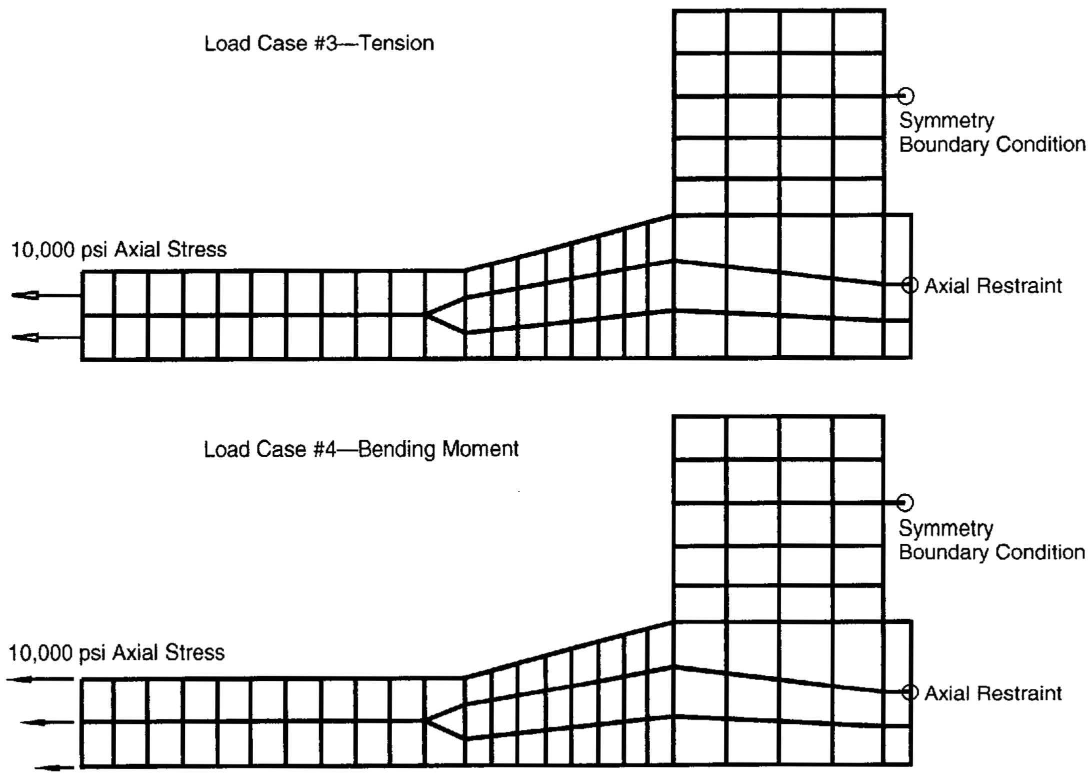


Figure 6—Load Conditions for Tension and Bending Moment

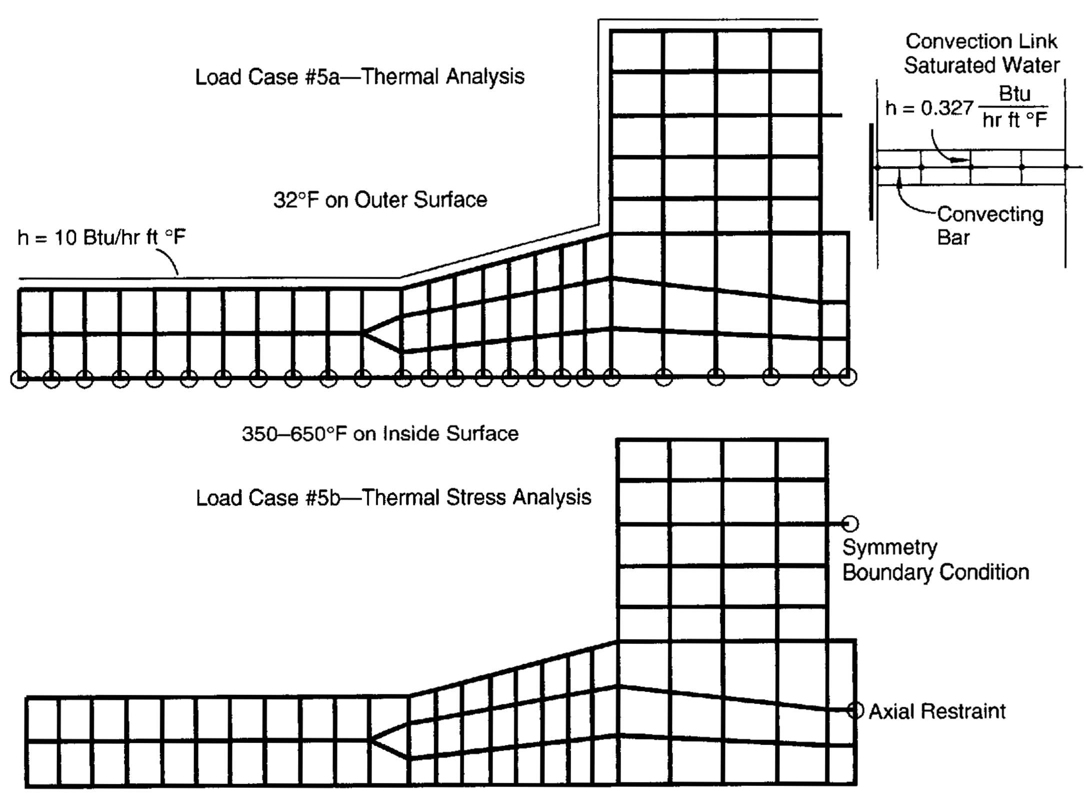


Figure 7—Load Conditions for Thermal and Thermal Stress Analysis

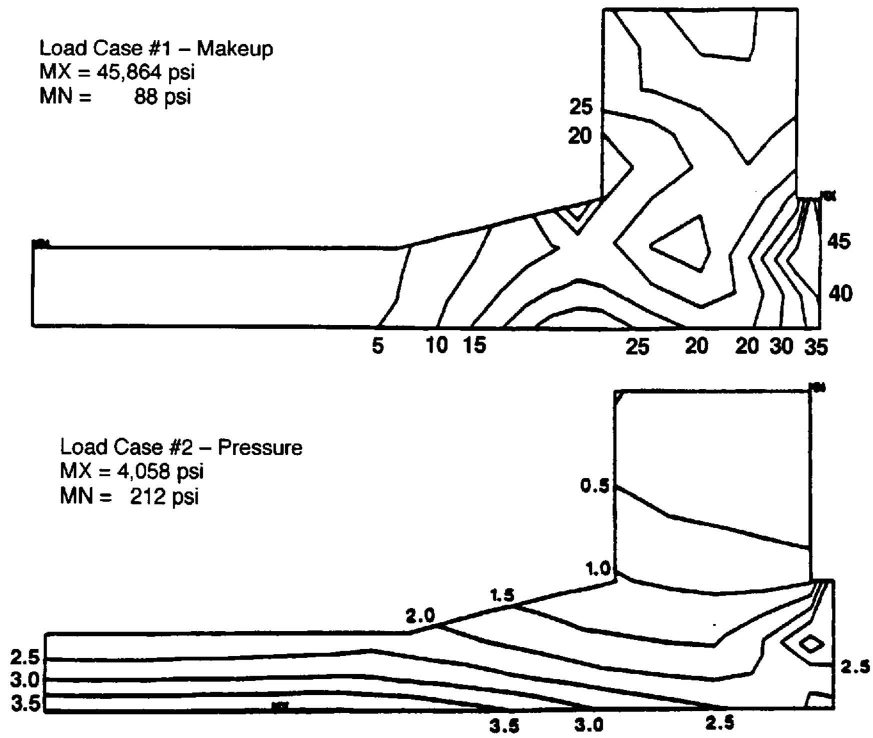


Figure 8—Typical Stress Intensity Contour Plots for Makeup and Pressure Load Conditions
$7^1/_{16}$" 10,000 6BX Flange

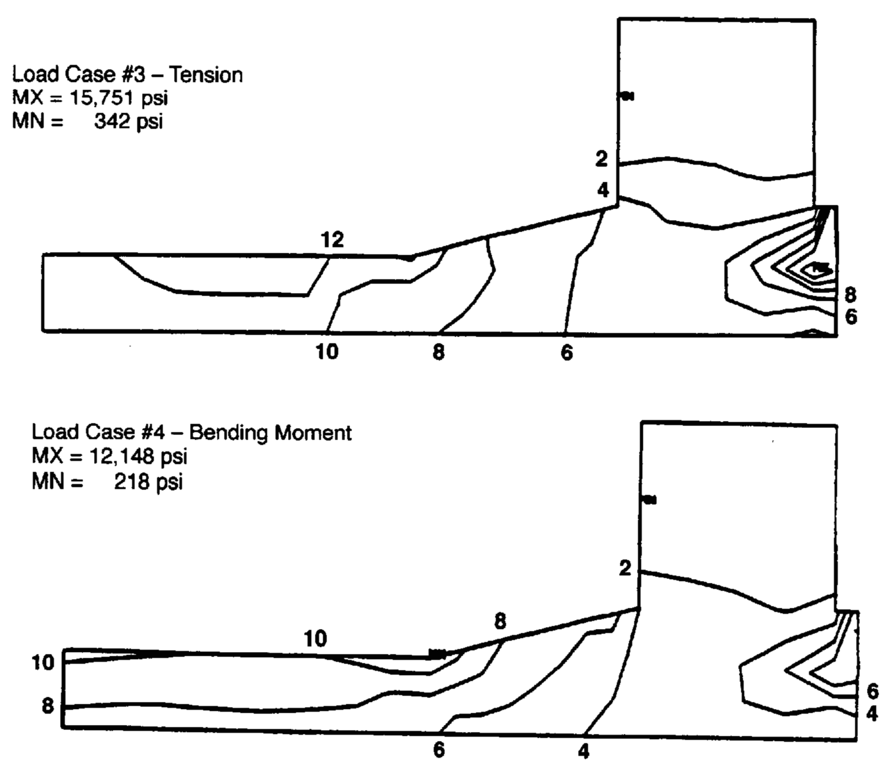


Figure 9—Typical Stress Intensity Contour Plots for Tension and Bending Moment Load Conditions

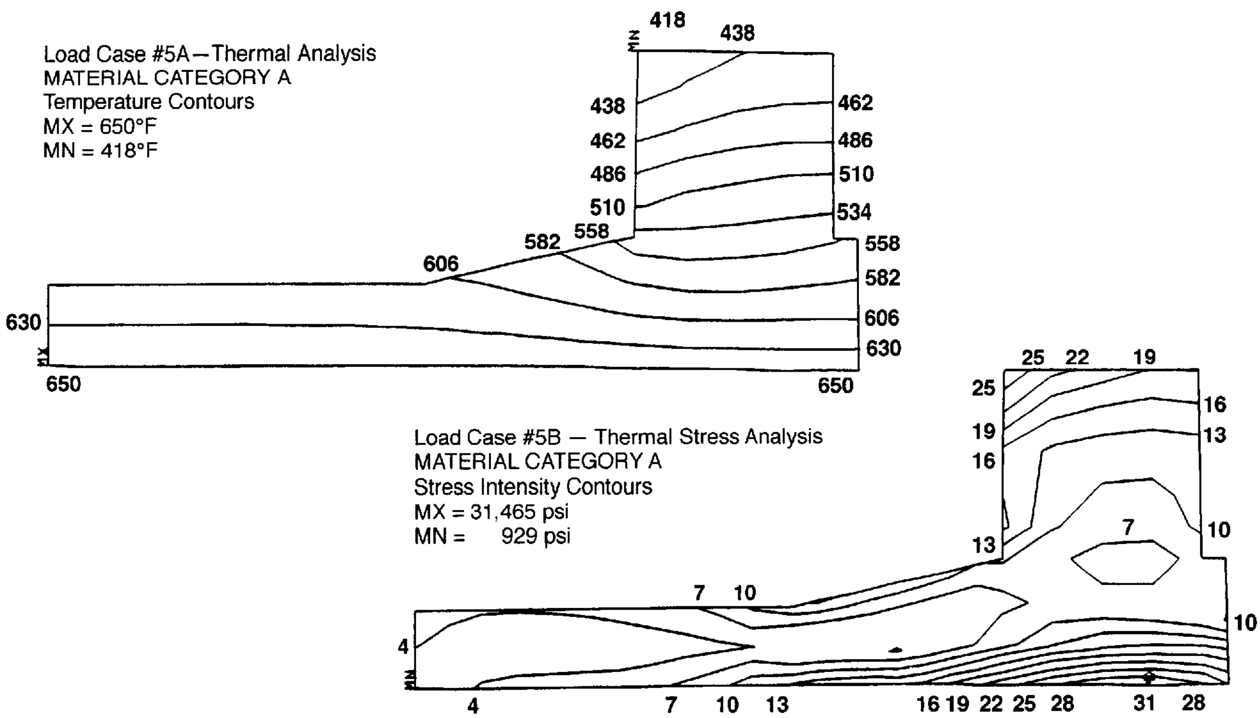


Figure 10—Typical Contour Plots for Thermal Analysis Load Conditions
$7^1/_{16}$" 10,000 6BX Flange

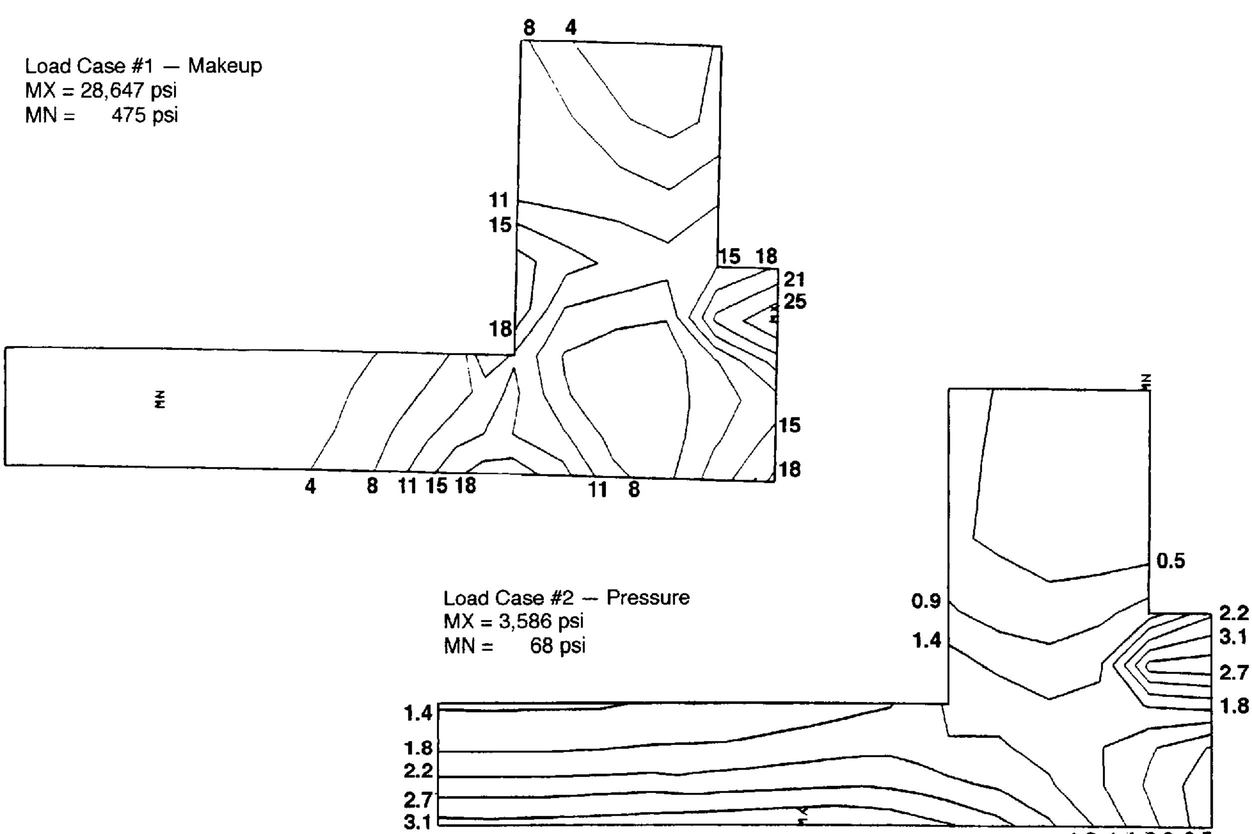


Figure 11—Typical Stress Intensity Contour Plots for Makeup and Pressure Load Conditions
$2^1/_{16}$" 2,000 6B Flange

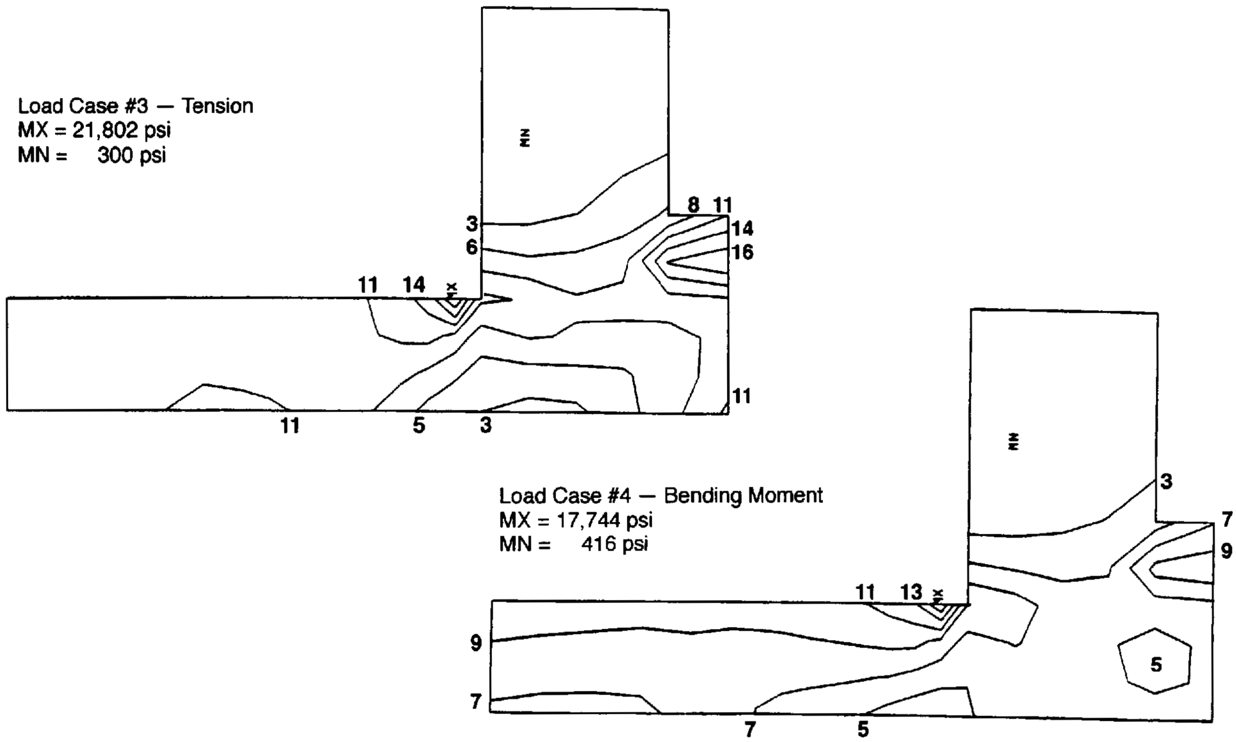


Figure 12—Typical Stress Intensity Contour Plots for Tension and Bending Moment Load Conditions $2^1/_{16}$" 2,000 6B Flange

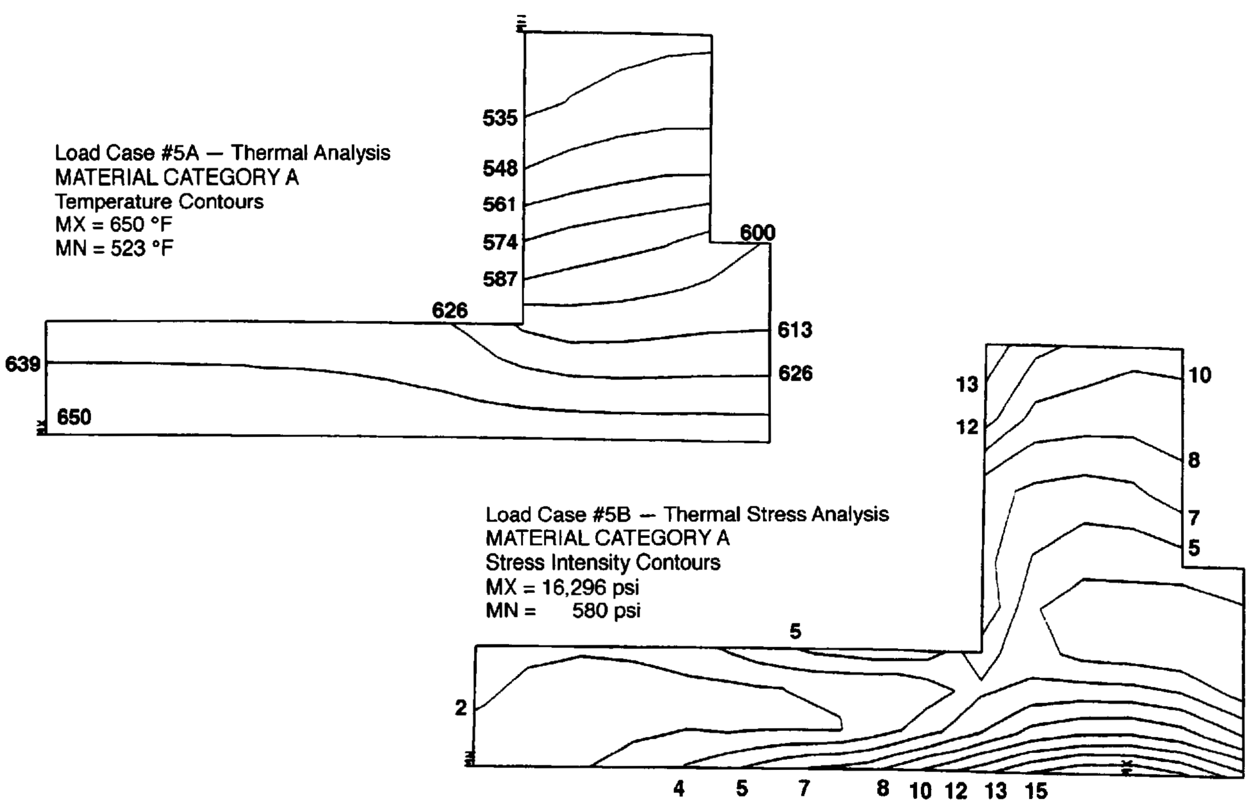


Figure 13—Typical Contour Plots for Thermal Analysis Load Conditions $2^1/_{16}$" 8,000 6B Flange

5 Flange Combined Load Capacities

5.1 INTRODUCTION

Once the results from the finite element analysis have been obtained, several steps are still required to establish a combined load rating for each flange. First, allowable stress criteria must be established for the many stress categories that are defined in the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 2, Appendix 4. Also, leak criteria must be established since this is also a "failure" of the flange to perform its intended function. Next, the finite element results from Section 4 must be reduced to a form that can be compared to the allowable stress criteria. The stresses and loads from each load case must then be combined and checked against this criteria to determine the maximum load combinations. Finally, the results must be plotted in a usable form for general use. The stresses and leak criteria must be presented separately in each rating chart. This process is fully described below.

5.2 ALLOWABLE STRESS CRITERIA

The allowable stress criteria is based on the ASME Code stress categories using the basic allowable membrane stress intensities defined by API 6A. The stress intensity at any point is twice the maximum shear stress at that point. The ASME code is based on the maximum shear stress theory of failure, which is more conservative and easier to apply than the distortion energy theory.

The basic allowable membrane stress intensity is defined in API 6A, Section 303 as:

$$S_m = \tfrac{2}{3} S_y,$$

where

S_m = design Stress Intensity at rated working pressure,

S_y = minimum specified yield strength.

The allowable stress intensity for hydrostatic pressure testing is also defined in API Spec 6A[3], Section 303 as:

$$S_T = 0.83\, S_y,$$

where

S_T = General Primary Membrane Stress Intensity at hydrostatic test pressure.

The allowable tensile stress in the closure bolting is defined as:

$$S_A = 0.83\, S_y,$$

where

S_A = maximum stress in the bolting for all loads,

S_y = specified minimum yield strength of bolting.

This allowable is applied only to tensile stress since bolt bending stresses were ignored (see Section 4.3 for discussion). The allowable is compared to combined loading first with, and then without thermal loads.

To apply the stress categories given by the ASME code, the linearized membrane and bending stresses at each section have to be categorized into primary and secondary stresses. The code established an allowable stress at each point in the structure by applying different factors to the Design Stress Intensity depending on the location and category of the stress. The stress categories for each load case/flange section are discussed below.

Stresses due to makeup loads only are classified as primary stresses at all sections. Stresses due to hydrostatic test pressure only are also classified as primary stresses, using the increased allowable specified for this case: Stress due to makeup with test pressure is considered to be a primary stress in flange sections (with the increased allowable), but is considered a secondary stress in all other sections. Stress due to any combination of tension, working pressure, and moment is a primary stress at all sections. In flange sections, makeup added to pressure, tension, and moment is a primary stress. However, this is a secondary stress at all other sections.

Note: Stresses due to thermal gradients considered are always defined as secondary stresses.

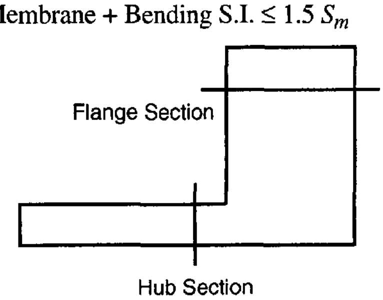
Based on this discussion of stress categories, the allowable stress criteria for each load case/section is given below:

1. Makeup Only—All Sections:
   Membrane S. I. ≤ S_m
   Membrane + Bending S.I. ≤ 1.5 S_m
2. Hydrostatic Test Pressure Only—All Sections:
   Membrane S.I. ≤ S_t
   Membrane + Bending S.I. based on ASME Code Paragraph AD -151.1

3.a Hydrostatic Test Pressure + Makeup—Flange Section:
   Membrane S.I. ≤ S_t
   Membrane + Bending S.I. based on ASME Code Paragraph AD-151.1

b Hydrostatic Test Pressure + Makeup—Hub Section:
   Membrane S.I. ≤ 1.5 S_m
   Membrane + Bending S.I. ≤ 3.0 S_m

4. Pressure + Tension + Moment—All Sections:
   Membrane S.I. ≤ S_m
   Membrane + Bending S.I. ≤ 1.5 S_m



5.a Makeup + Pressure + Tension + Moment—Flange Section:
Membrane S.I. ≤ S_m
Membrane + Bending S.I. ≤ 1.5 S_m

5.b Makeup + Pressure + Tension + Moment—Hub Sections:
Membrane S.I. ≤ S_m
Membrane + Bending S.I. ≤ 3.0 S_m

6. Makeup + Pressure + Tension + Moment + Temperature—All Sections:
Membrane S.I. ≤ 1.5 S_m
Membrane + Bending S.I. ≤ 3.0 S_m

5.3 LEAK CRITERIA

Leakage was assumed to occur when the reaction force at the gasket due to preload was relieved by the sum of the pressure, tension, and moment load cases. This is a conservative assumption since it neglects the gasket's ability to work as a pressure-energized seal. However, these ring gaskets are also known to be very sensitive to relative movement between flanges. For this reason, no attempt was made to establish the amount of face separation that could be expected before a leak would occur. These criteria are presented separately from other criteria (stress criteria). The increase or decrease in bolt stress due to thermal gradient is ignored.

5.4 STRESS LINEARIZATION

The allowable stress categories given by the ASME code were organically developed before the finite element method was available as an analysis tool. Therefore, only brief mention of linearization is given in the code. Appendix 4, Section 4-112 defines an equivalent stress distribution as the linear stress distribution that has the same net bending moment as the actual stress distribution.

Linearization is necessary because the finite element method gives peak stresses due to local fillet radii, etc. However, the intent of the code allowables, except for peak stresses considered in a fatigue analysis, is to compare with the equivalent linear stress distribution. Thus this equivalent linear stress distribution must be computed from the raw finite element results.

The correct linear stress distribution is done in a two-step process on a component-by-component basis. First, the element stresses are numerically integrated to get the total force and moment at a cross-section. Since these are axisymmetric analysis, the integration includes the "wedge" shape of the element when calculating the cross-sectional area. With the force and moment known, calculate an equivalent linear stress distribution. The stresses at the extreme fibers are the two unknowns that are determined using the equilibrium equations for force and moment.

A post-processor was written for PRAC 86-21[2] to automate the stress linearization for each flange and load case. The post-processor linearized stresses at each requested section for all five load steps, and then output the membrane, near side, and far side stress components for later use in the load rating calculations. The bolt stress and reaction force on the ring gasket were also output for later use.

5.5 LOAD RATING METHODOLOGY

With the allowable stress categories established and the linearized stresses from the finite element analysis, the calculations for each flange's moment capacity at various tensions and pressures was possible. All stress criteria were based on material properties specified in API 6A Tables 404.1 and 404.2. This information is given in Table 5 of this report.

A second post-processing program was written for PRAC 86-21[2] to calculate the load ratings and plot the results in a standard form for use in flange evaluation. This post-processor was modified to perform slightly different operations than the previous use. The post-processor had to sum stress components for each load-case combination and perform stress checks for all the stress criteria above. In addition, the possibility of leak/loss of preload on the tension side of bending was checked and plotted separately.

The load combinations and stress criteria were checked according to a series of possible limiting conditions. These conditions are summarized below:

1. Does the flange meet stress criteria for makeup only?
2. Does the flange meet stress criteria for hydrostatic test pressure only?
3. Does the flange meet stress criteria for makeup and hydrostatic test pressure?
4. What is the maximum moment that can be carried with pressure and tension based on leak criteria?
5. What is the maximum moment that can be carried (with or without thermal effects) based on bolt stress criteria?
6. What is the maximum moment that can be carried with pressure and tension based on stress criteria?
7. What is the maximum moment that can be carried with makeup, pressure, and tension based on stress criteria?
8. What is the maximum moment that can be carried with thermal makeup, pressure, and tension based on stress criteria?

If the flange does not meet the criteria given in items 1–3, the condition is reported; but the moment capacity is calculated based on criteria in items 4, 5, 6, 7 and 8. The calculated moment capacity based on criteria in item 4 (leak/loss of preload) is to be plotted separately from the capacity based on the stress criteria in items 5, 6, 7 and 8.

Table 5—API Physical Properties and Material Types
From API Spec 6A, Sixteenth Edition, October 1, 1989

Table 404.1, Spec 6A, 16th Edition
API Material Property Requirements
Bodies, Bonnets, and End and Outlet Connections

API Material Designation	0.2% Yield Strength, minimum (psi)	Tensile Strength, minimum (psi)	Elongation in 2 in., minimum (%)	Reduction in Area, minimum (%)
36K	36,000	70,000	21	No Requirement
45K	45,000	70,000	19	32
60K	60,000	85,000	18	35
75K	75,000	95,000	18	35

Table 404.2, Spec 6A, 16th Edition
API Material Applications for Bodies, Bonnets, and End and Outlet Connections

Part	Pressure Ratings (psi)						
	1000	2000	3000	5000	10,000	15,000	20,000
	API MATERIAL DESIGNATION						
Body, Bonnet[a]	NA	36K, 45K 60K, 75K	36K, 45K 60K, 75K	36K, 45K 60K, 75K	36K, 45K 60K, 75K	45K,60K 75K	60K,75K
Integral End Connection							
Flanged	NA	60K	60K	60K	60K	75K	75K
Threaded	NA	60K	60K	60K	NA	NA	NA
Other	b	b	b	b	b	b	b
Independent Screwed Wellhead Equipment	36K, 45K 60K, 75K	36K, 45K 60K, 75K	NA	NA	NA	NA	NA
Loose Connectors							
Weld Neck	NA	45K	45K	45K	60K	75K	75K
Blind	NA	60K	60K	60K	60K	75K	75K
Threaded	NA	60K	60K	60K	NA	NA	NA
Other	b	b	b	b	b	b	b

Notes:
[a]Provided end connections are of the API material designation indicated, welding is done in accordance with Section 500 and design is performed in accordance with Section 300.
[b]As specified by manufacturer.

5.6 RESULTS

The plotted results for the combined load capacity of each flange analyzed in this project are given in Appendices A, B, C, and D. The rating charts for each material category are presented in a separate Appendix. The results for each category are arranged in the same order as found in API 6A, first at 350°F and then at 650°F. The 6B flanges are first, followed by 6BX flanges. For each flange style the results are given in order of increasing diameter within each working pressure rating. (Thus, the $21^1/_4$" 2,000 psi 6B flange is before the $2^1/_{16}$" 3,000 psi 6B flange; and the 11" 5,000 psi 6B flange is before the $26^3/_4$" 2,000 psi 6BX flange.)

For the first two material categories (Appendices A and B) combined load ratings were determined for each flange with two different bolt makeup stresses. The first rating was determined for bolts made up to 52.5 ksi, and the second was done for a makeup stress of 40 ksi. The two plots are given on the same page to help evaluate the effect of a reduced preload on a flange's bending capacity. For each of the first two material categories two separate sets of plots are provided at 350°F and at 650°F.

For the last two material categories (Appendices C and D), combined load ratings were determined for each flange with only one bolt makeup stress. The rating charts were determined for bolts make up to 42.5 ksi. Therefore, the charts for the two temperature ratings are provided in the same plot. Bolt makeup is taken as half the yield strength of the bolts.

To assist the user in better understanding the rating charts, a table of controlling criteria has been established (see Table 6). Each identification number corresponds to one of the stress conditions presented in 3.1. Also included in the table is ID=11 which denotes leak/loss of preload. The controlling capacity curve with ID=11 is shown in the rating charts with a continuous line. Therefore, shown in the rating charts will be only the identification of the controlling stress criteria. ID=1 means that primary stresses control at section 1-1. ID=101 means that secondary stresses (not including thermal stresses) control at section 1-1 while ID=202 means that secondary stresses, including thermal stresses, control at section 2-2. A negative ID number means that the compression side of bending controls (i.e., ID=–1).

When studying these results, one should keep in mind that for a particular flange the moment capacity based on leak/loss of preload criteria is assumed not to be affected by temperature variations, thus no difference exists between material categories or between temperatures within a material category. This assumption was made because, in general, the thermal boundary conditions chosen result in the flanged joint preload increasingly due to temperature. This increase, if accounted for, would allow higher moments for the leak criterion. However, if the thermal boundary conditions are not as severe, then accounting for thermal preload increase is unconservative.

On the other hand, leak/loss of preload is affected by bolt makeup. In addition, when primary loads (without makeup) control, the moment capacity based on stress criteria is the same for any material category with the same flange material (compare material categories A and D at equal temperatures). The latest observation (when primary loads control) is also true for flanges made up of different flange material but with the same yield strength derating factors (compare material categories A and B at equal temperatures). When reviewing the rating charts, note that the moment capacity range is kept the same as in API Bulletin 6AF[4], to aid comparison between rating charts.

The load-carrying capacity of material category A flanges was dominated by bolt stresses (controlling condition ID=12), especially for the bore temperature at 650°F. No significant capacity, if any, exists for 6BX flanges larger than 9" in size (5,000 psi and above) but the same is not true for 6B flanges. This is because the bolt allowable is exceeded by the stress of the four loads plus the thermal stress. This is a direct result of lower bolt stresses on 6B flanges as compared to 6BX flanges, due to temperature-loading. The variation is attributed to differences in geometry and the level of maximum working pressure between the two types of flanges. However, the results for 2,000 psi and 3,000 psi of 6BX flange at 650°F require some further explanation. An increase in pressure (at low levels of bore pressure) results in higher moment capacity. Due to the geometry of the 2,000 psi and 3,000 psi 6BX, and the majority of 6B flanges, pressure loading results in some preload loss. The large diameter flanges rotate towards each other enough under load that bolt stress due to pressure actually decreases. Therefore, with the preload reducing higher capacity is expected when bolt-stress criteria control. Also note that a total of six 6B flanges (11" 2,000 psi and 3,000 psi $7^1/_{16}$" and above) exhibit higher capacities at lower bolt makeup at 650°F. Thermal stresses, plus makeup, plus stresses control (see Section 5.2 criteria 5a for secondary stresses with ID=202) for higher bolt makeup; while pressure, tension, and moment (primary stresses, ID=2) control for 40 ksi makeup. At 650°F the 6 smaller-size 10,000 psi 6B flange rating charts level off at pressures close to the maximum working pressure. In all cases the controlling condition is ID=1 for both slopes, meaning stresses control at section 1-1. No distinction is made between membrane and membrane plus bending controlling. It so happens that for these flanges, membrane and membrane-plus-bending control at different levels for the same section.

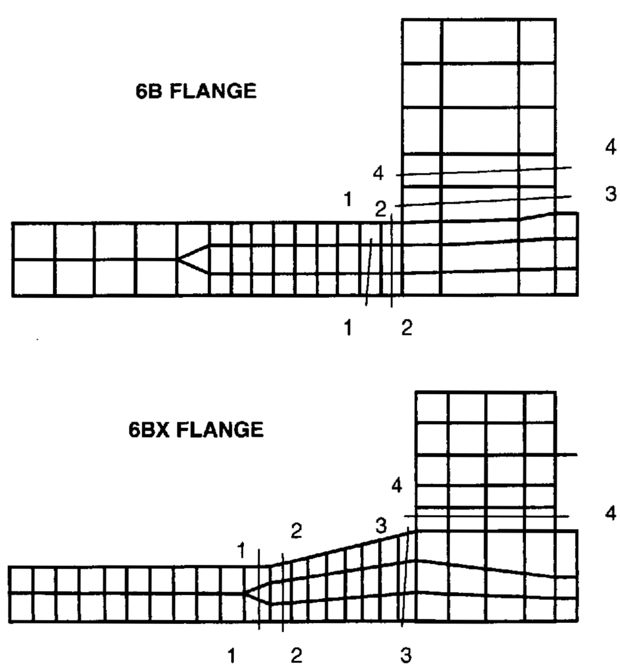
No significant difference exists between material categories A and B at 350°F. At this temperature, the moment capacity, based on stress criteria, controls over leak/loss of preload criteria for several small size flanges. Flange stresses control at smaller six flanges (10,000 psi up to $7^1/_{16}$, 15,000 psi up to $4^1/_{16}$, 2,000 psi and 3,000 psi up to $4^1/_{16}$ and all 5,000 psi 6B flanges). Stress criteria control for larger flanges, when the controlling stress criteria is the bolt-stress criteria. At 650°F, 6BX flanges, made up of material categories A and B, behave differently. This is greatly due to lower bolt-stress of category B caused by the lower thermal-conductivity of material B, hence, higher moment capacity. When neither bolt stresses nor thermal gradient controls, the two materials have exactly the same capacity (almost all 6B flanges).

Material categories C and D generally exhibit higher capacity capabilities than categories A and B. The comparison between the two sets of categories is better accomplished through a comparison of material categories A and D, since they have the same flange material. Comparing bolt makeup of 40 ksi and 42.5 ksi for A and D respectively, leak/loss of preload gives slightly higher capacity for material D (due to difference in bolt makeup). Material category D has higher capacity based on stress criteria, since bolt-stress criteria almost never control. This was not true for material A which was dominated by bolt stresses. This is evident, considering the difference in derated bolt yield strength allowables of 52.4 ksi for A and 66.9 ksi for D (0.83 factor also included). The A286 bolts do not derate as much as the SA193 B7 and SA 193 B7M bolts at elevated temperatures. As noted in 4.3, bolt temperatures were taken conservatively at 650°F rather than using their actual temperature. Using the actual temperatures would definitely improve the capacity capabilities of category A and B flanges.

Table 6—Controlling Criteria Identification Numbers (ID Numbers Appear in the Rating Charts)

ID		Controlling Condition
11		Leak/Loss of Preload[a]
12	Bolt Stress	
1	Section 1-1	Tension Side of Bending (Primary Loads)
3	Section 2-2	Tension Side of Bending
3	Section 3-3	Tension Side of Bending
4	Section 4-4	Tension Side of Bending
101	Section 1-1	Tension Side of Bending w/Makeup (Secondary Loads)
102	Section 2-2	Tension Side of Bending w/Makeup
103	Section 3-3	Tension Side of Bending w/Makeup
104	Section 4-4	Tension Side of Bending w/Makeup
201	Section 1-1	Tension Side of Bending w/Makeup + Temperature
202	Section 2-2	Tension Side of Bending w/Makeup + Temperature
203	Section 3-3	Tension Side of Bending w/Makeup + Temperature
204	Section 4-4	Tension Side of Bending w/Makeup + Temperature
*	Negative ID value represents stress control by the compression side of bending	

[a]Leak is shown with continuous line so no ID is provided in charts.



5.7 USE OF RATING CHARTS

An explanation of the proper use of the plotted results in Appendices A, B, C, and D is given below. Also, a procedure to use in evaluating a flange for a particular combination of loads is outlined to aid those who will be using these results. Figure 14 is reproduced from Appendix A for the $3^1/_{16}$" 10,000 psi 6BX flange at 350°F for reference in the discussion below.

The plotted results given in Appendices A, B, C, and D show limiting load combinations of temperature, makeup, pressure, tension, and moment. The results are based on the stress criteria (shown with dashed lines) as well as leak criteria (shown with continuous lines) that control at each load combination. Some curves have a "knee" in them when the controlling criteria changes from a flange-stress limitation to a bolt-stress limitation, or even within the same flange-stress limitation. Thus, the minimum capacity of a flange could be derived based on both leak control and stress control if the user is concerned about leakage. Otherwise, the user can base his design only on stress criteria.

The steps outlined below are provided to simplify the use of the curves to evaluate a particular flange.

1. Establish magnitude of each load condition:
   a. Bolt makeup stress (52.5, 42.5 or 40 ksi).
   b. Pressure (psi).
   c. Tension (lb).
   d. Moment (ft-lb).
   e. Bore temperature (°F).

(Remember, the pressure load condition includes the tension due to the pressure-end load, so if no other tensile loads are present, the Tension = 0 lb curve should be used.)

2. Determine appropriate material category.
3. Determine flange load capacity:
   a. Pick appropriate figure based on material, bore temperature, and makeup desired.
   b. Determine if leak/loss of preload is of concern. If not, ignore continuous line in figures. If leak/loss of preload is of concern, use minimum of continuous and dashed lines.
   c. Enter figure from left side with Pressure.
   d. Move to right to find required Moment.
   e. Intersection is point that defines Max Tension rating.
   f. Interpolate between lines to get Max Tension rating.
4. Evaluation:
   a. If the Max Tension rating is greater than the required tension, the flange is satisfactory for the intended use, based on the axisymmetric analysis.
   b. If the Max Tension rating is less than the required tension, the flange cannot carry the desired load combination, based on the axisymmetric analyses. The pressure, tension, or moment will have to be reduced; or in some cases, increasing the bolt makeup from 40 ksi to 52.5 ksi will help. If these changes are not acceptable, a more refined stress analysis will be required.

Example 1

Using the $3^1/_{16}$" 10,000 psi 6BX flange as an example, check the load rating for the following combination of loads:

a. Bolt Makeup Stress = 52.5 ksi.
b. Pressure = 10,000 psi.
c. Tension = 0 lb.
d. Moment = 5,000 ft-lb.
e. Temperature = 350°F.

Reading from Figure 15 and considering leak/loss of preload as well as stress criteria, the Max Tension rating for this Pressure/Moment combination is:

Max Tension rating = 61,000 lb
(same as PRAC 86-21[2])

Since the required Tension is 0 lb, the flange is okay.

Example 2

For the same flange, check the following combination:

a. Bolt Makeup Stress = 52.5 ksi.
b. Pressure = 8,000 psi.
c. Tension = 80,000 lb.
d. Moment = 15,000 ft-lb.
e. Temperature = 350°F.

Reading from Figure 15, the Max Tension rating for this Pressure/Moment combination is:

Max Tension rating = 0 lb

Since the required Tension is 80,000 lbs., the flange is not adequate for this application. Possible lower combinations for this example were recommended in PRAC 86-21.[2] Because of reduced capacity at 350°F, the maximum tension that can be carried (for Pressure = 0 psi) is:

Max Tension rating = 55,000 lb

Therefore, the moment applied on the flange has to be reduced to at least 13,000 ft-lb to be able to carry 80,000 lb tension.

Example 3

Reconsider the above flange with the applied moment equal to 10,000 ft-lb. Possible lower combinations to satisfy the tension or the pressure are:

1. Reduced Tension:

   P = 8,000 psi, T = 33,000 lb, M = 10,000 ft-lb

2. Reduced Pressure:

   P = 3,600 psi, T = 80,000 lb, M = 10,000 ft-lb

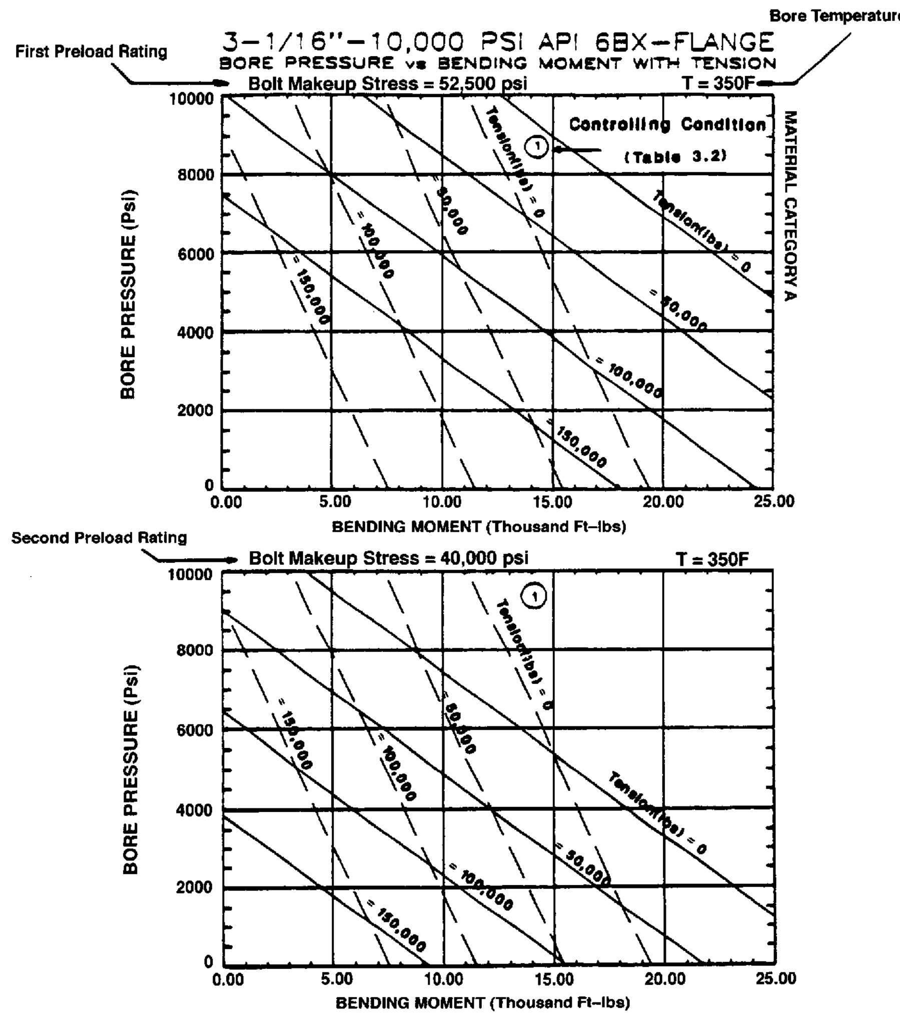


Figure 14—Typical Combined Load Capacity Results

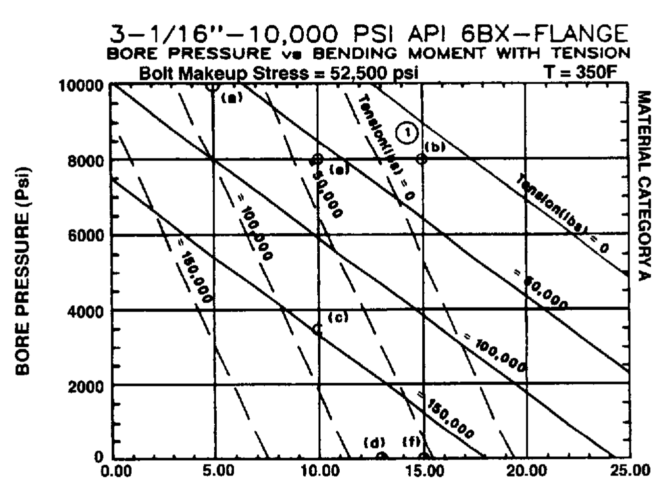


Figure 15—Load Capacity Results to Use with Example Problems

6 Conclusions and Recommendations

6.1 SUMMARY

The progress attained by the previous report (PRAC 86-21)[2] and API Bulletin 6AF[4] established the base of this current work. The in depth study of the effects of severe thermal gradient in the analysis of API 6A flanges has accomplished a number of important items.

a. The combined load capacity of all 6A flanges for different materials and elevated bore temperatures of 350°F and 650°F has been established considering flange stresses, bolt stresses and gasket leak due to loss of preload.

b. The general method of analysis and evaluation developed in the previous study and published as API Bulletin 6AF provided direction for this current work.

c. Special post-processing programs have been modified to ease the data reduction required to evaluate a flange's combined load capacity.

d. The effect of a severe thermal gradient on the load capacity of a flange has been given extended study.

e. The resultant graphical output provides quick access to capacity data on API flange designs.

6.2 CONCLUSION

Several conclusions can be made from the results of the analysis performed in this project.

a. Thermal stresses due to a severe temperature gradient (32°F–350°F and 650°F) significantly reduced the load capacity of two of the four material categories considered. The outside temperature was taken at 32°F (in lieu of 0°F) in order to be consistent with a high convection coefficient value and therefore produce a more conservative load capacity.

b. Bolt stress allowables proved to be important in a number of flanges. As a result, the derated bolt yield strength proved to be very important. Makeup torque should be applied at half the yield strength of the bolts. Users of the charts are advised that bolt-bending stresses due to flange bending are not included in this analysis. They should only be of concern when the flange is subject to cyclic loading.

6.3 RECOMMENDATIONS

This is an analytical work. Other work could be directed at experimentally validating the findings of this report.

The results herein are specific to temperature gradients across the flange and should be conservative when elevated temperatures exist, but with the absence of temperature gradients.

APPENDIX A—MATERIAL CATEGORY A

Material Category A
Bore Temperature—350°F

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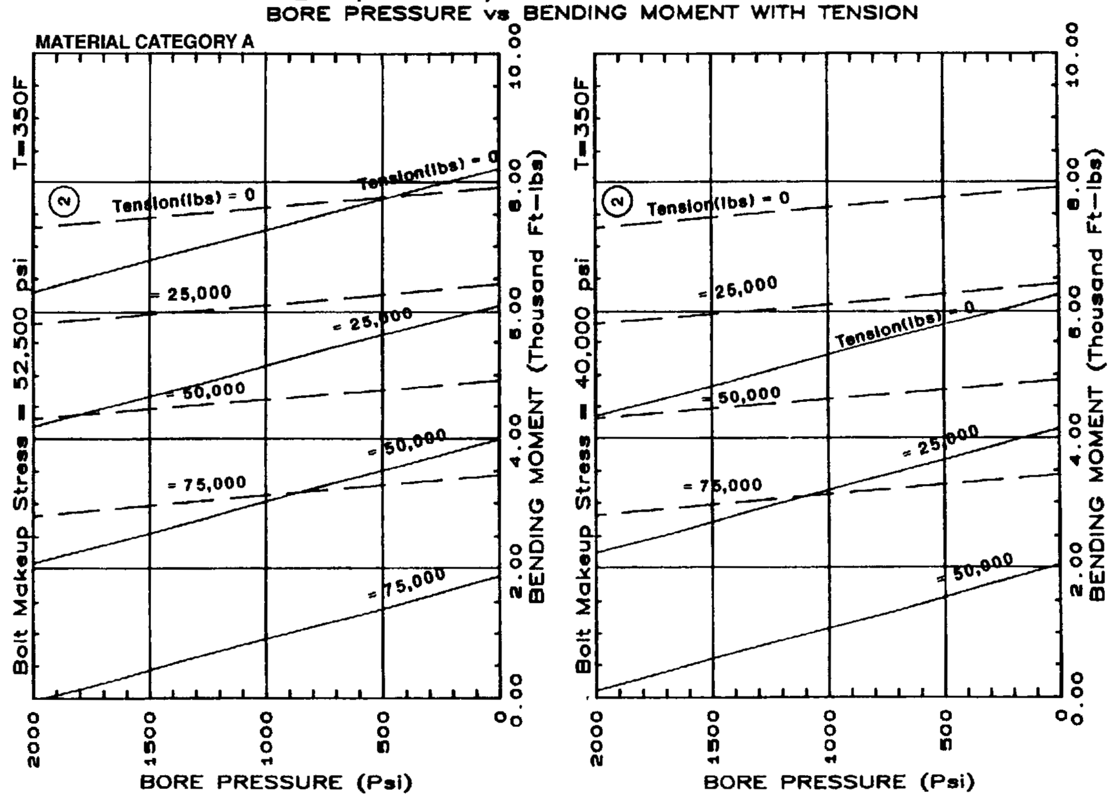
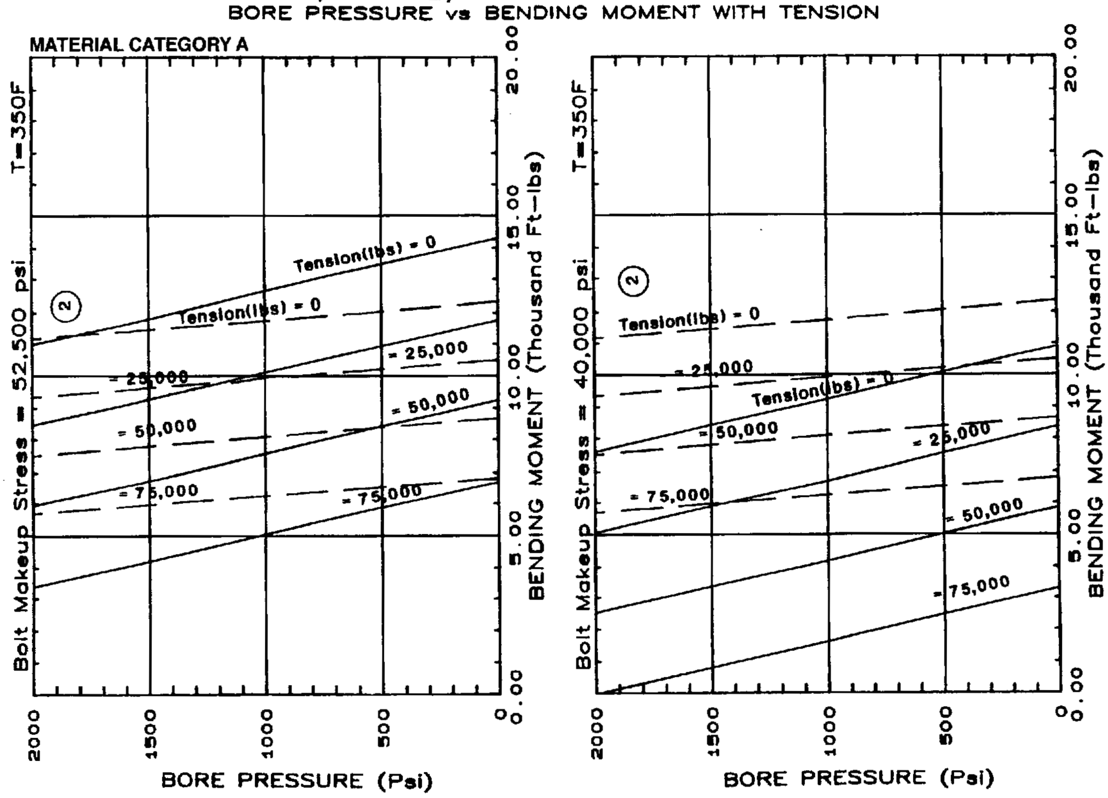
2–1/16"–2,000 PSI API 6B–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



2–9/16"–2,000 PSI API 6B–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



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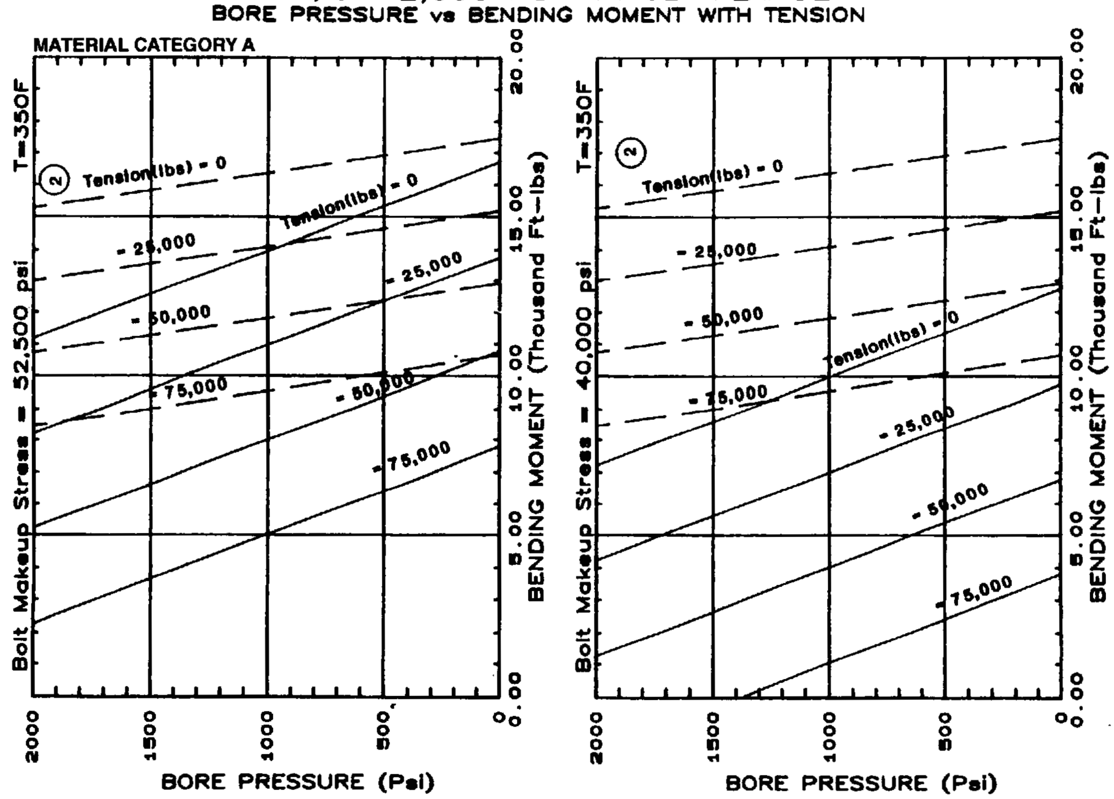
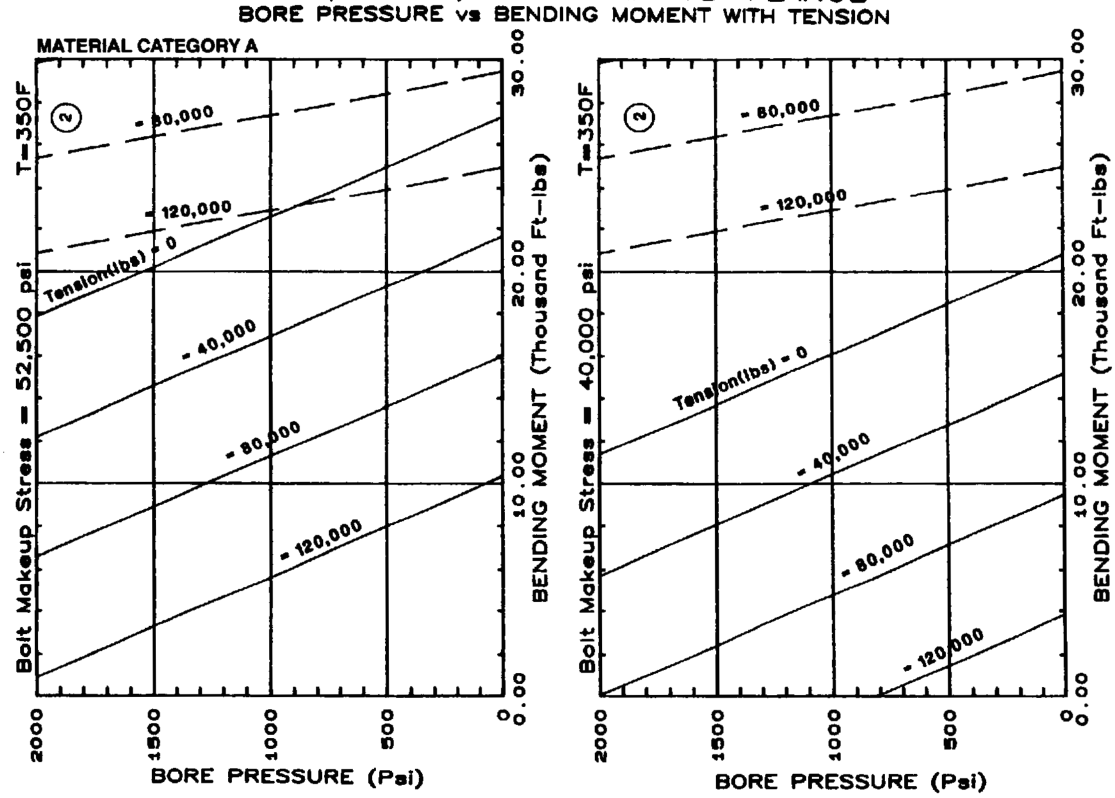
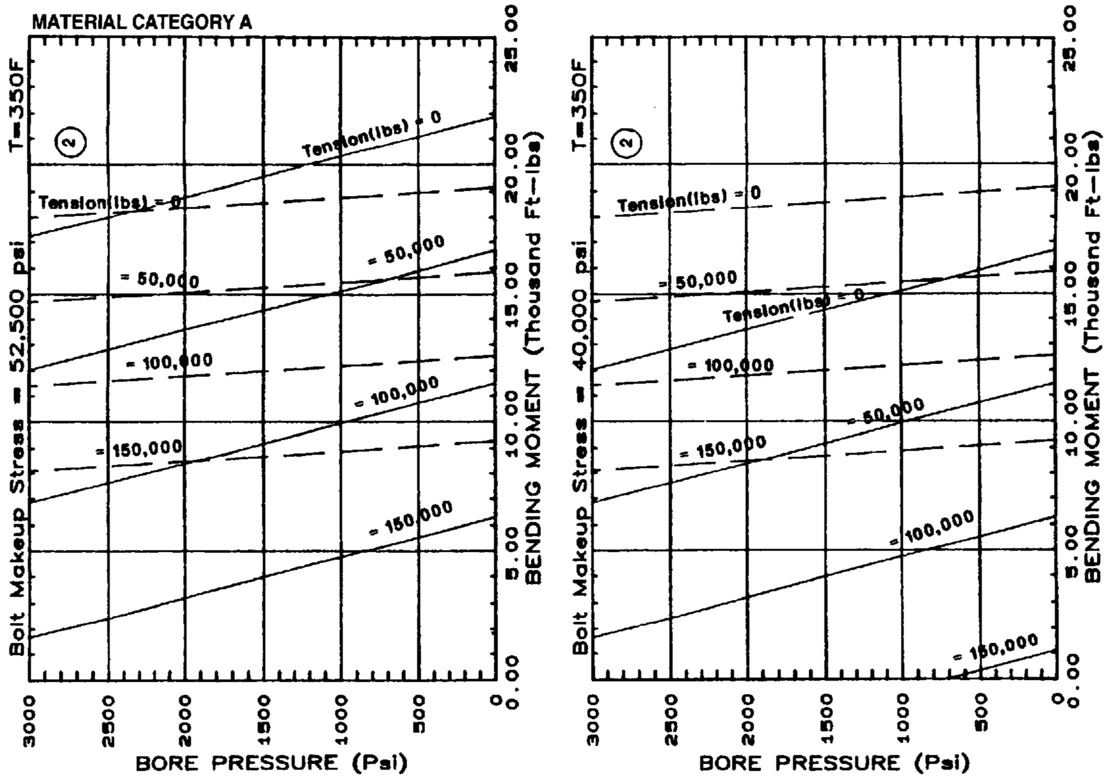
3-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



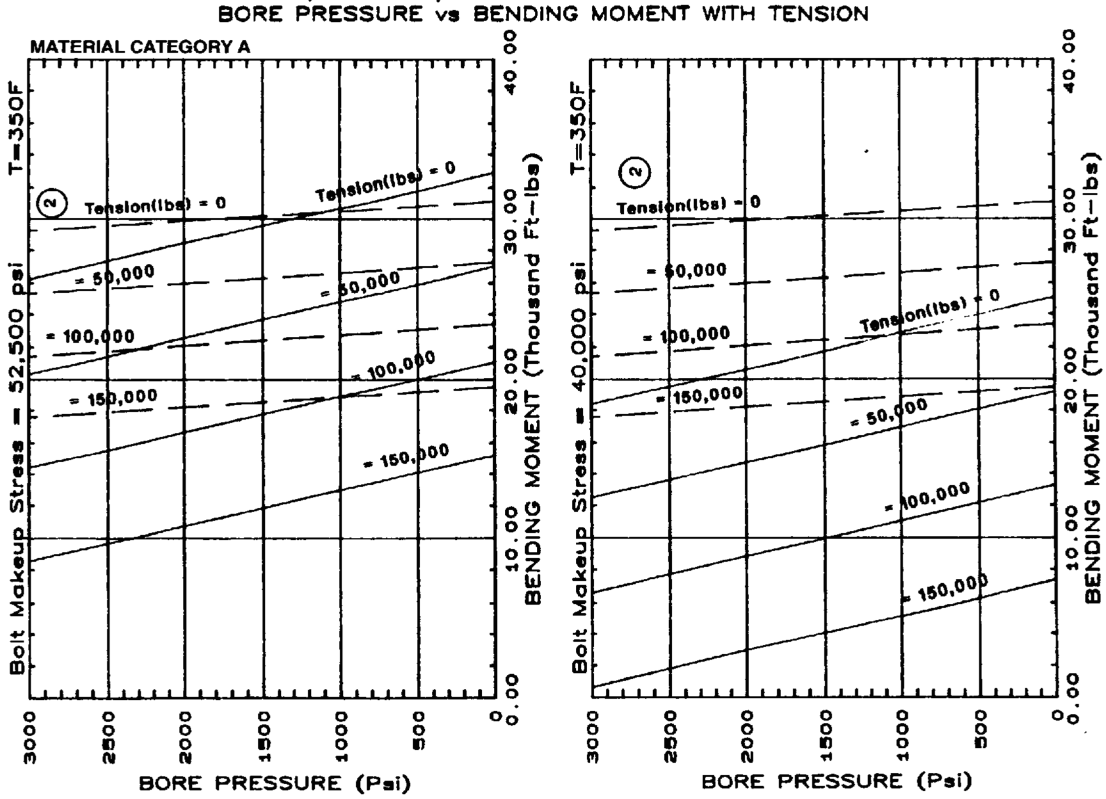
4-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



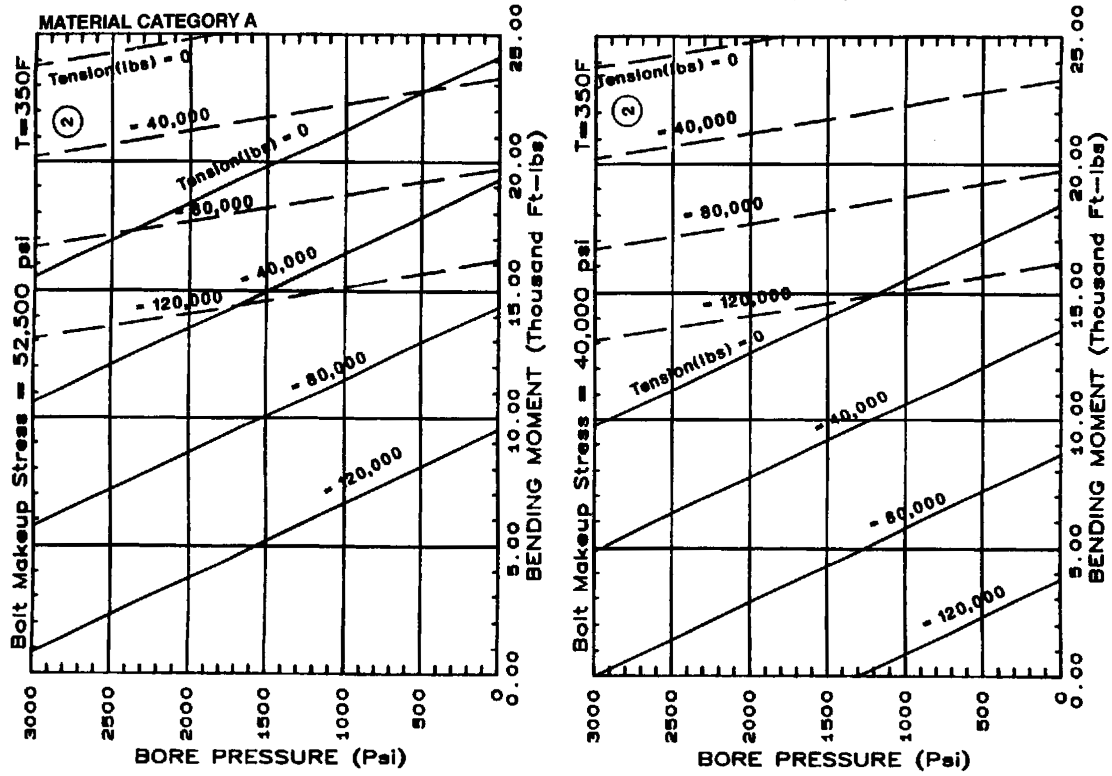
2-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



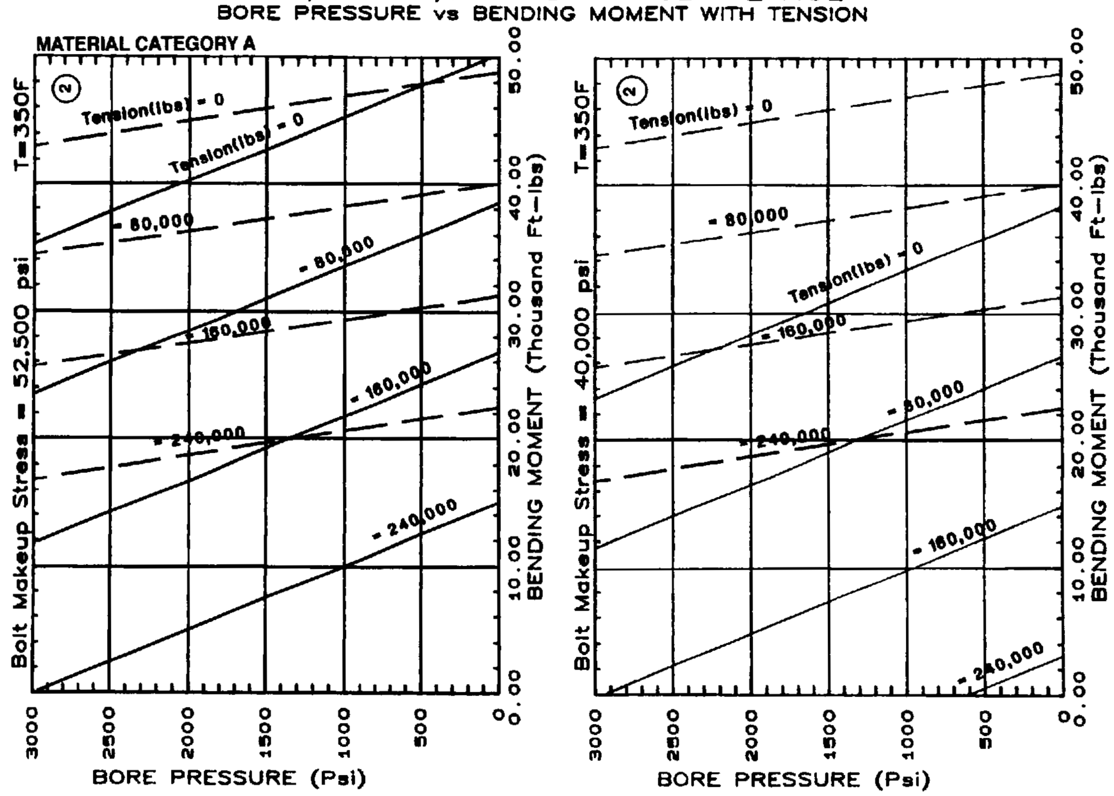
2-9/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

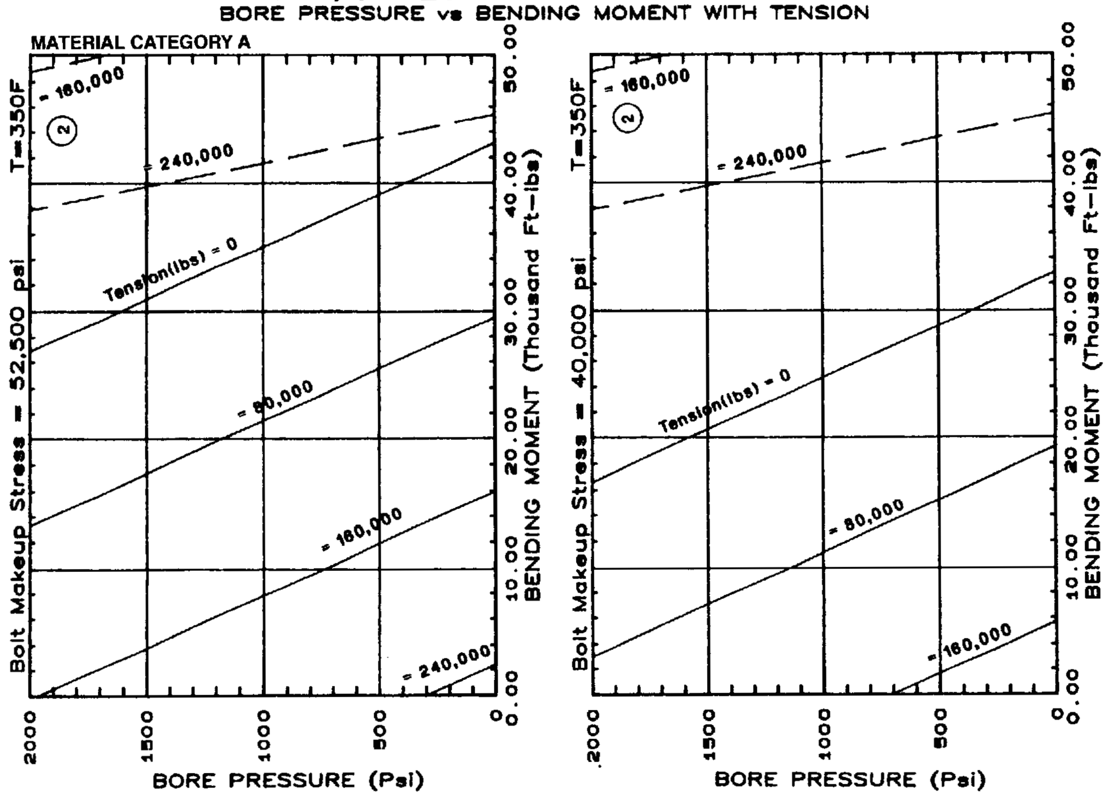


4-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



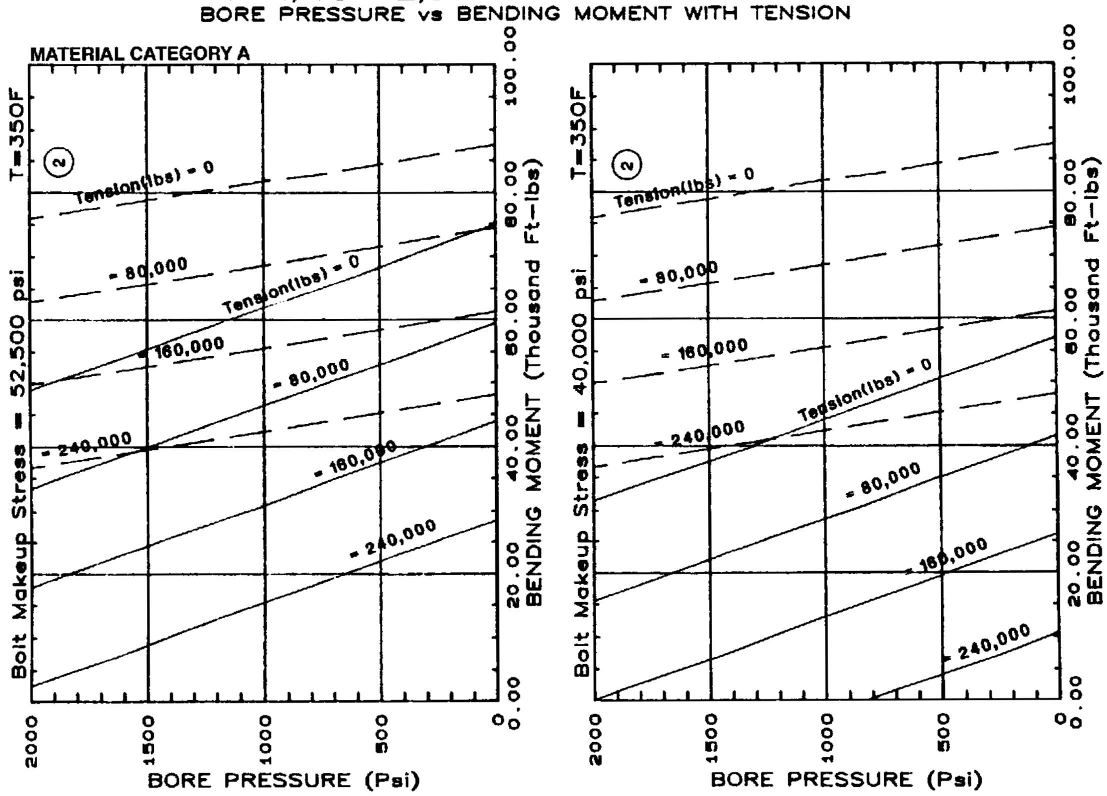
5–1/8"–2000 PSI API 6B–FLANGE

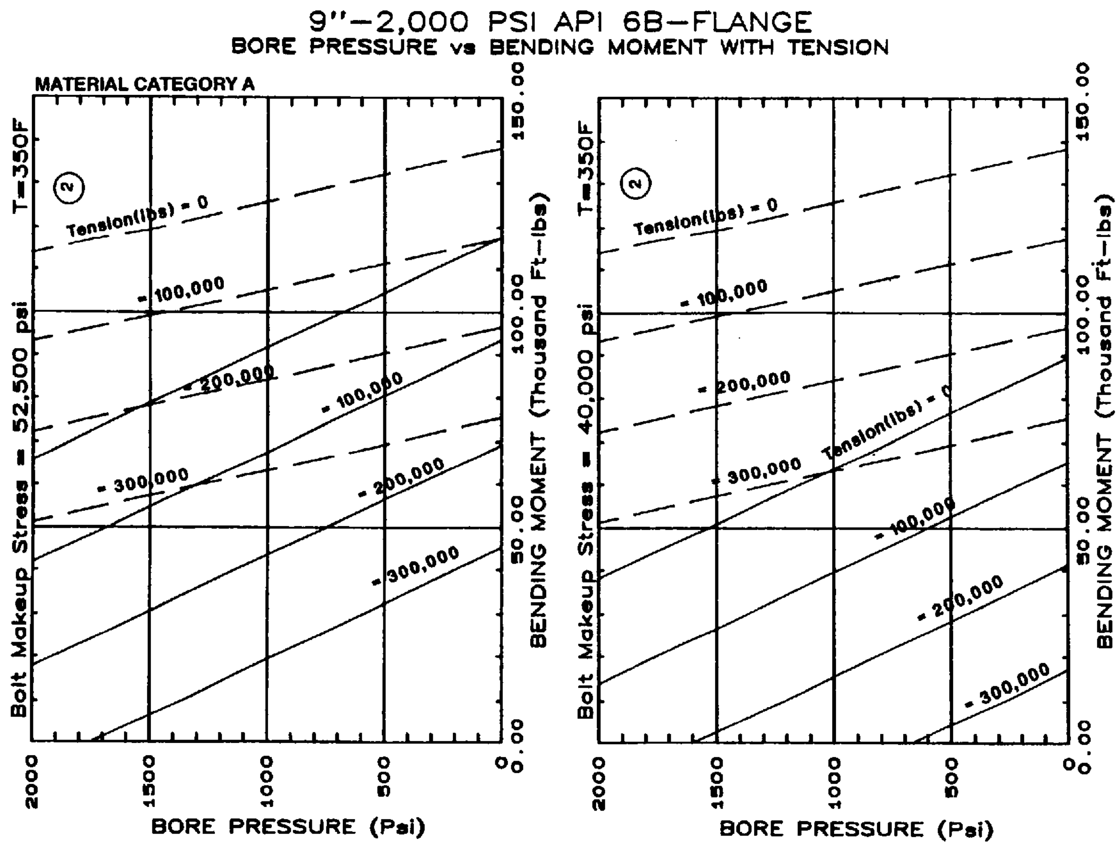
BORE PRESSURE vs BENDING MOMENT WITH TENSION

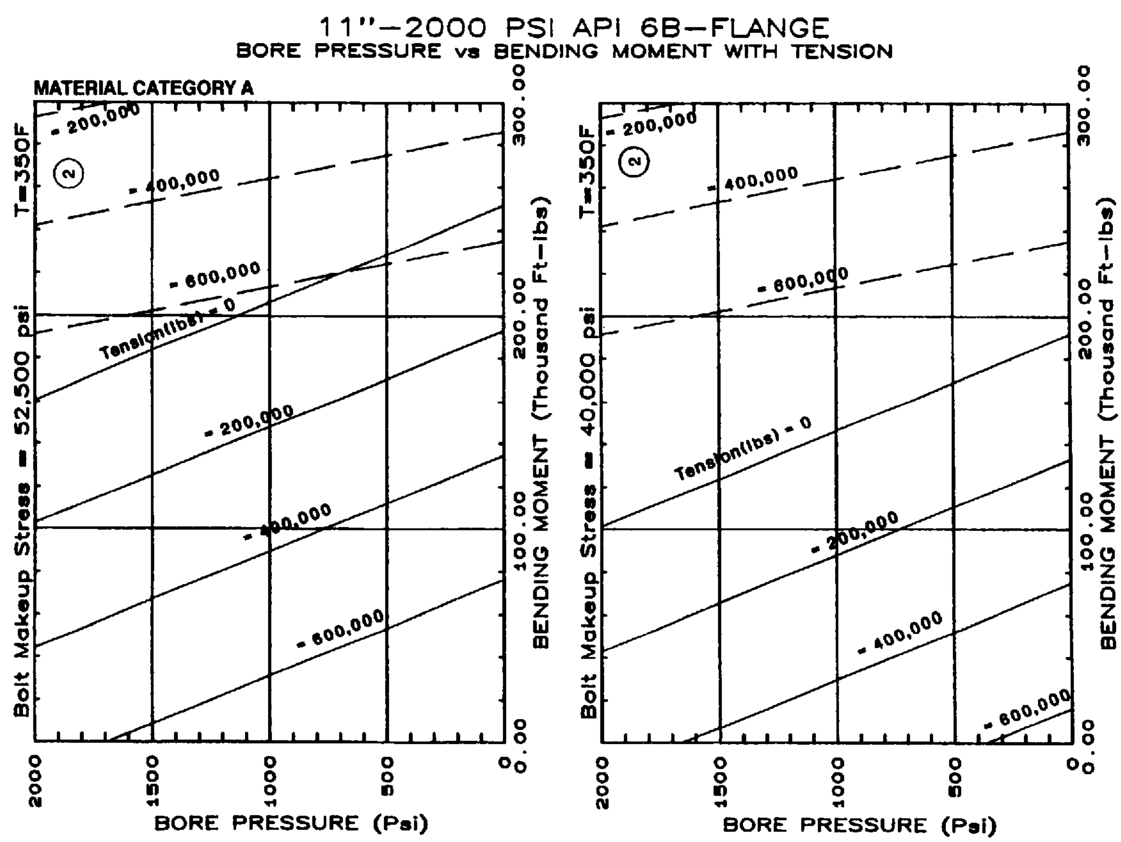


7–1/16"–2,000 PSI API 6B–FLANGE

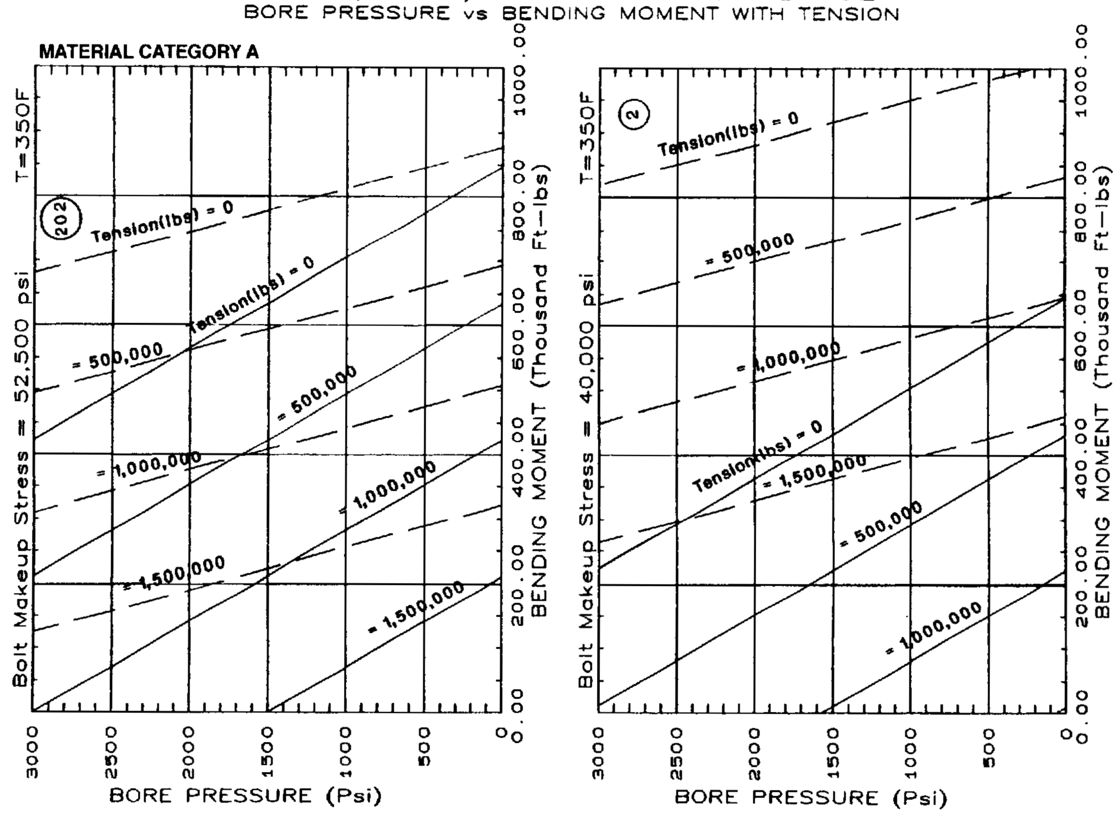
BORE PRESSURE vs BENDING MOMENT WITH TENSION



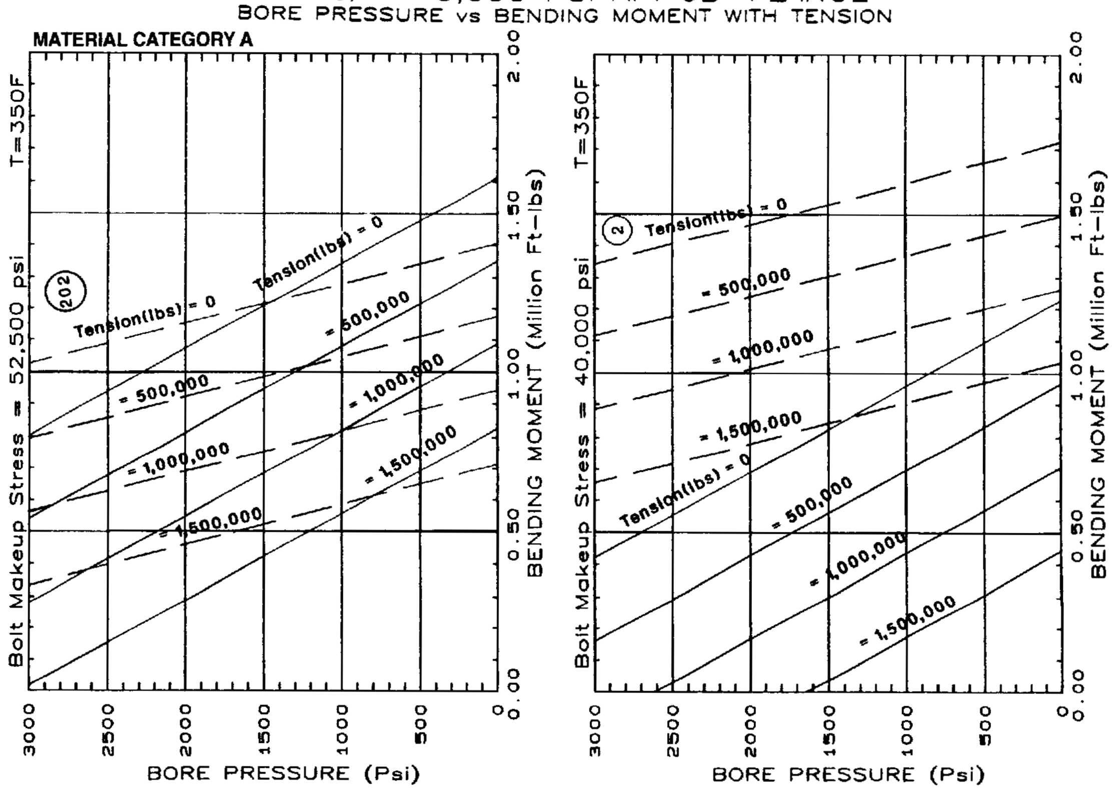

9"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY A
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
= 100,000
= 200,000
= 300,000
BENDING MOMENT (Thousand Ft–lbs)
0.00
50.00
100.00
150.00
BORE PRESSURE (Psi)
2000
1500
1000
500
0


11"–2000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY A
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
= 200,000
= 400,000
= 600,000
BENDING MOMENT (Thousand Ft–lbs)
0.00
100.00
200.00
300.00
BORE PRESSURE (Psi)
2000
1500
1000
500
0

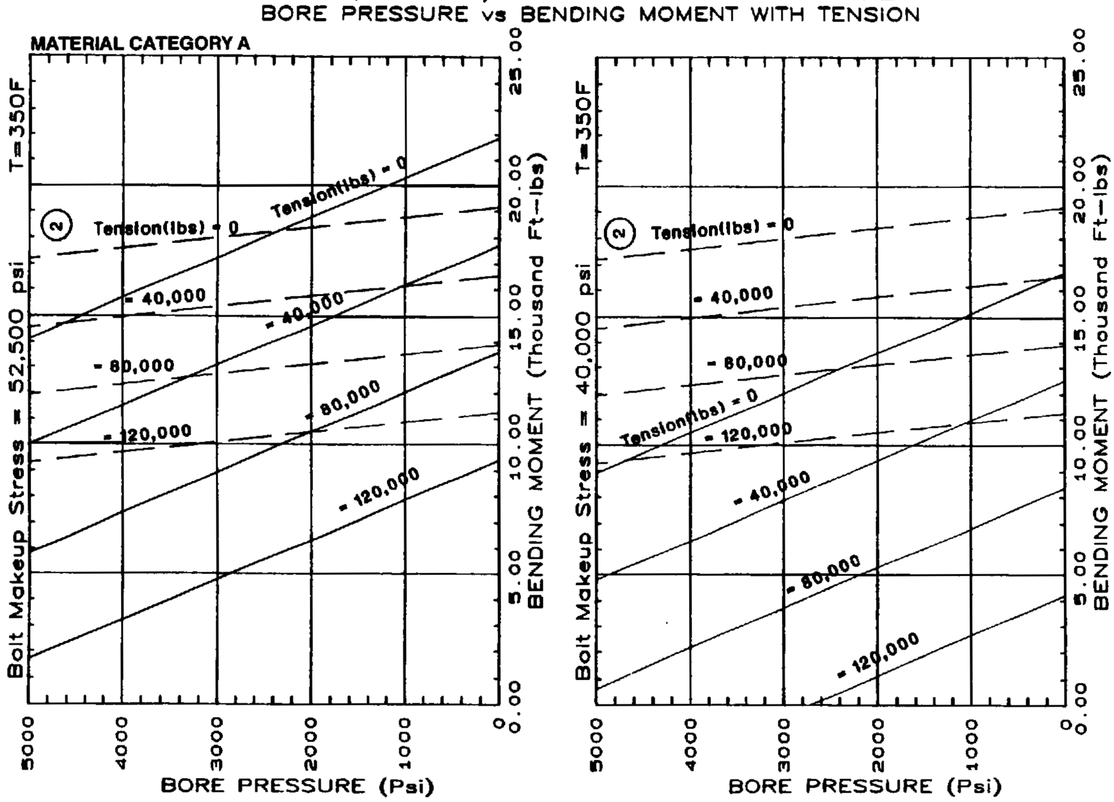
16–3/4"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



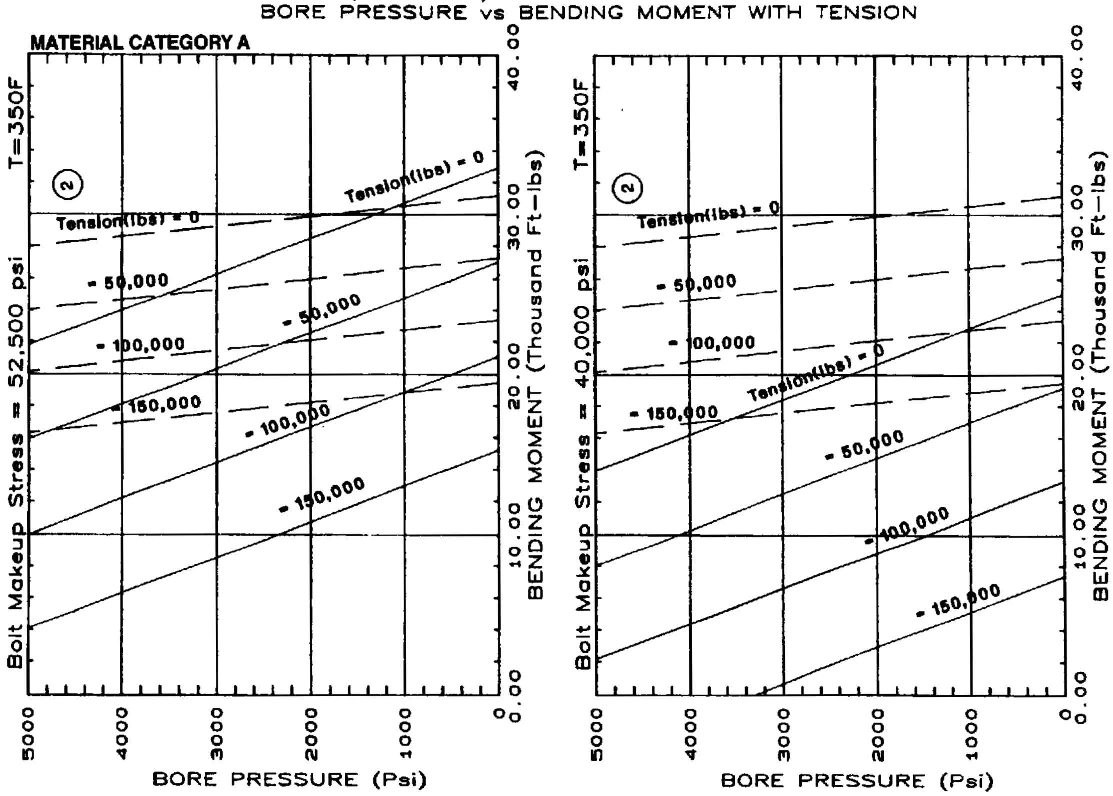
20–3/4"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



2-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

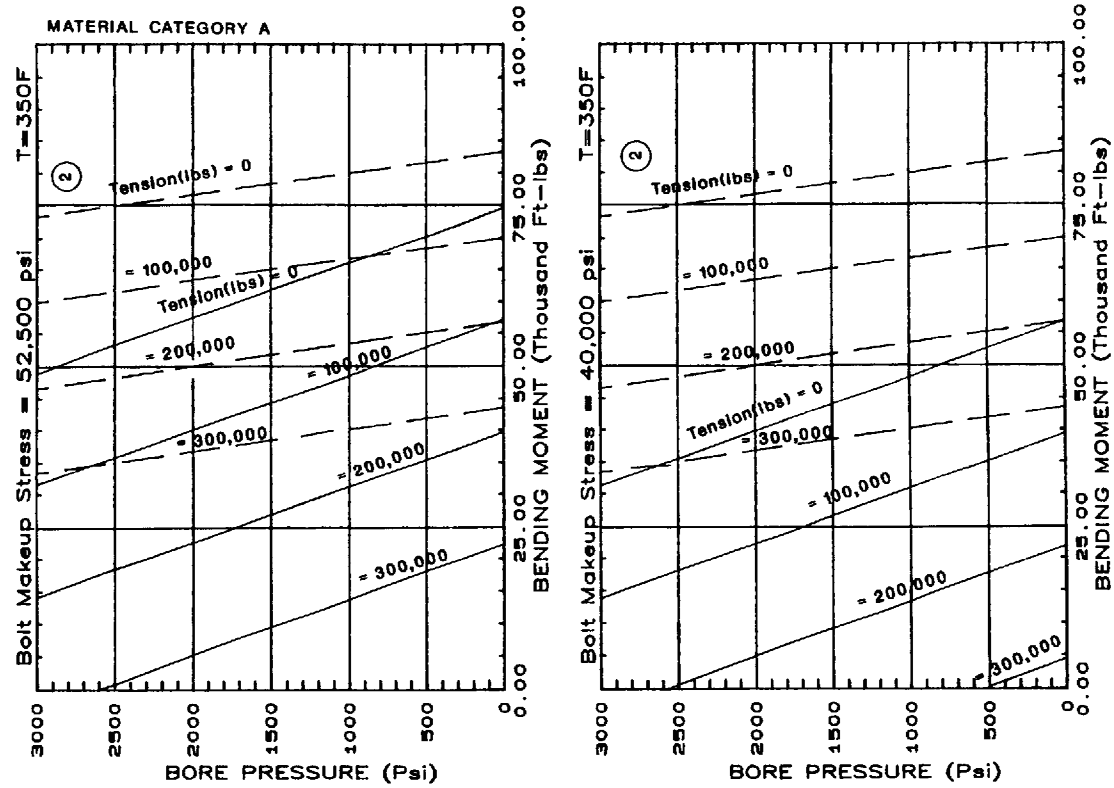


2-9/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



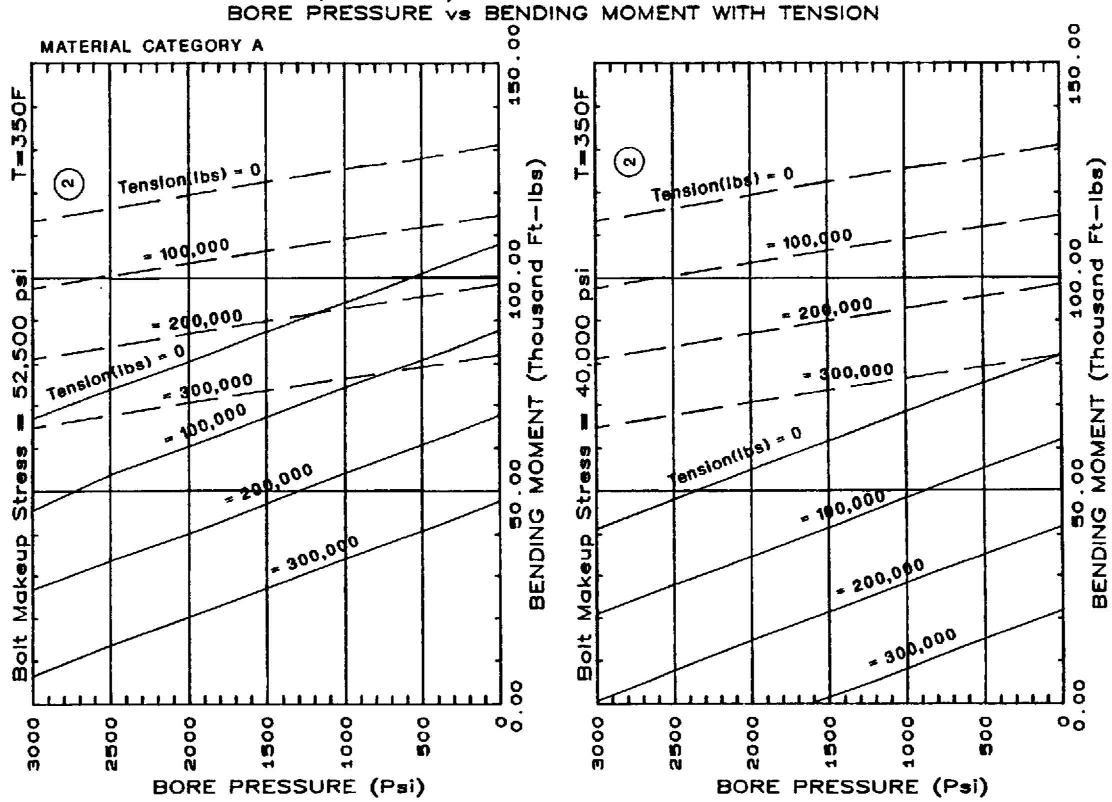
5-1/8"-3000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



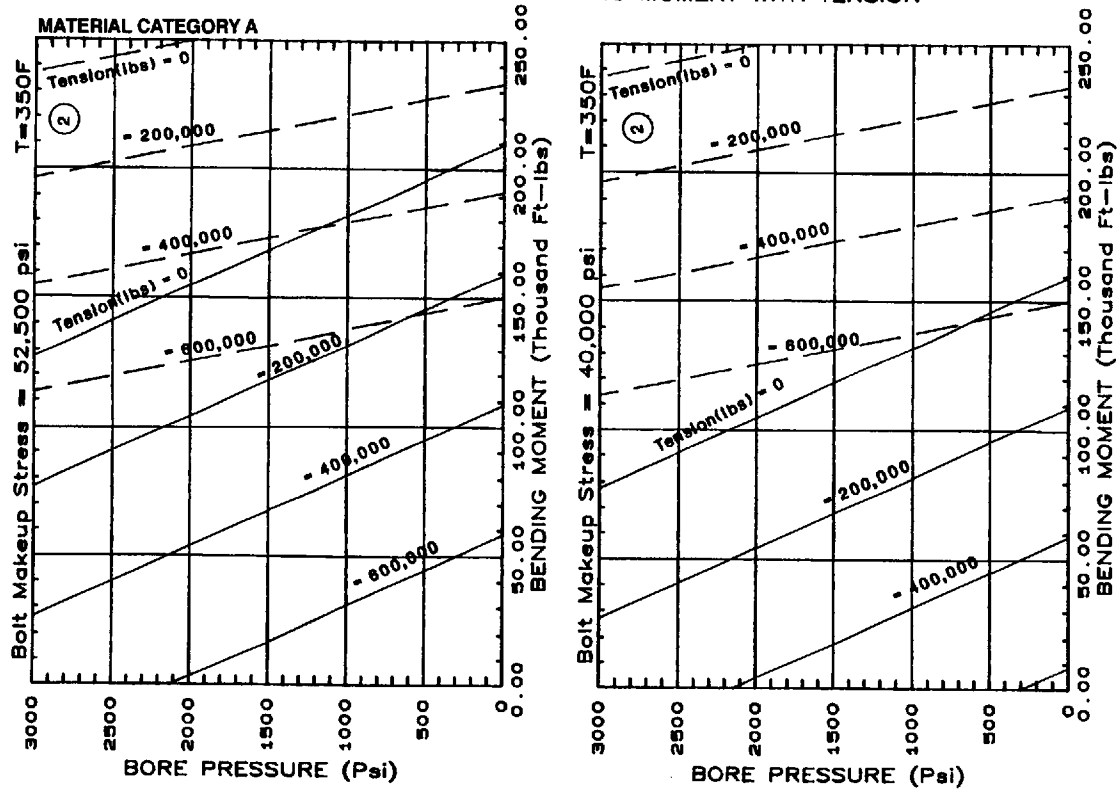
7-1/16"-3,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



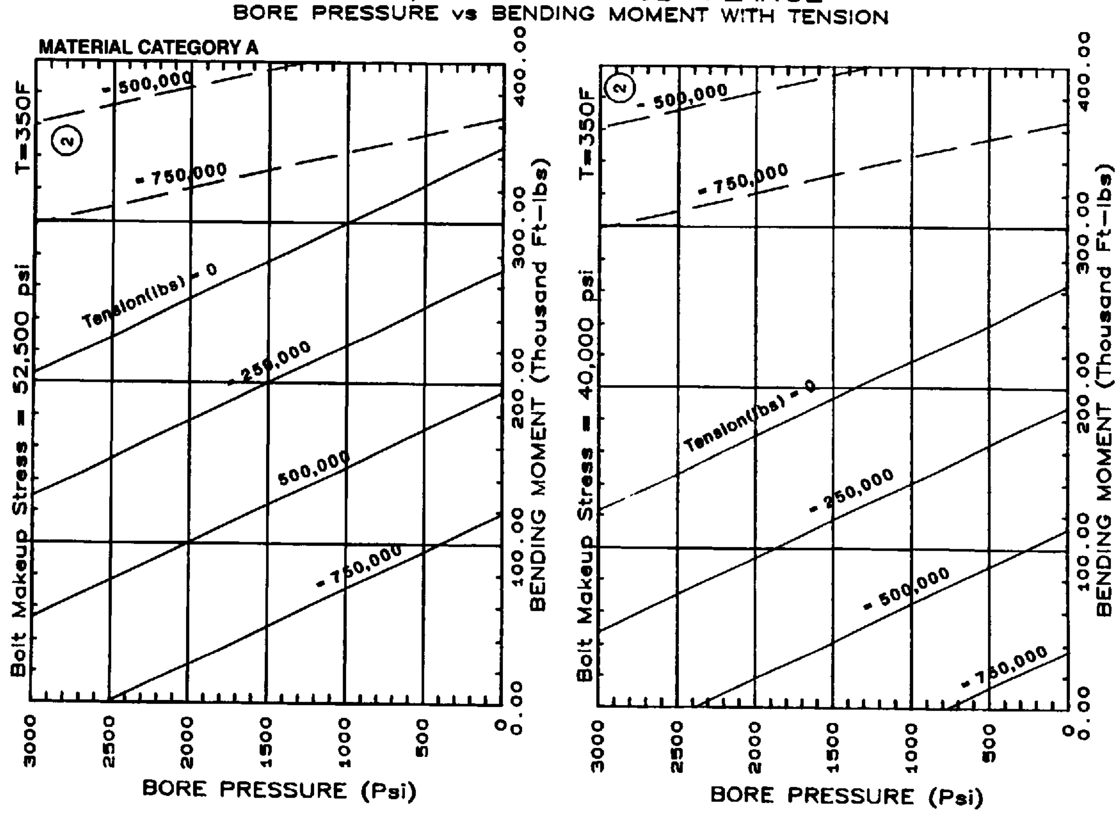
9"–3,000 PSI API 6B–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

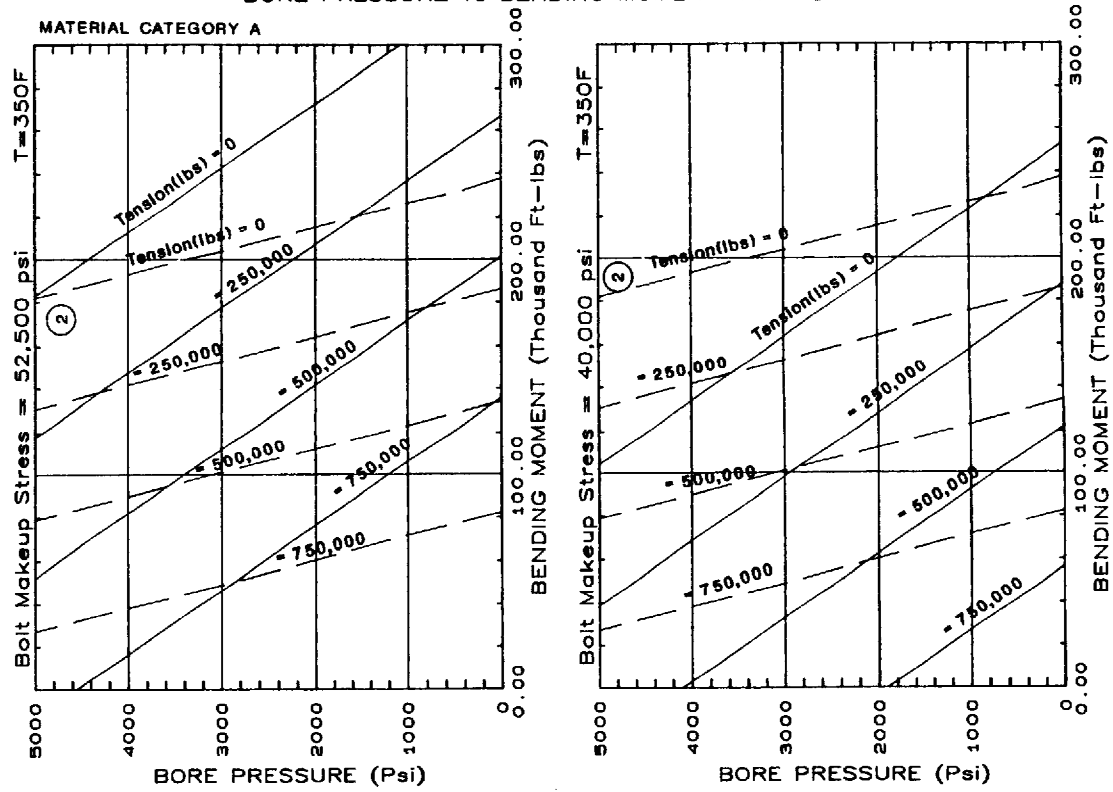


11"–3,000 PSI API 6B–FLANGE

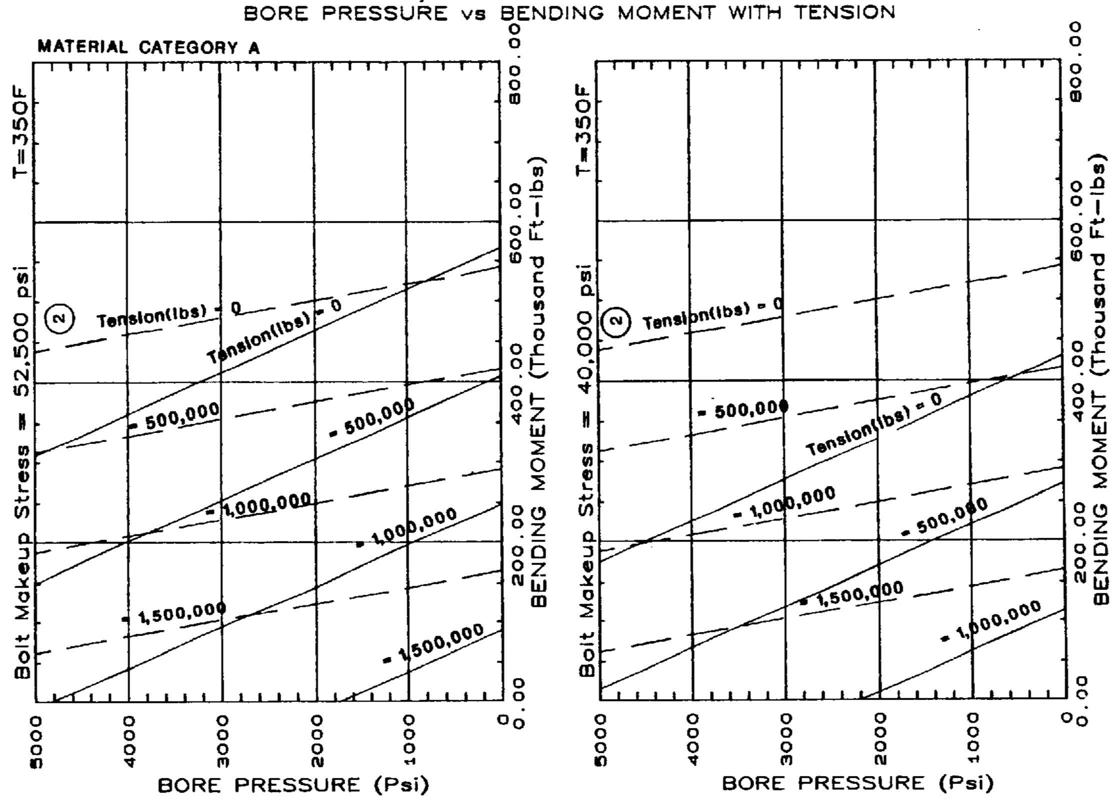
BORE PRESSURE vs BENDING MOMENT WITH TENSION



9"—5,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



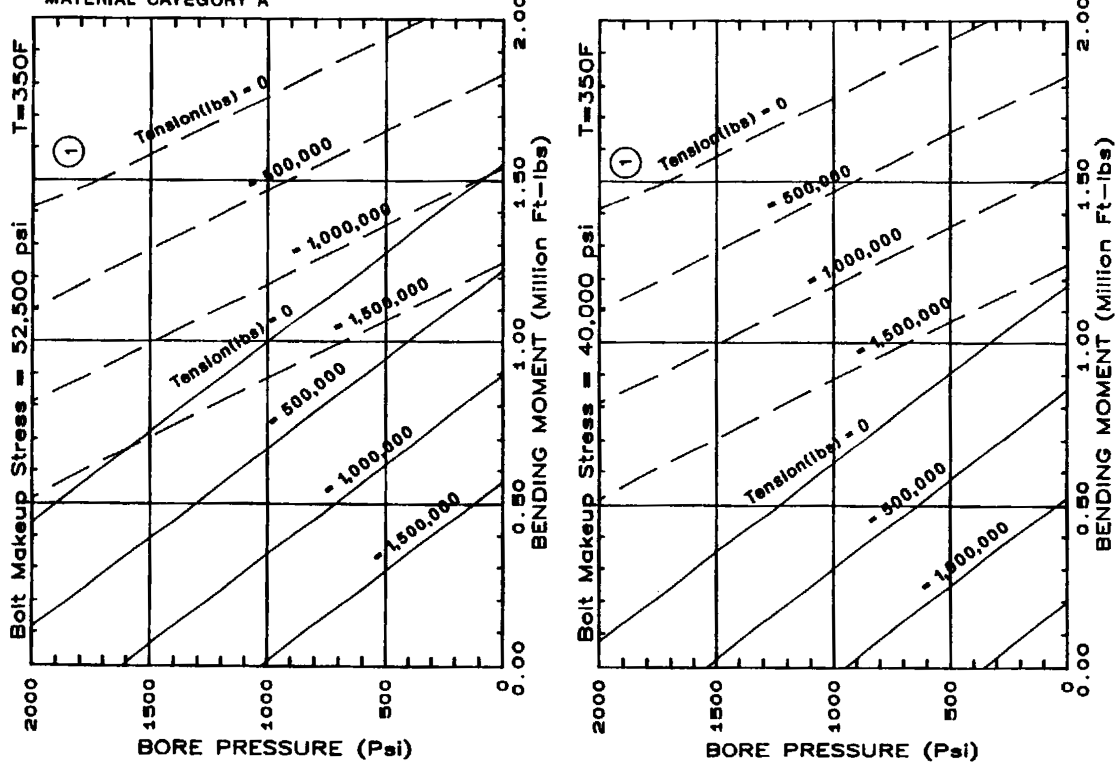
11"—5,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



26–3/4"–2,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

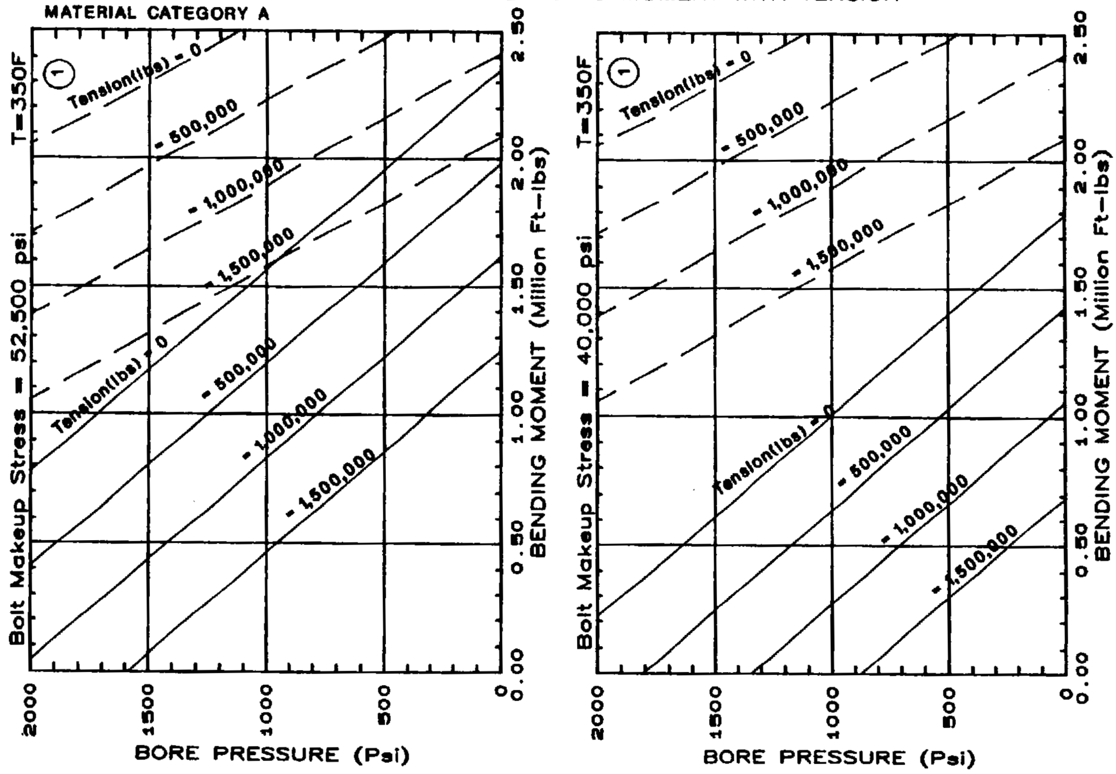
MATERIAL CATEGORY A



30"–2,000 PSI API 6BX–FLANGE

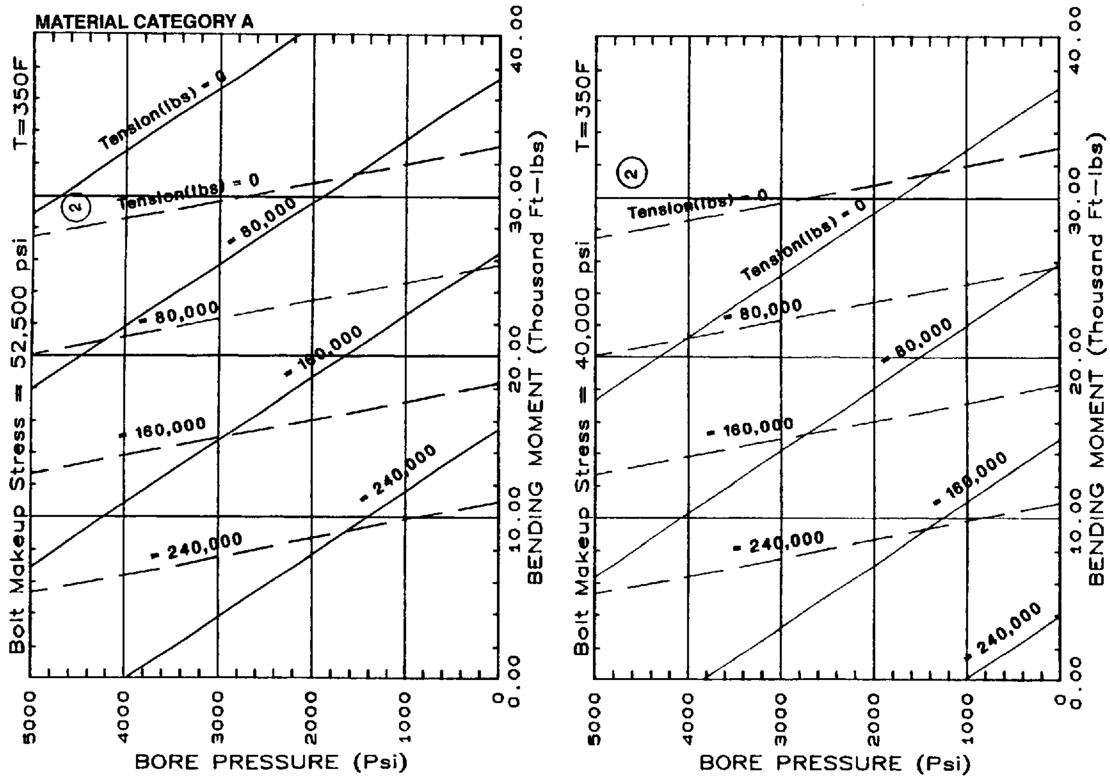
BORE PRESSURE vs BENDING MOMENT WITH TENSION

MATERIAL CATEGORY A



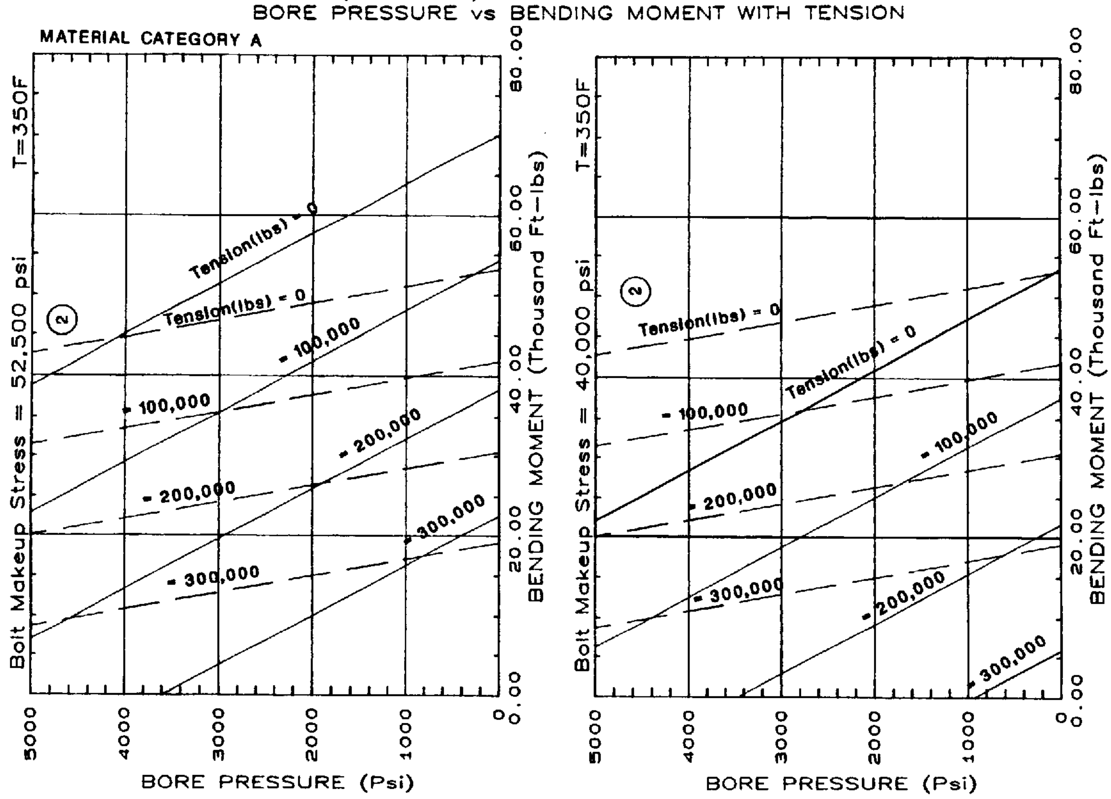
3-1/8"-5,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

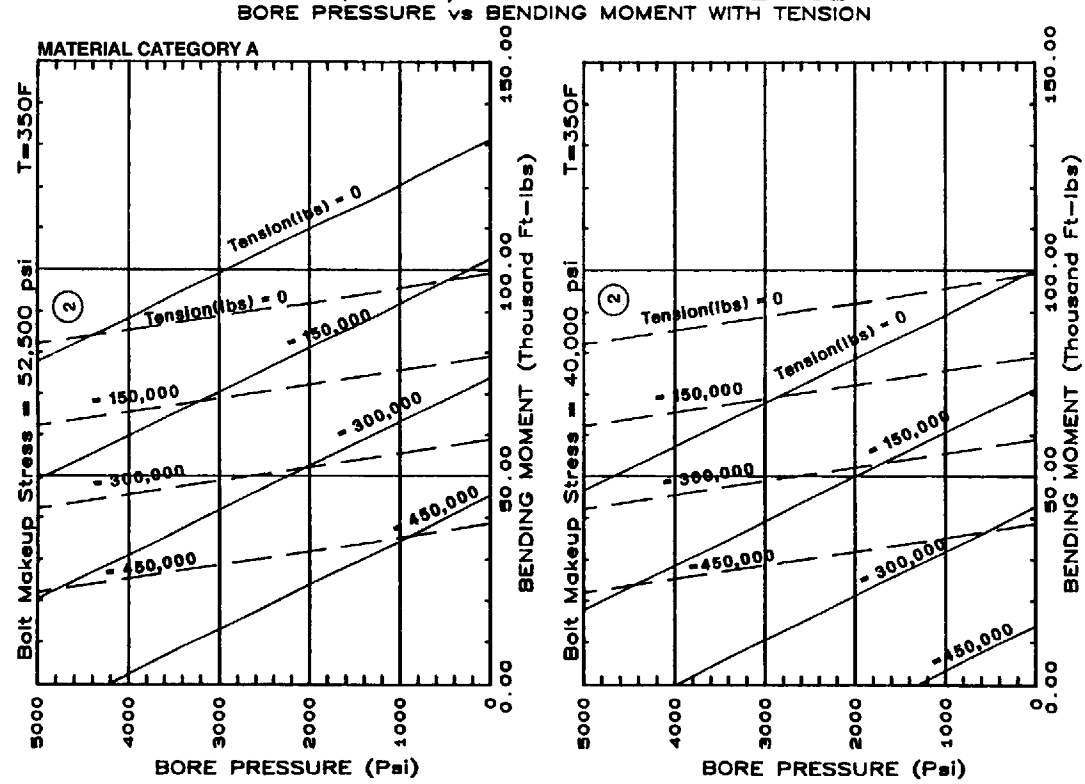


4-1/16"-5,000 PSI API 6B-FLANGE

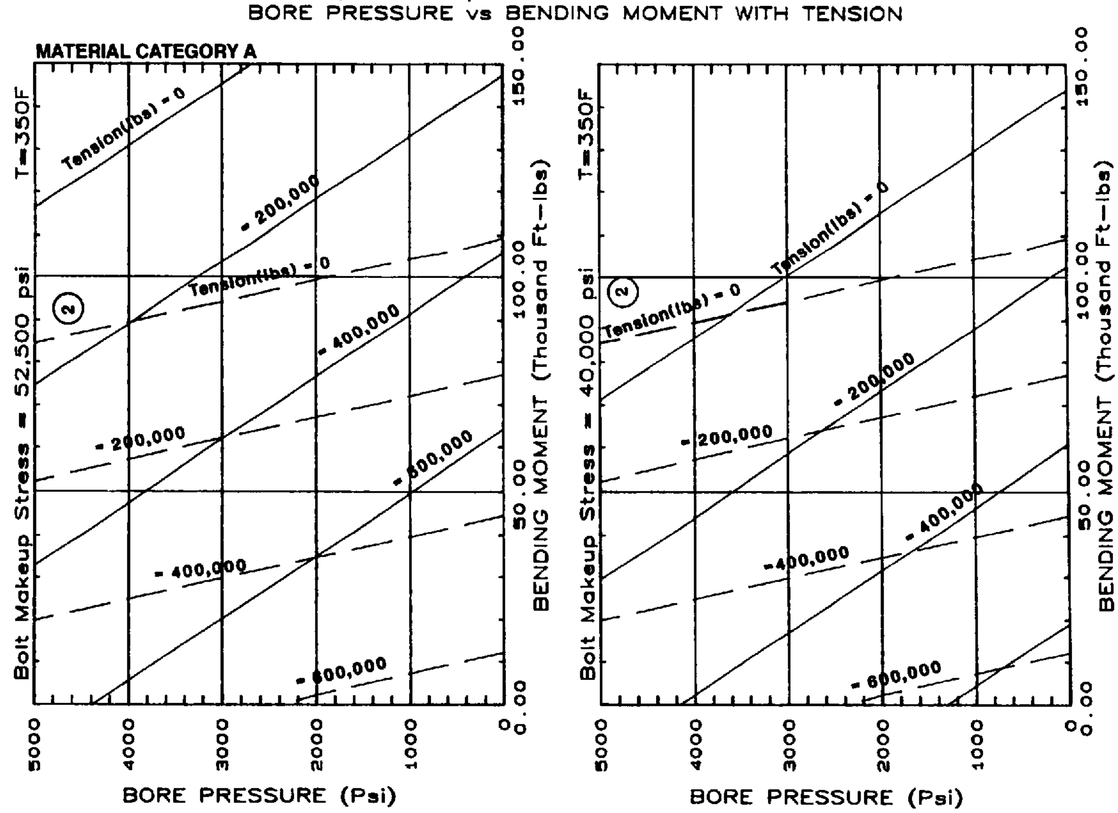
BORE PRESSURE vs BENDING MOMENT WITH TENSION



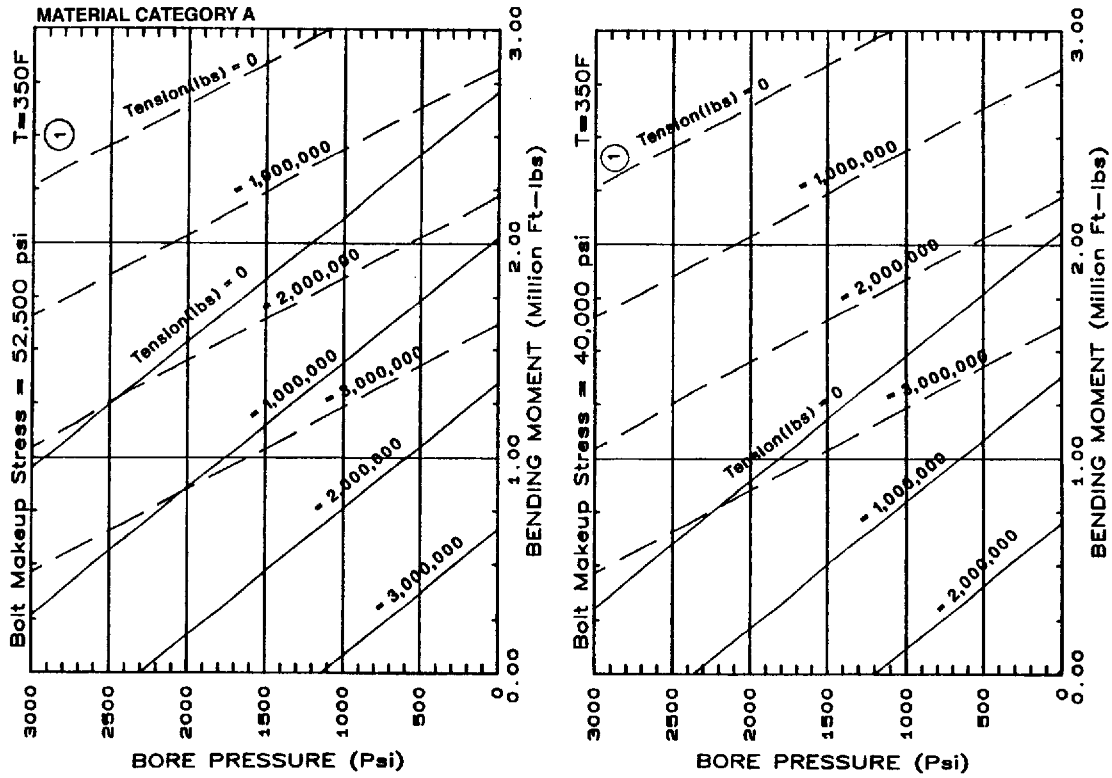
5-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



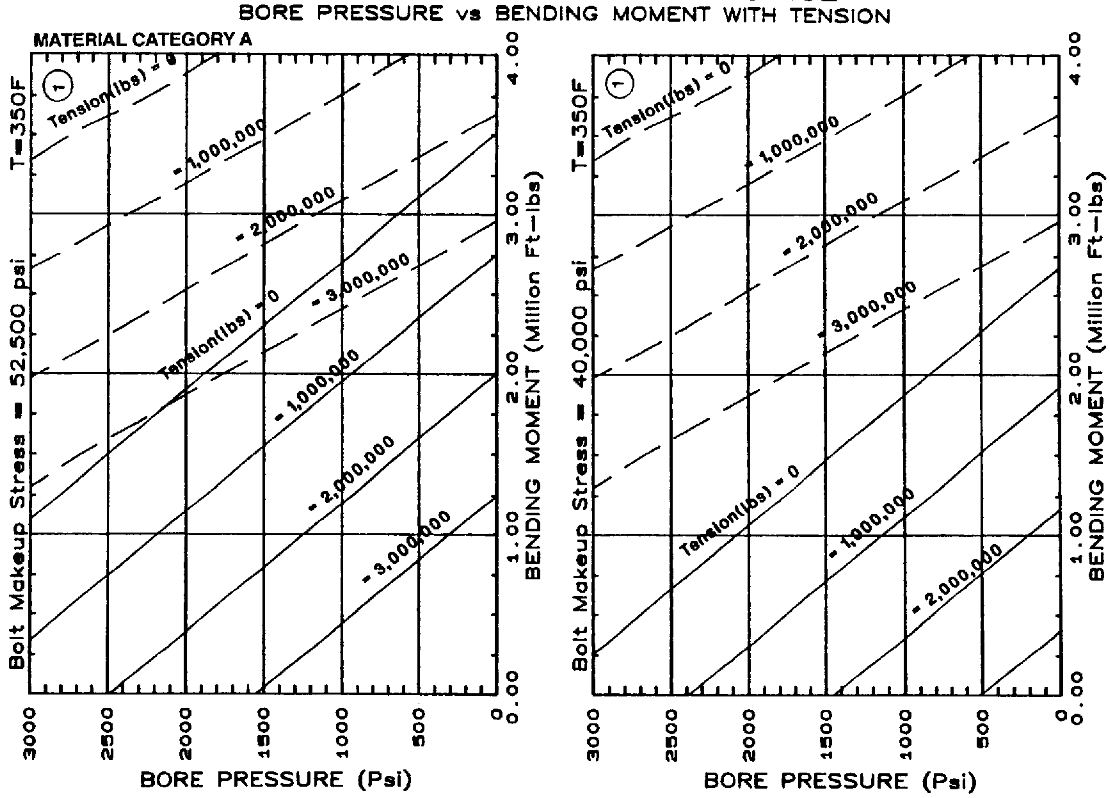
7-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



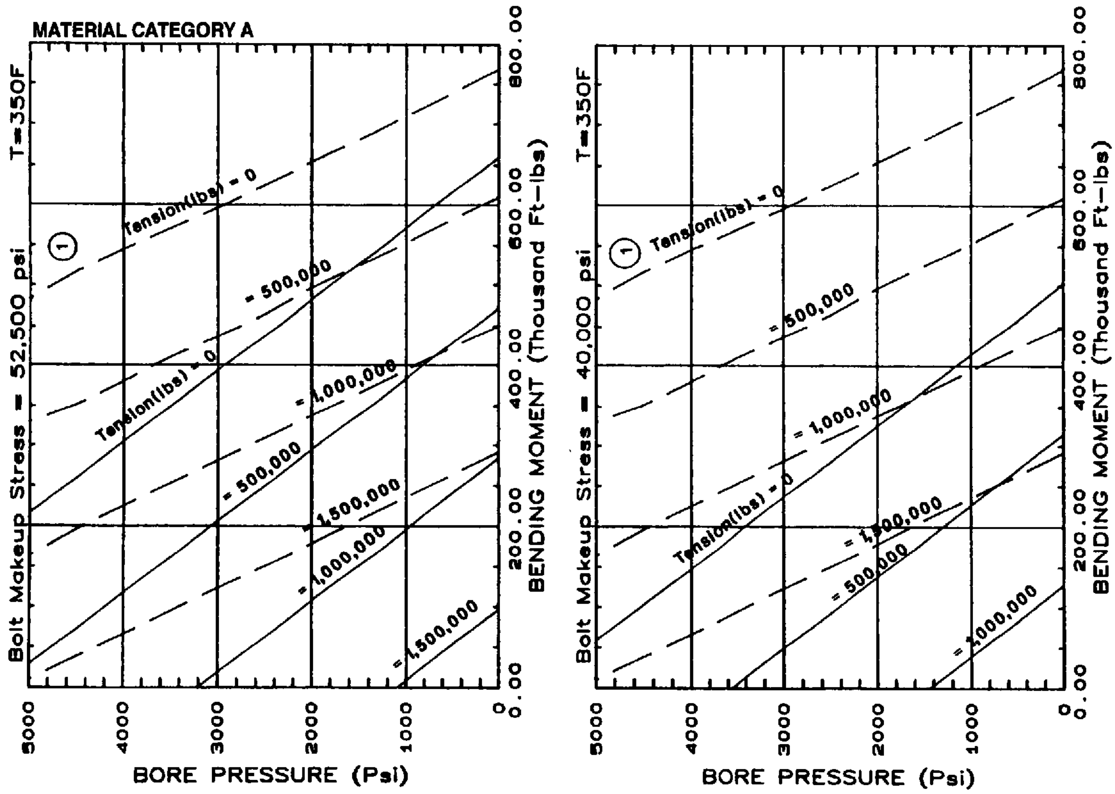
26—3/4"—3,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



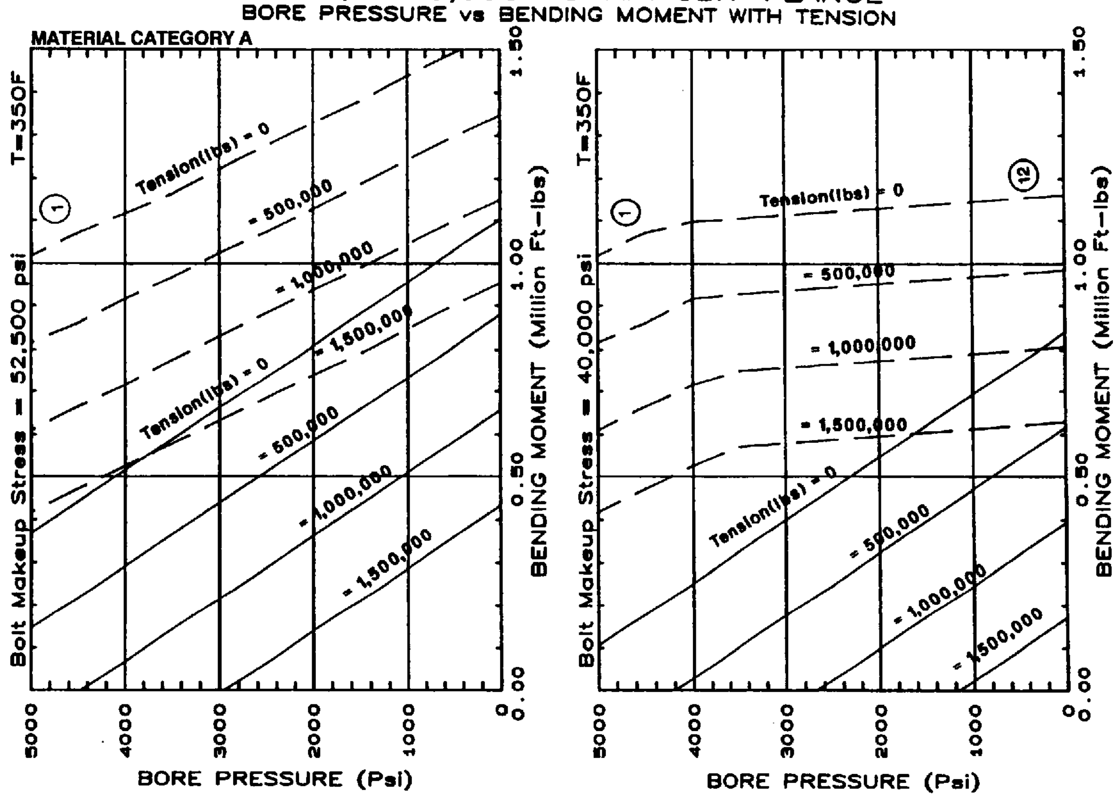
30"—3000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



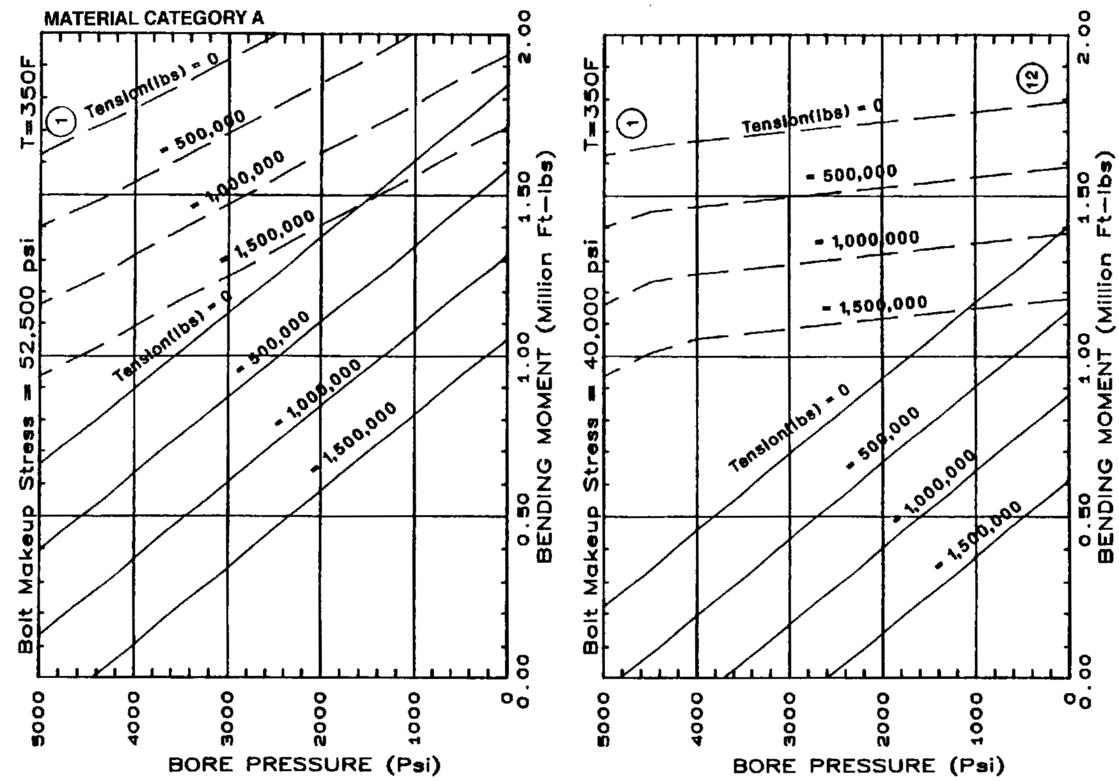
13-5/8"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



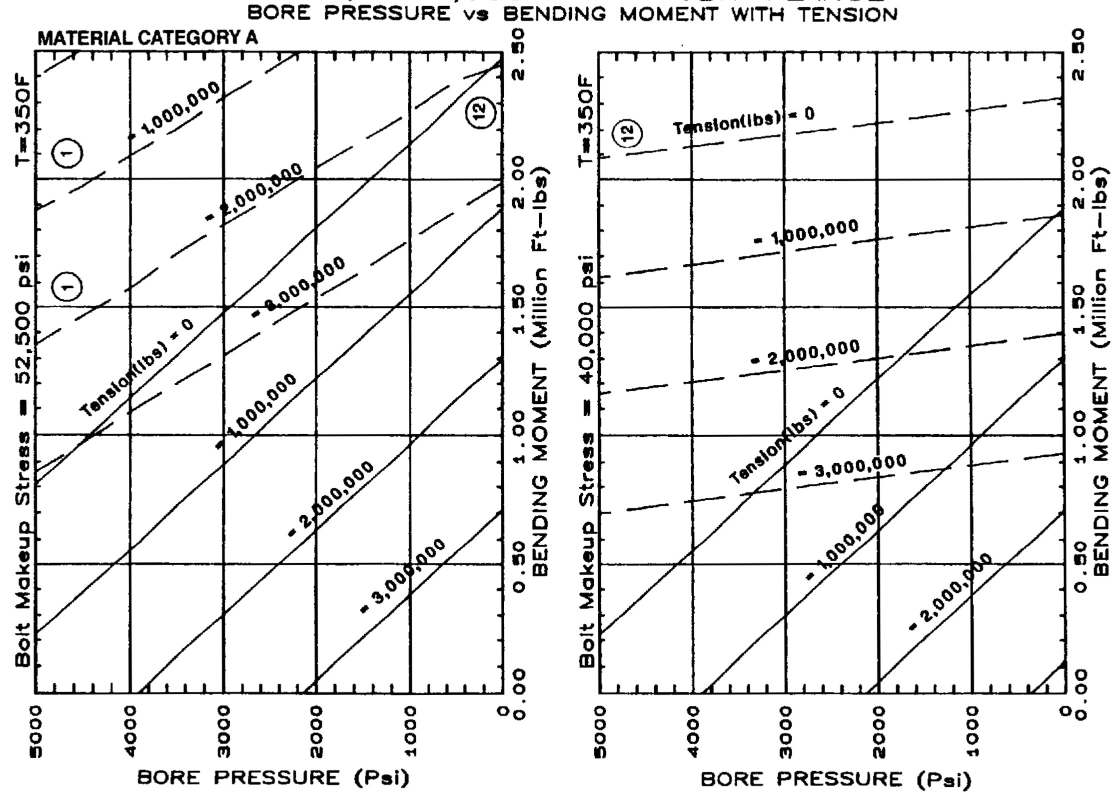
16-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



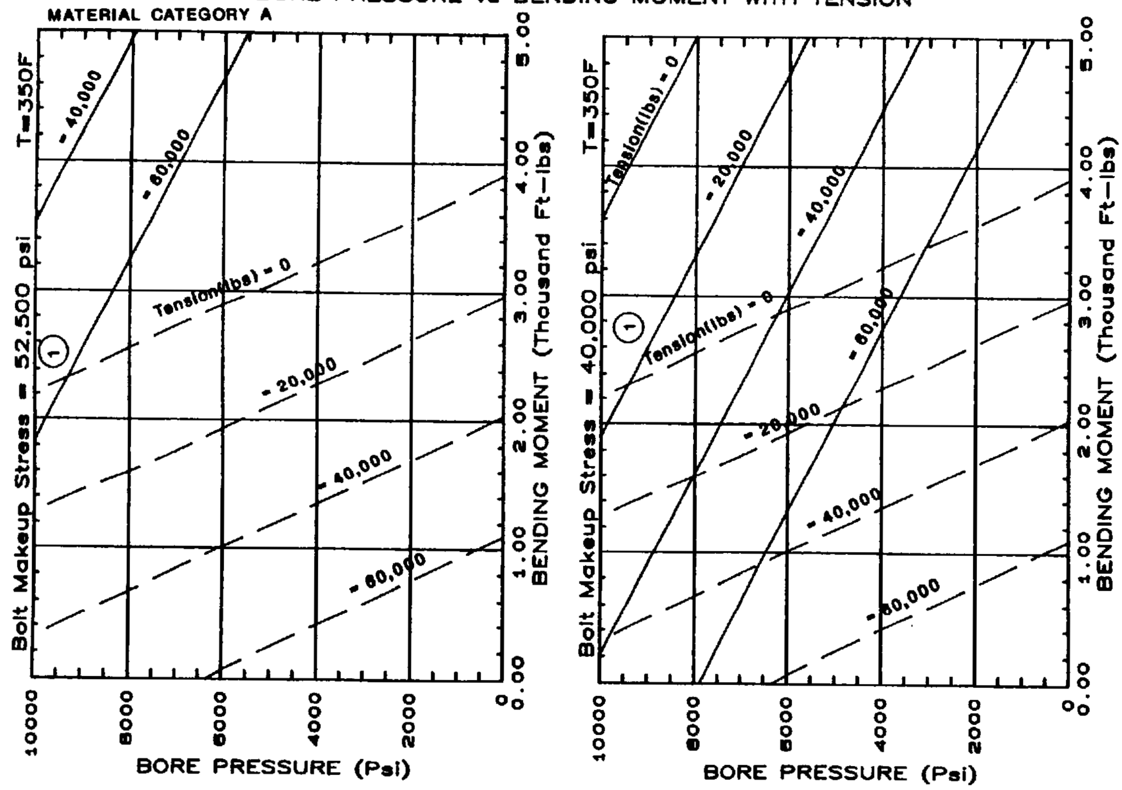
18-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



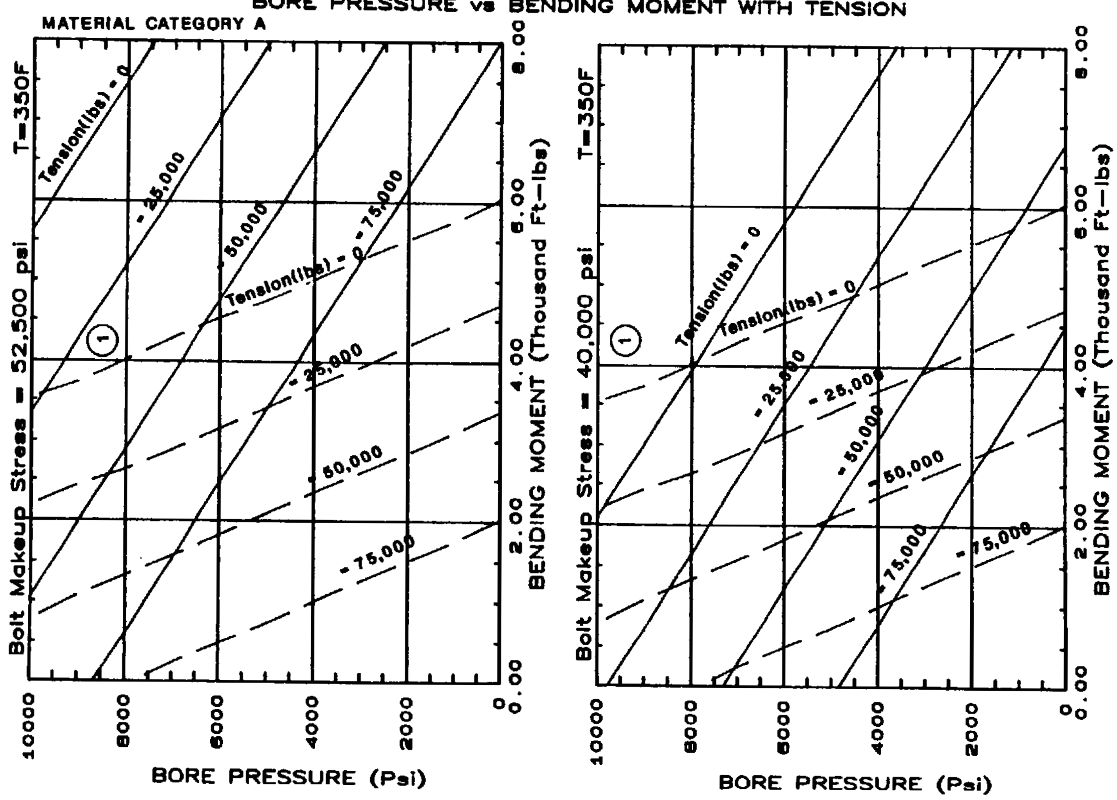
21-1/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



1-13/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

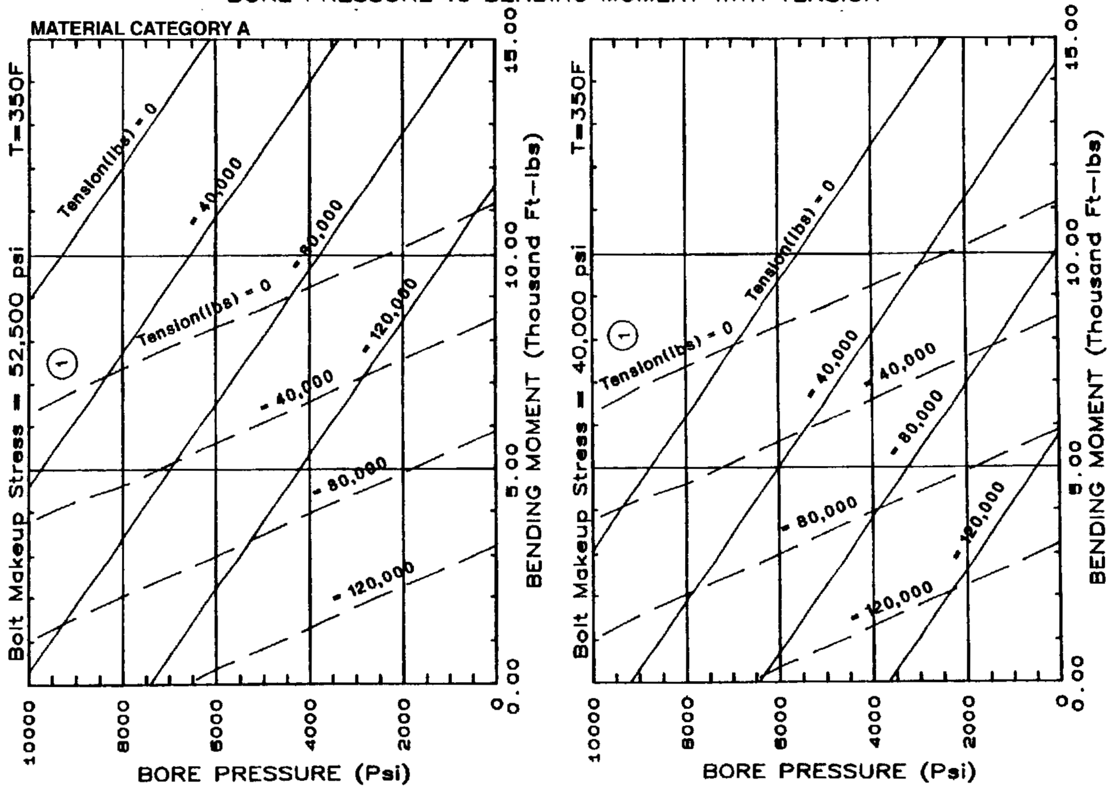


2-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



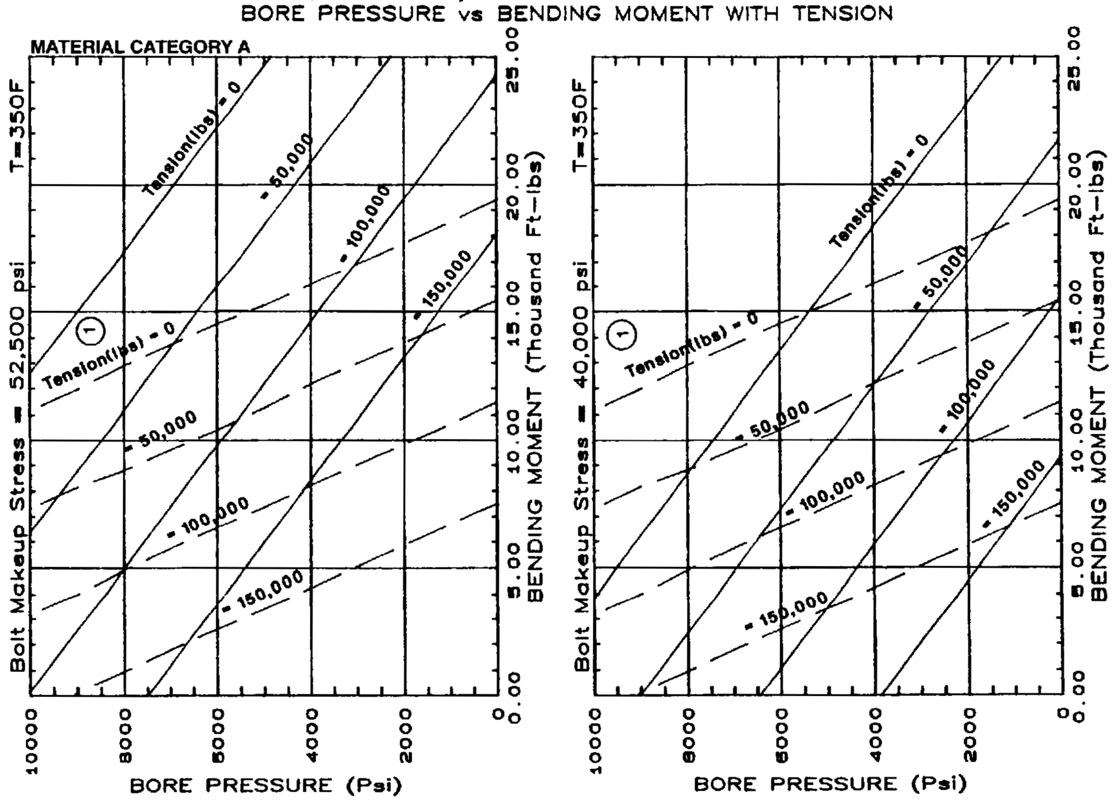
2-9/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

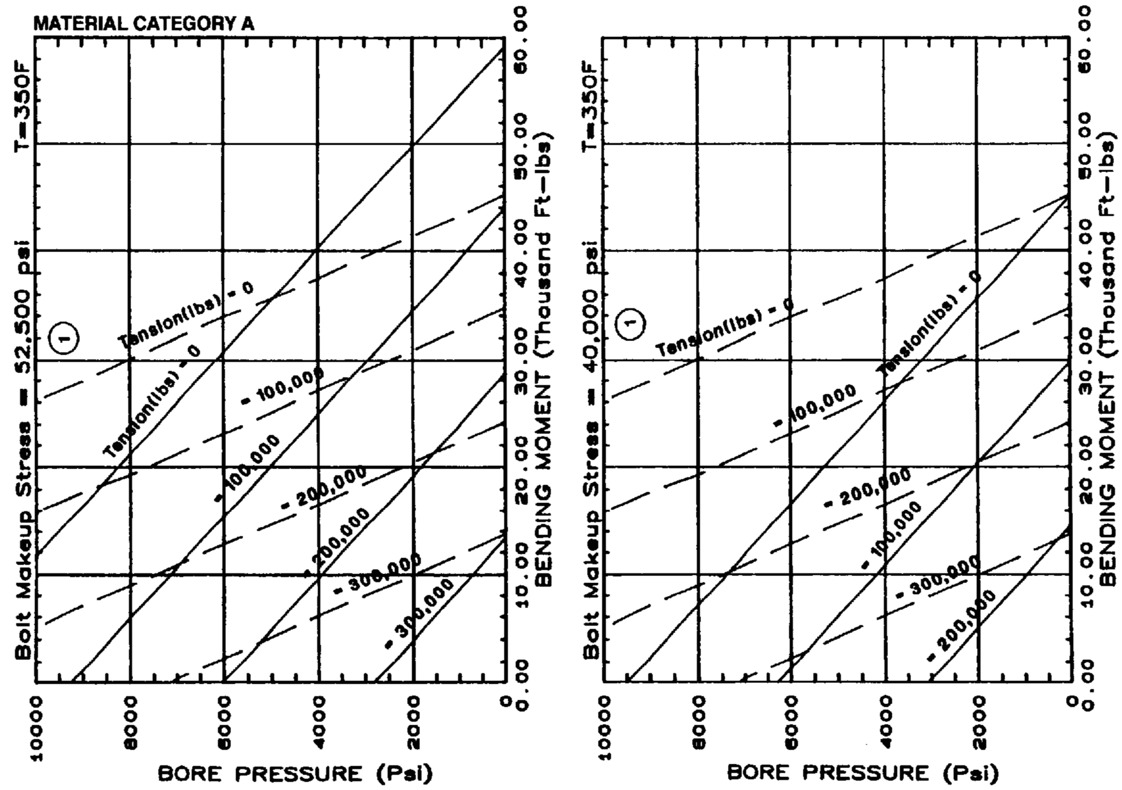


3-1/16"-10,000 PSI API 6BX-FLANGE

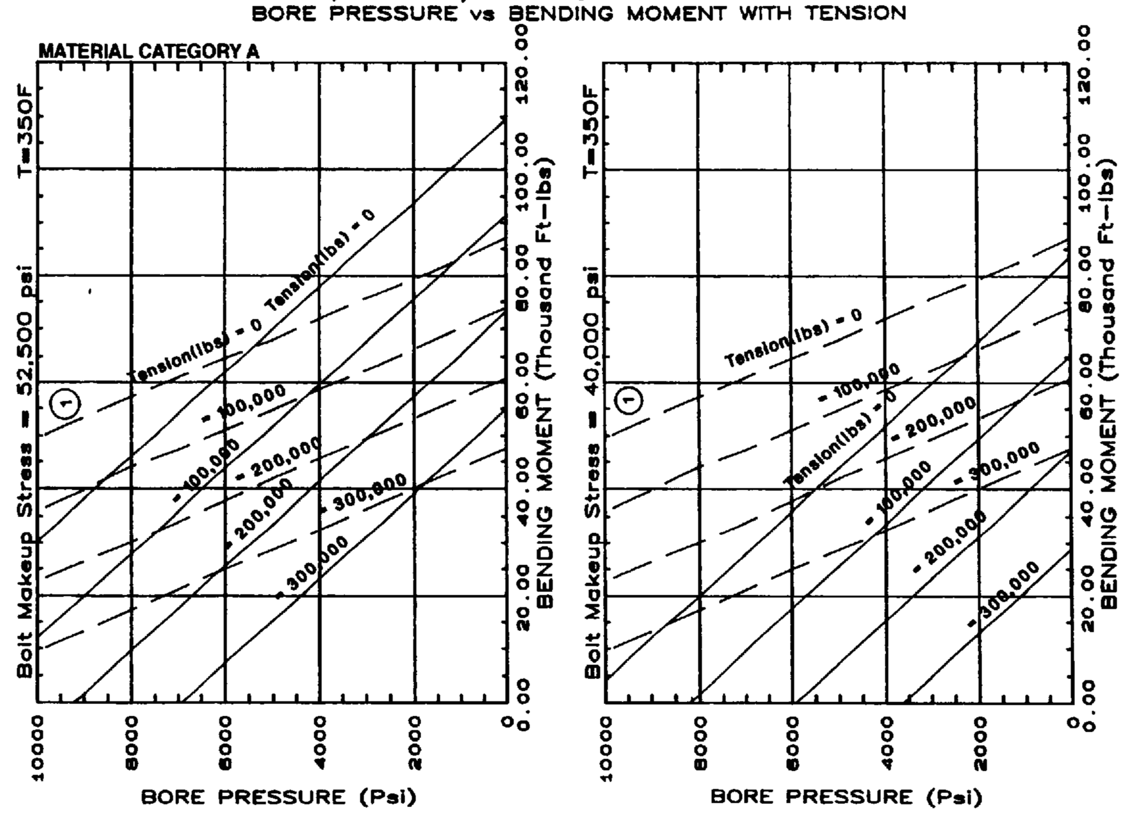
BORE PRESSURE vs BENDING MOMENT WITH TENSION



4-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

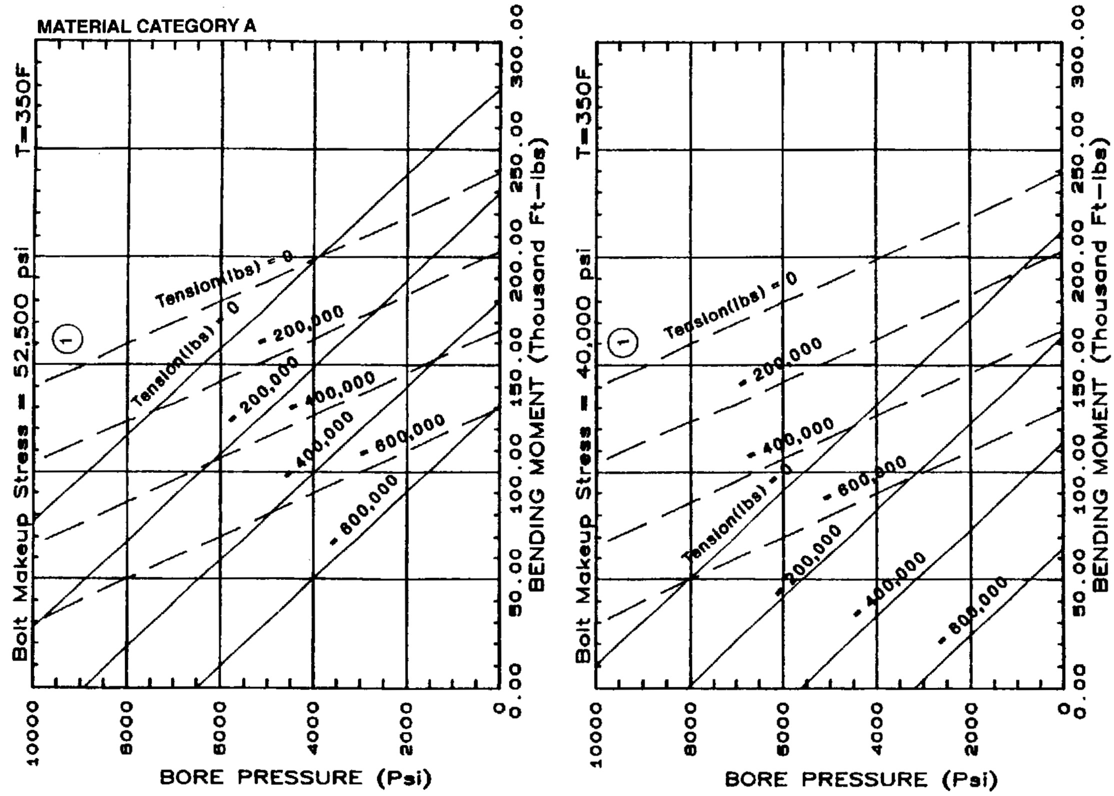


5-1/8"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



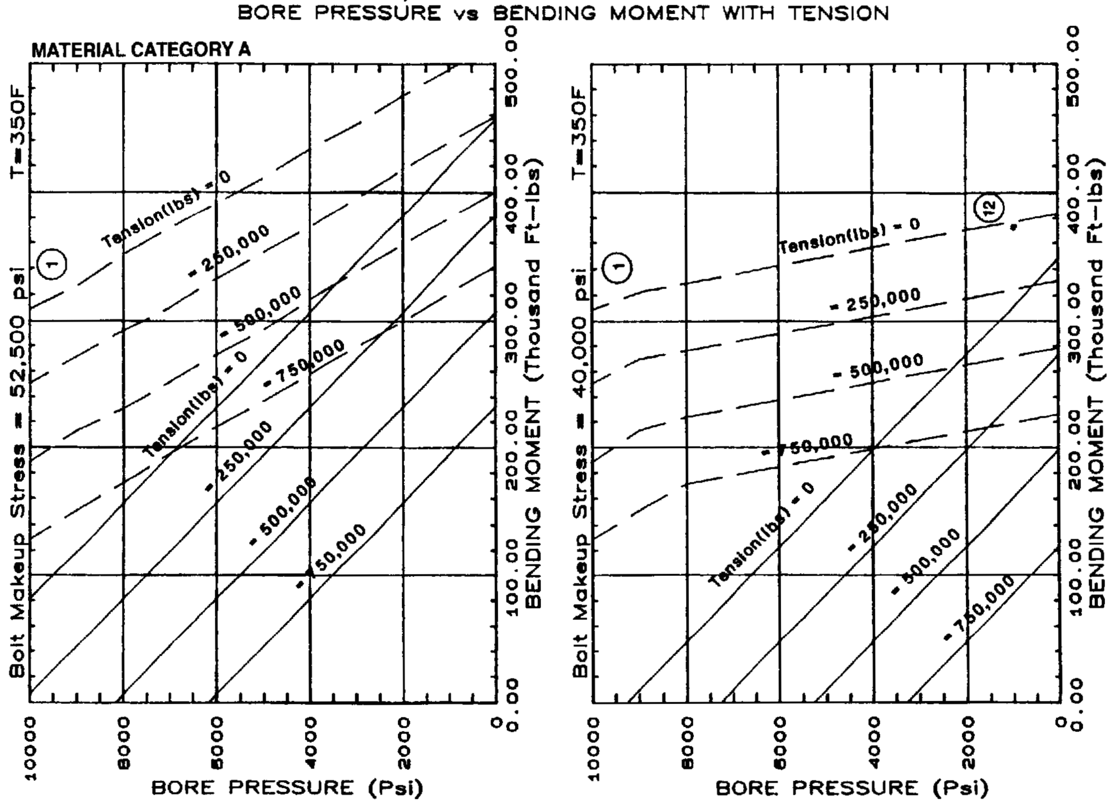
7-1/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



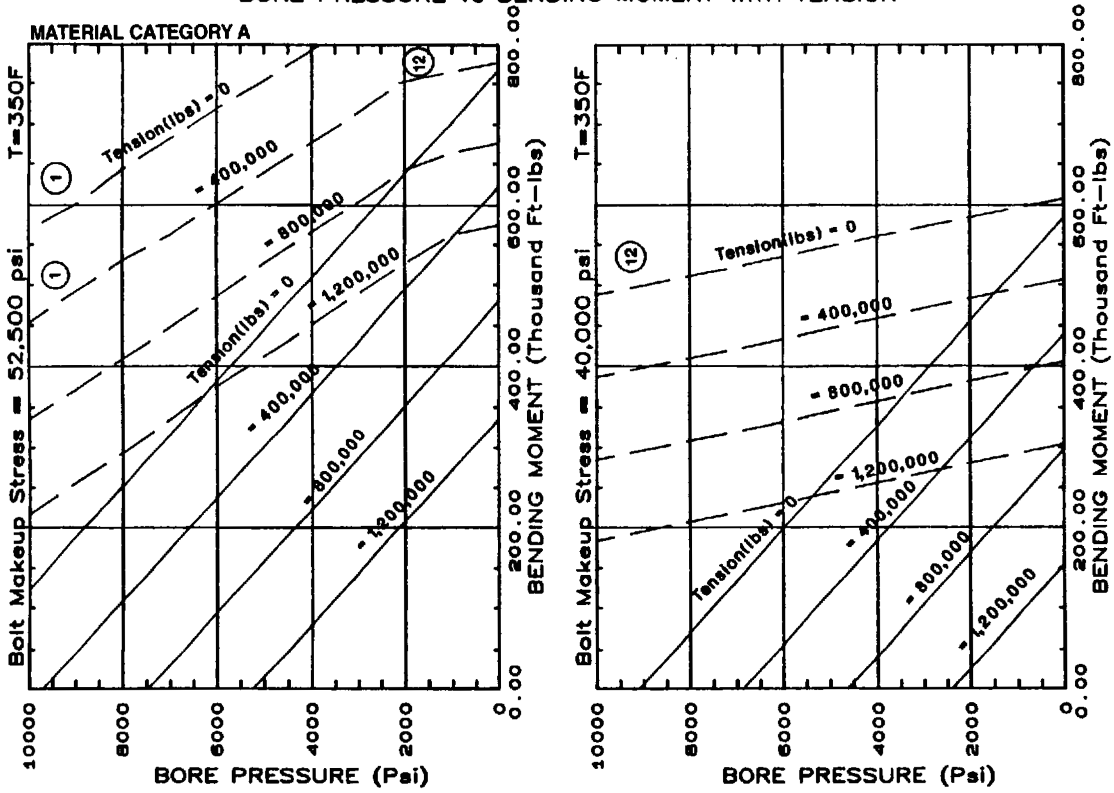
9"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



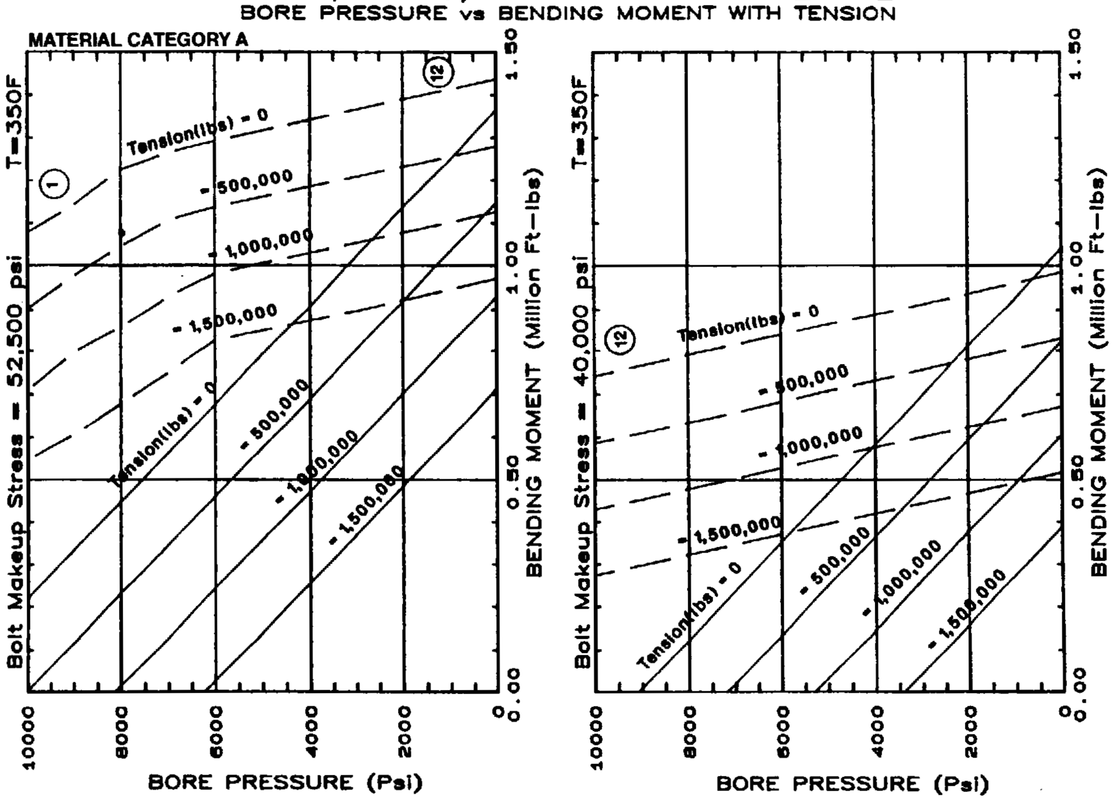
11"–10,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

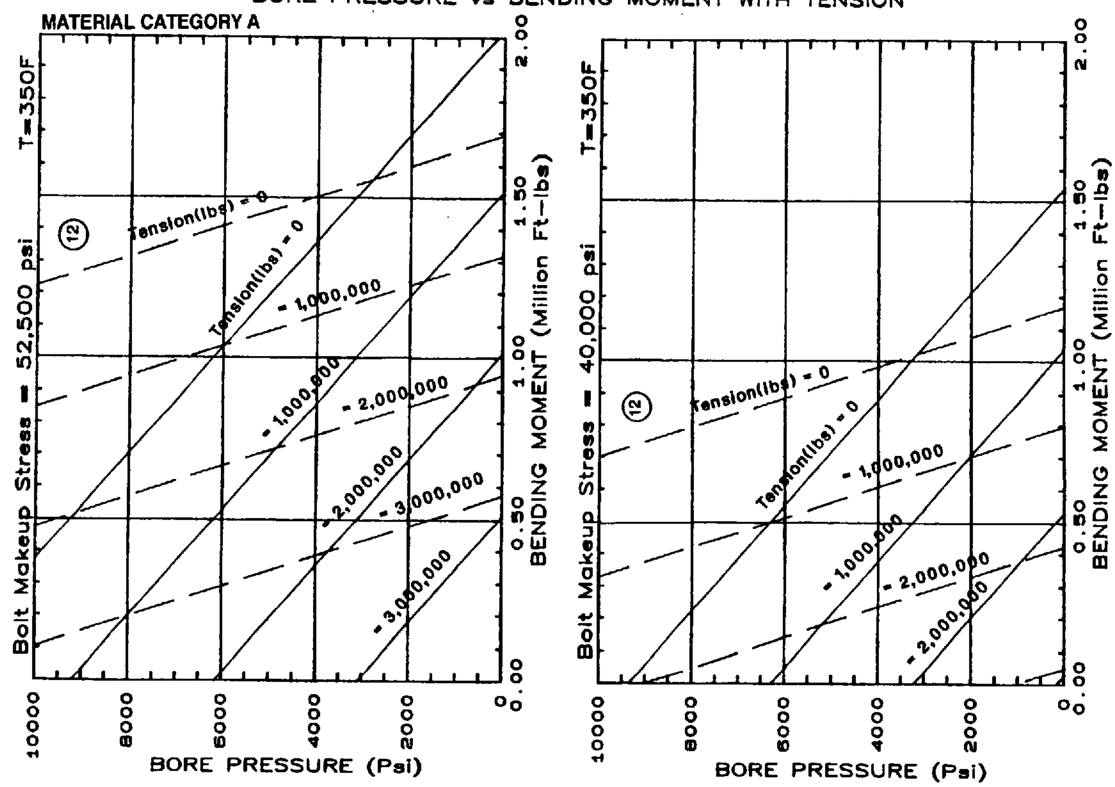


13–5/8"–10,000 PSI API 6BX–FLANGE

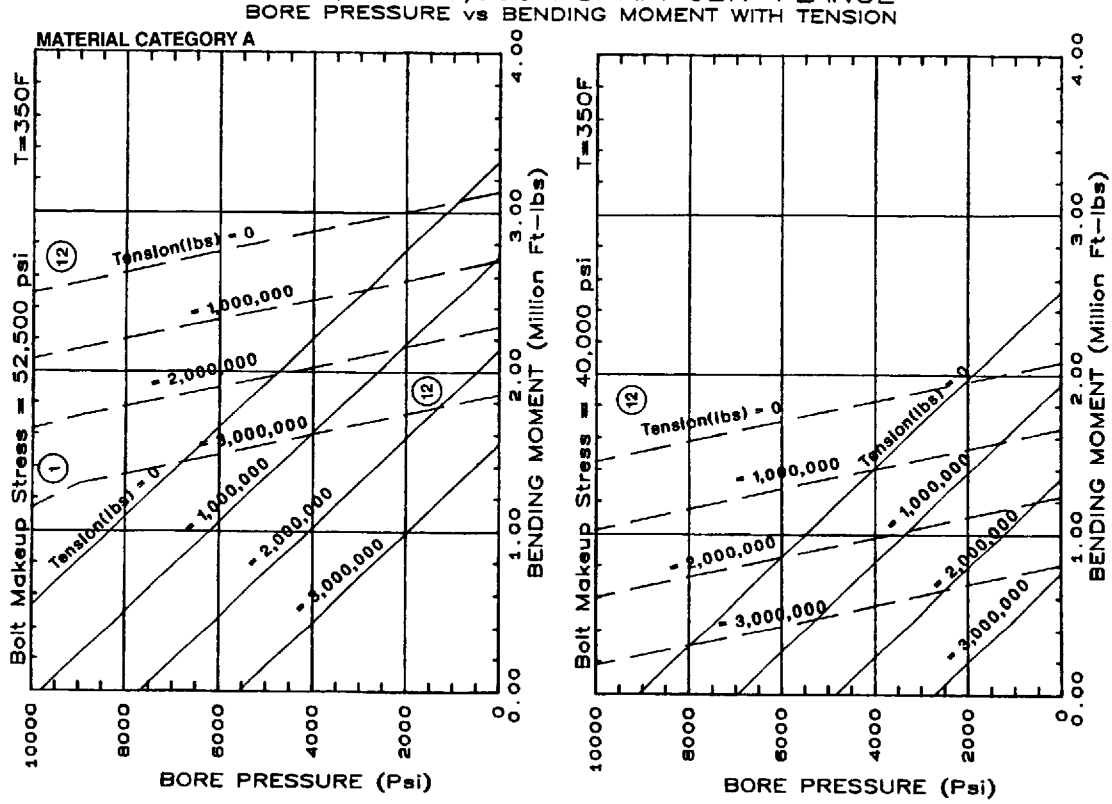
BORE PRESSURE vs BENDING MOMENT WITH TENSION



16-3/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

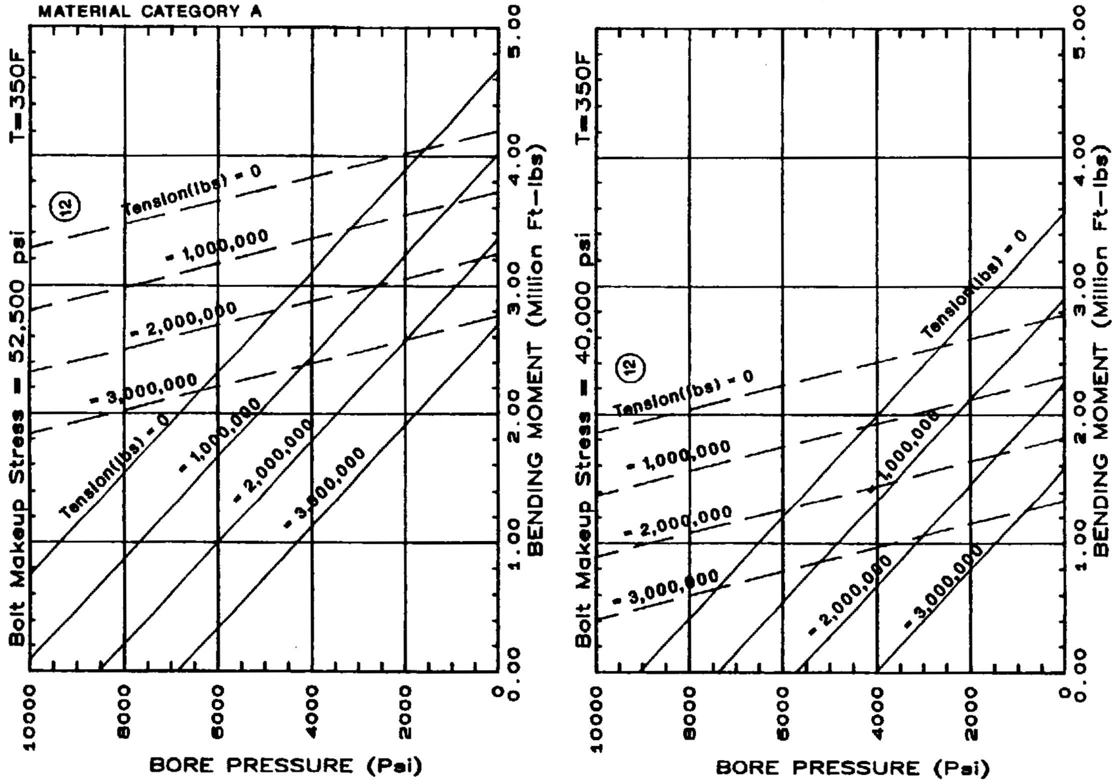


18-3/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



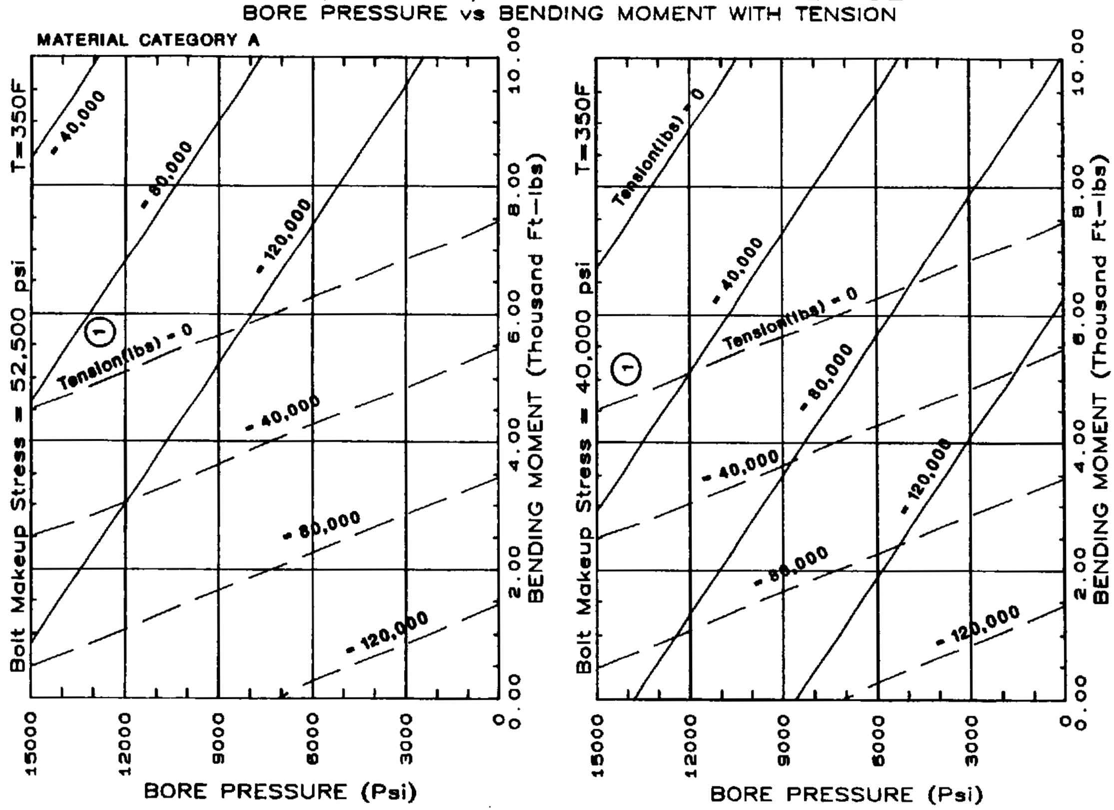
21-1/4"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



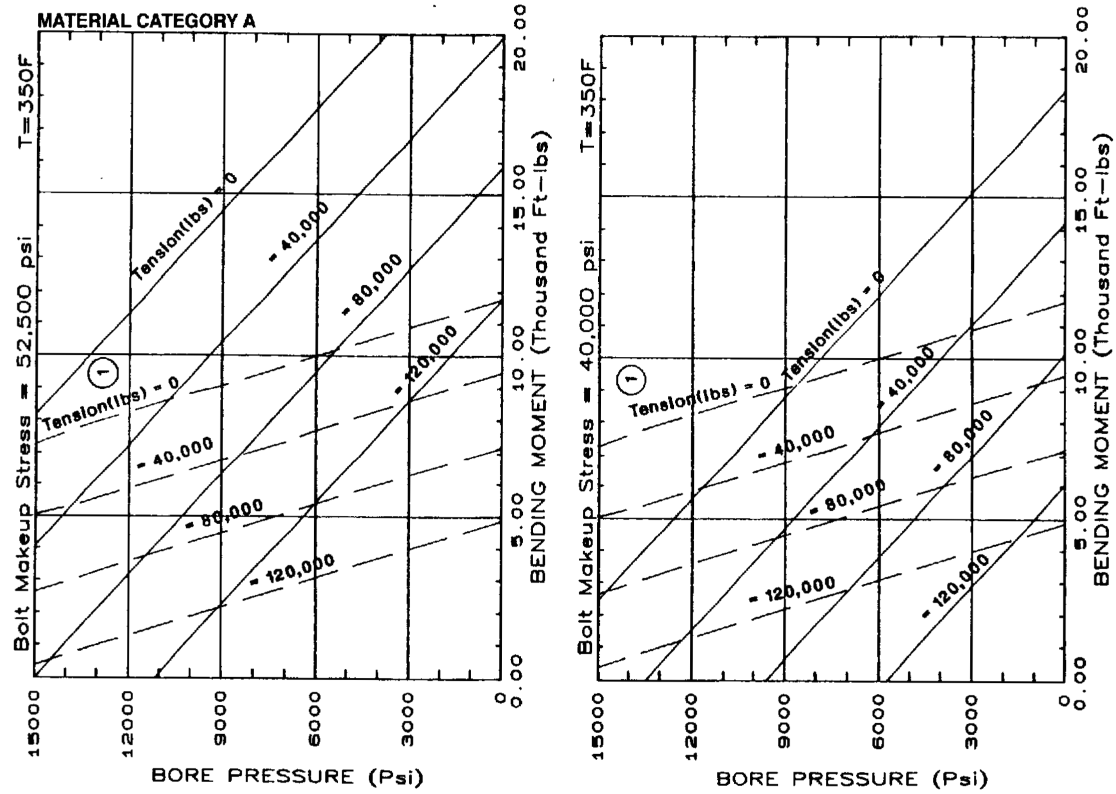
1-13/16"-15,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



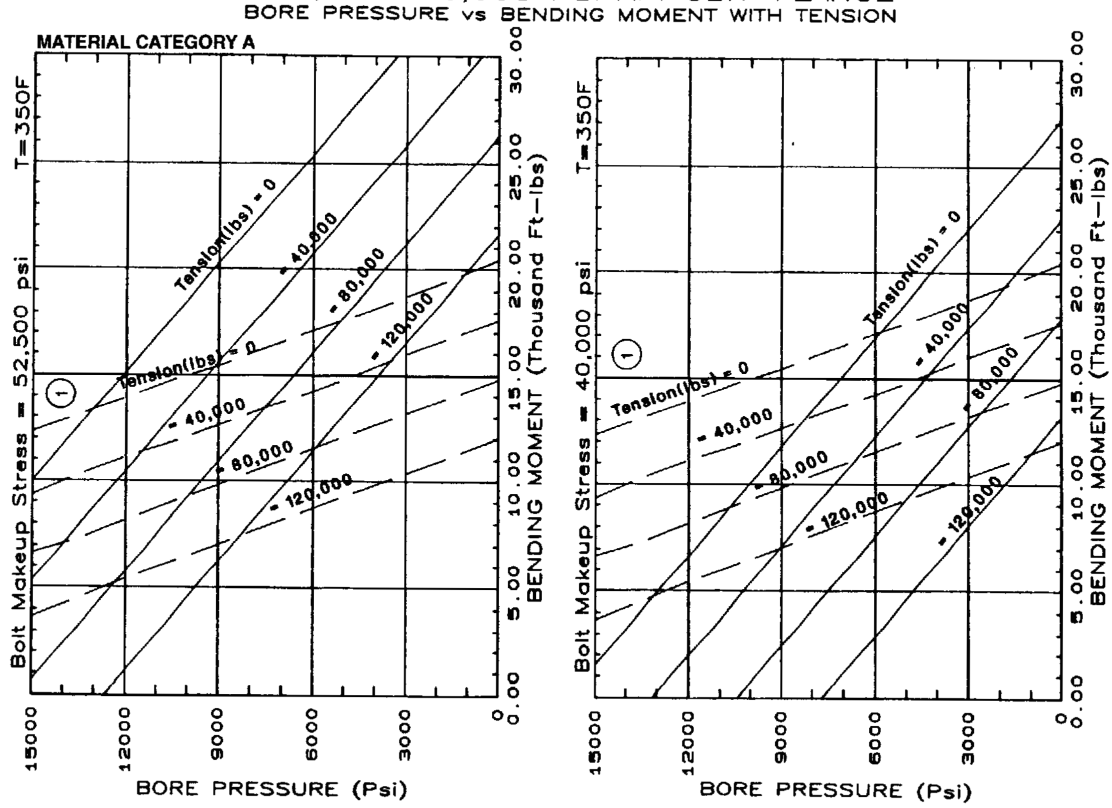
2-1/16"-15,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

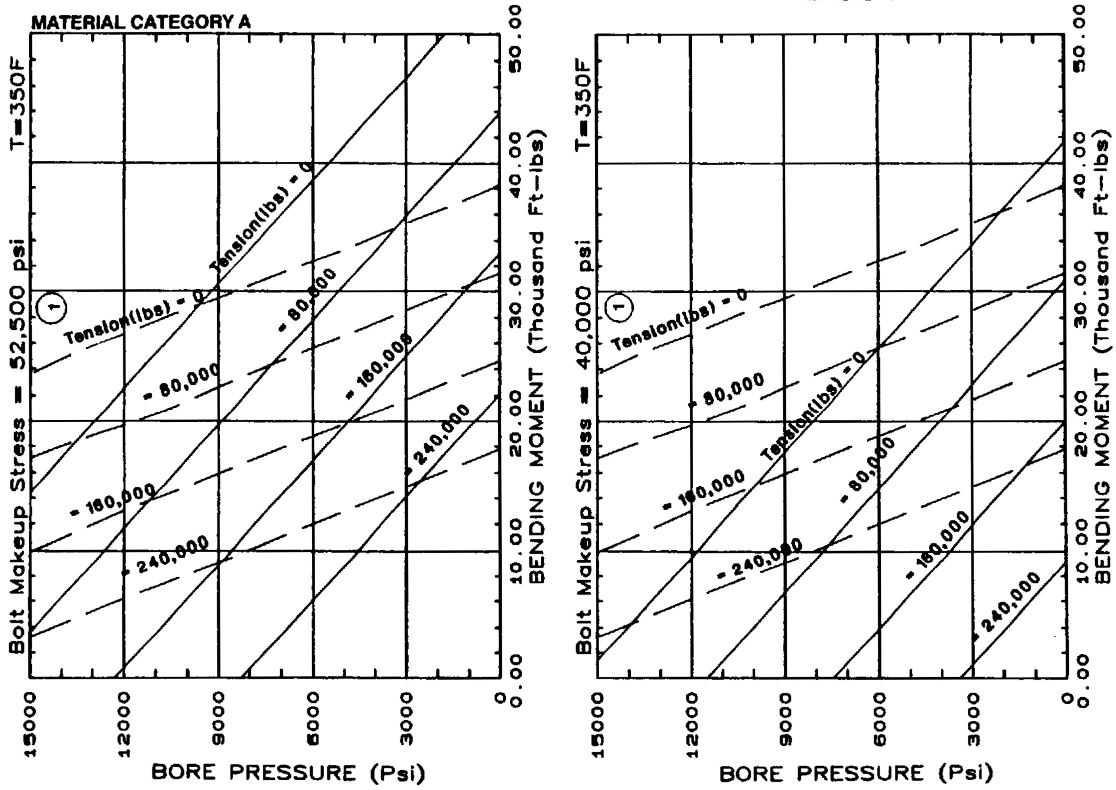


2-9/16"-15,000 PSI API 6BX-FLANGE

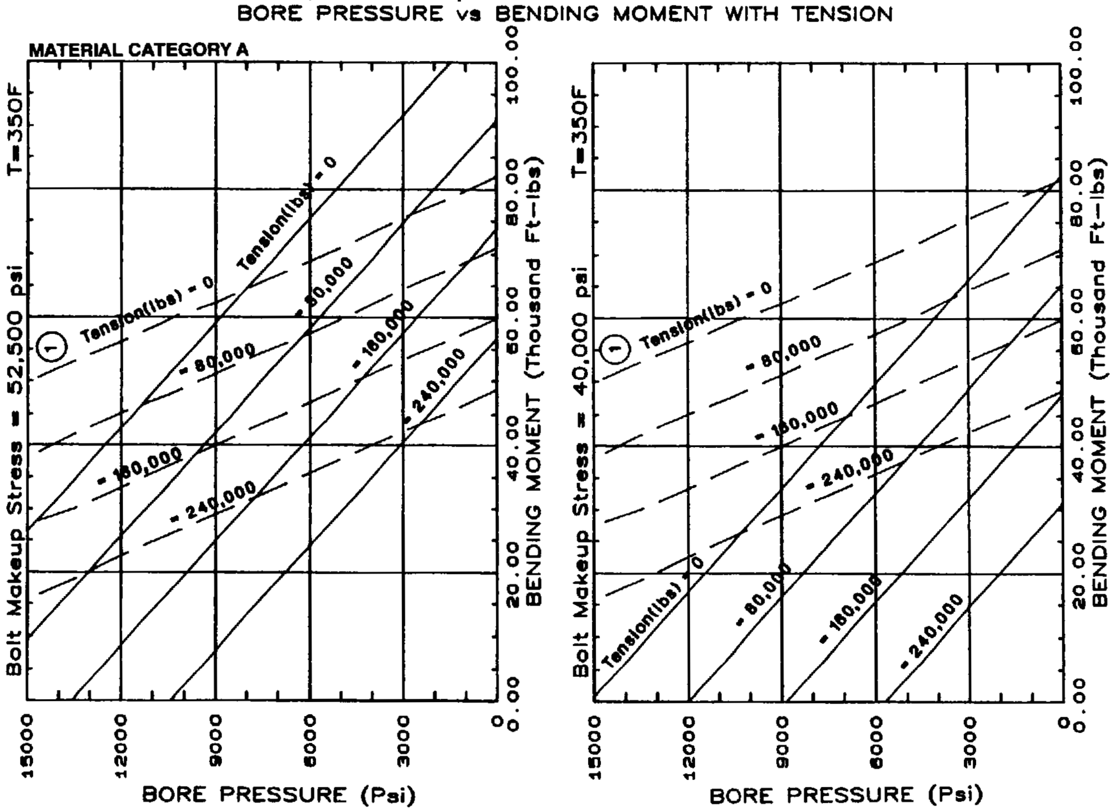
BORE PRESSURE vs BENDING MOMENT WITH TENSION



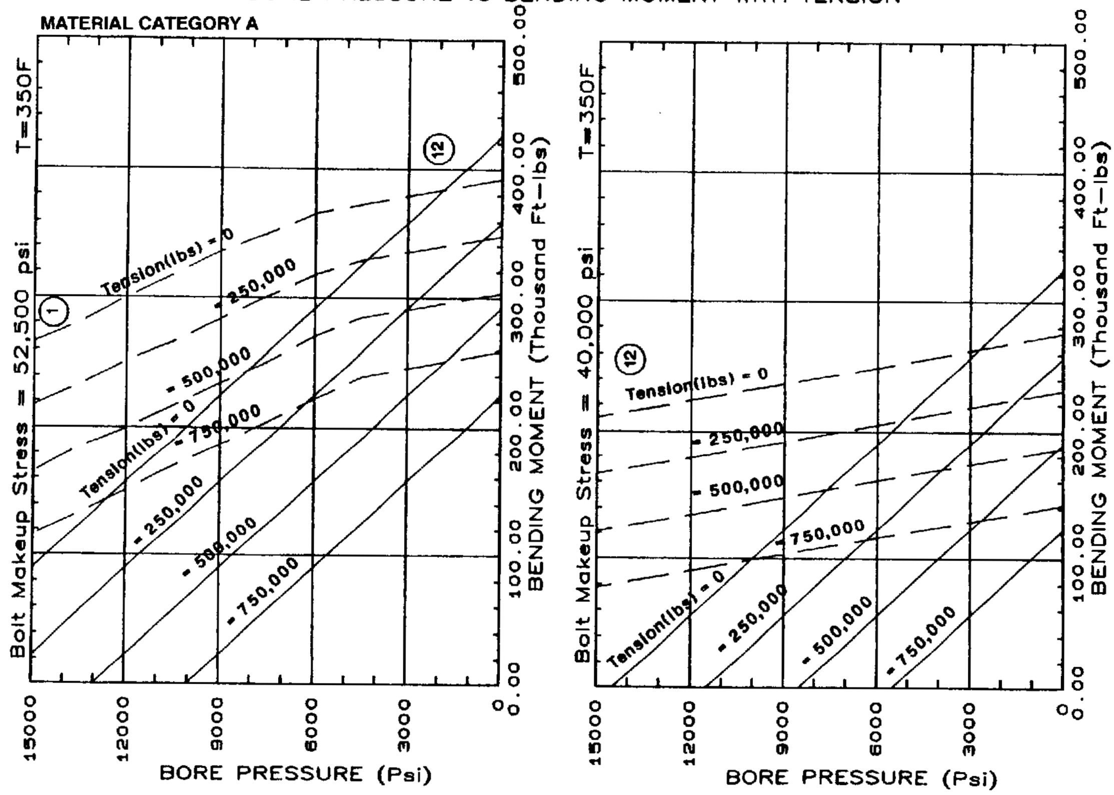
3-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



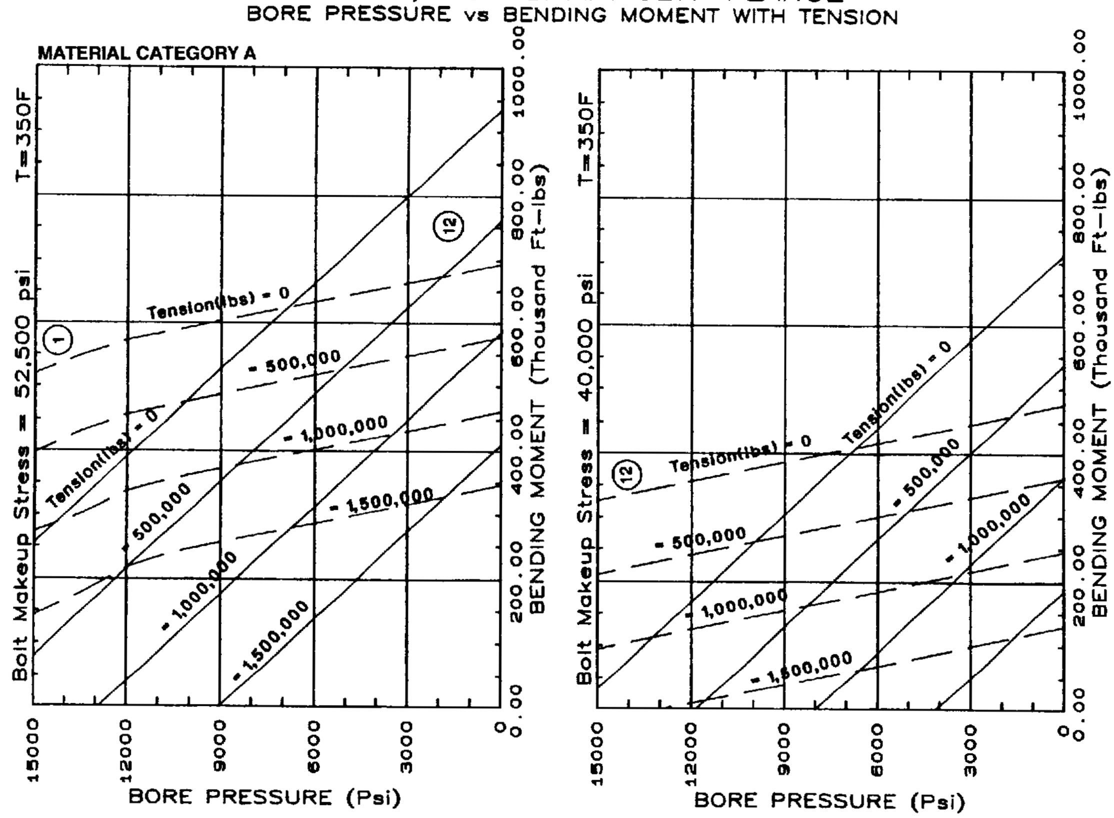
4-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



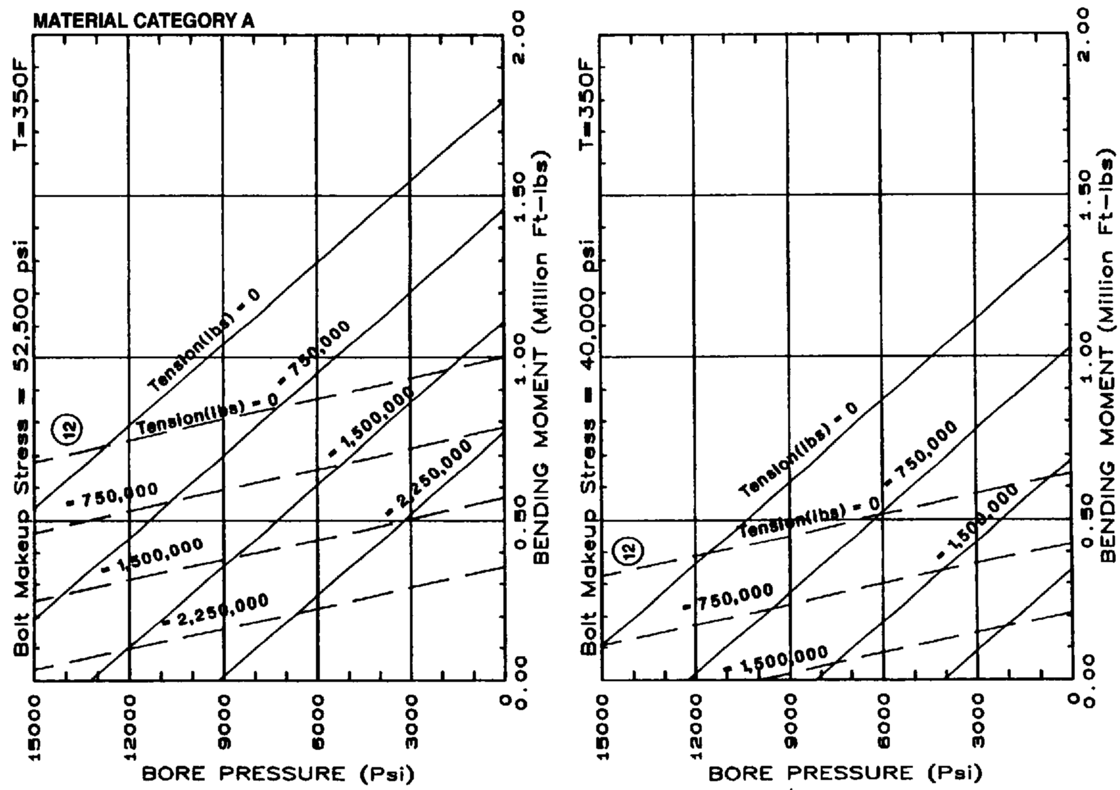
7-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



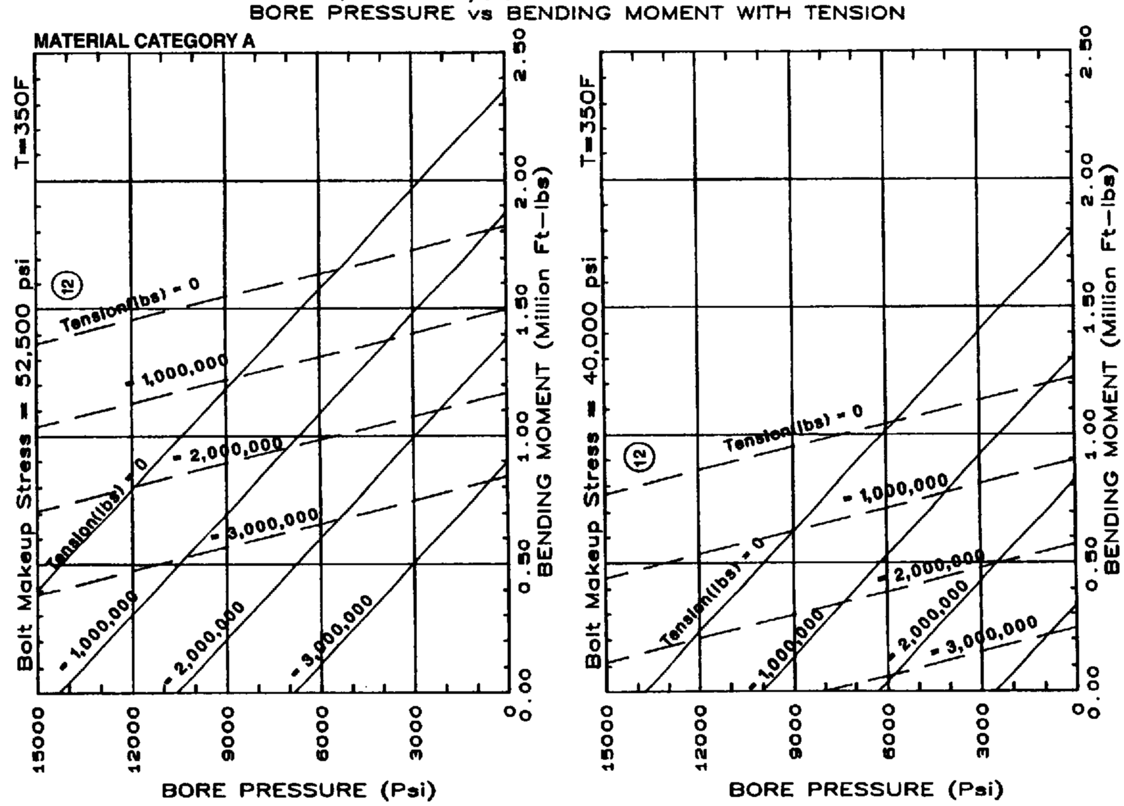
9"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

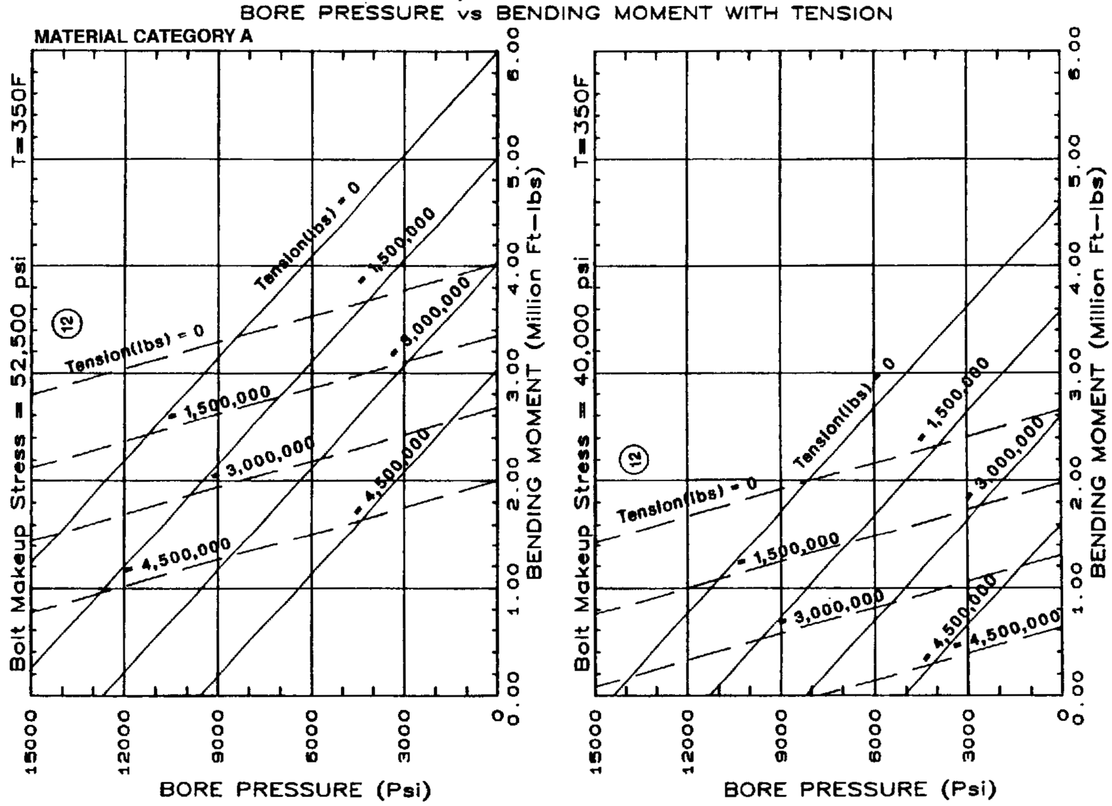


13-5/8"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



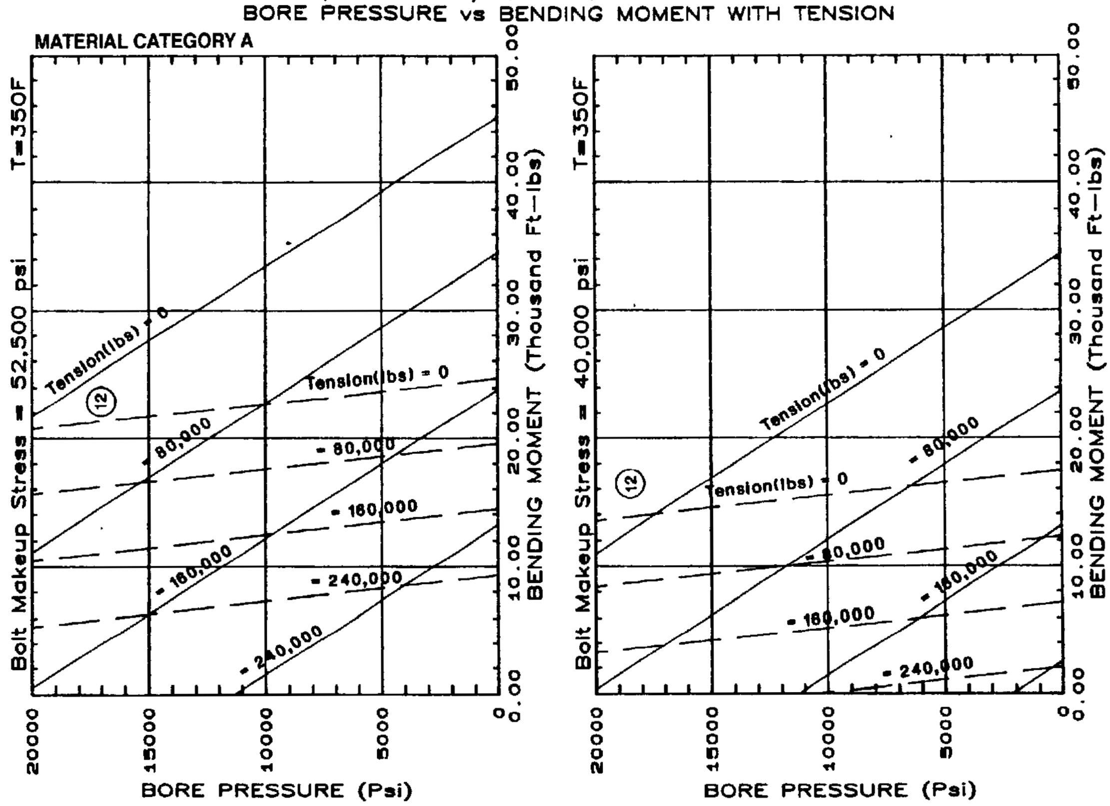
18-3/4"-15,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



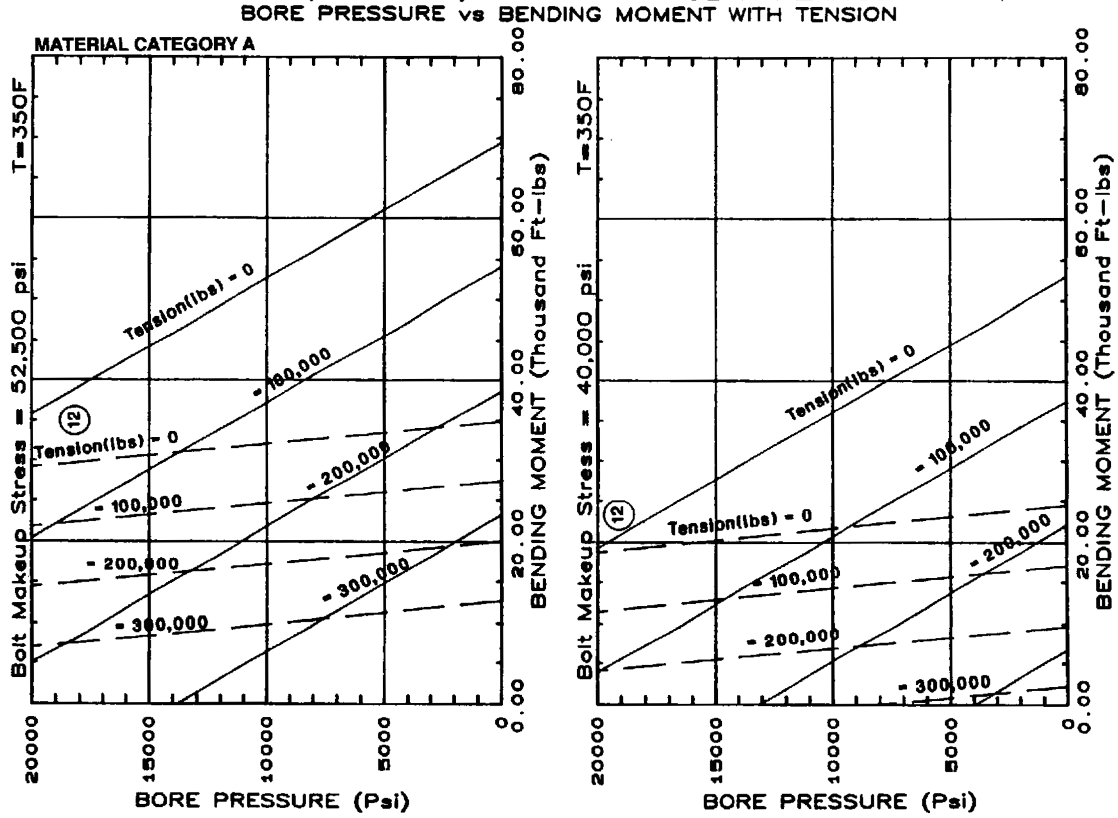
1-13/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



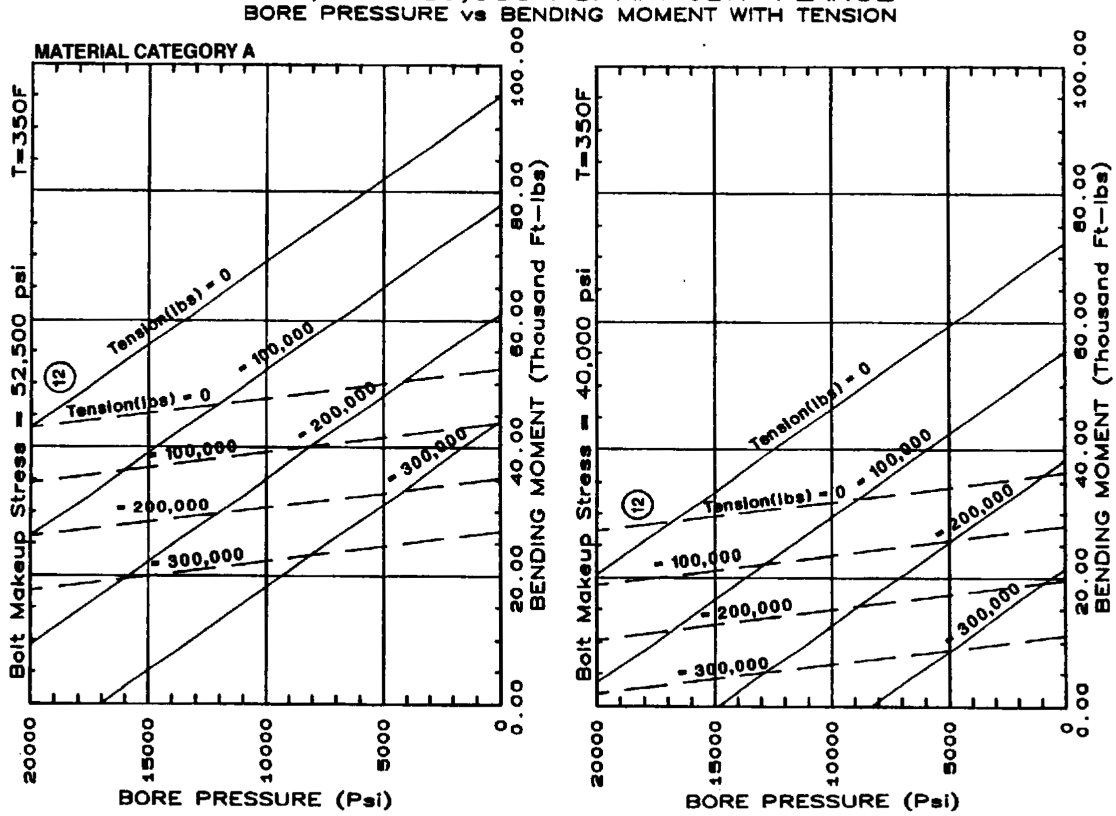
2-1/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



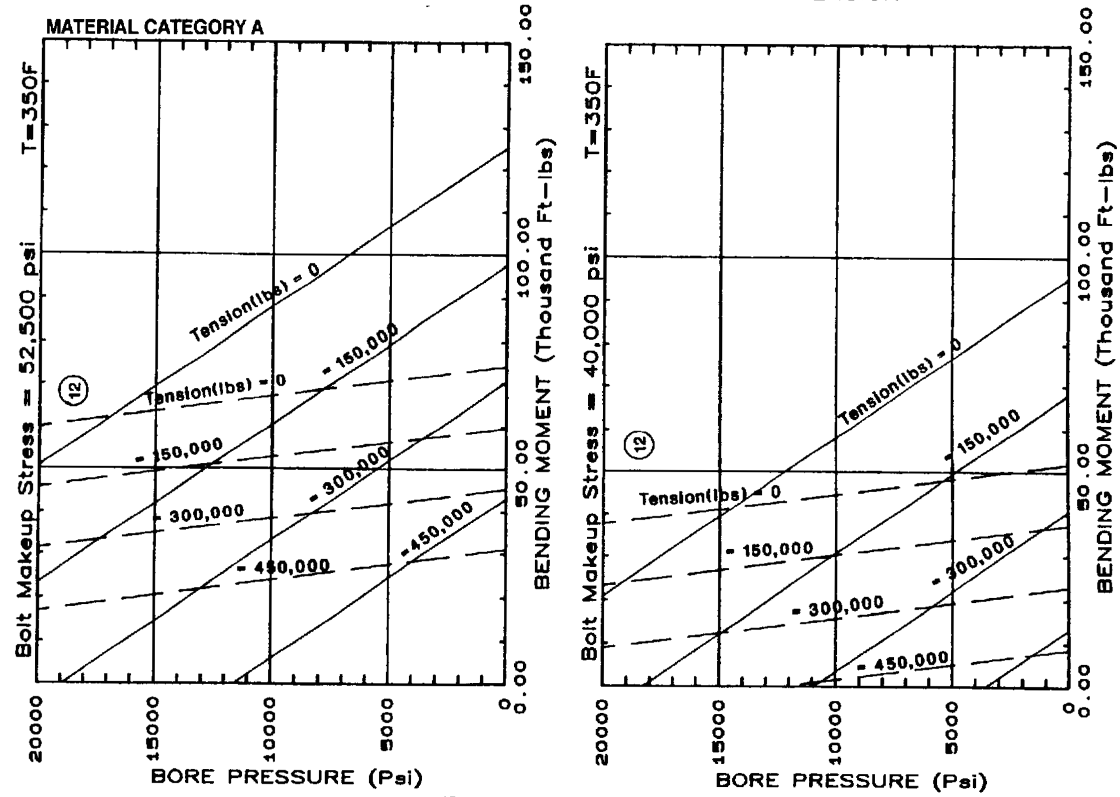
2-9/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



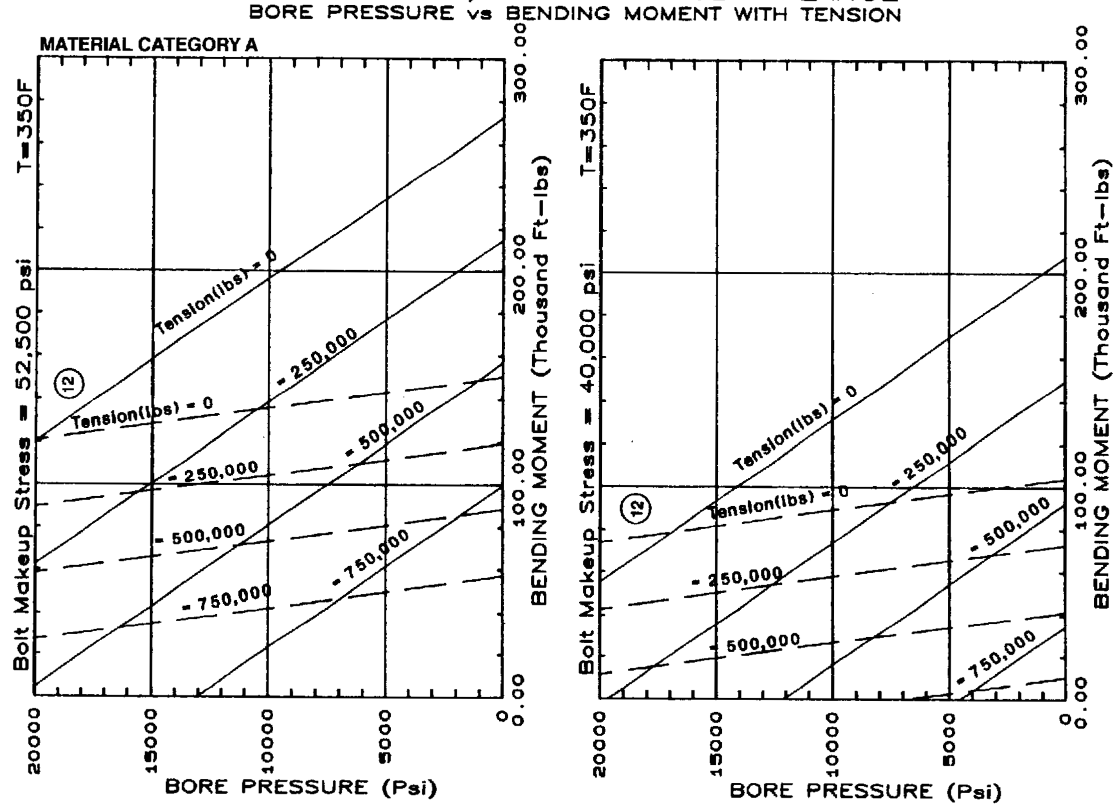
3–1/16"–20,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



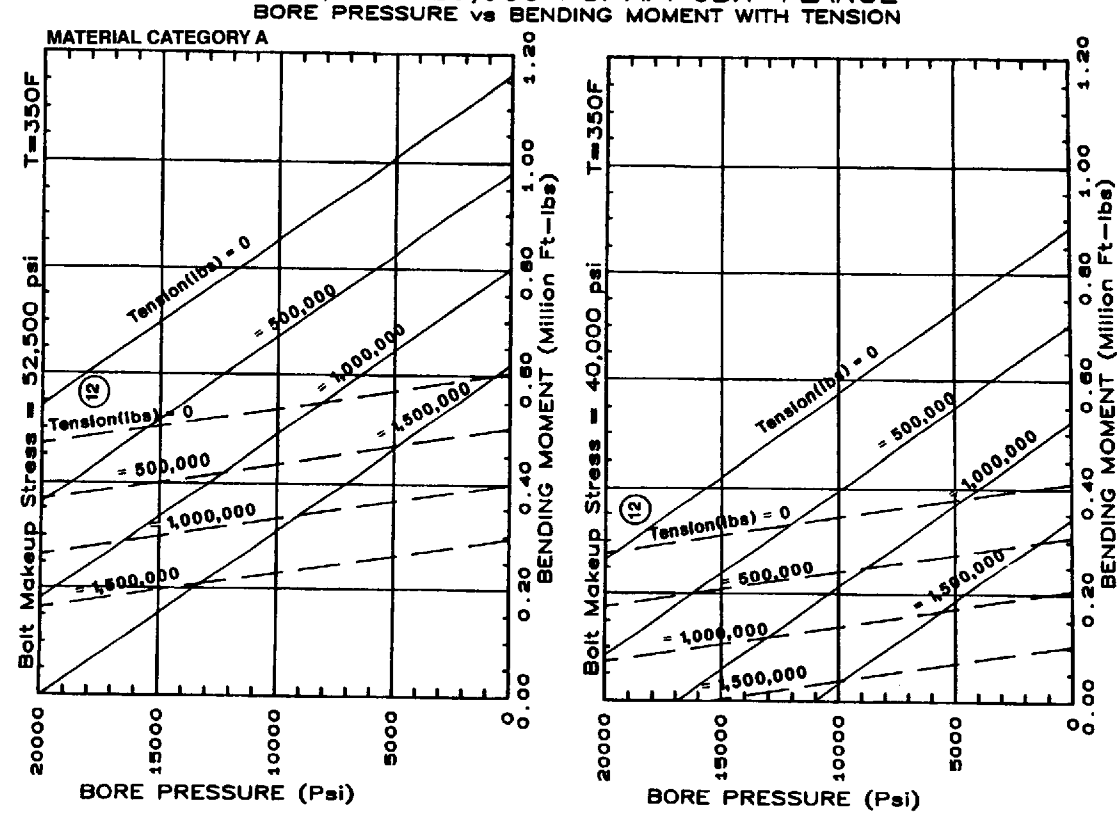
4–1/16"–20,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



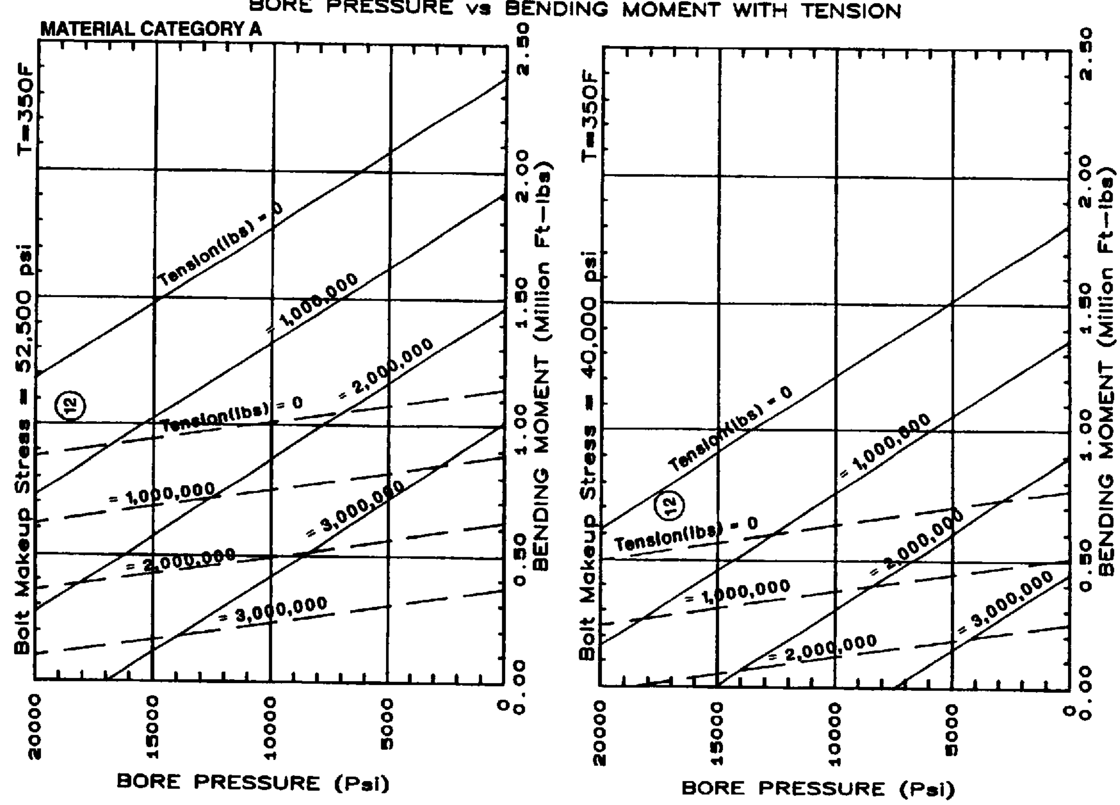
7-1/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



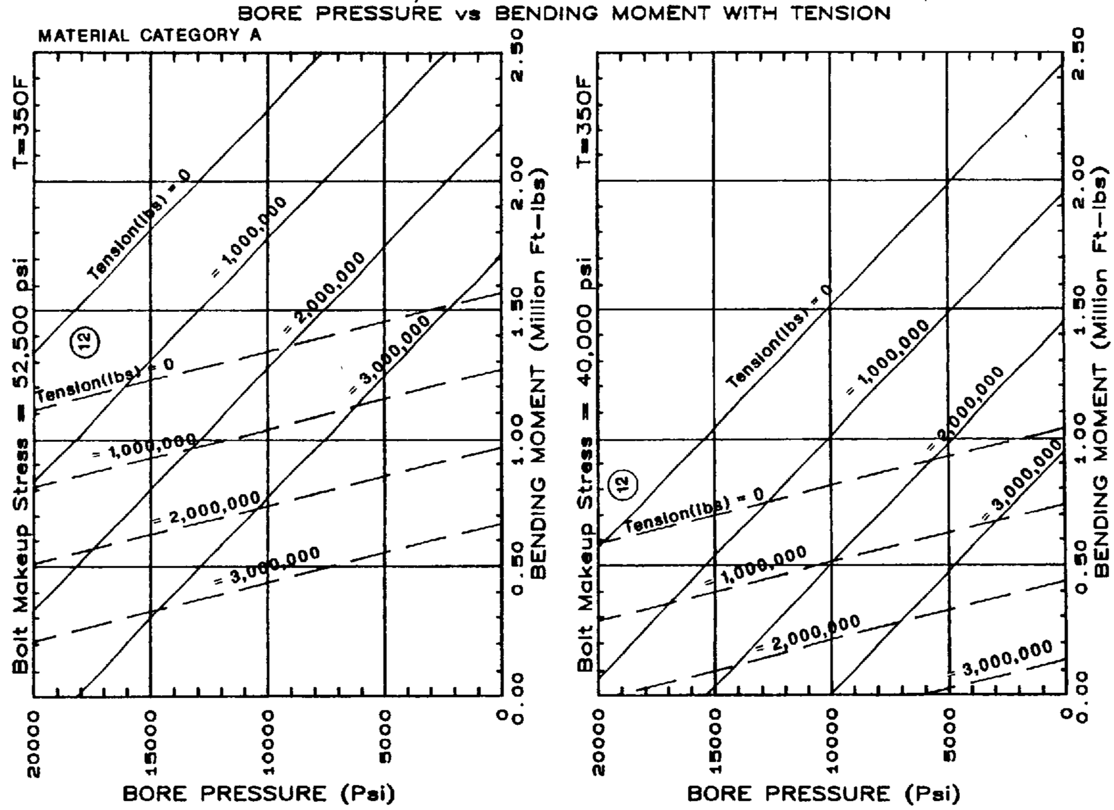
9"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



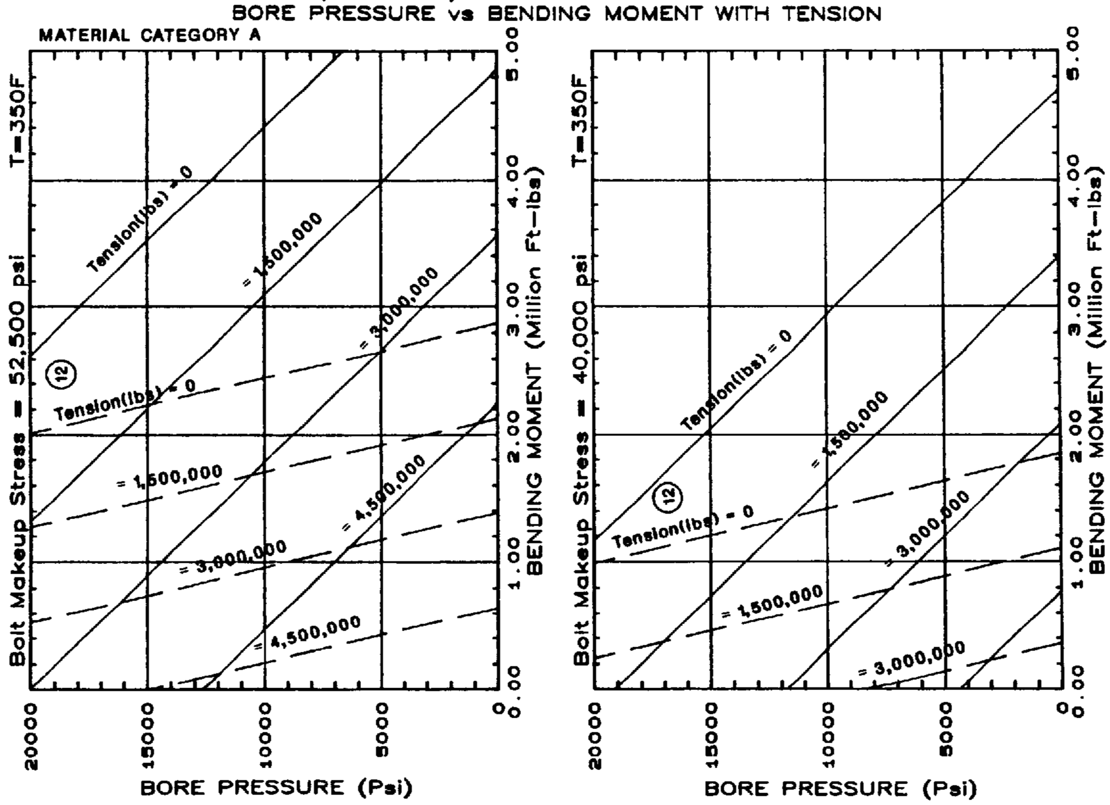
11"–20,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



13–5/8"–20,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



MATERIAL CATEGORY A
BORE TEMPERATURE—650°F

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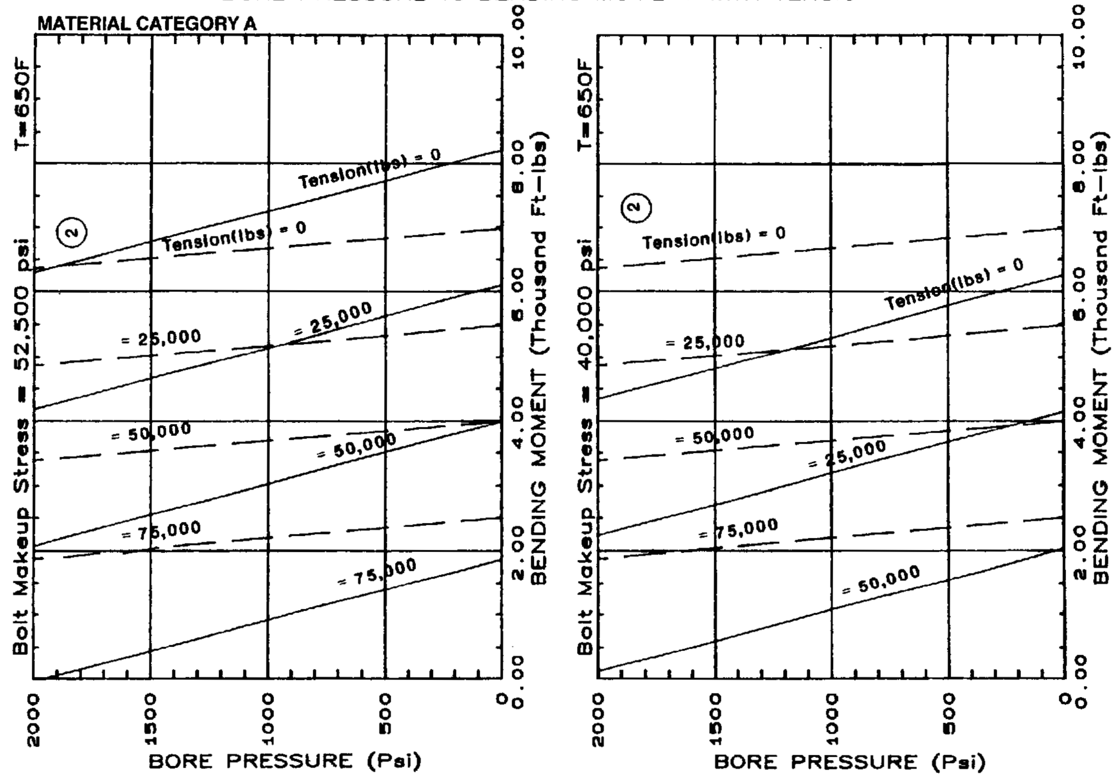
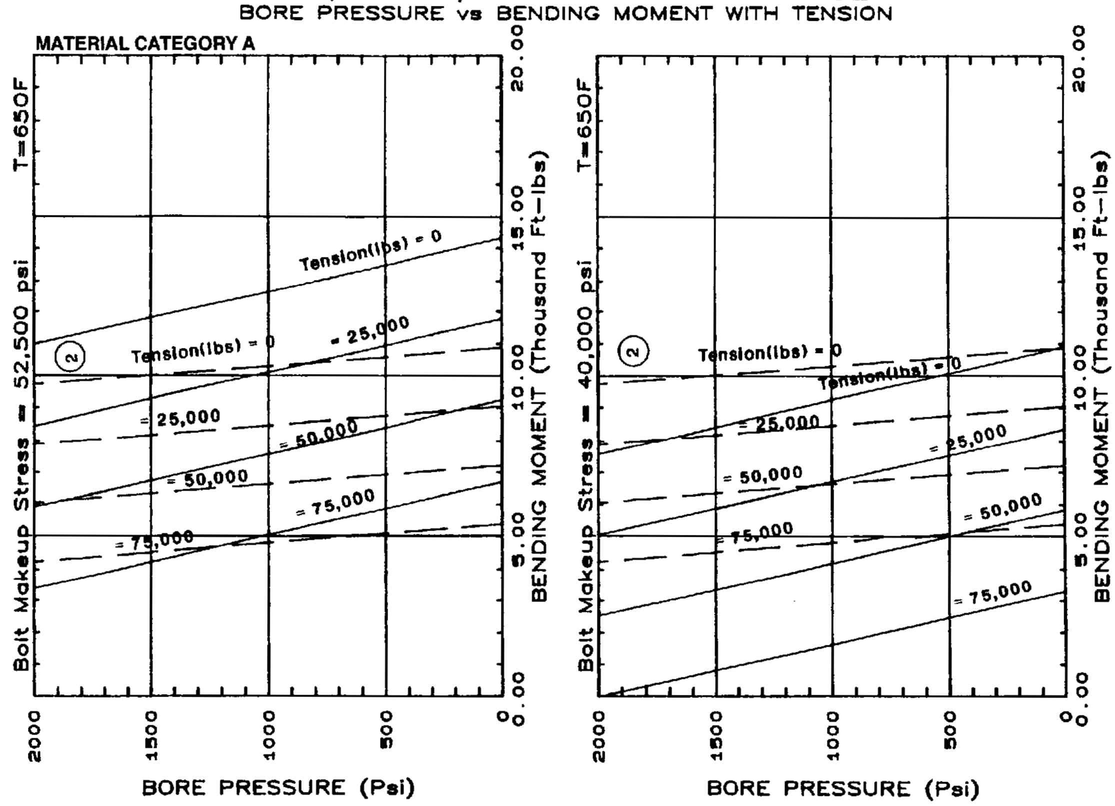
2-1/16"-2,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



2-9/16"-2,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



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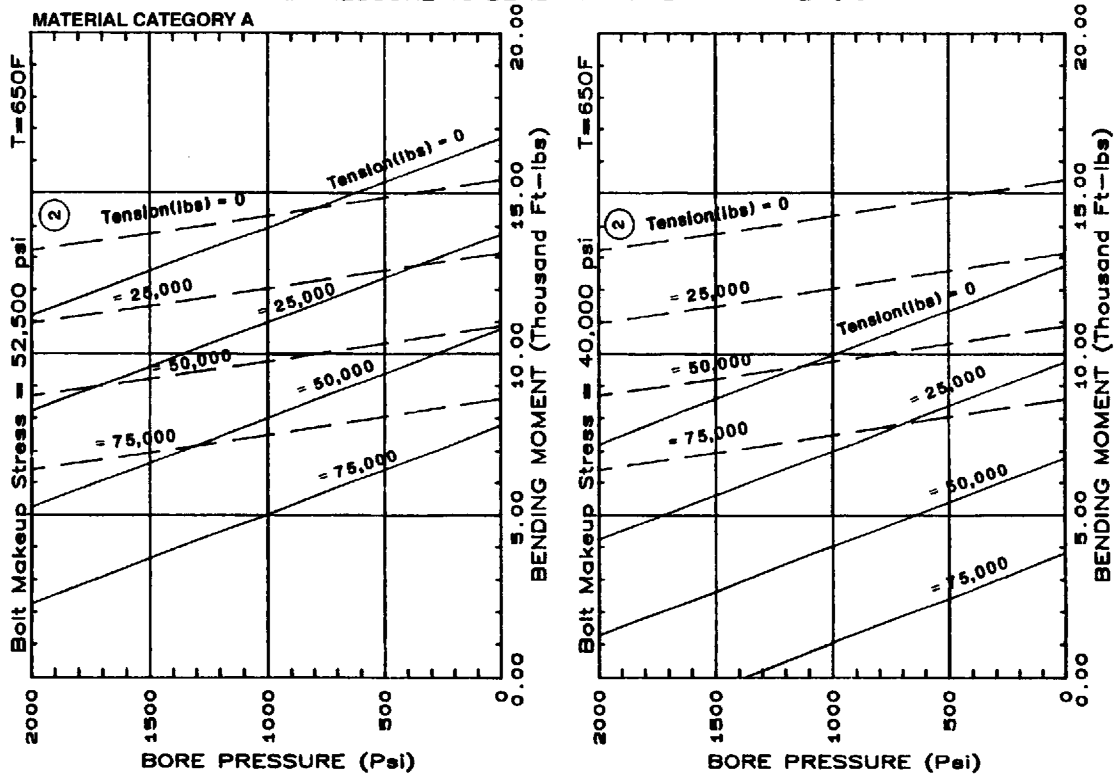
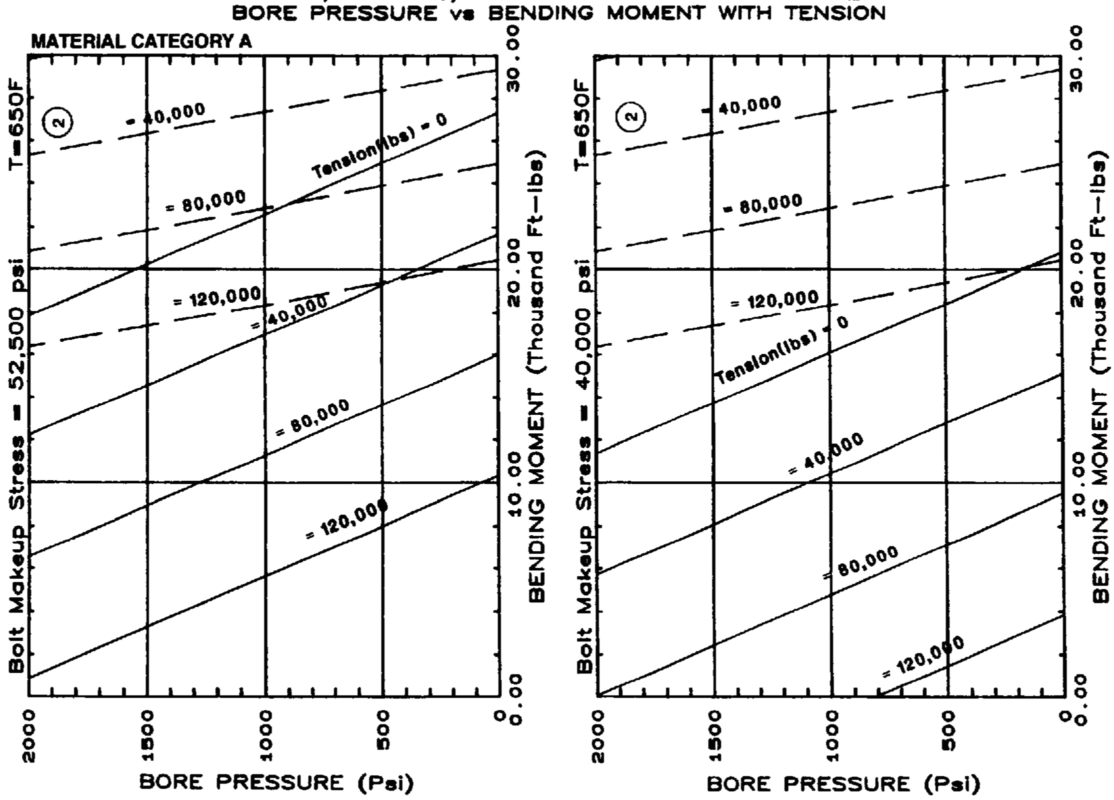
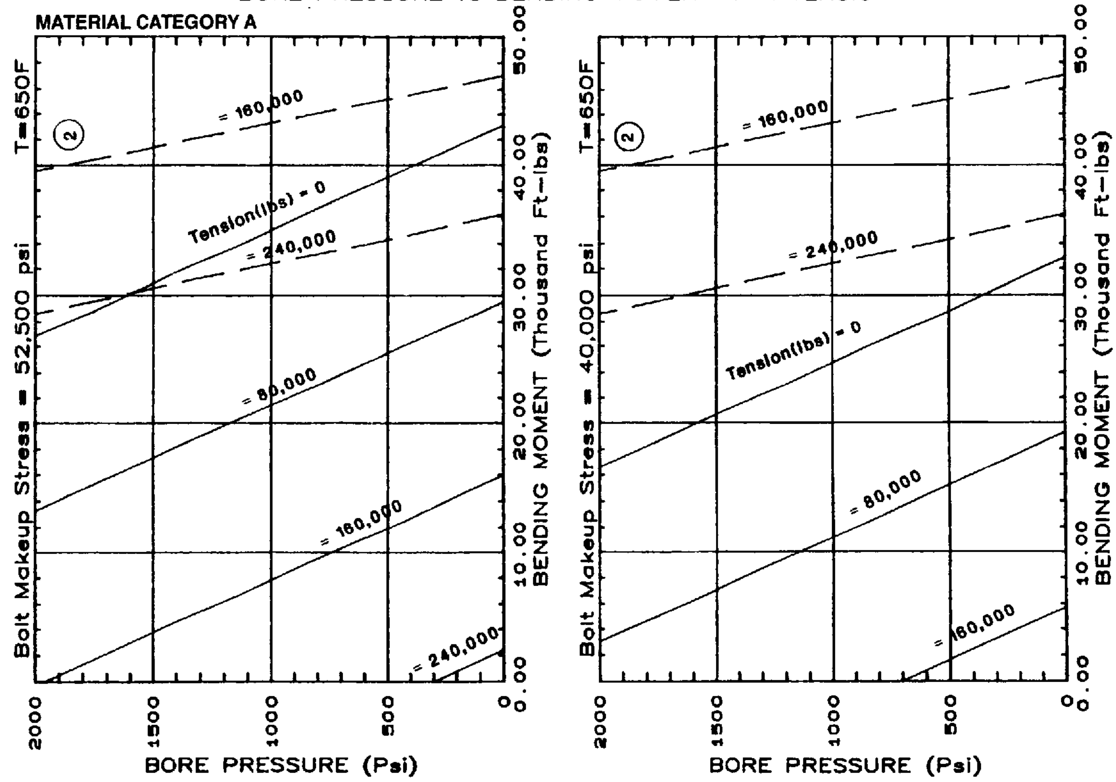
3-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



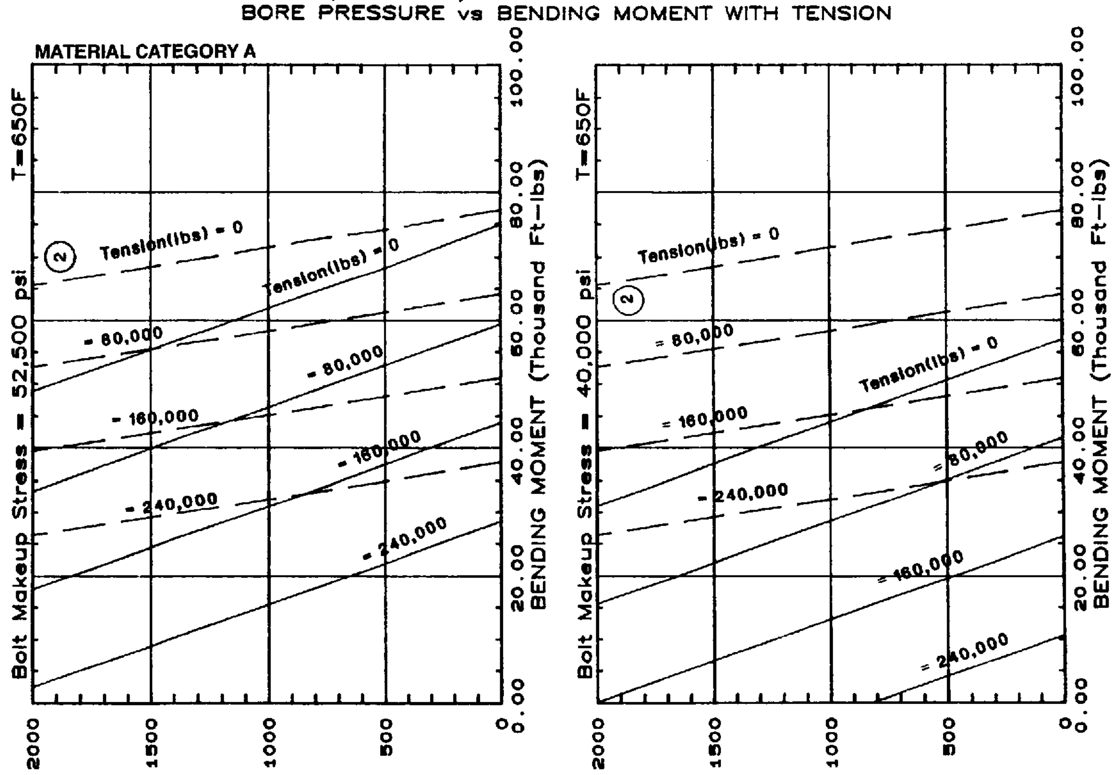
4-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

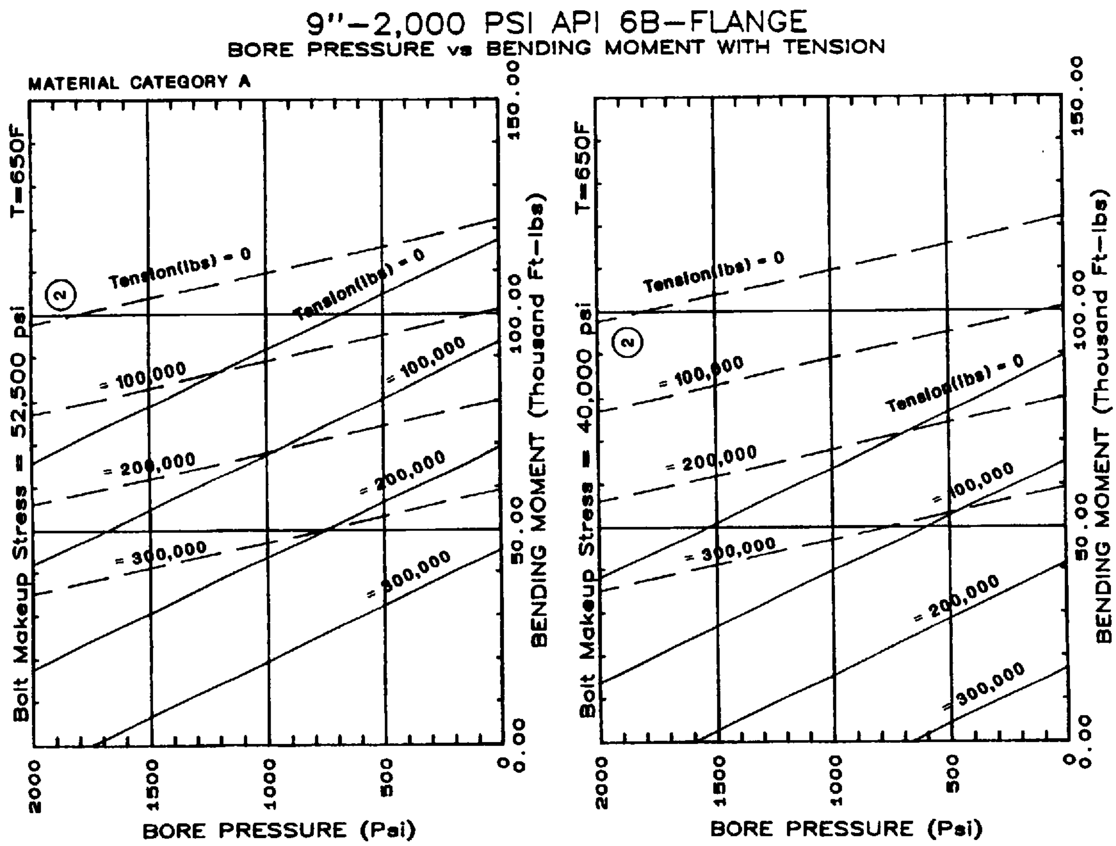


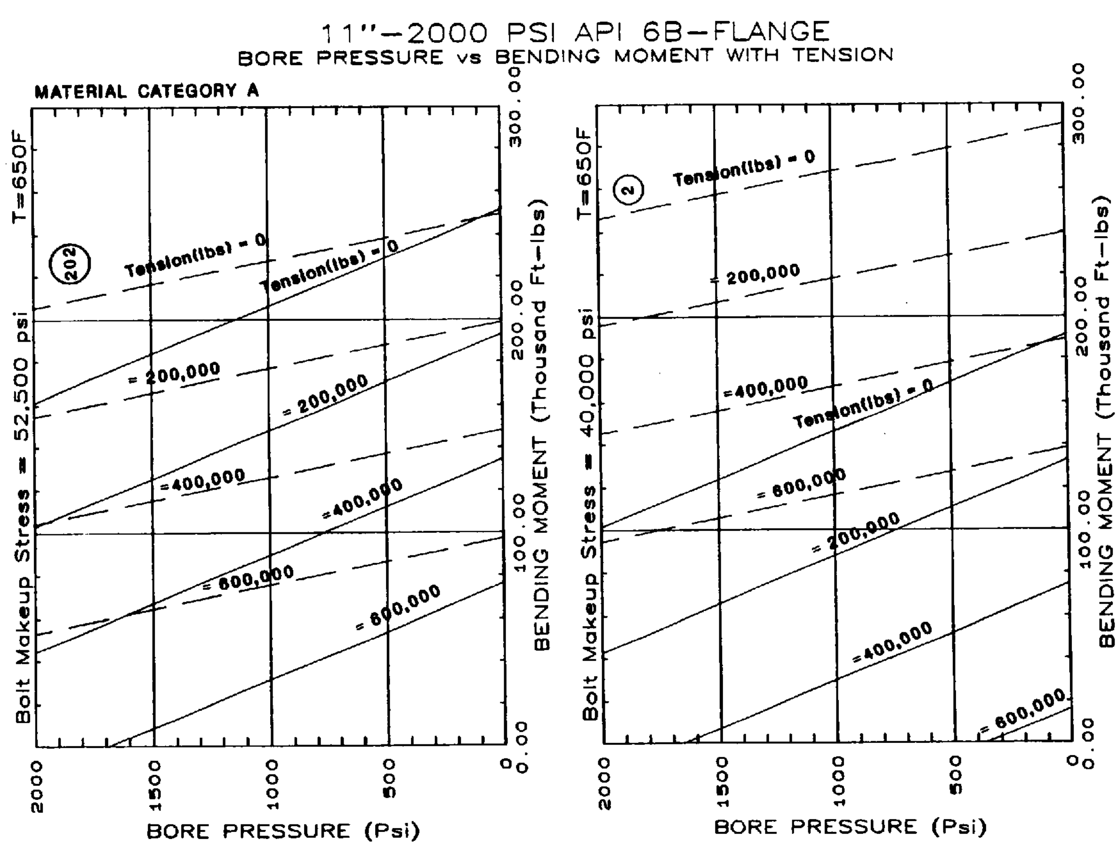
5–1/8"–2000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



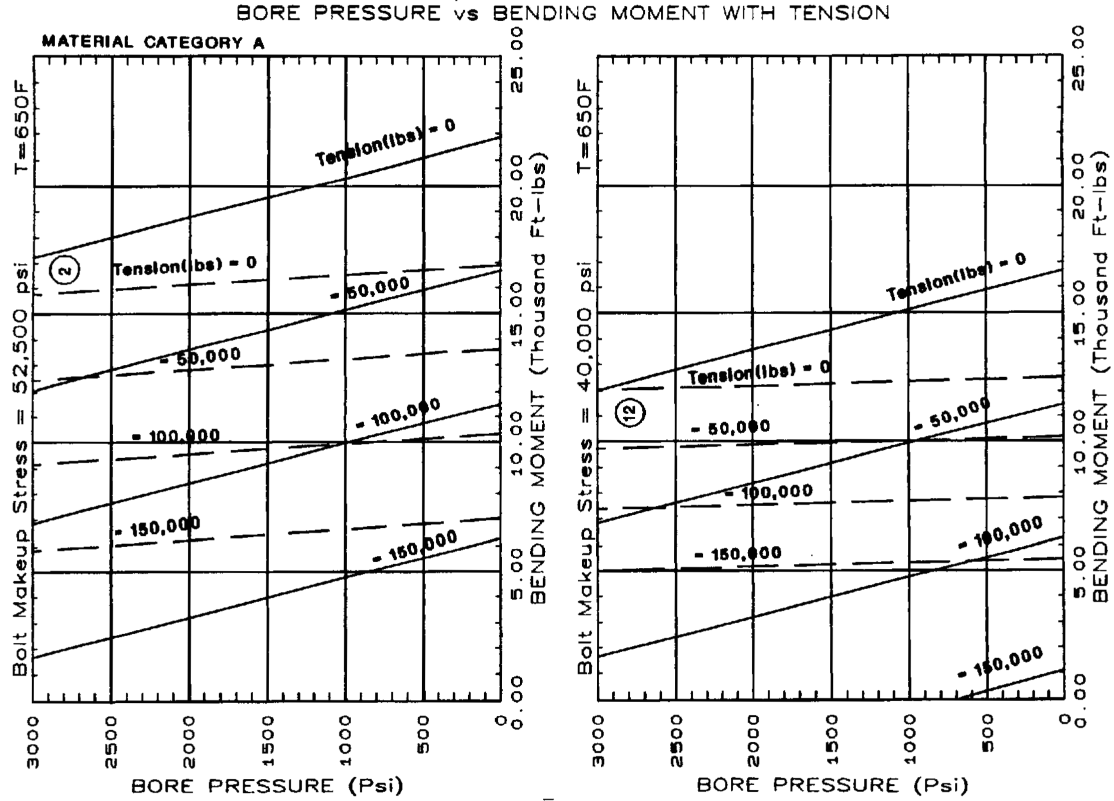
7–1/16"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



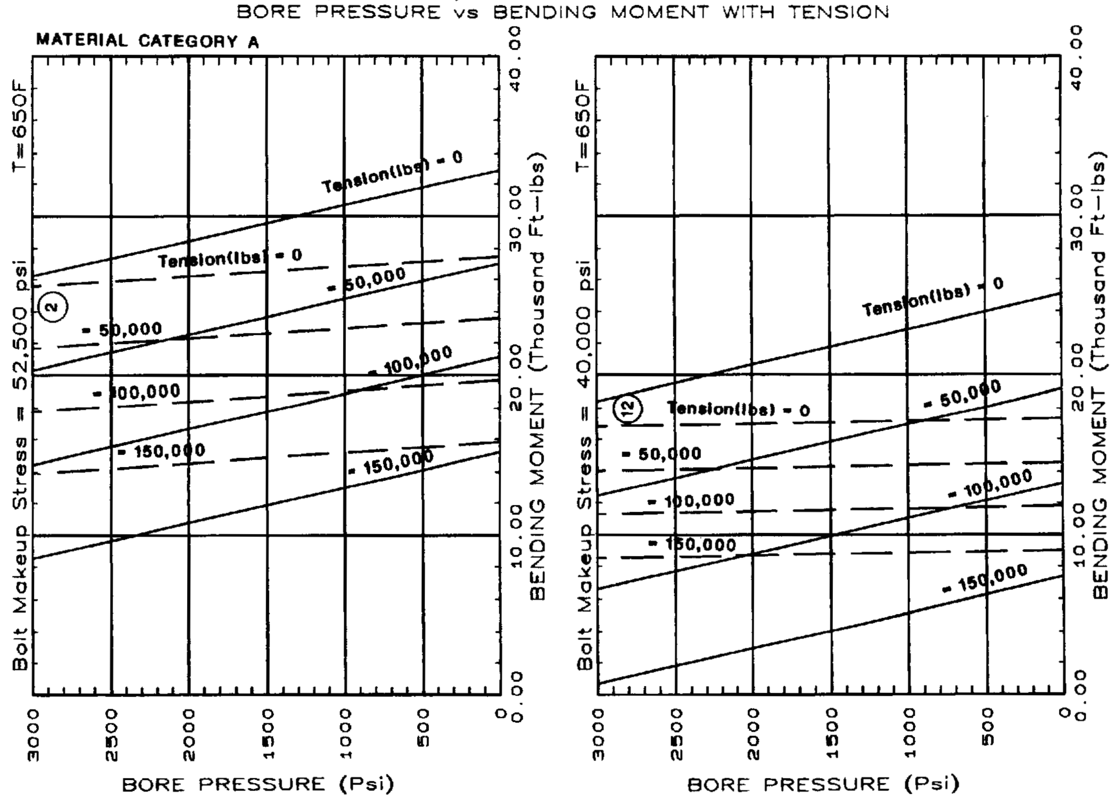

9"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY A
T=650F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
= 100,000
= 200,000
= 300,000
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)


11"-2000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY A
T=650F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
= 200,000
= 400,000
= 600,000
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)

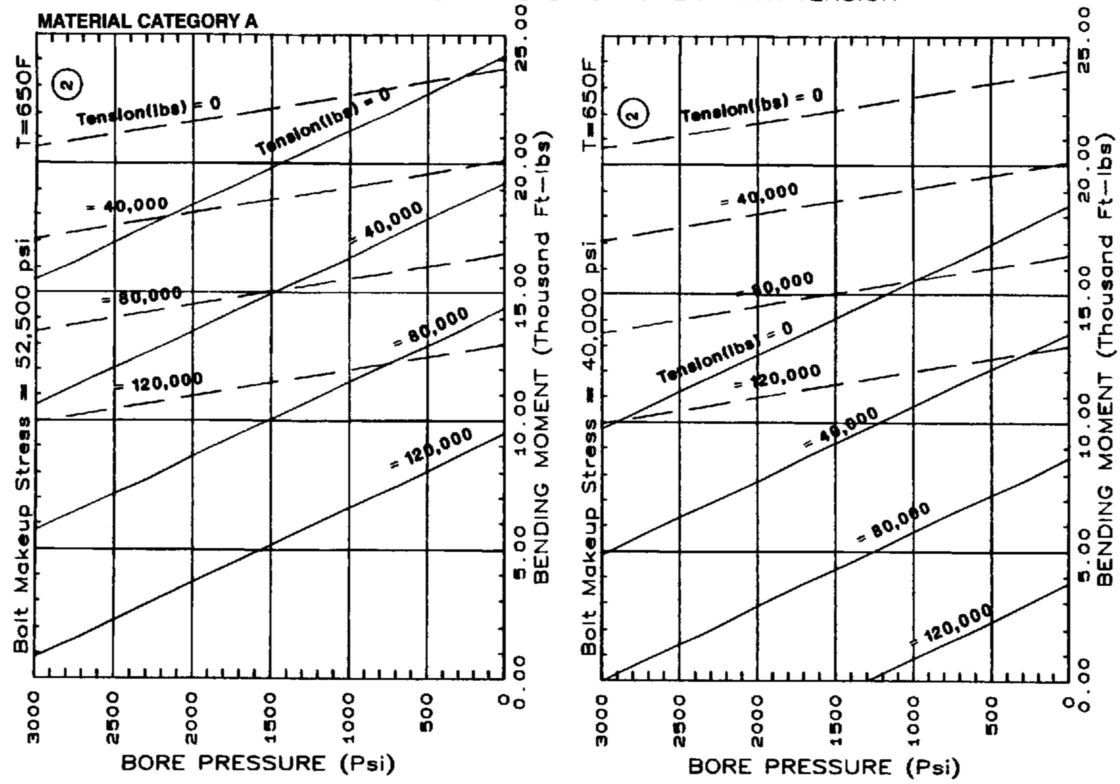
2-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



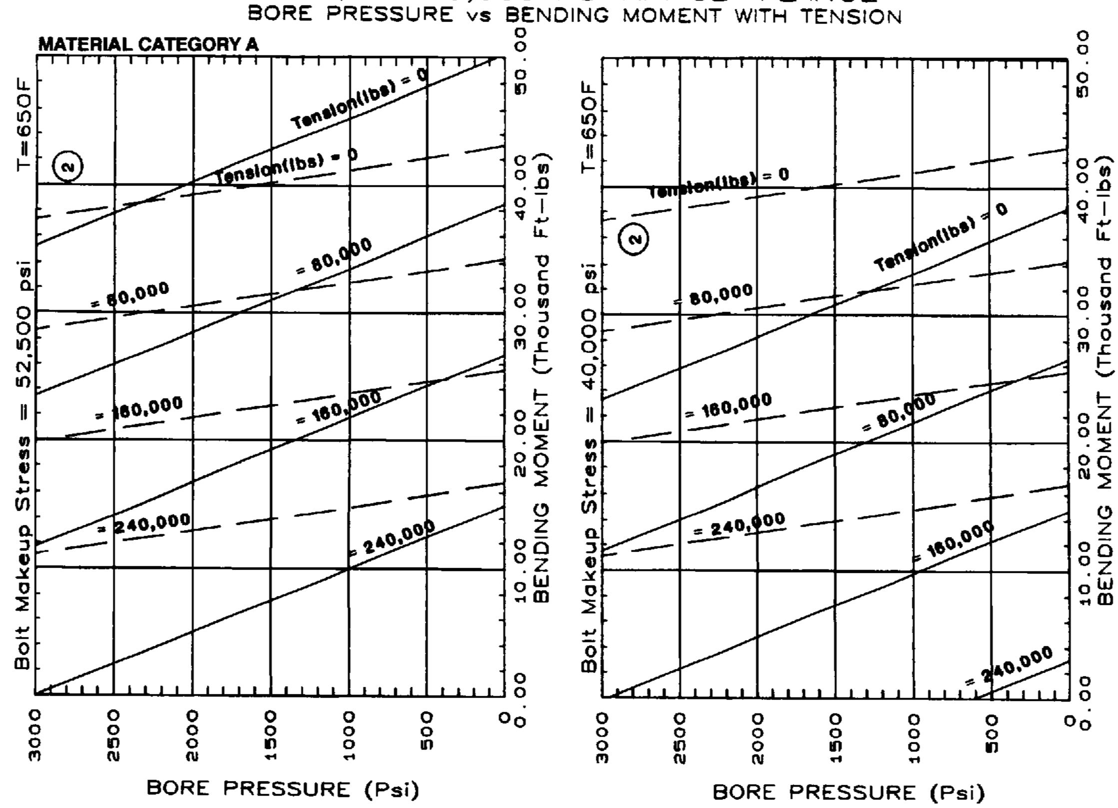
2-9/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

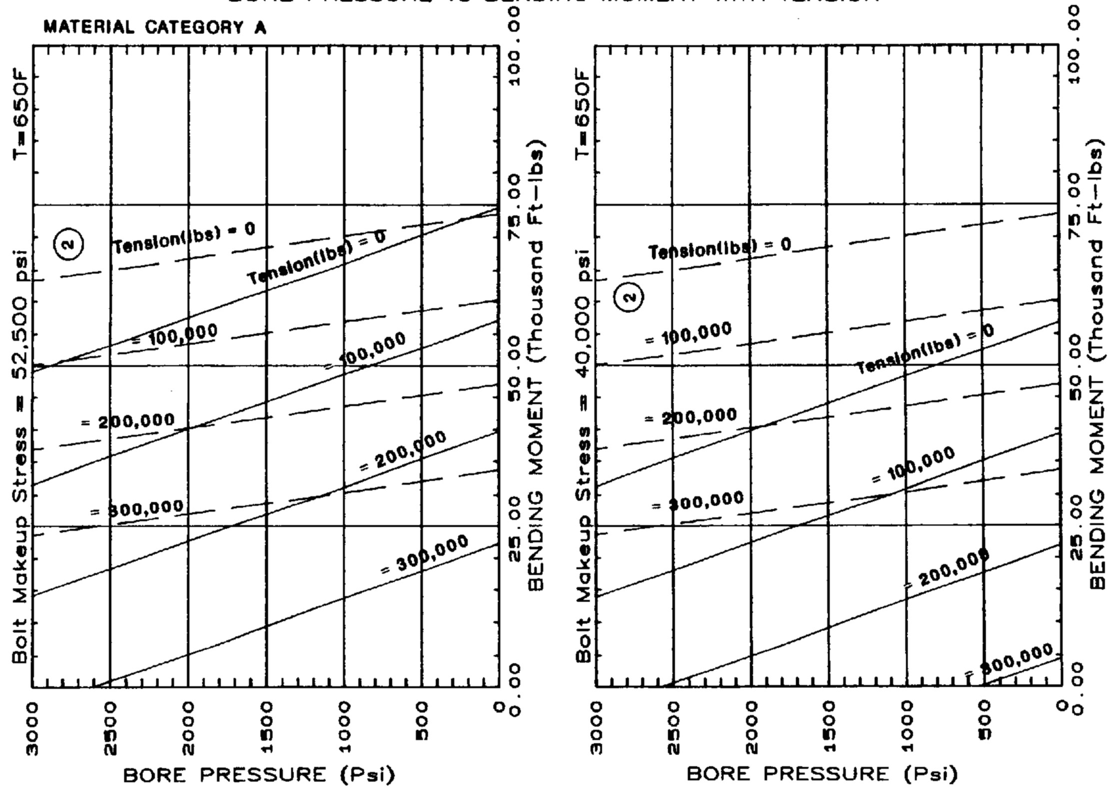


4-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



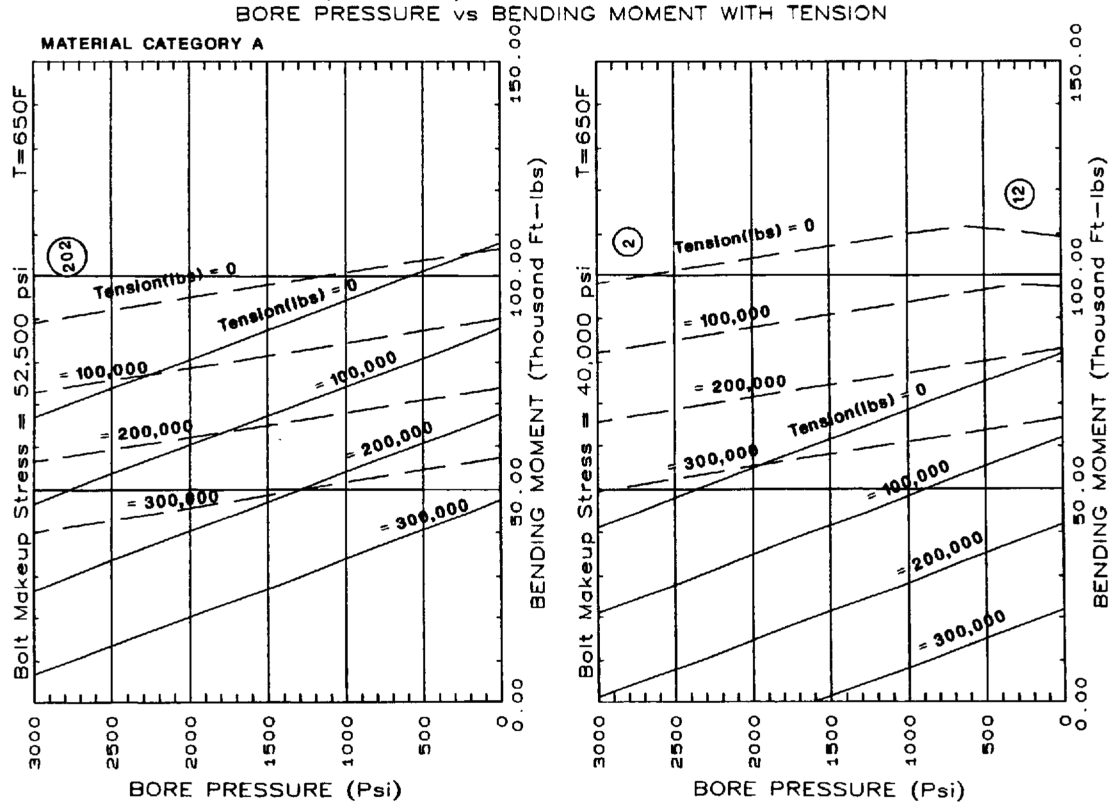
5-1/8"-3000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

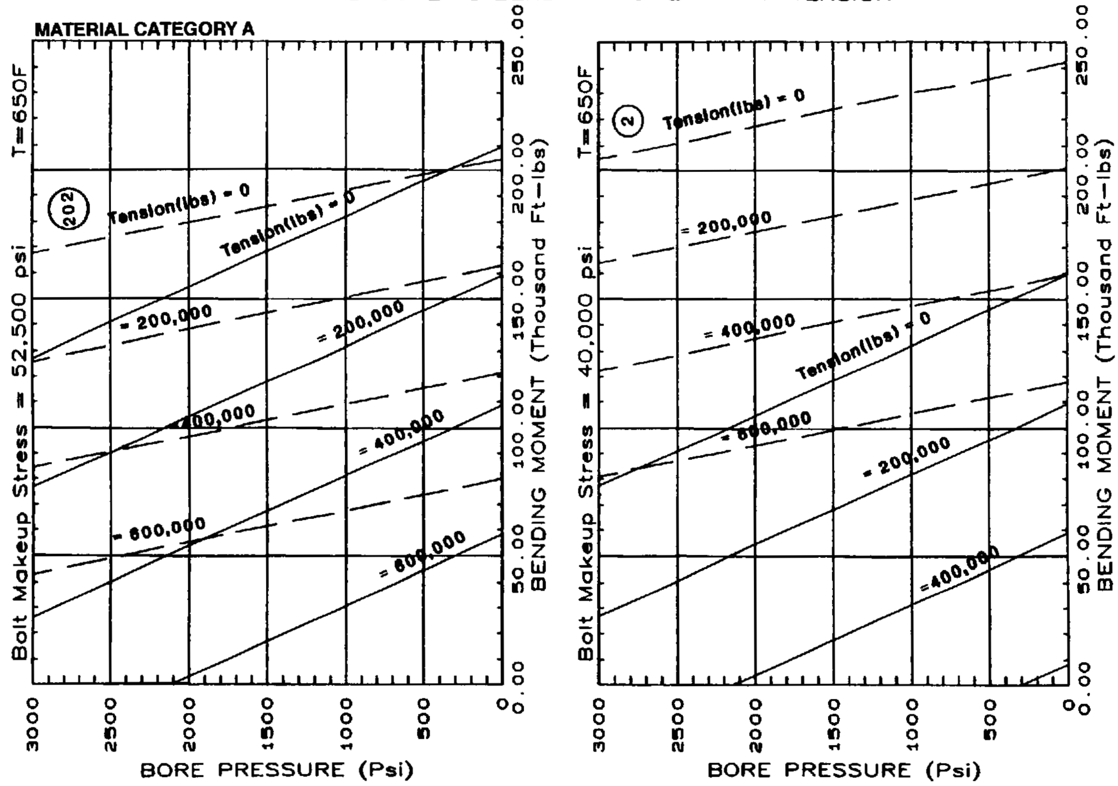


7-1/16"-3,000 PSI API 6B-FLANGE

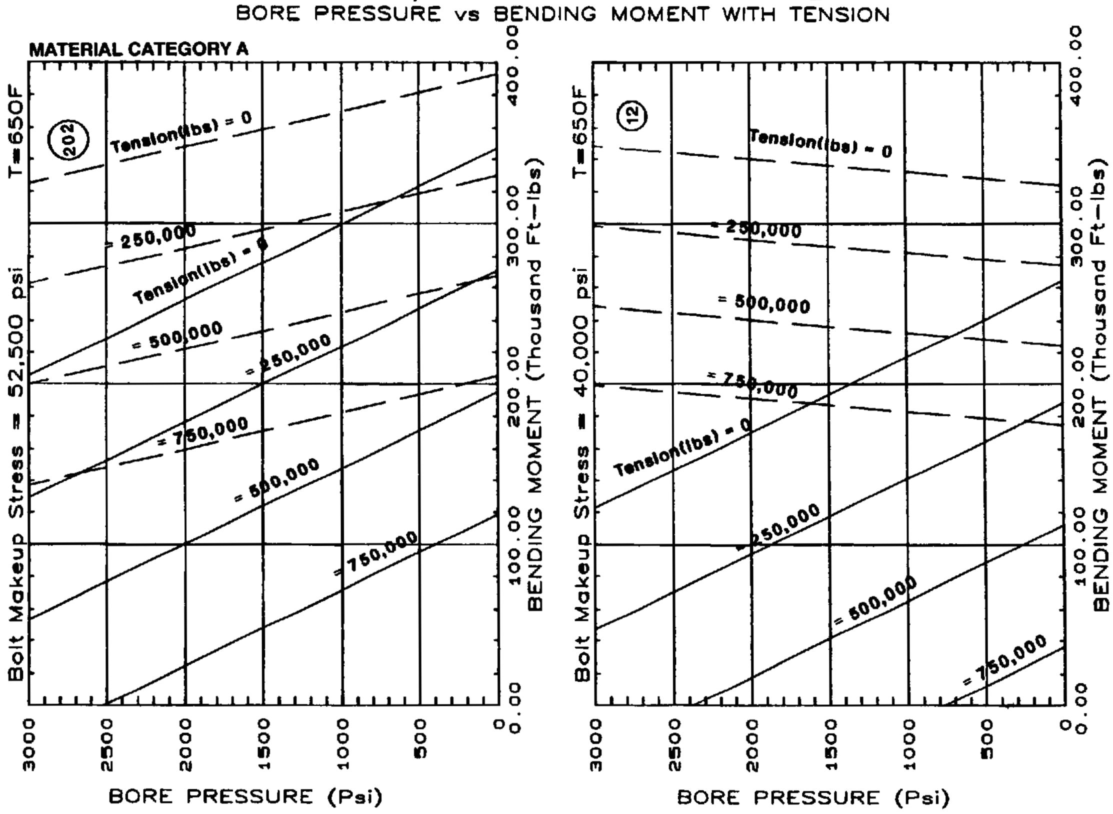
BORE PRESSURE vs BENDING MOMENT WITH TENSION



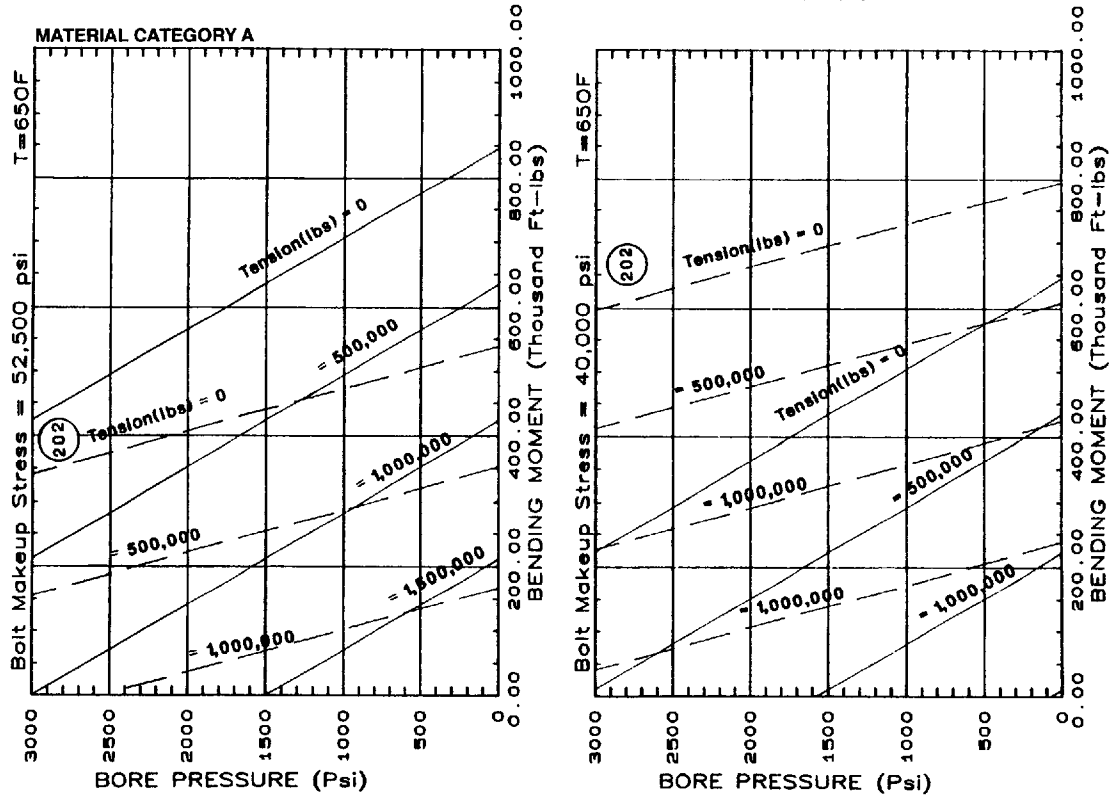
9"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



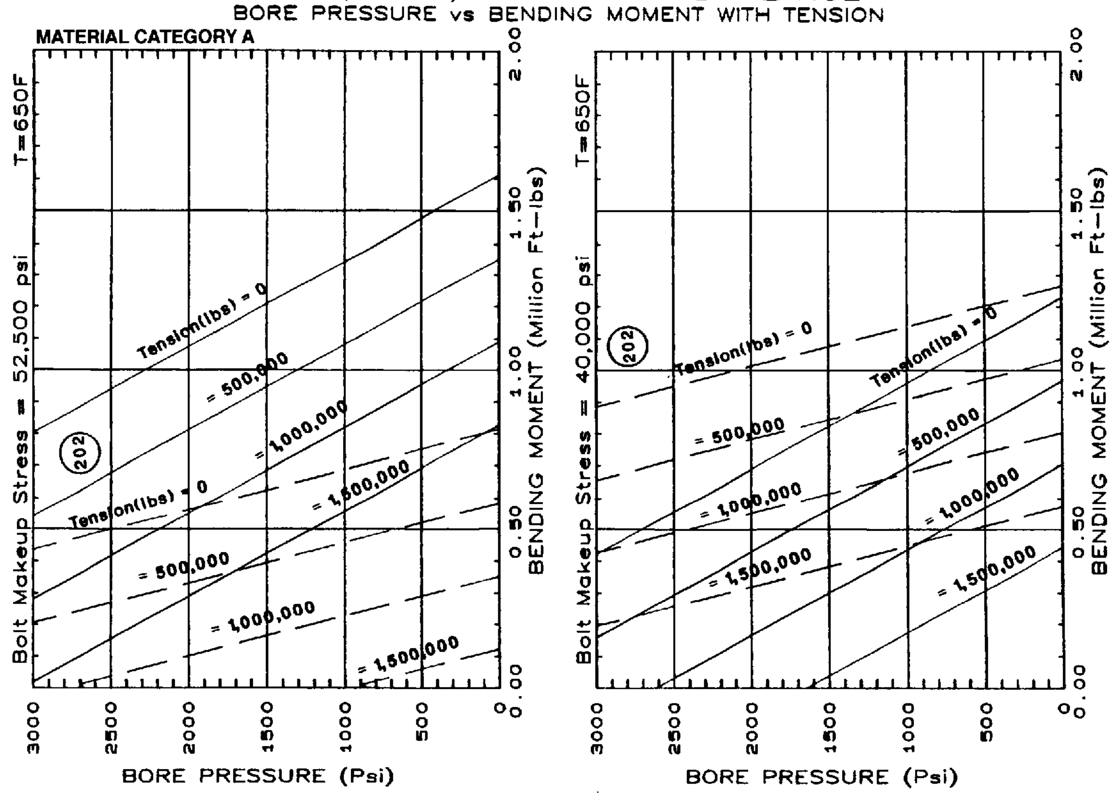
11"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



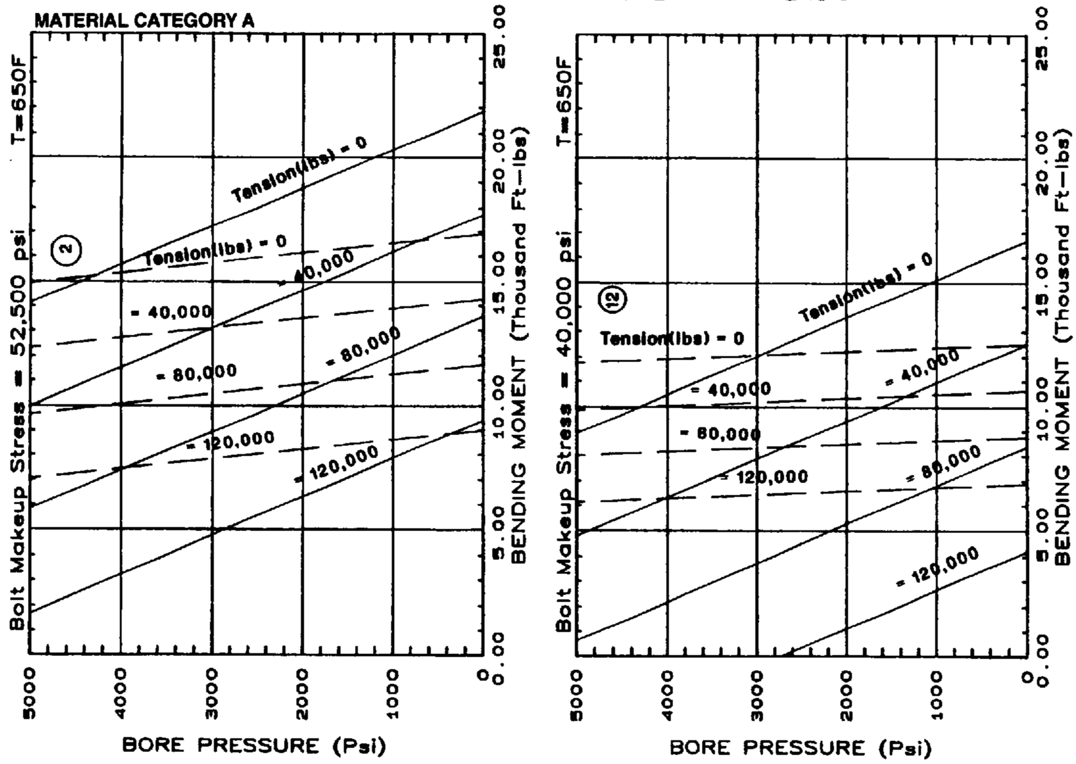
16-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



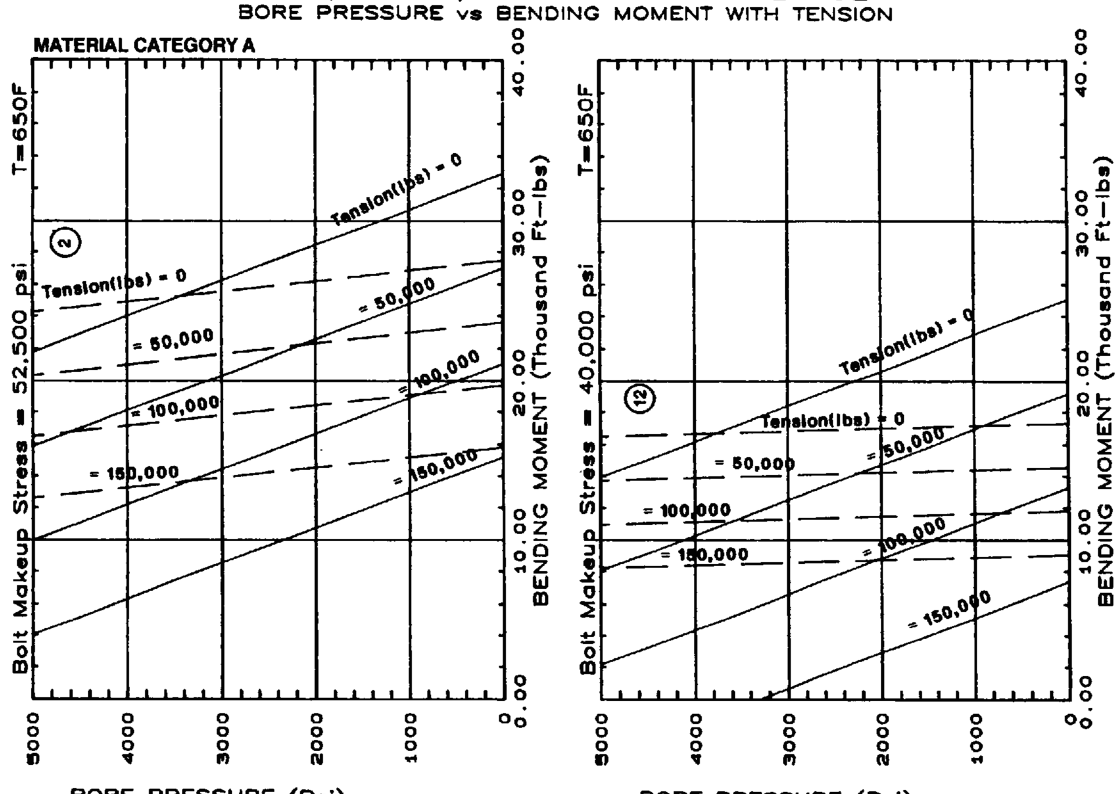
20-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



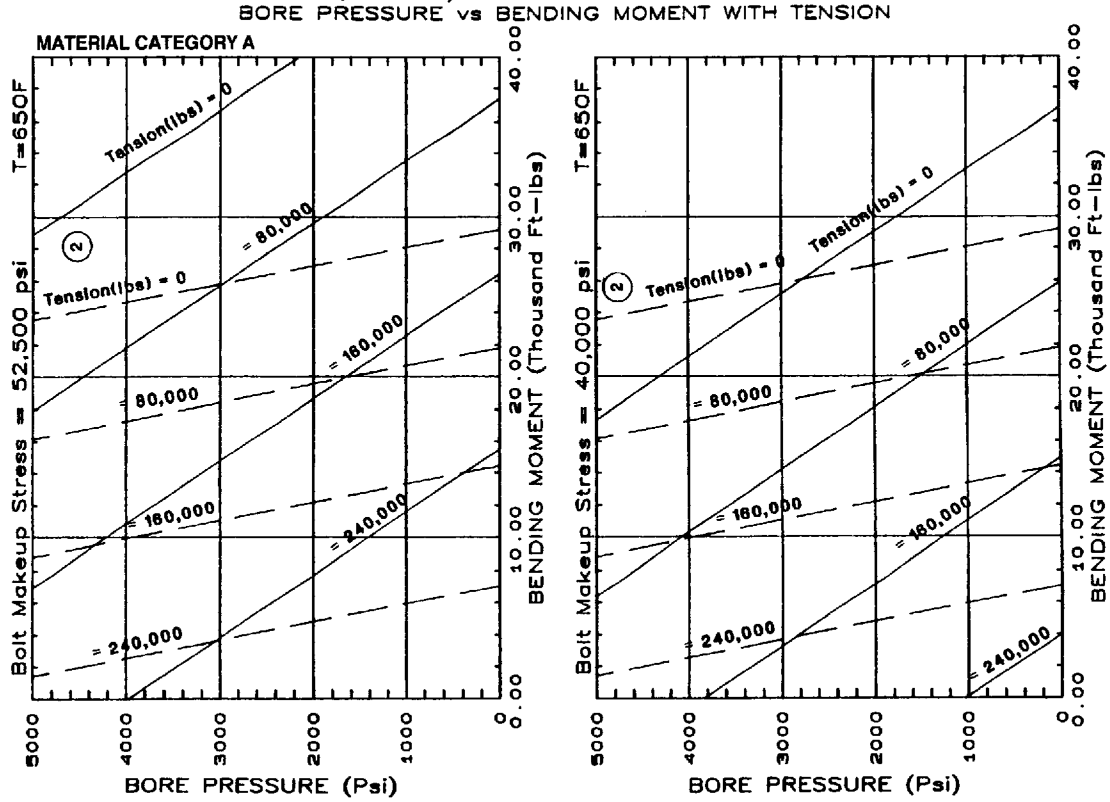
2-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



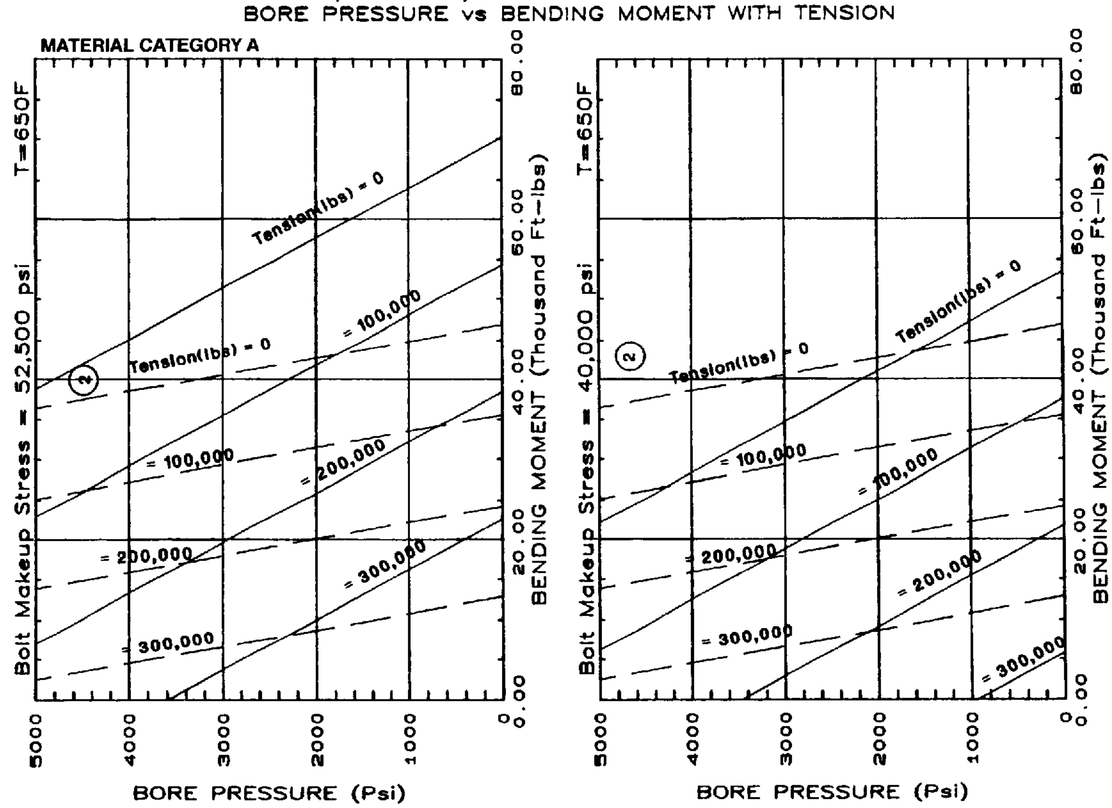
2-9/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



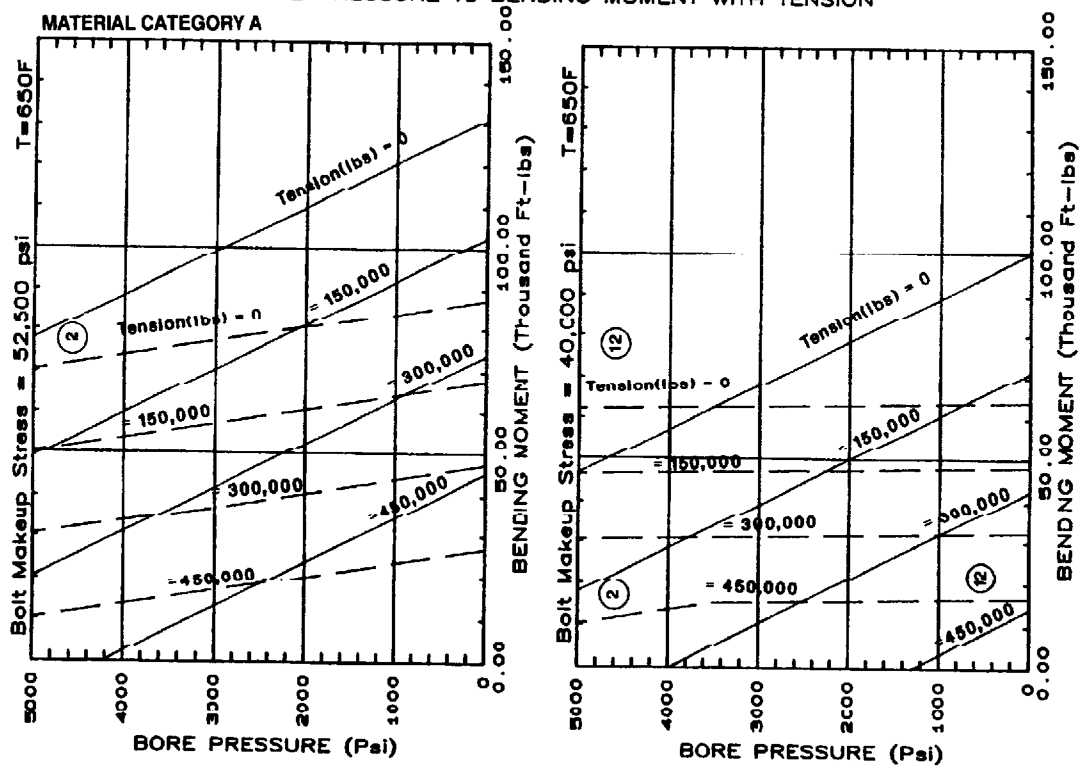
3-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



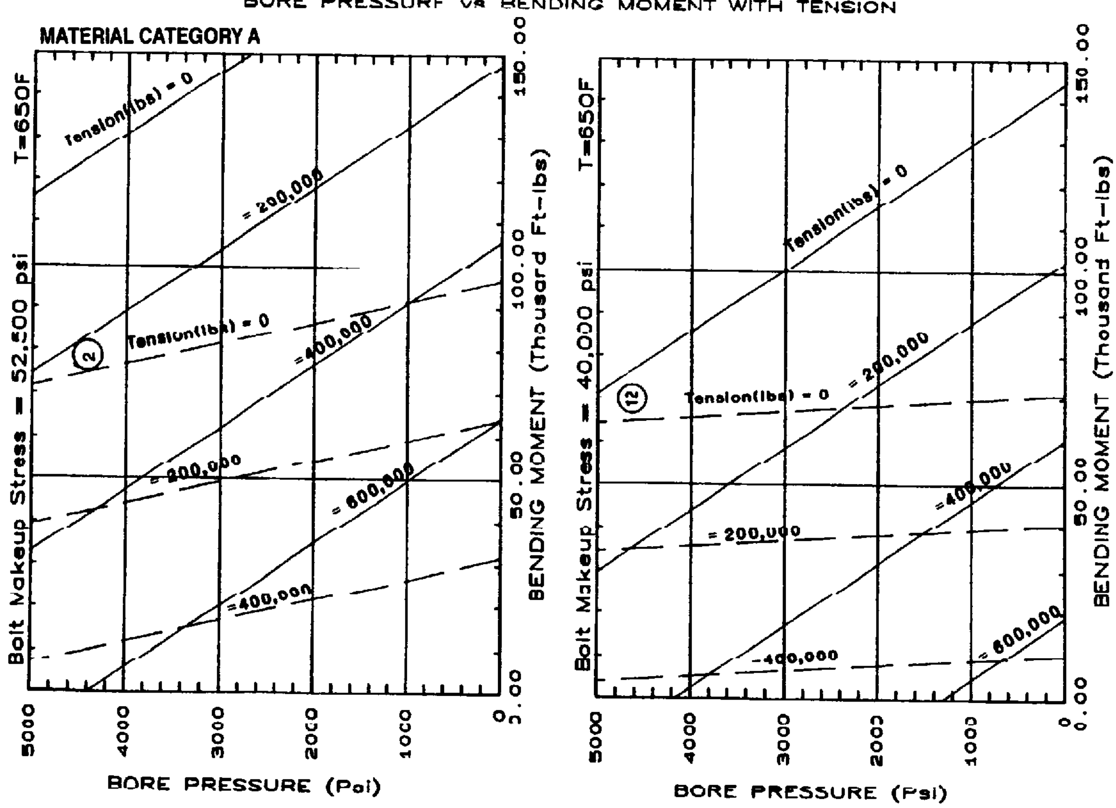
4-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



5-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

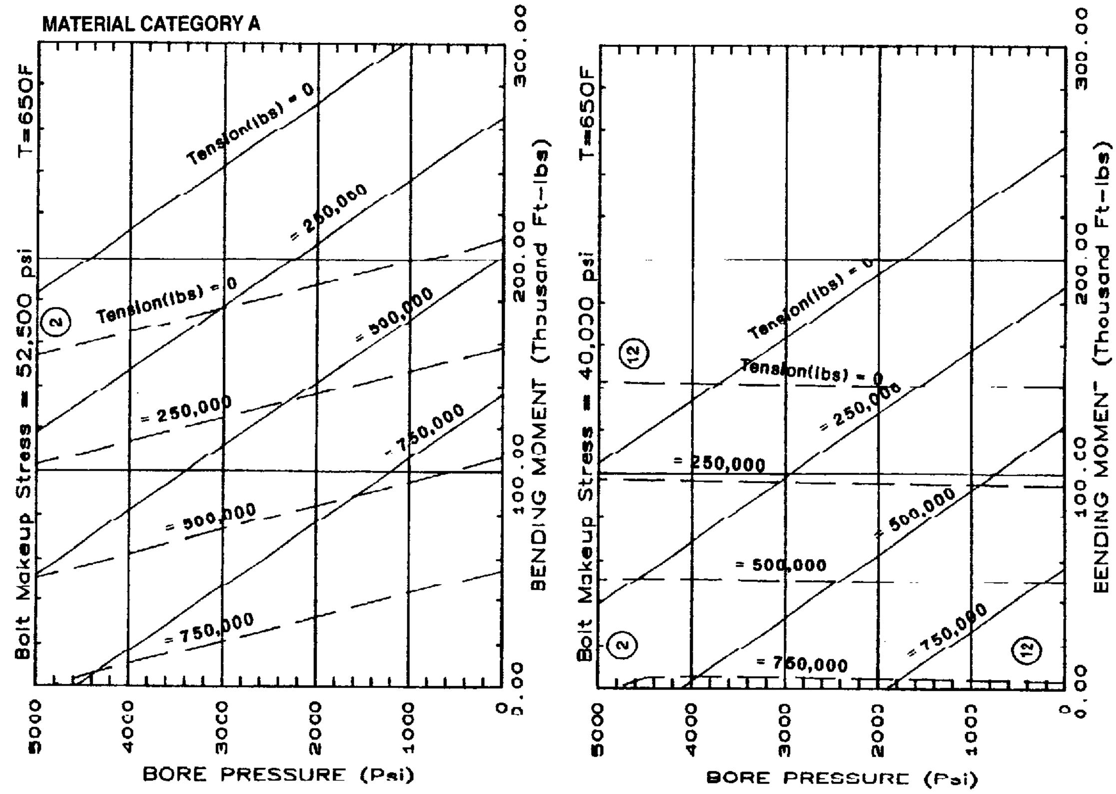


7-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



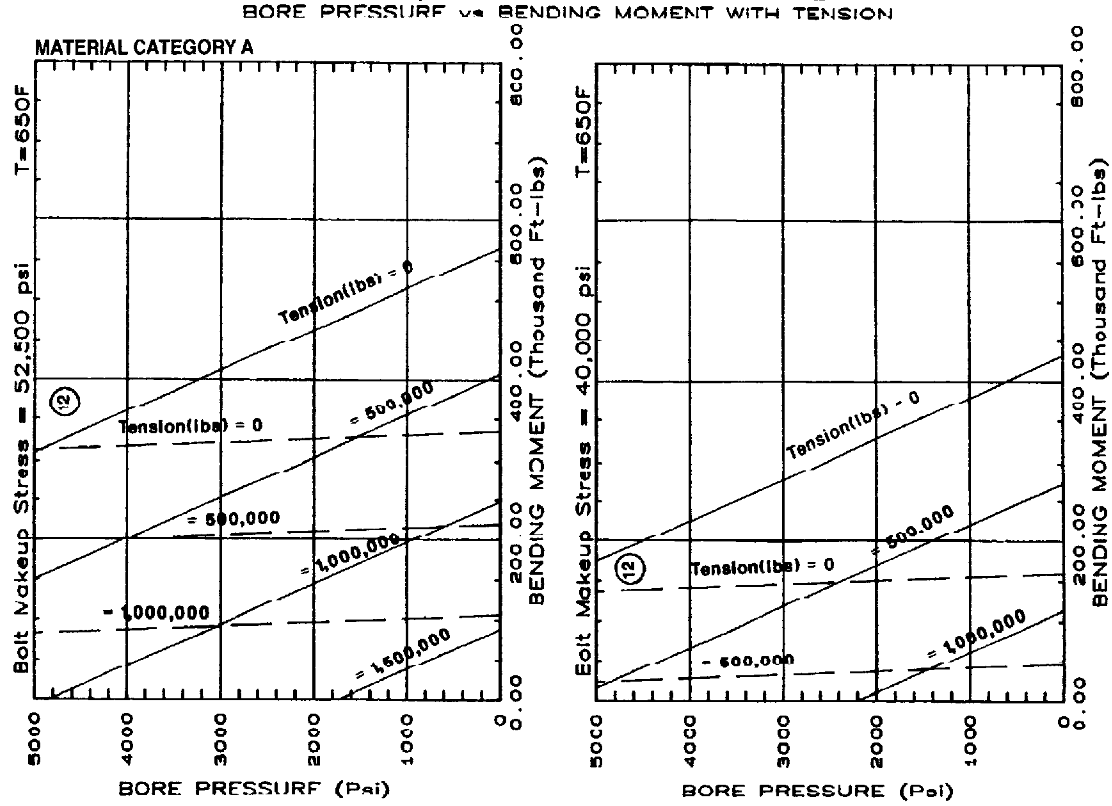
9"–5,000 PSI API 6B–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

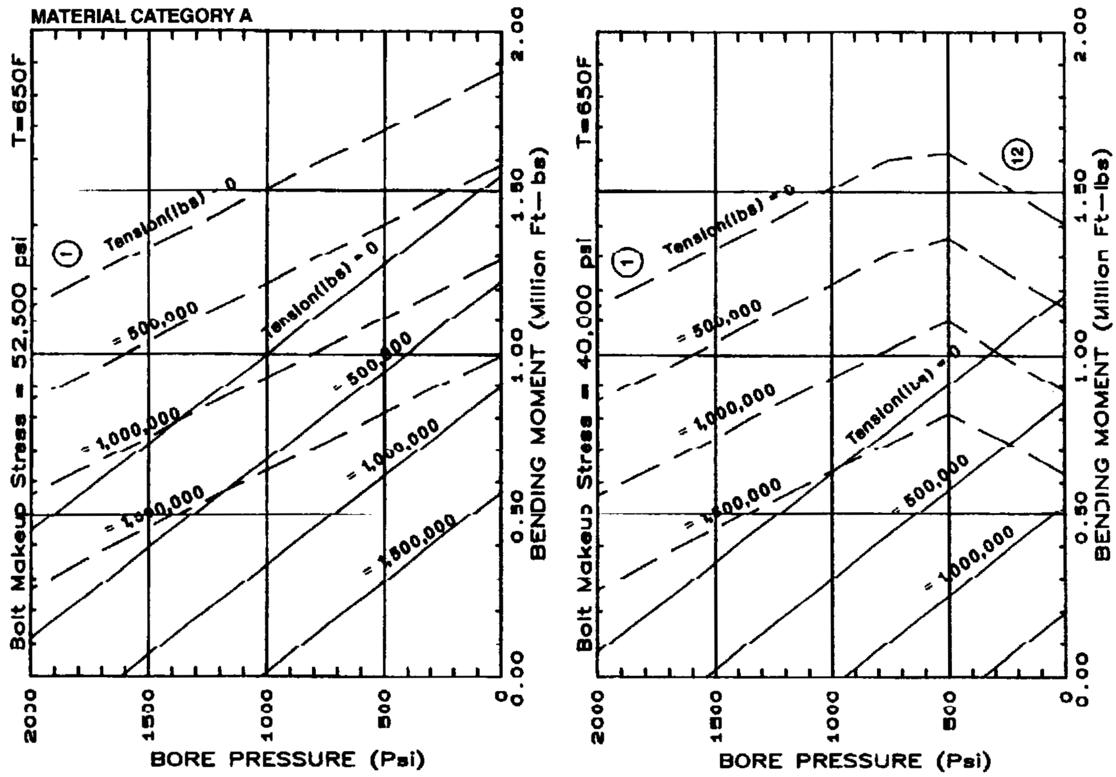


11"–5,000 PSI API 6B–FLANGE

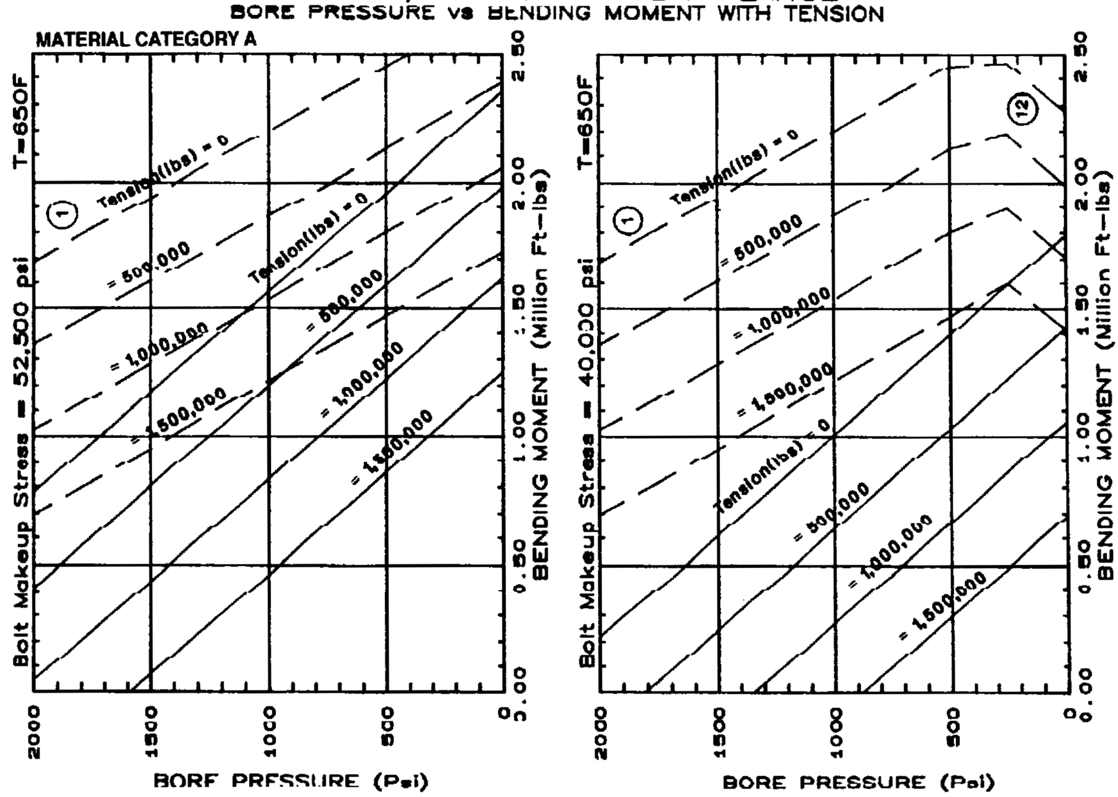
BORE PRESSURE vs BENDING MOMENT WITH TENSION



26-3/4"-2,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

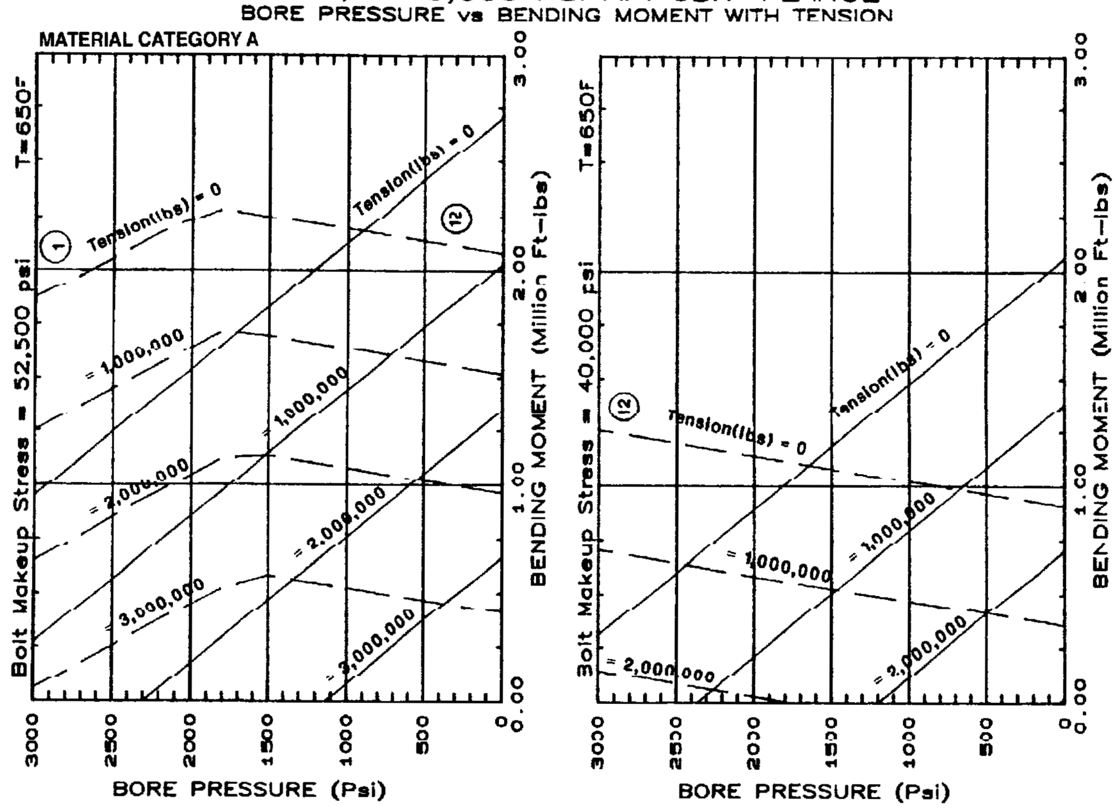


30"-2,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



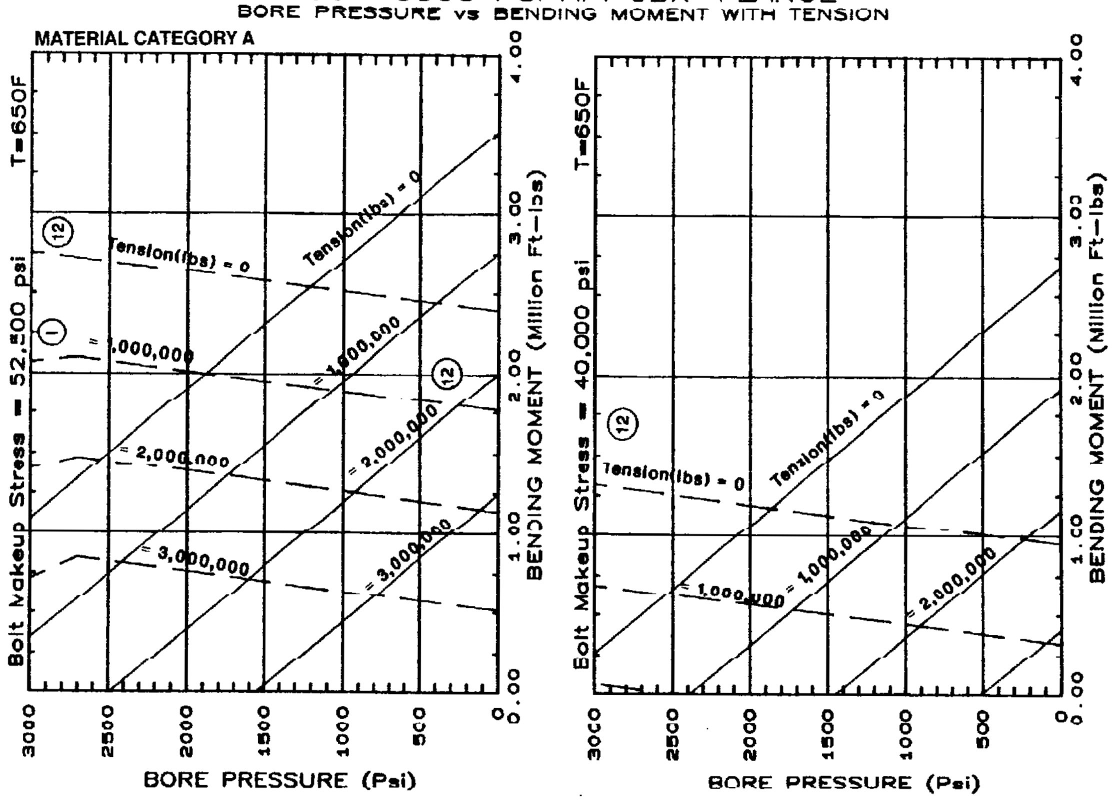
26-3/4"-3,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

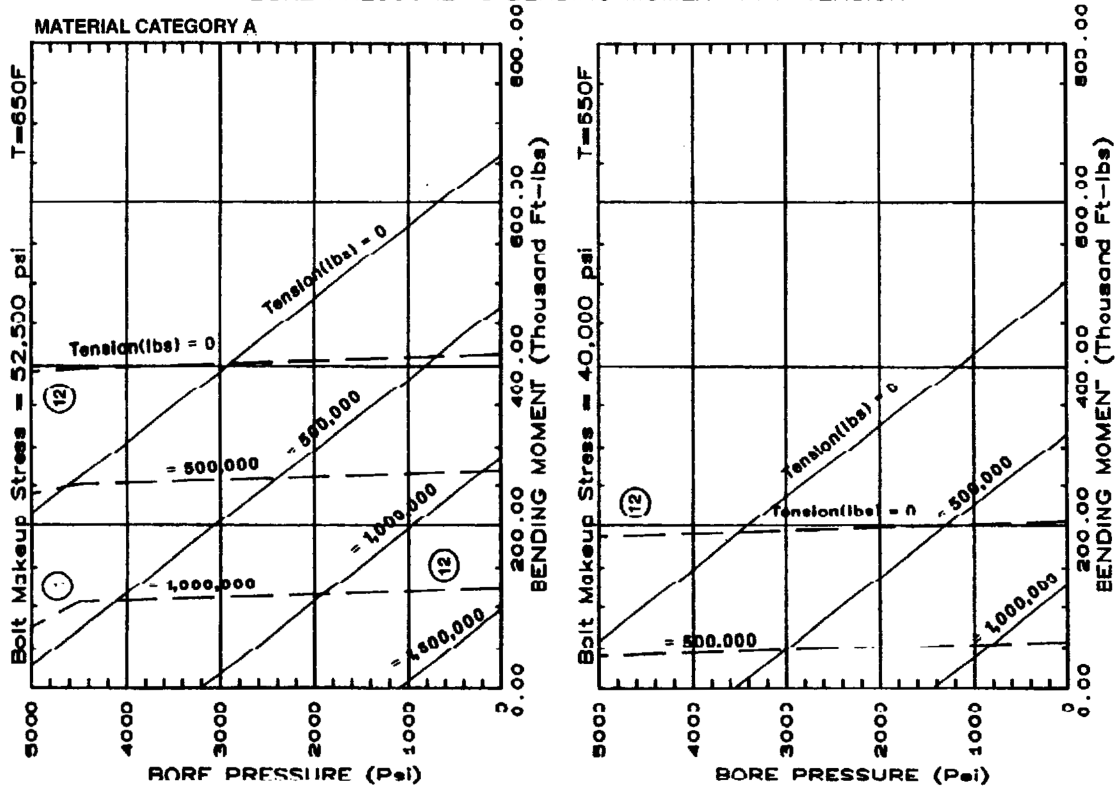


30"-3000 PSI API 6BX-FLANGE

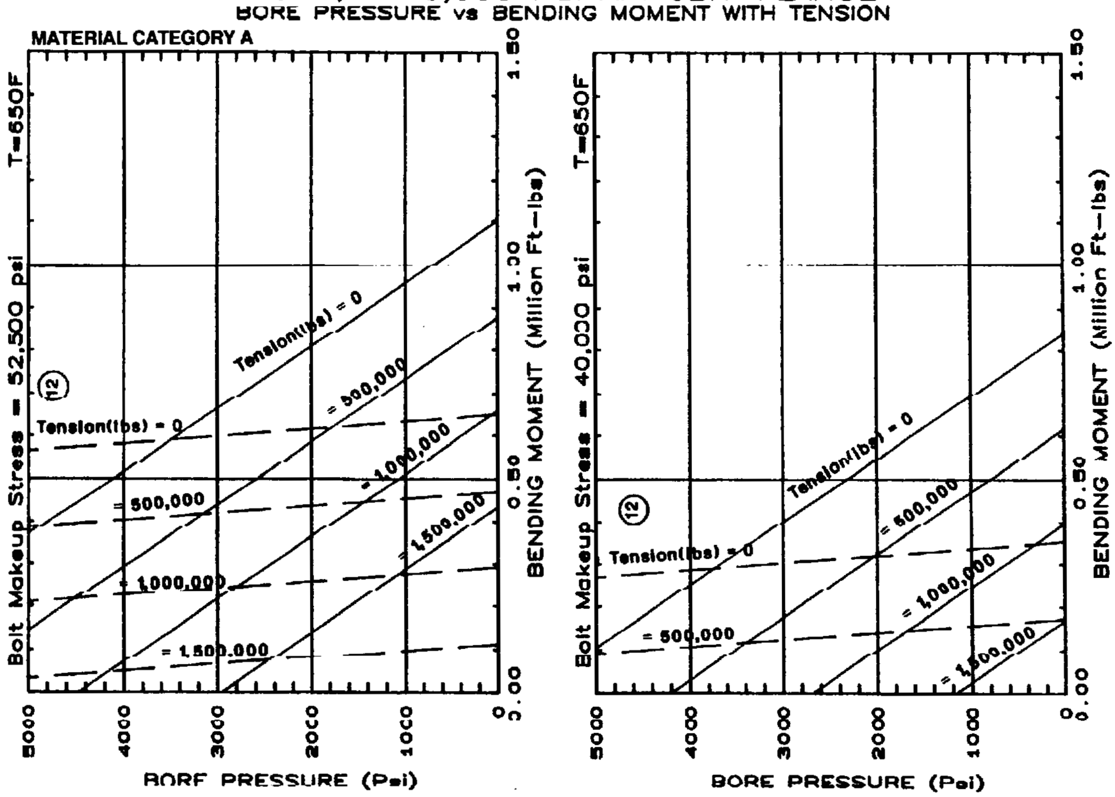
BORE PRESSURE vs BENDING MOMENT WITH TENSION



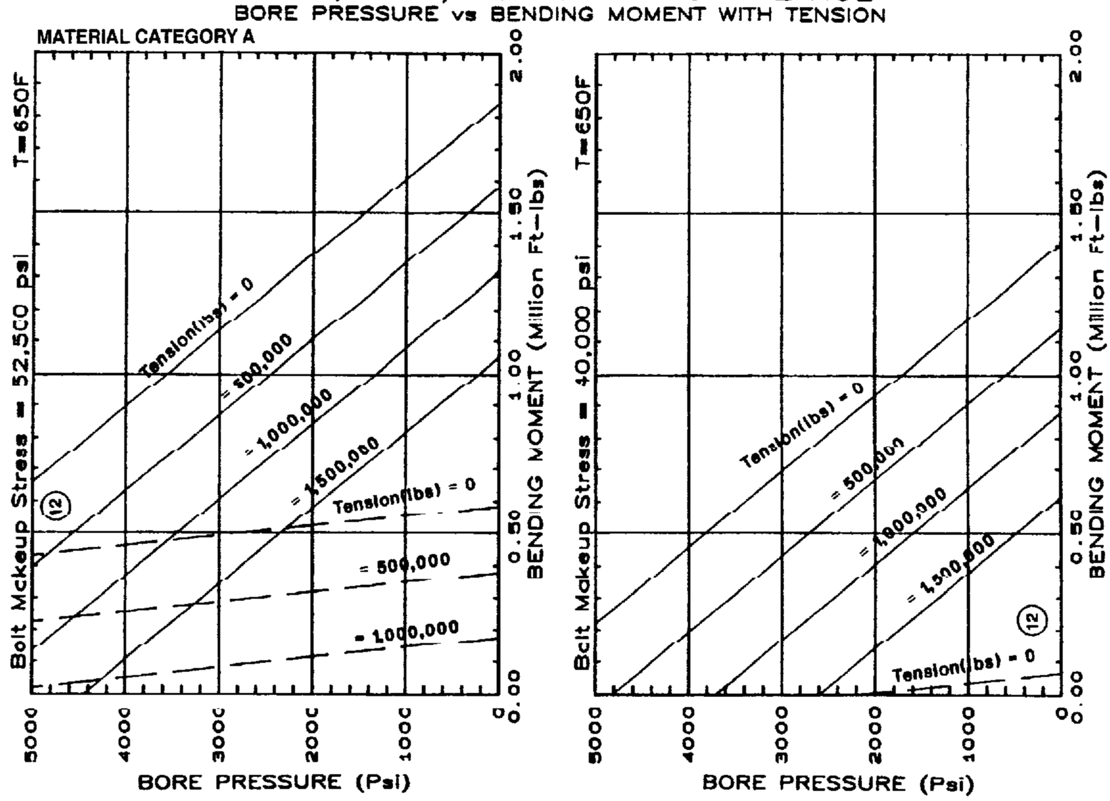
13-5/8"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



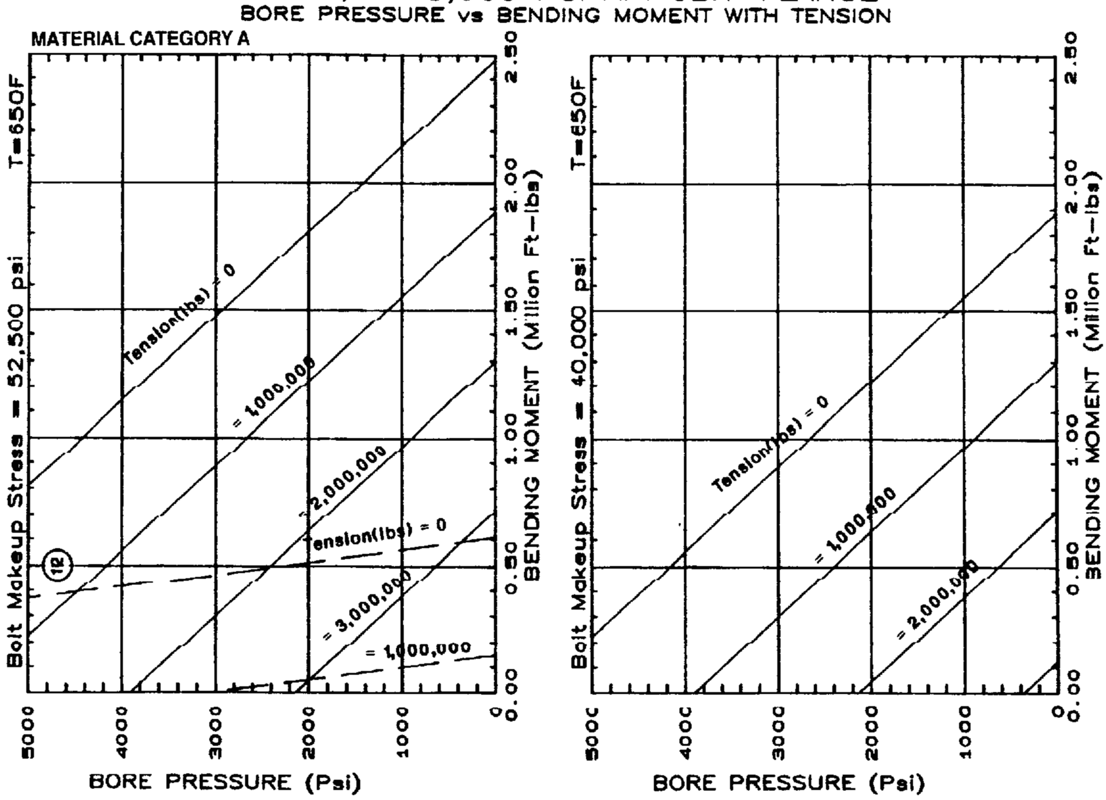
16-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



18-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

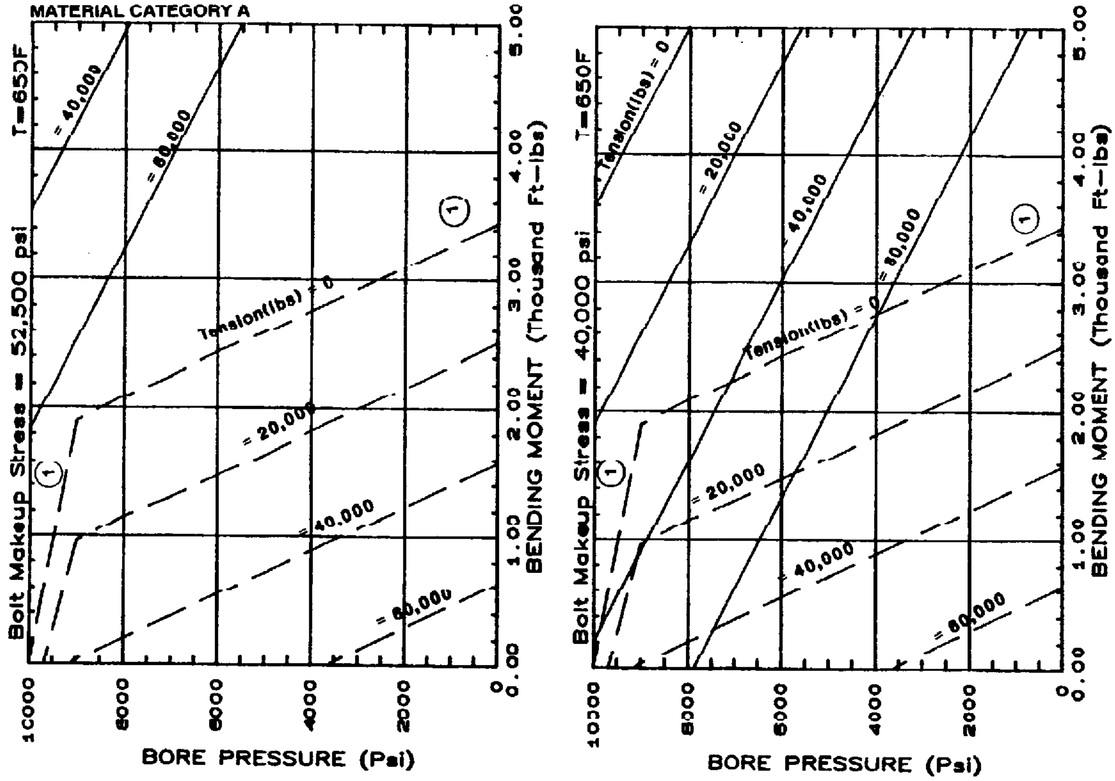


21-1/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



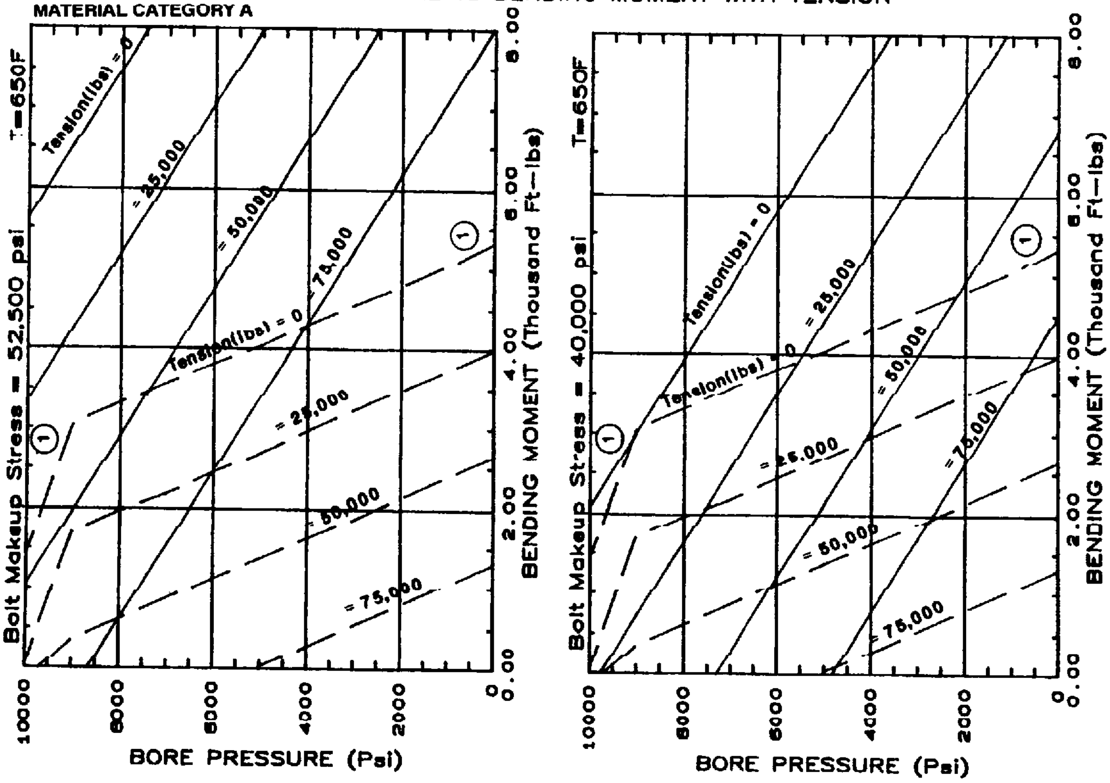
1-13/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

MATERIAL CATEGORY A

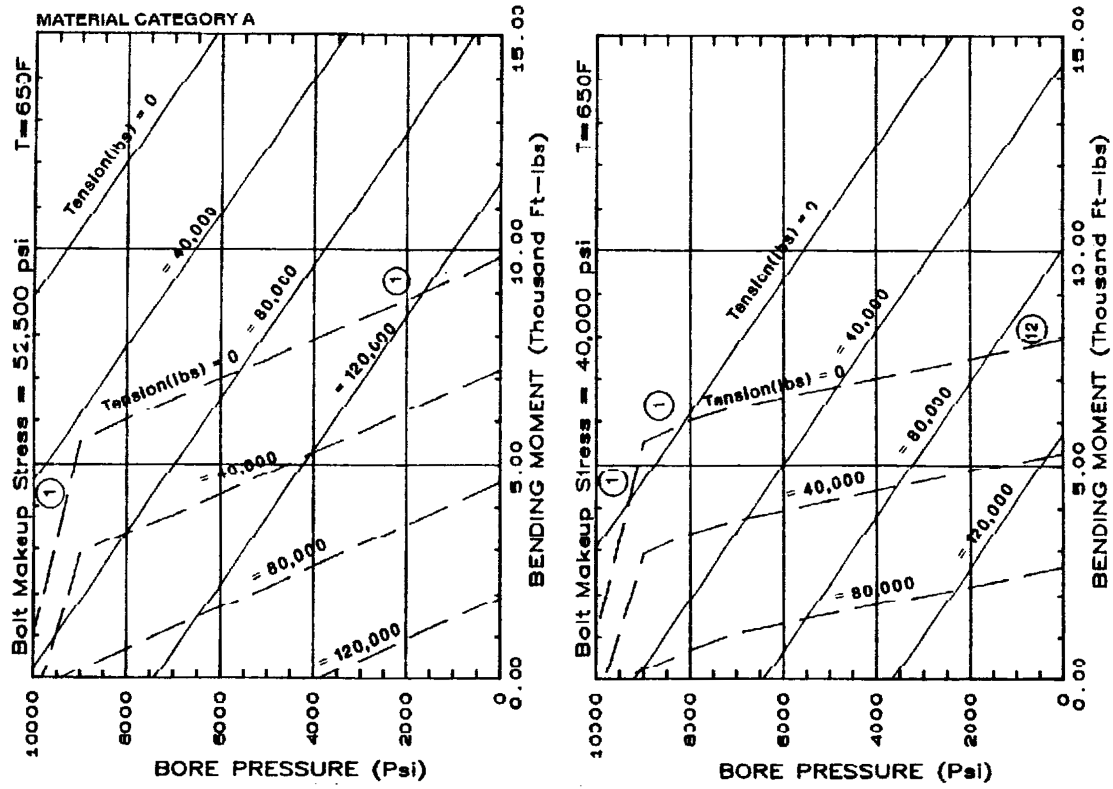


2-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

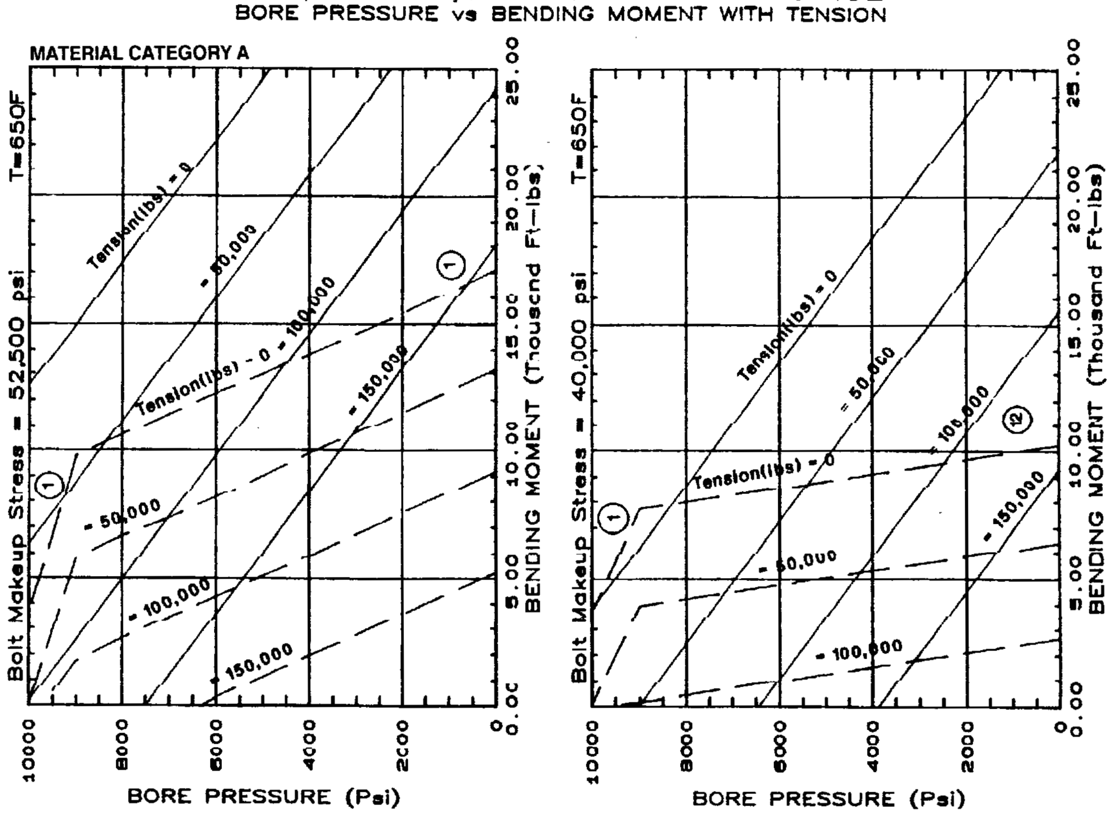
MATERIAL CATEGORY A



2-9/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

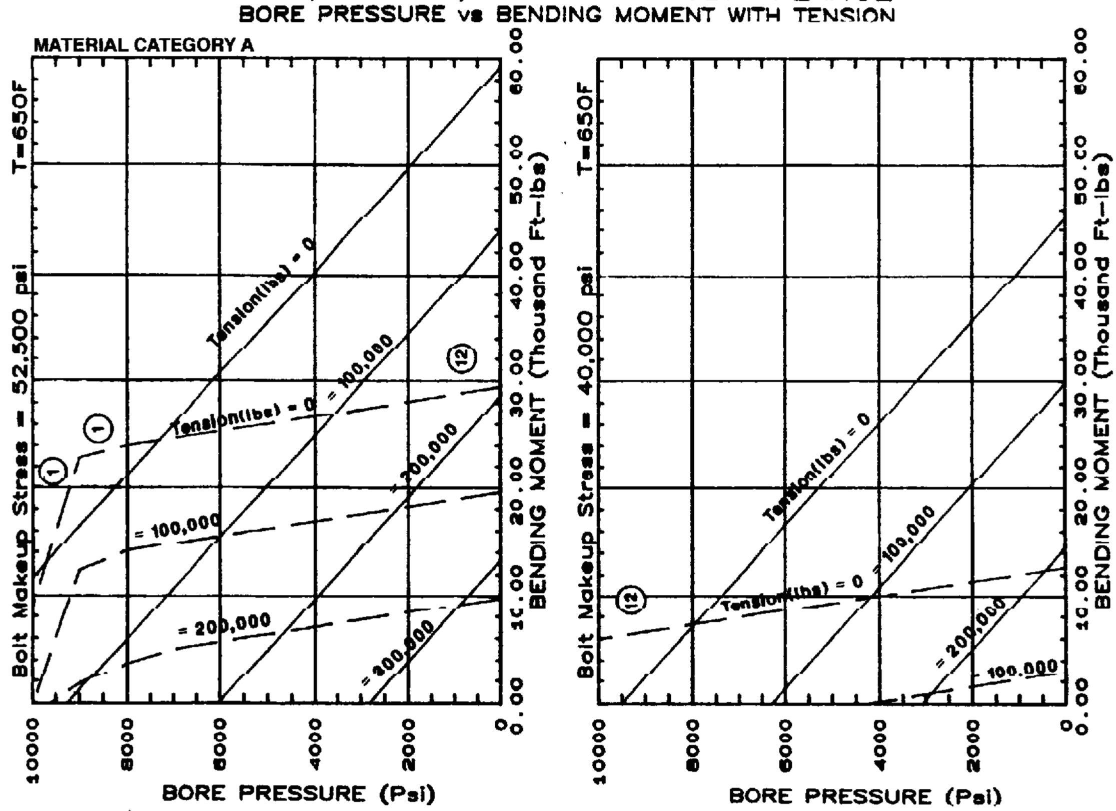


3-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



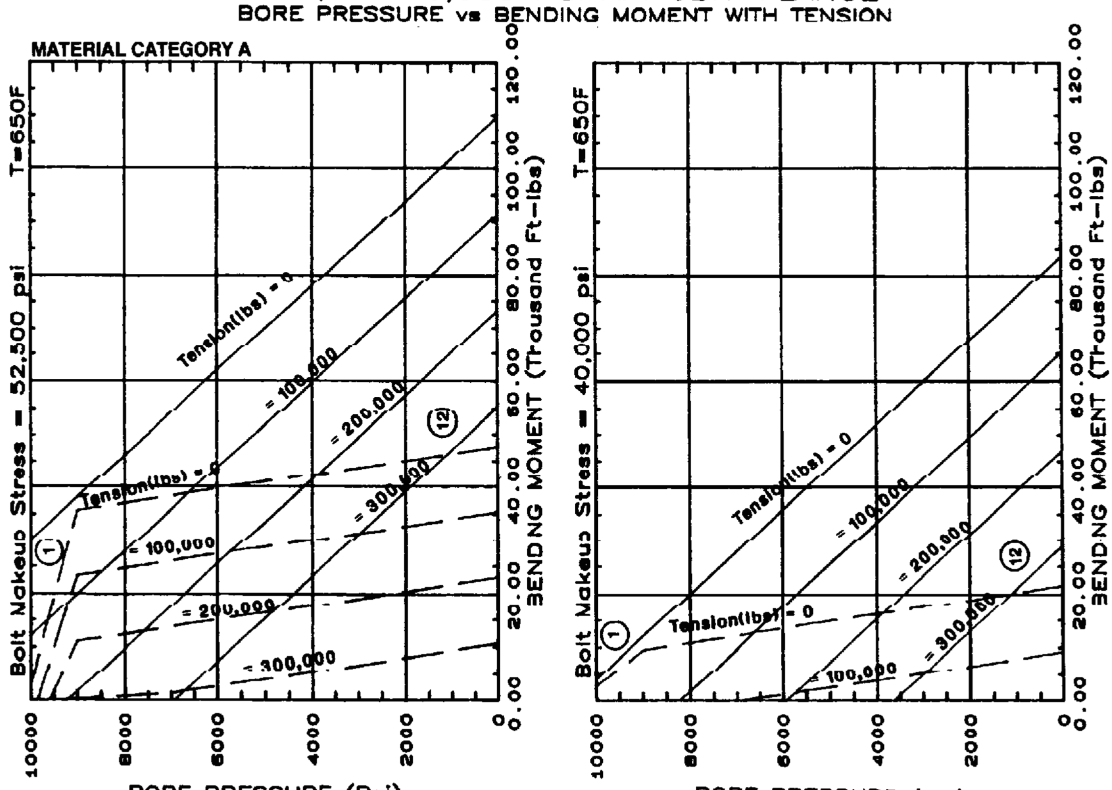
4-1/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

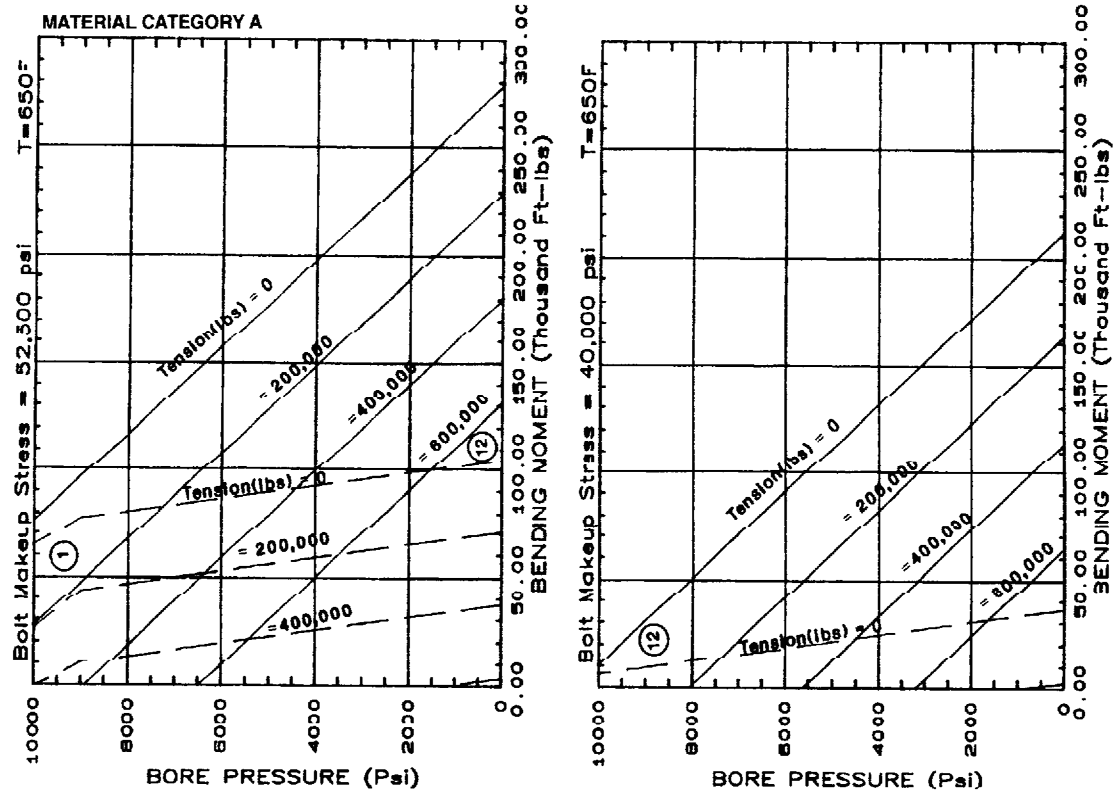


5-1/8"-10,000 PSI API 6BX-FLANGE

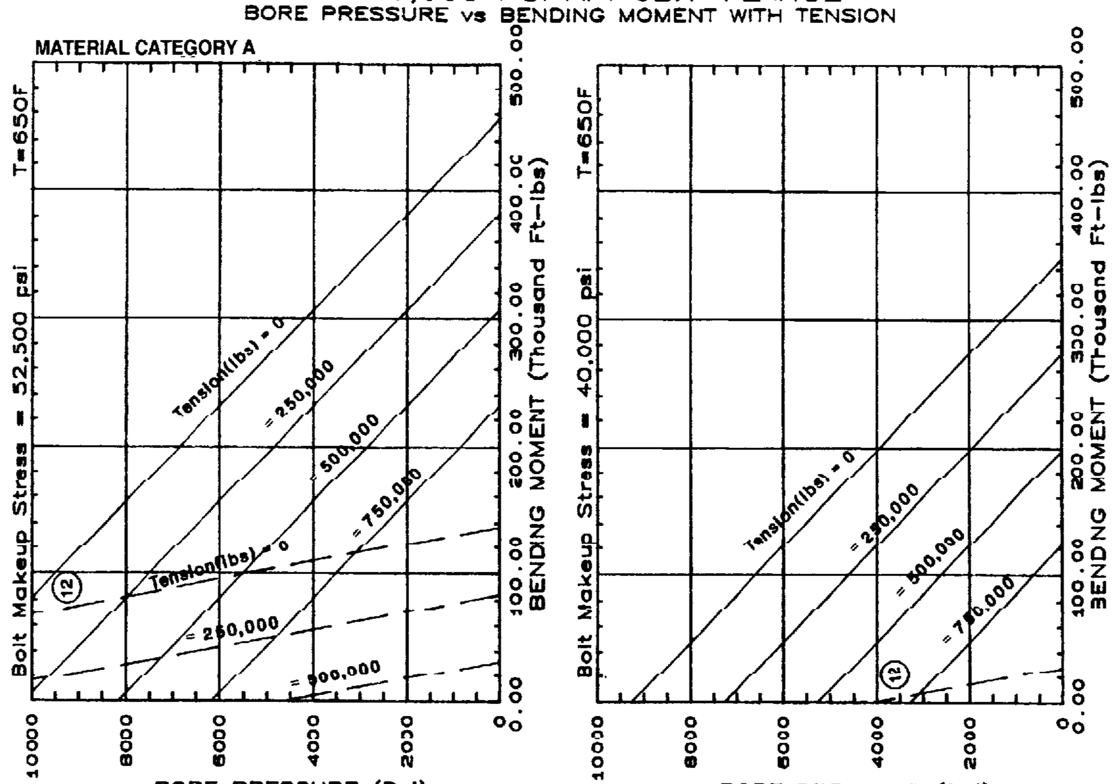
BORE PRESSURE vs BENDING MOMENT WITH TENSION



7-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

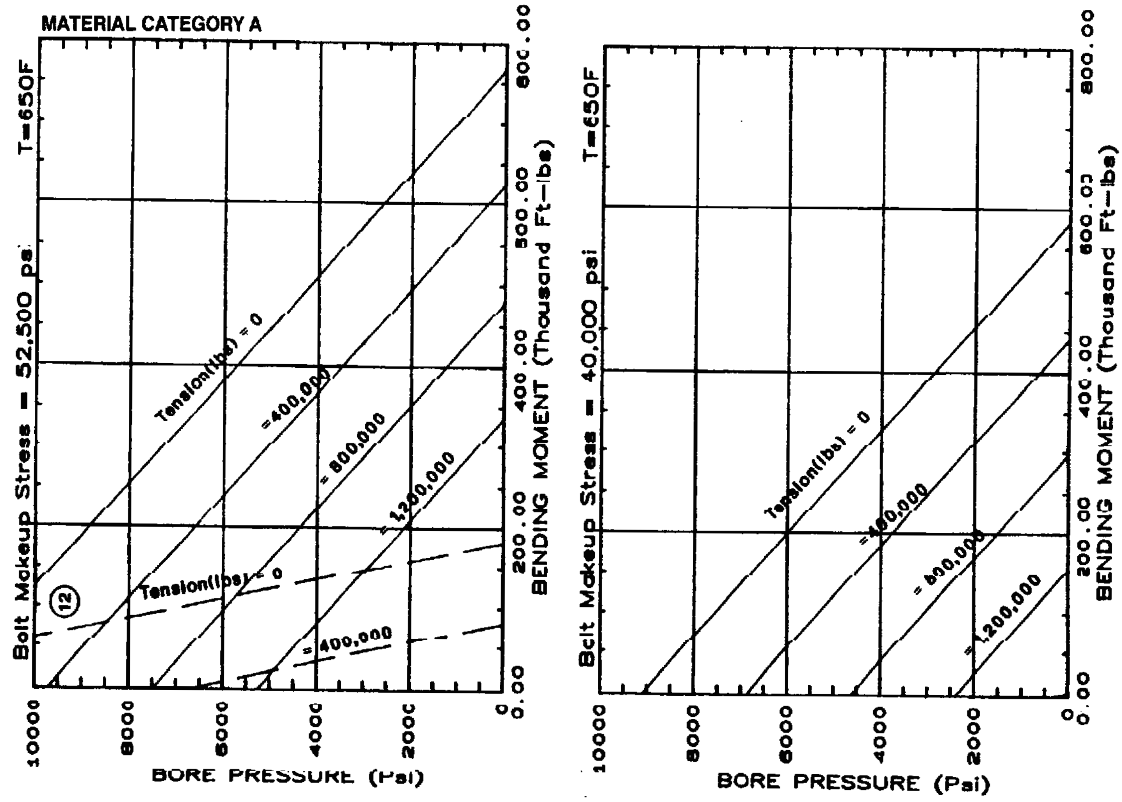


9"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



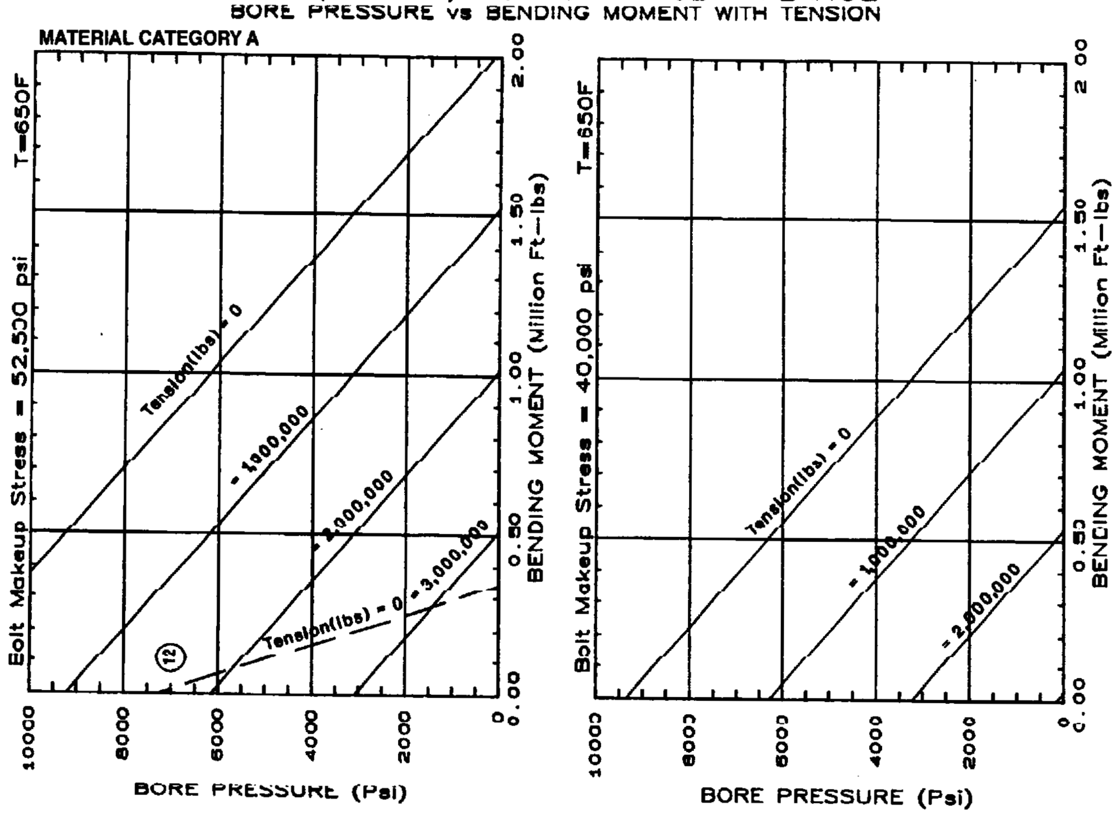
11"–10,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



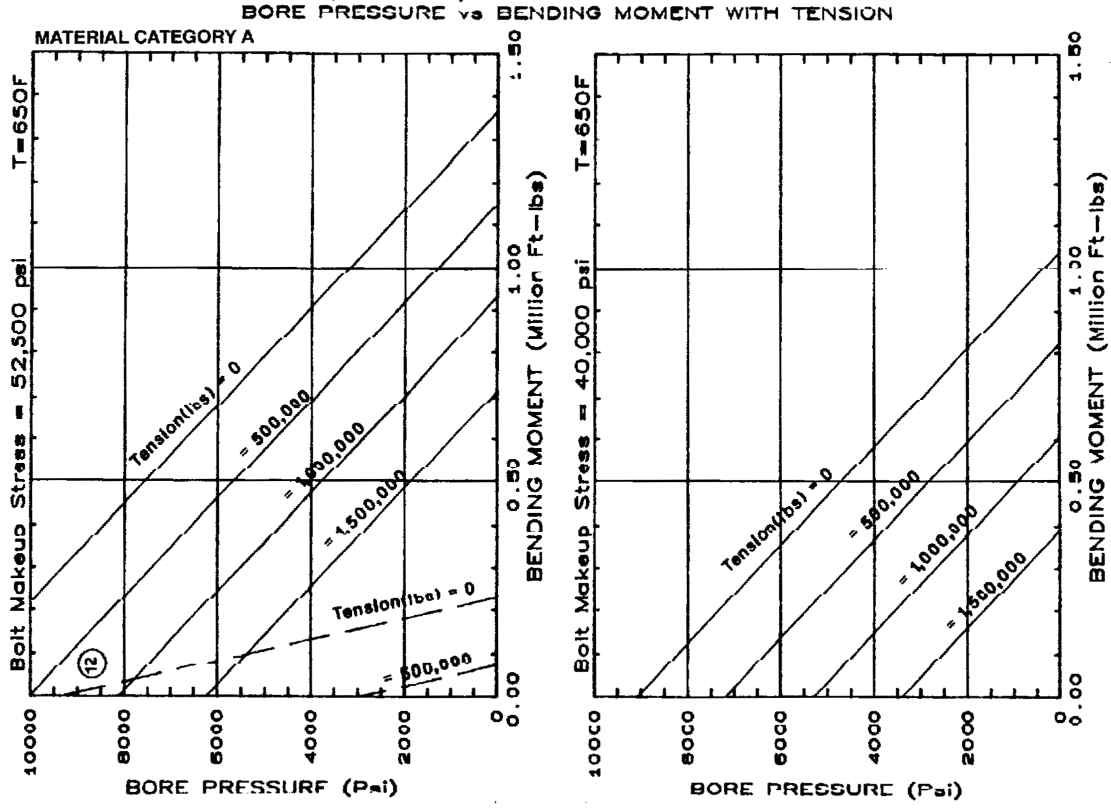
16–3/4"–10,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



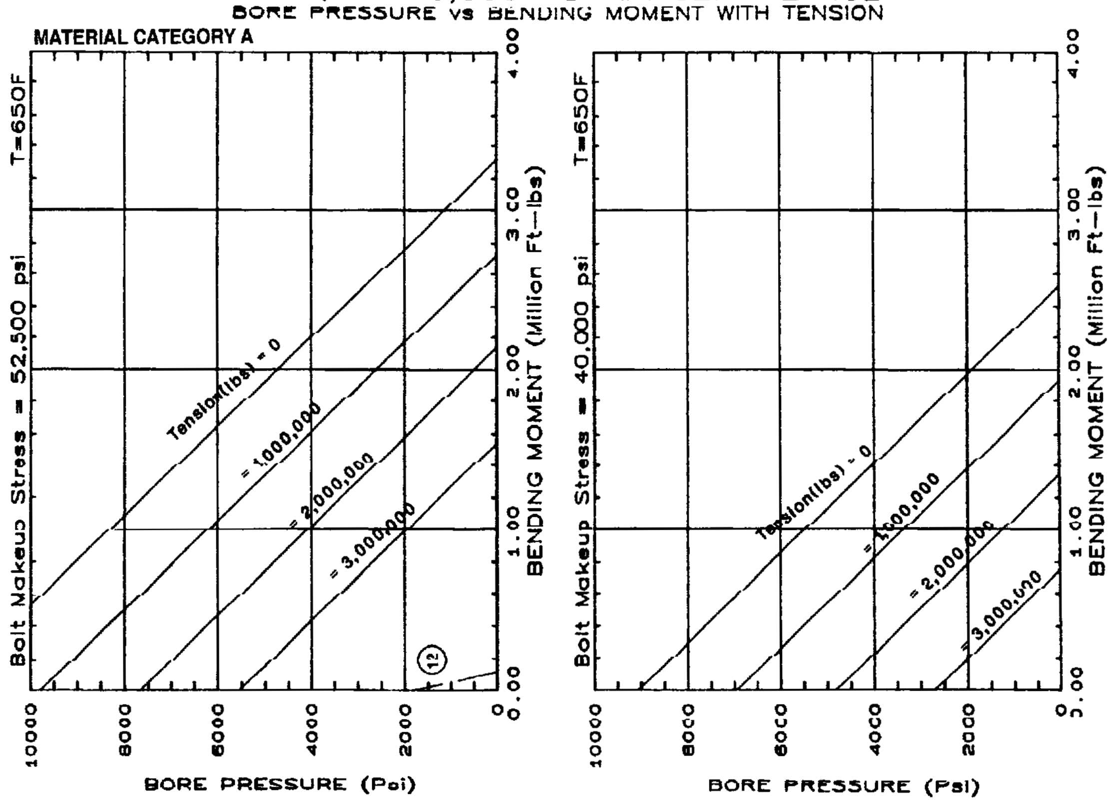
13-5/8"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

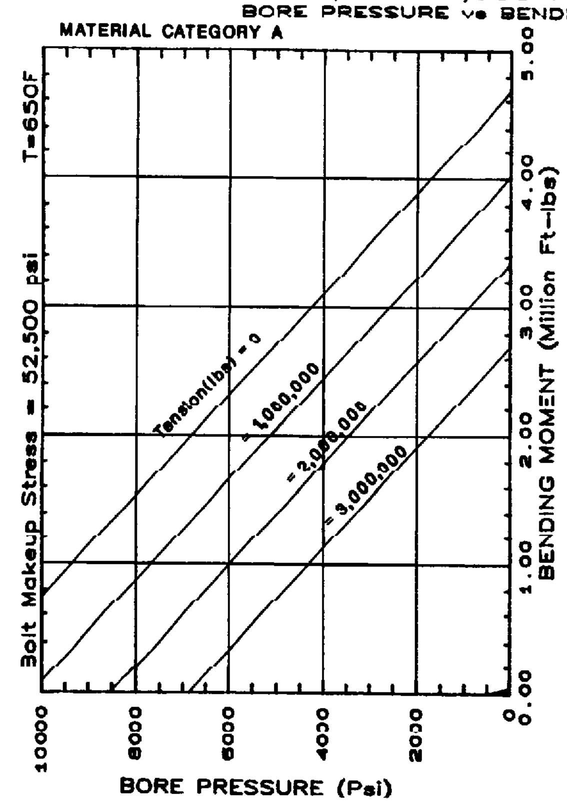


18-3/4"-10,000 PSI API 6BX-FLANGE

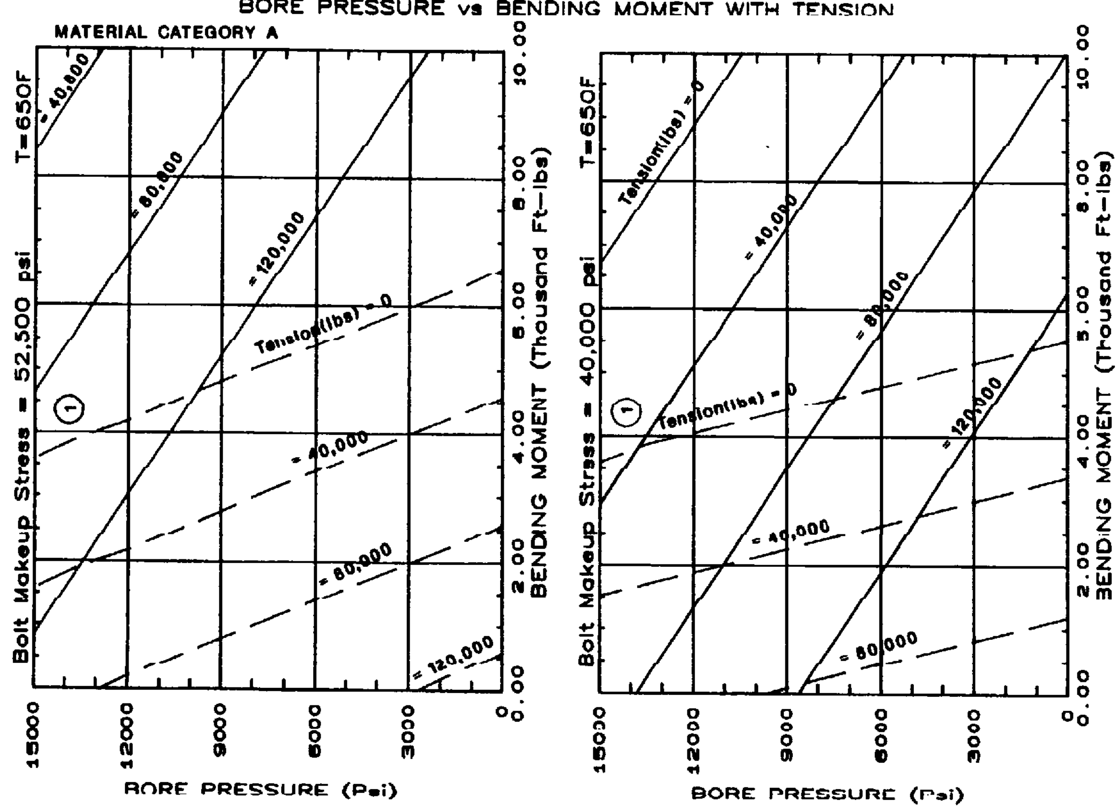
BORE PRESSURE vs BENDING MOMENT WITH TENSION



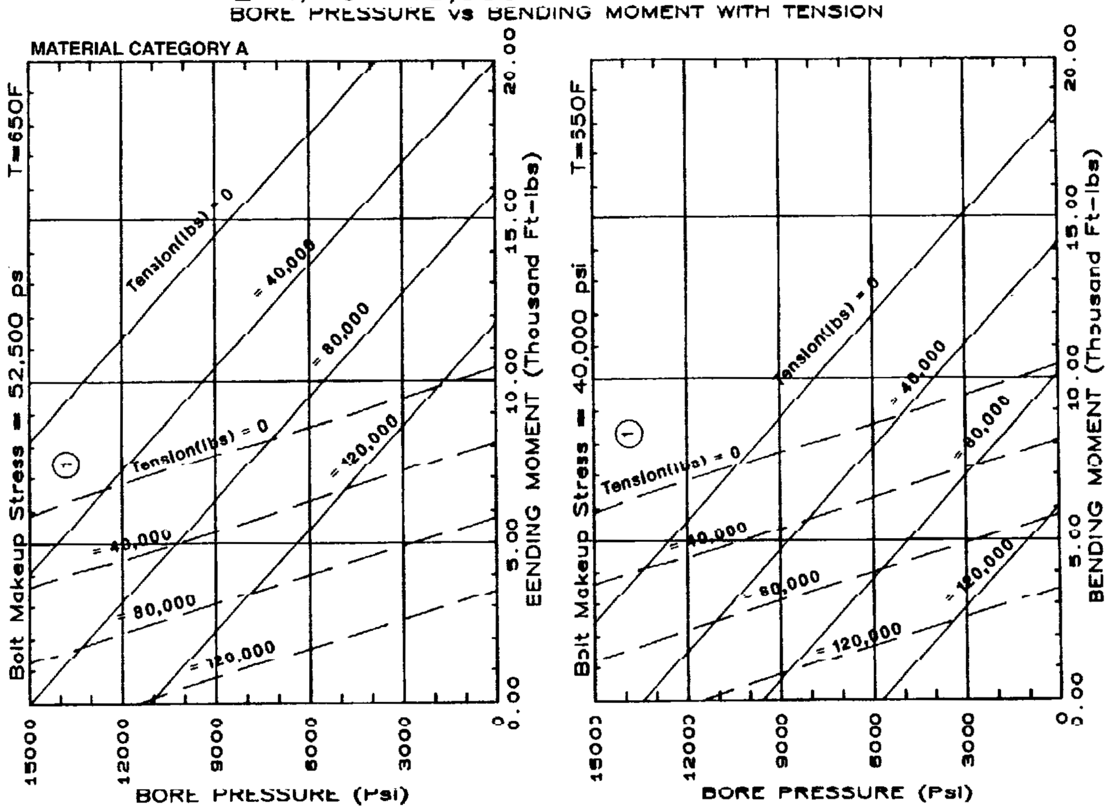
21-1/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



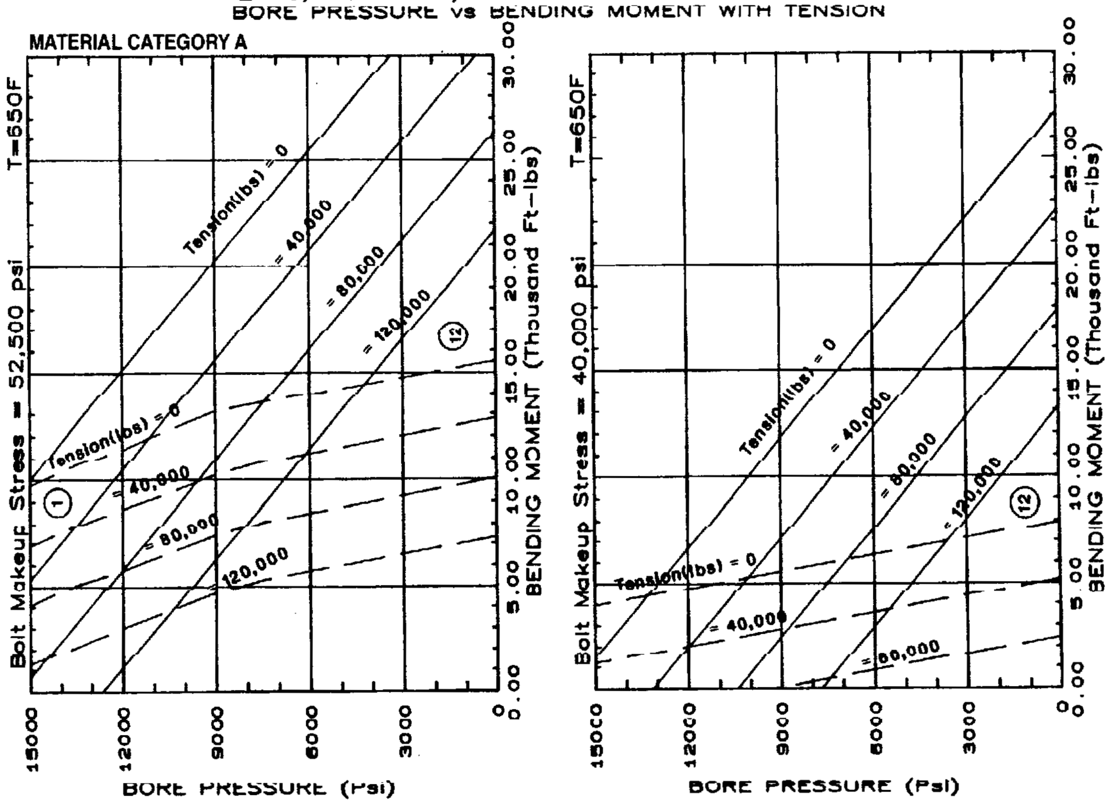
1-13/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



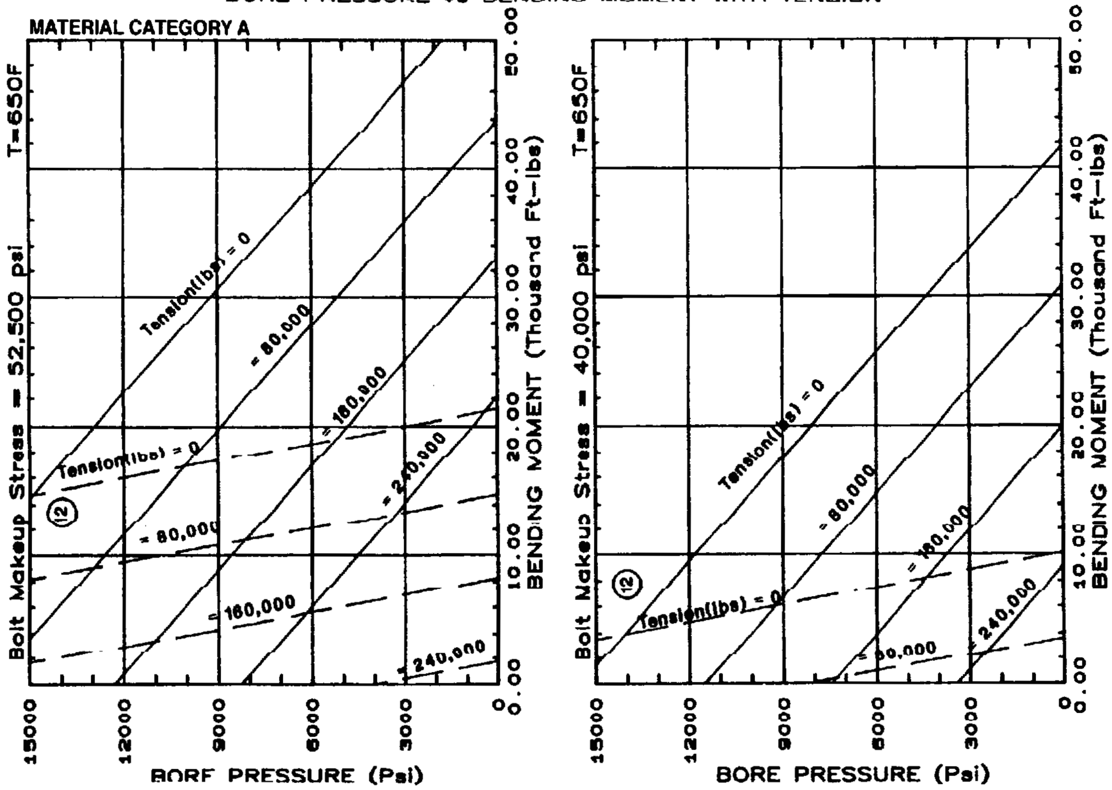
2-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



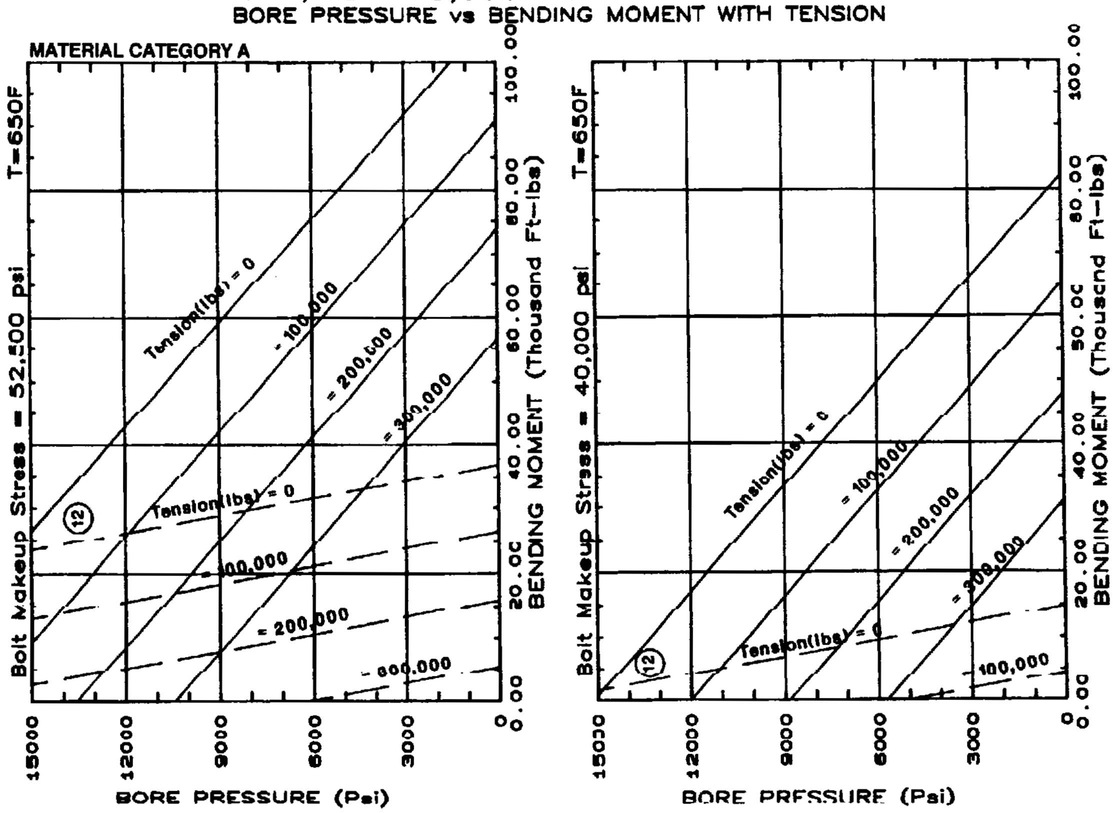
2-9/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

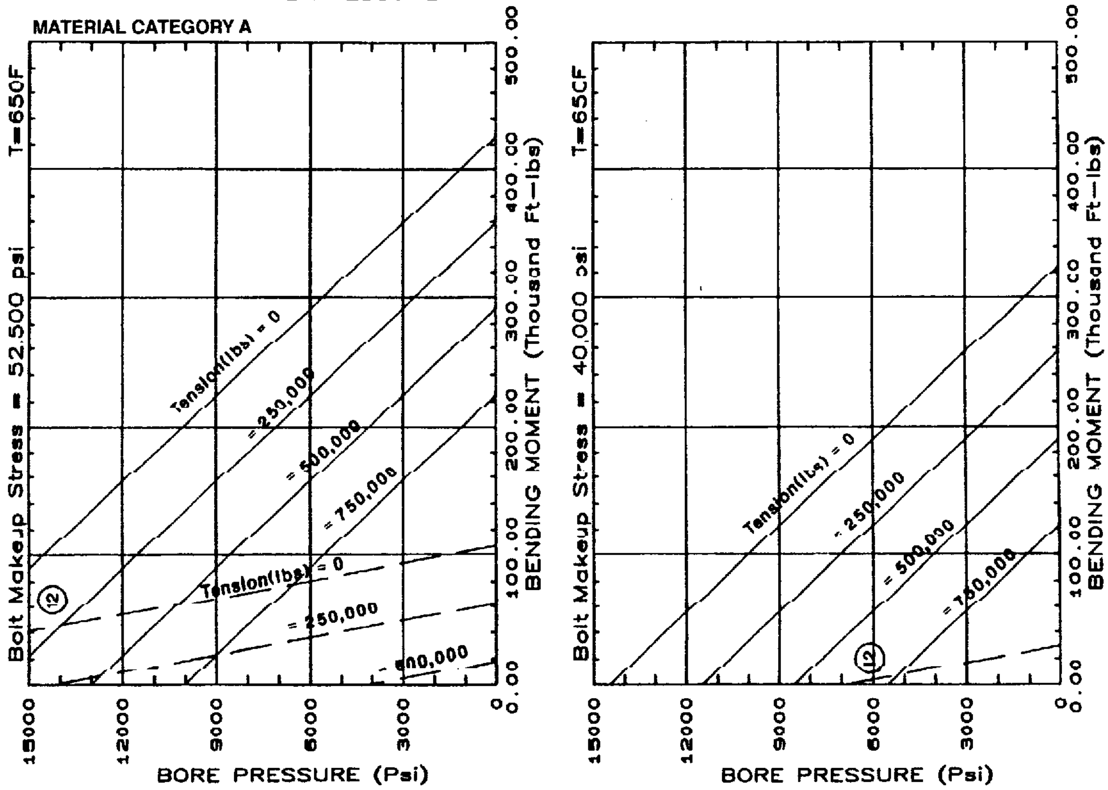


4-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



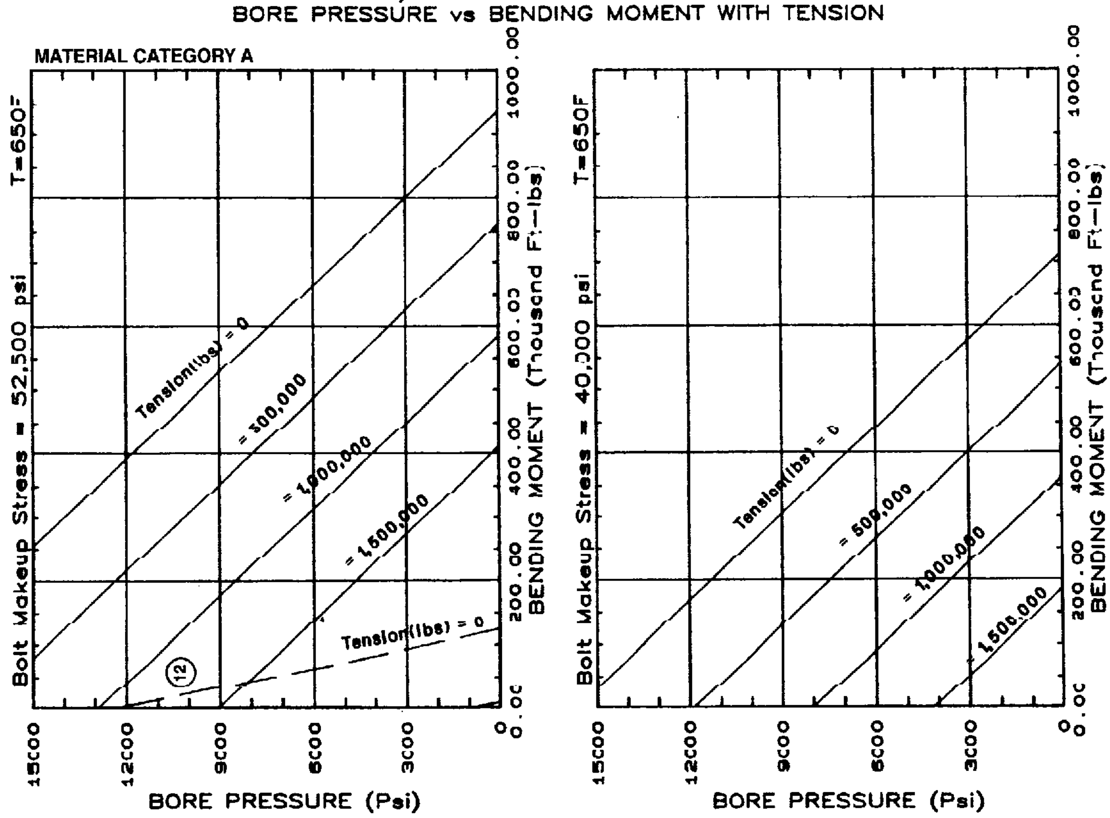
7-1/16"-15,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

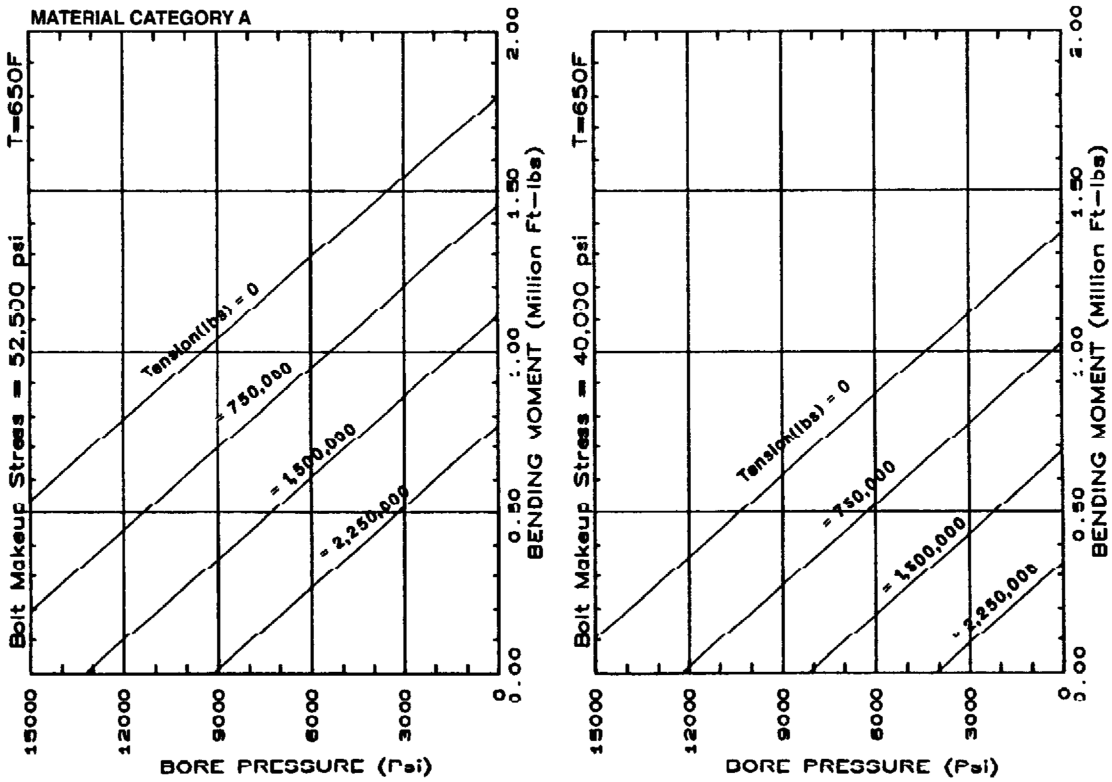


9"-15,000 PSI API 6BX-FLANGE

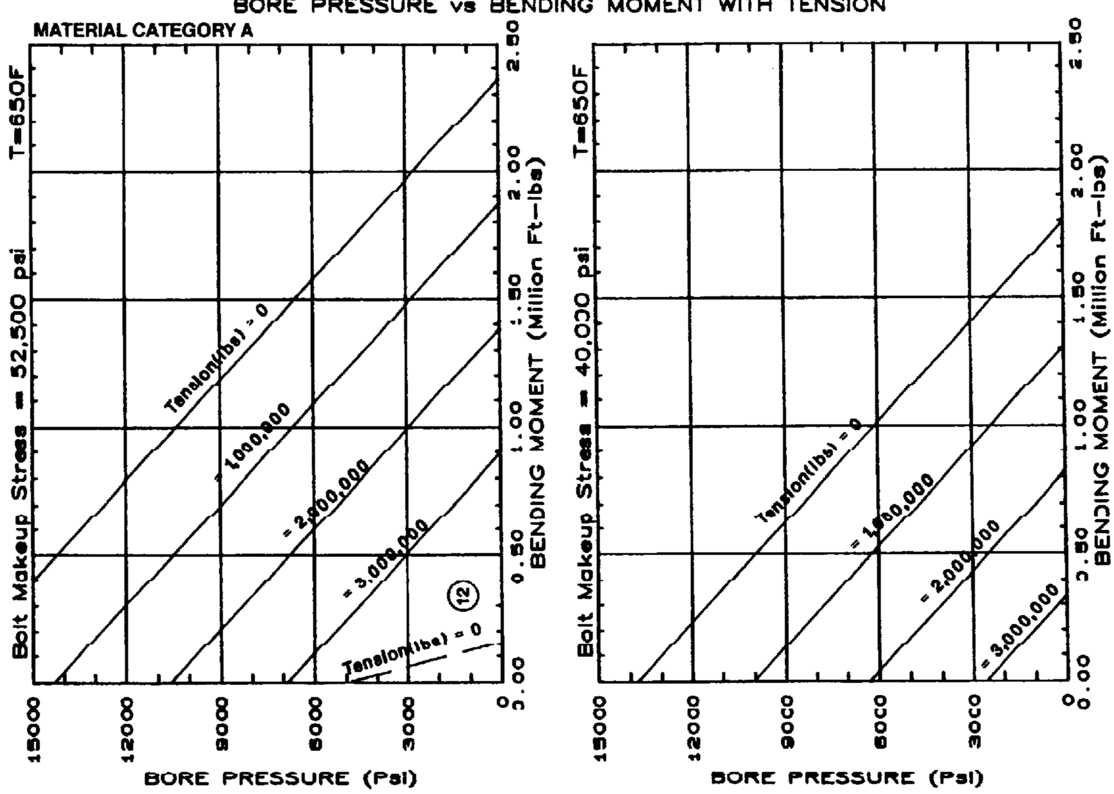
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

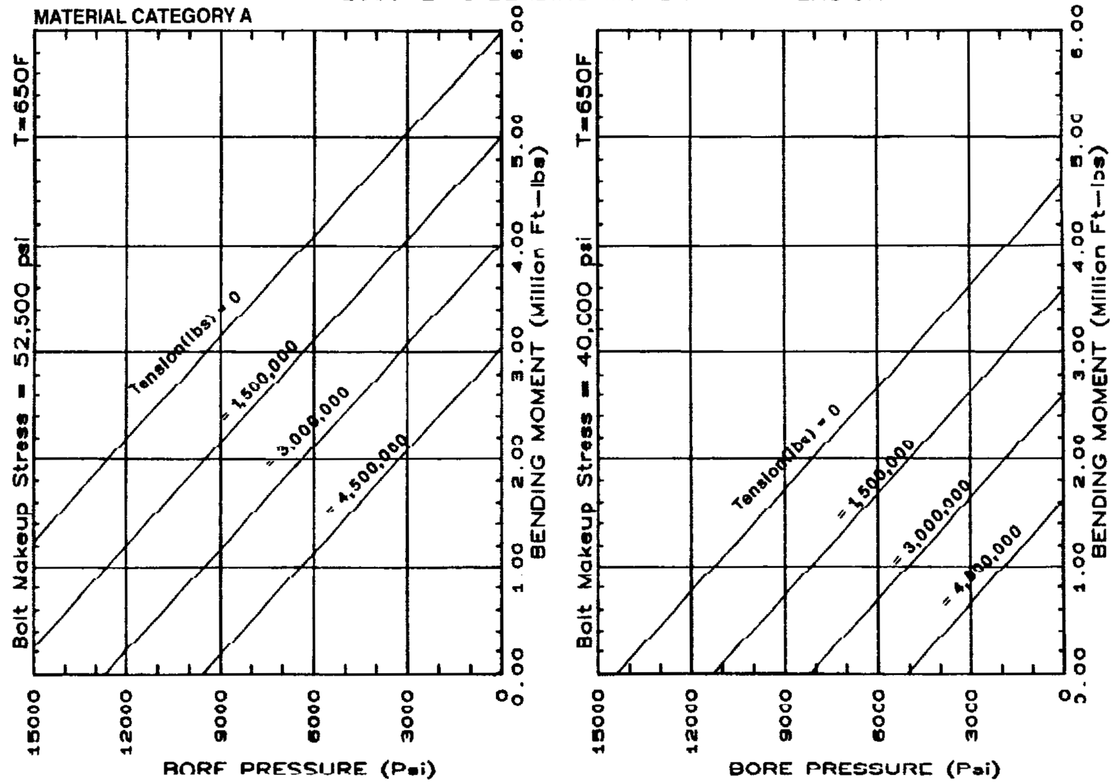


13-5/8"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



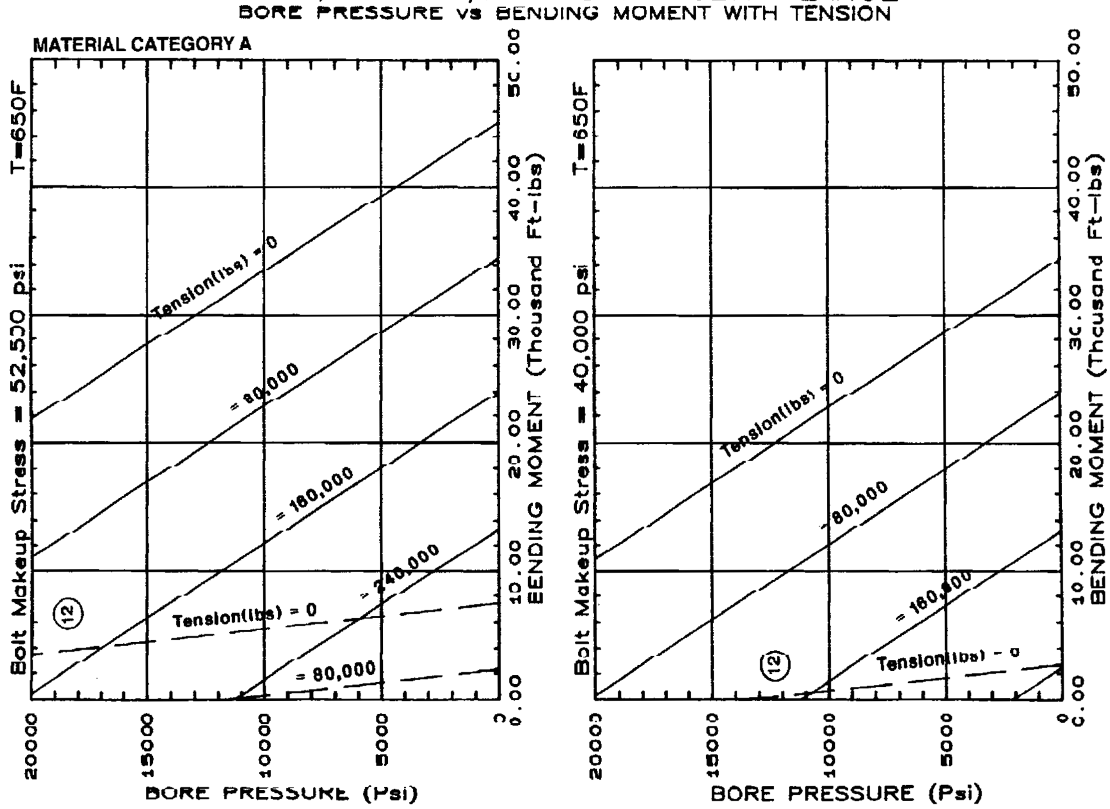
18-3/4"-15,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

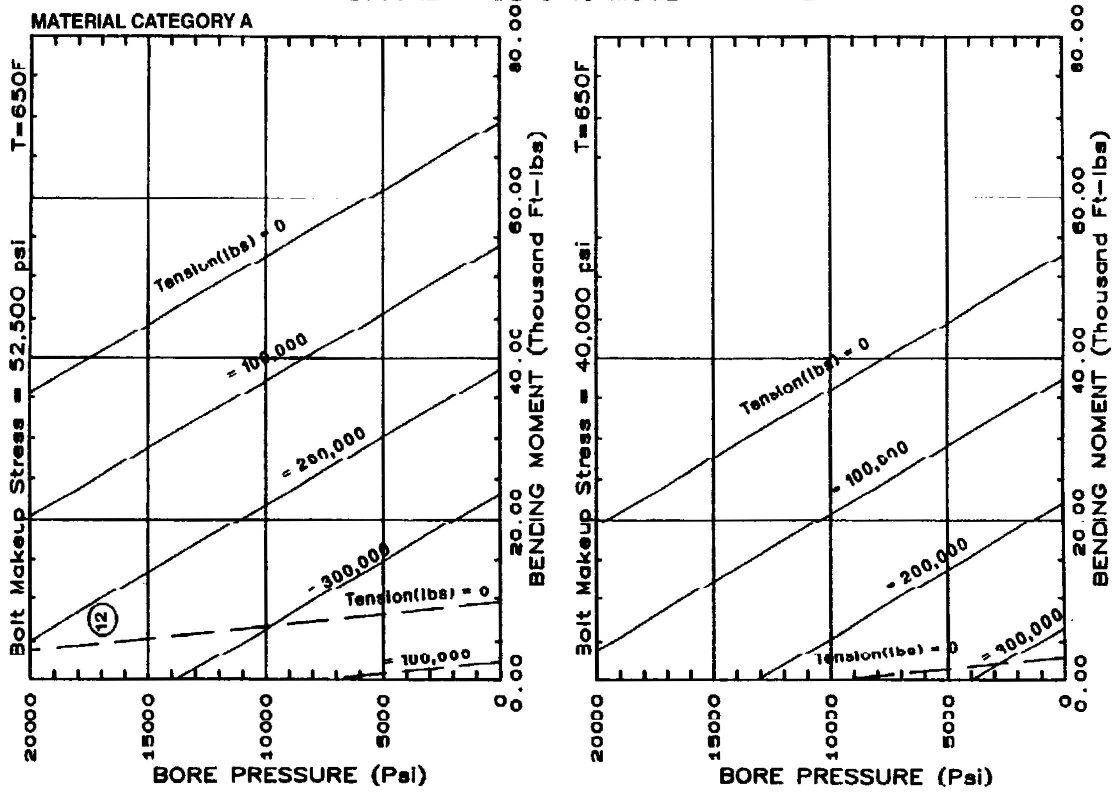


1-13/16"-20,000 PSI API 6BX-FLANGE

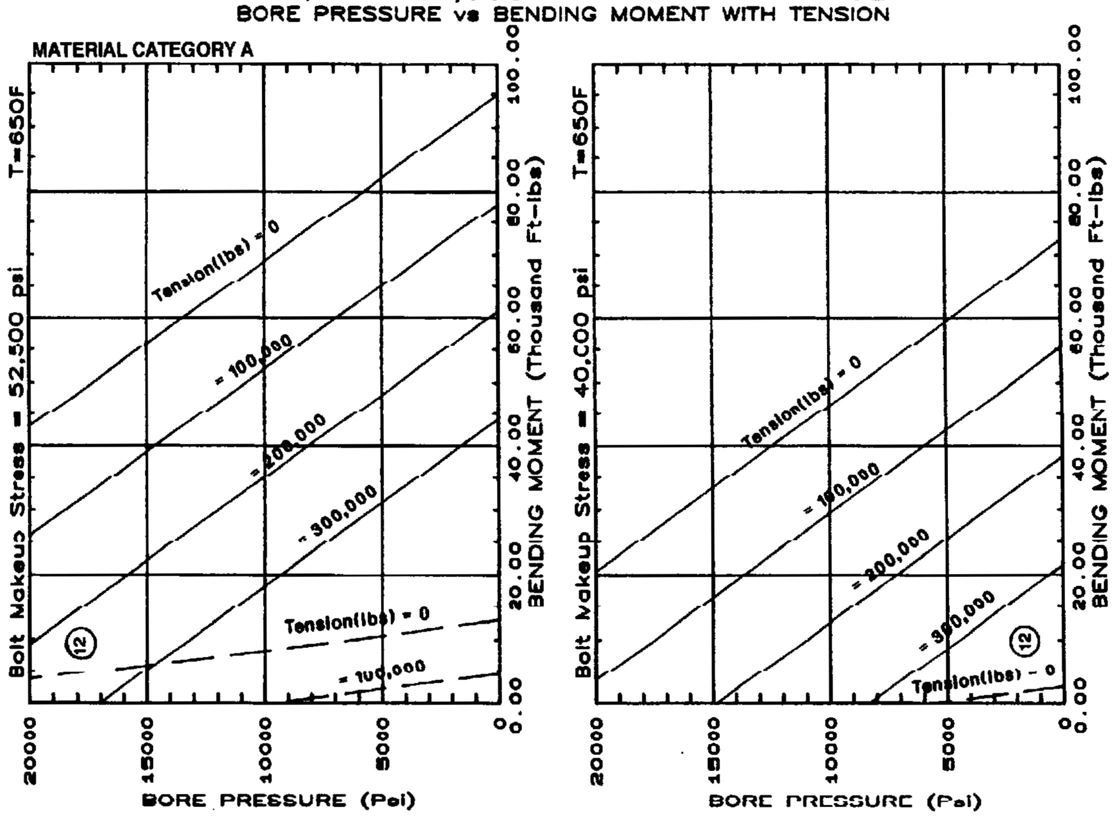
BORE PRESSURE vs BENDING MOMENT WITH TENSION



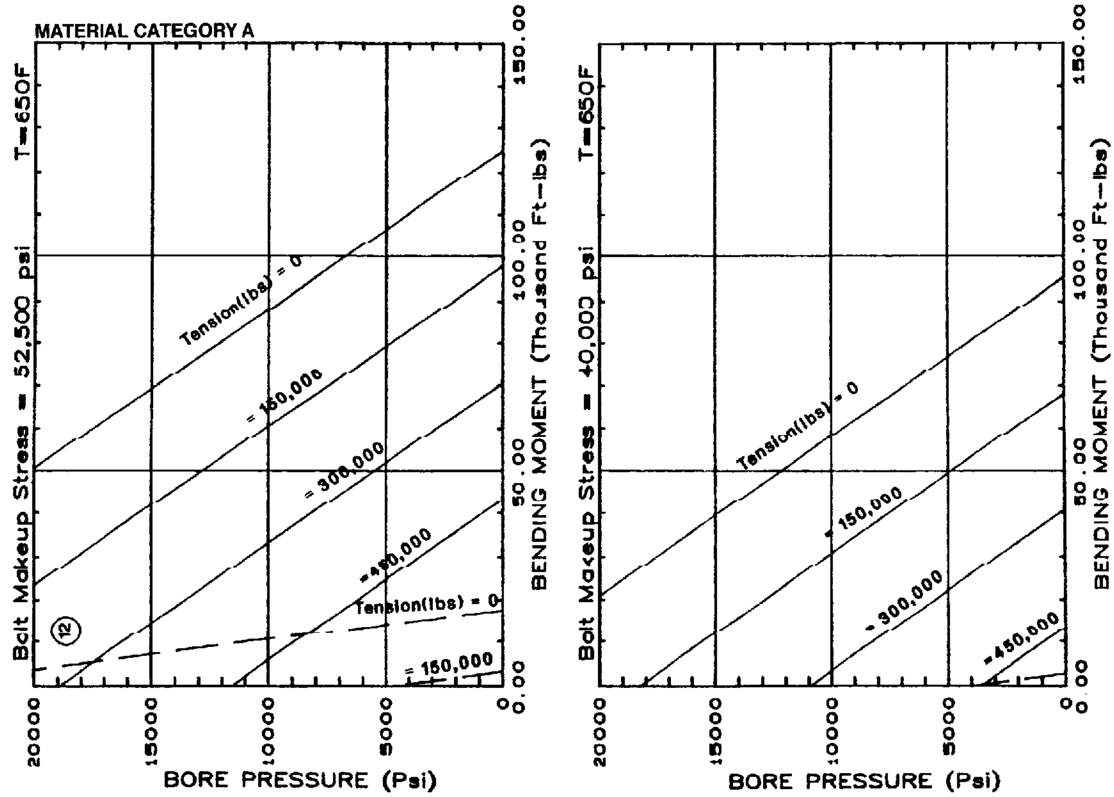
2-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



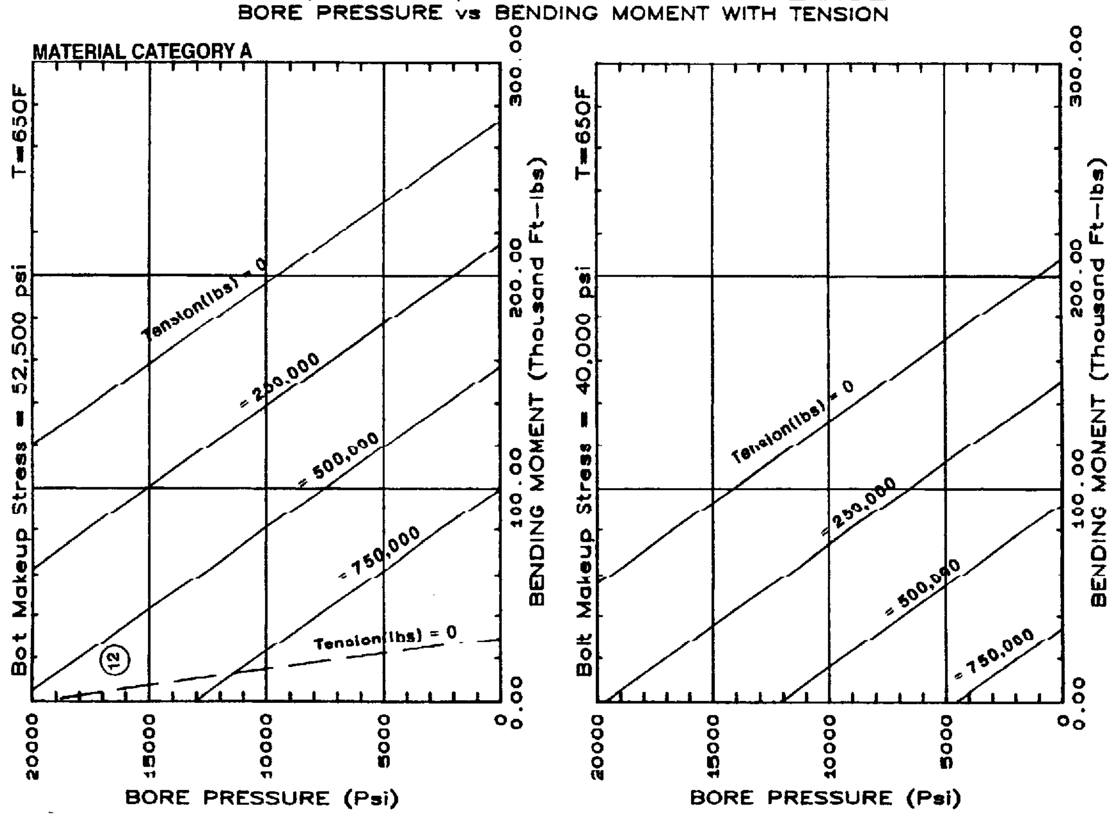
2-9/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

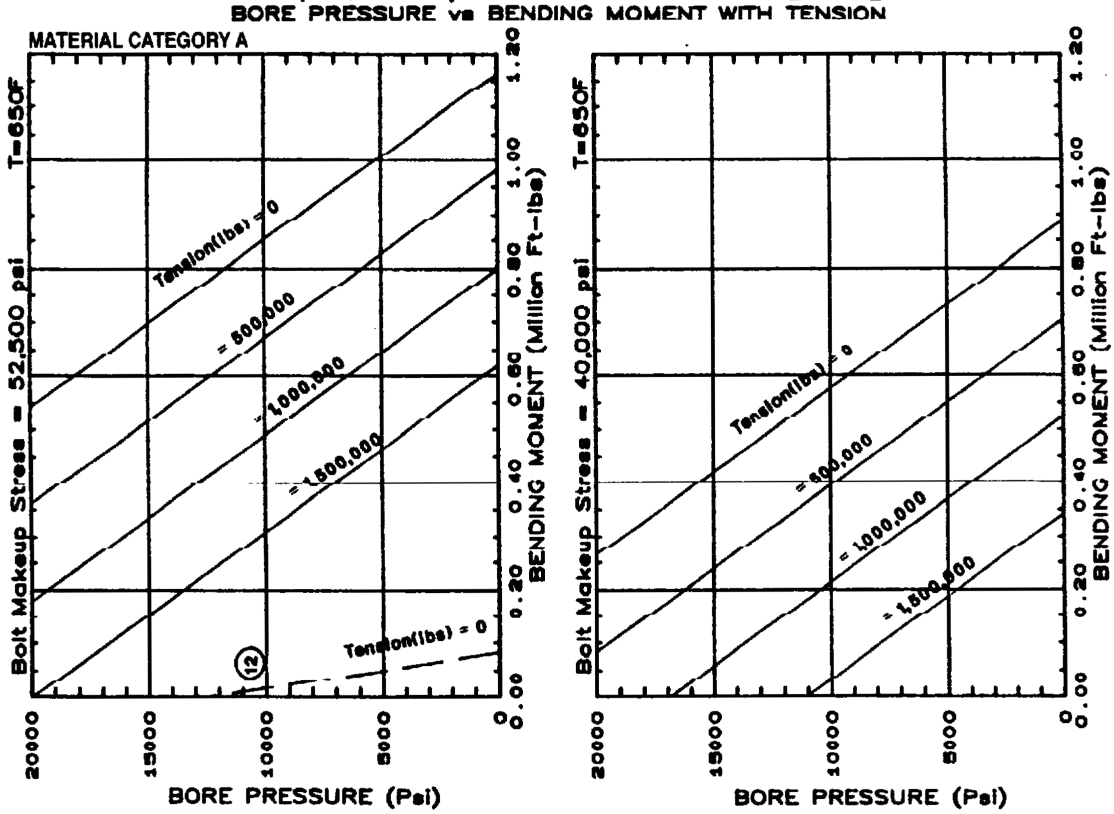


4-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



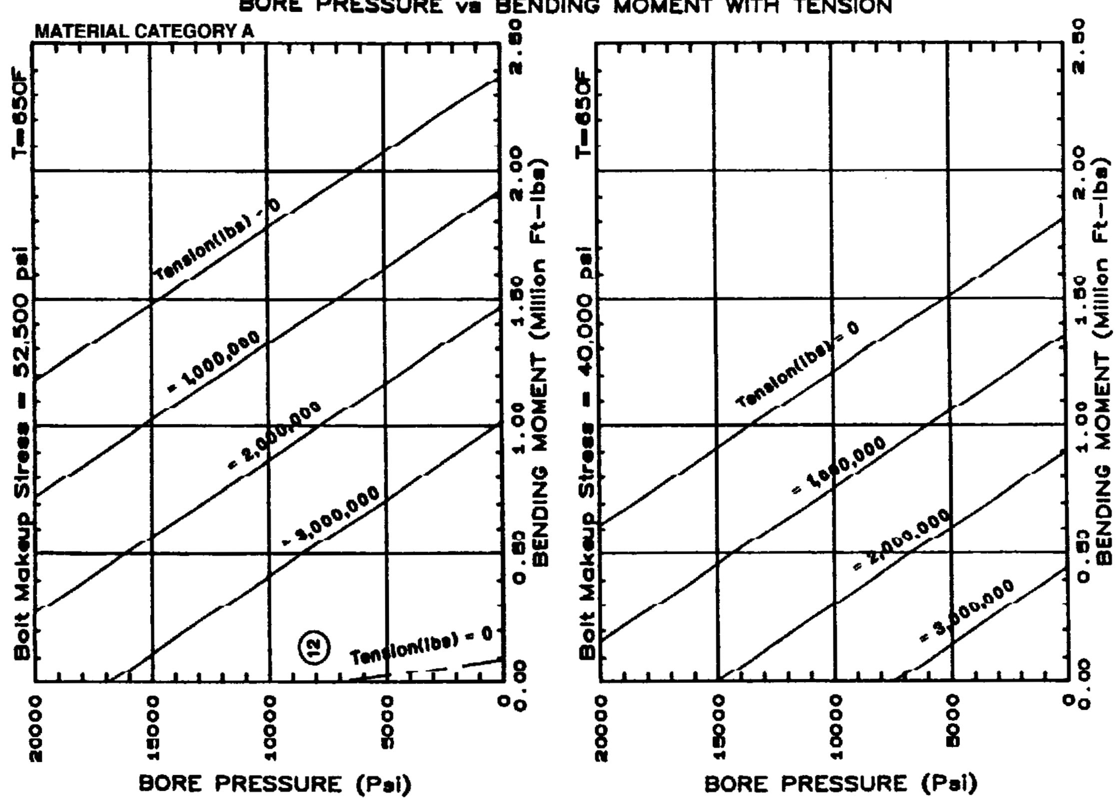
7-1/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

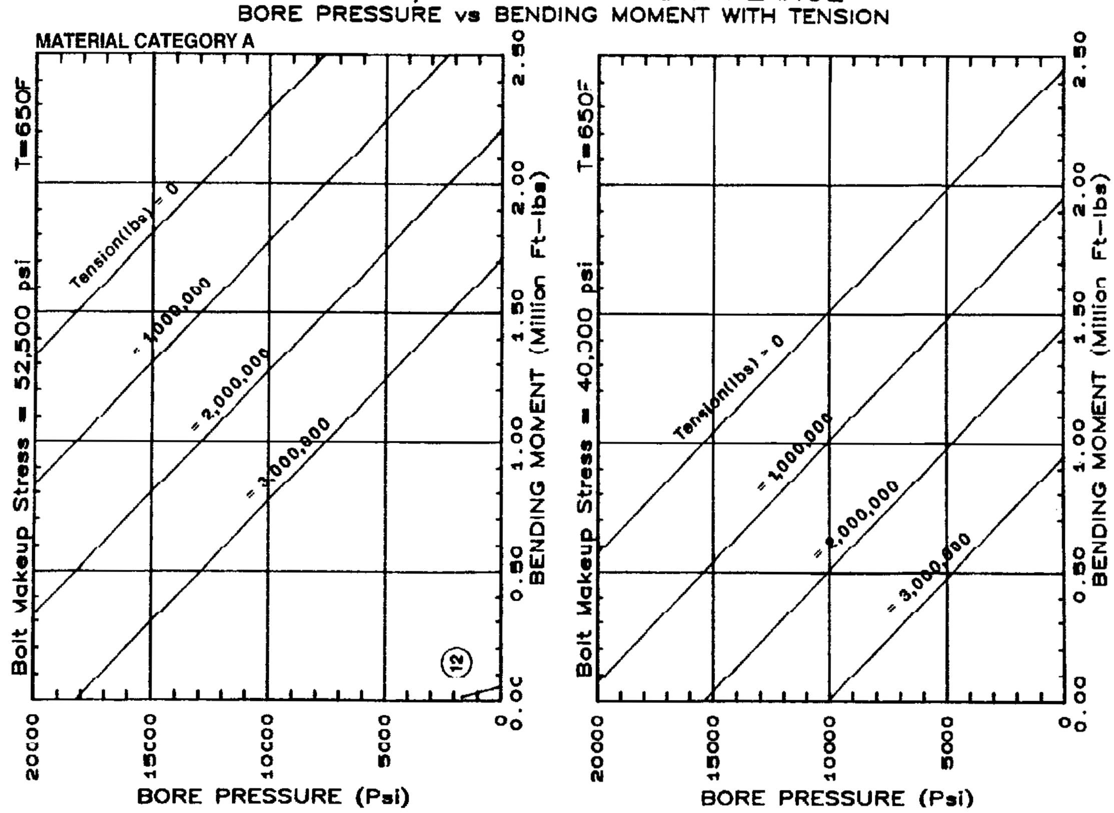


9"-20,000 PSI API 6BX-FLANGE

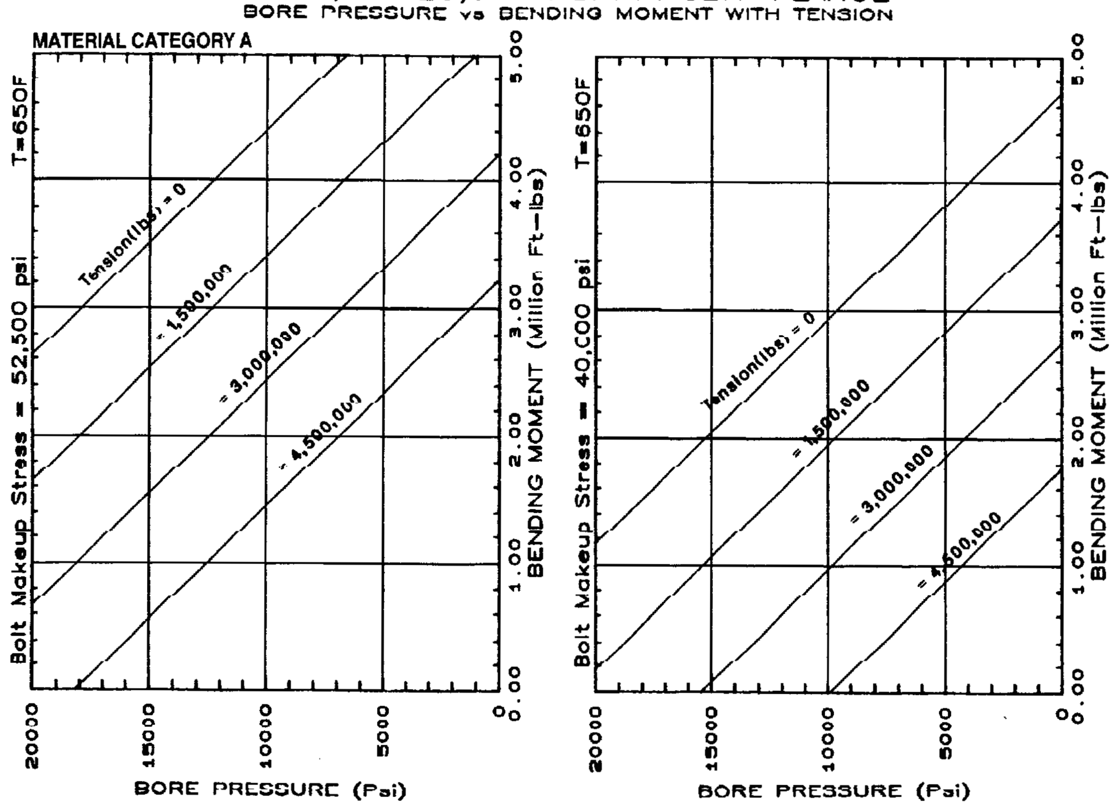
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



13–5/8"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



APPENDIX B—MATERIAL CATEGORY B

MATERIAL CATEGORY B
BORE TEMPERATURE—350°F

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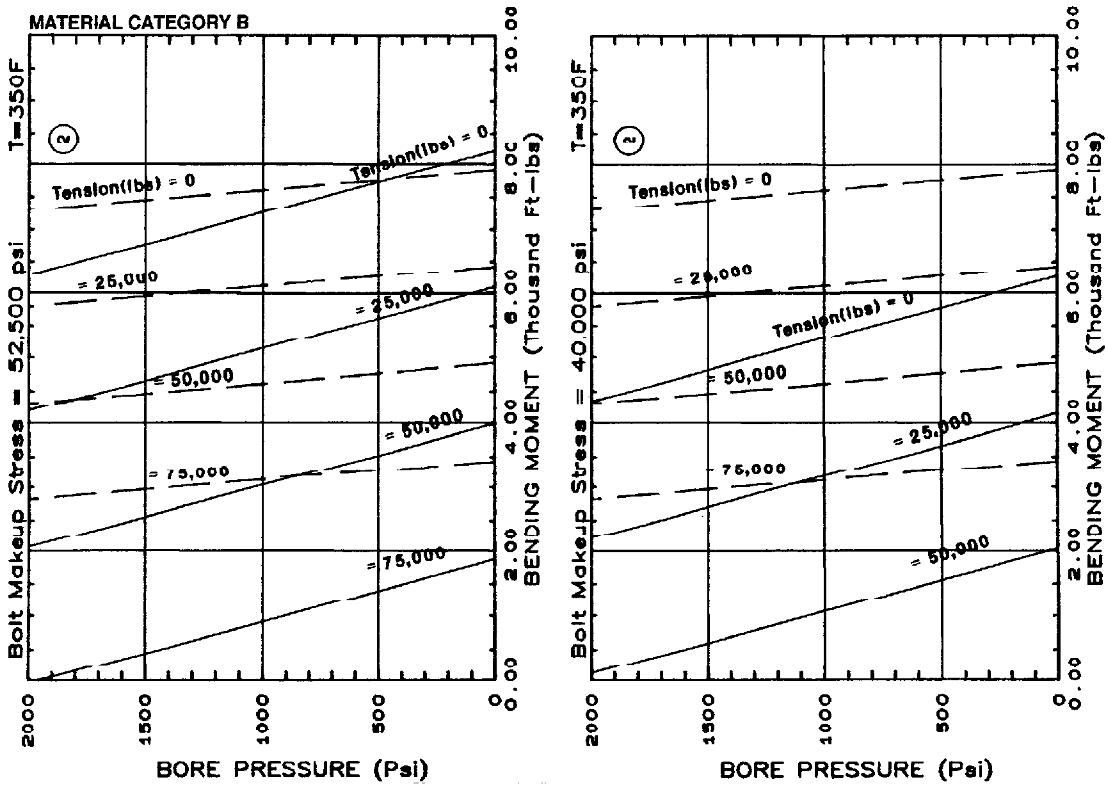
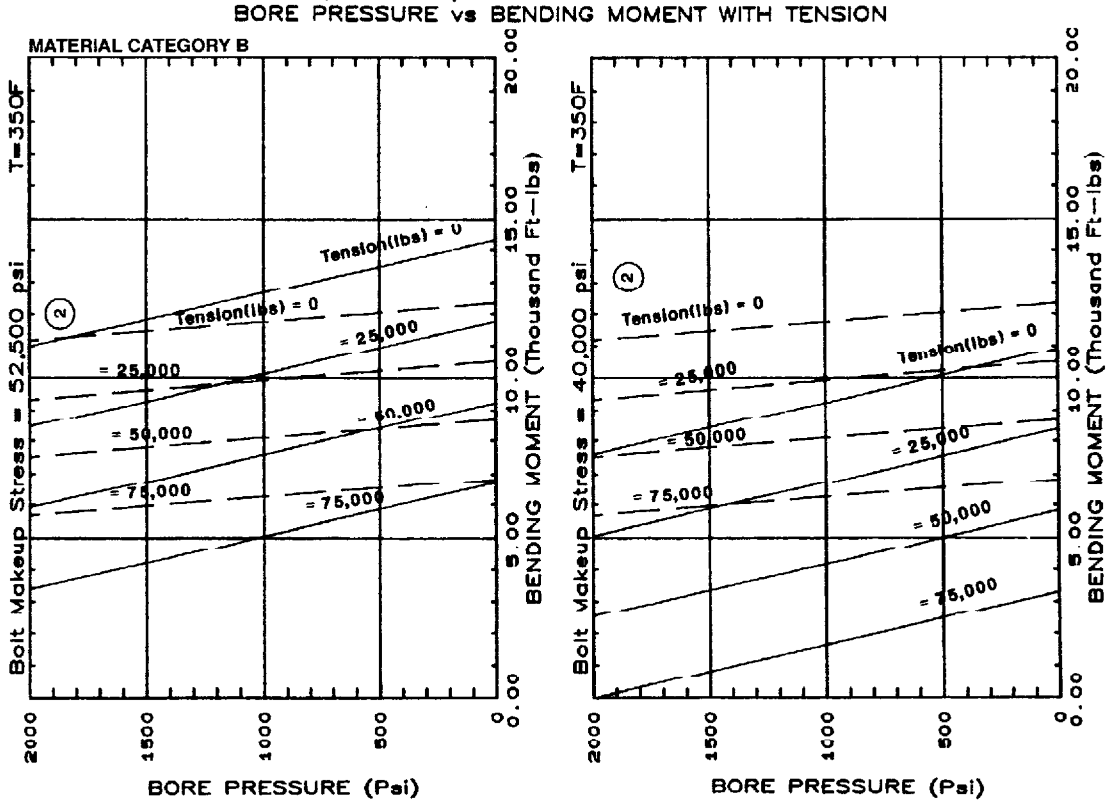
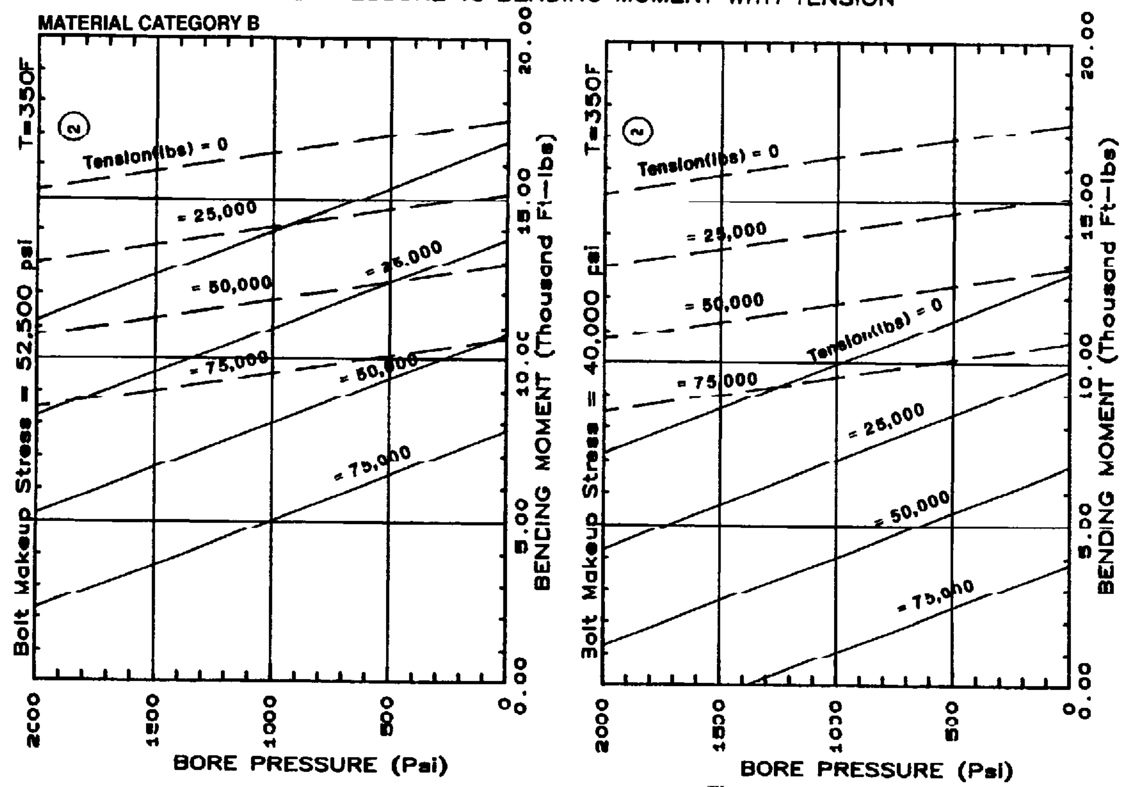
2-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



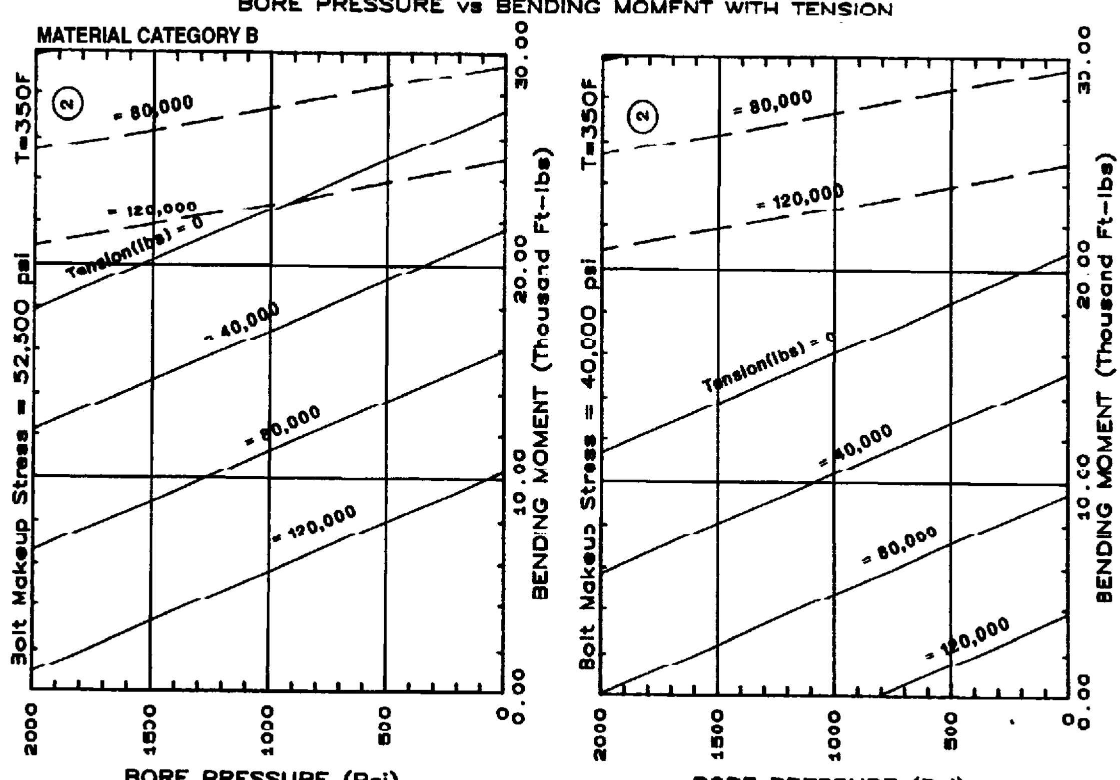
2-9/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

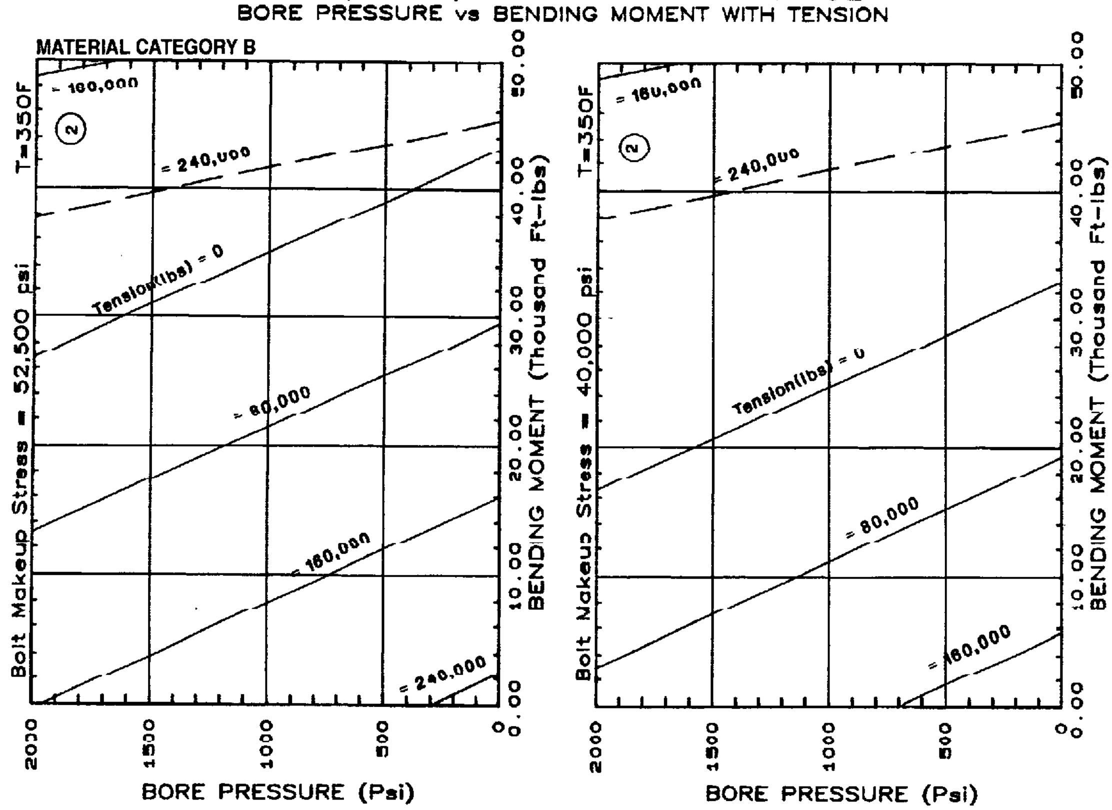


4-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



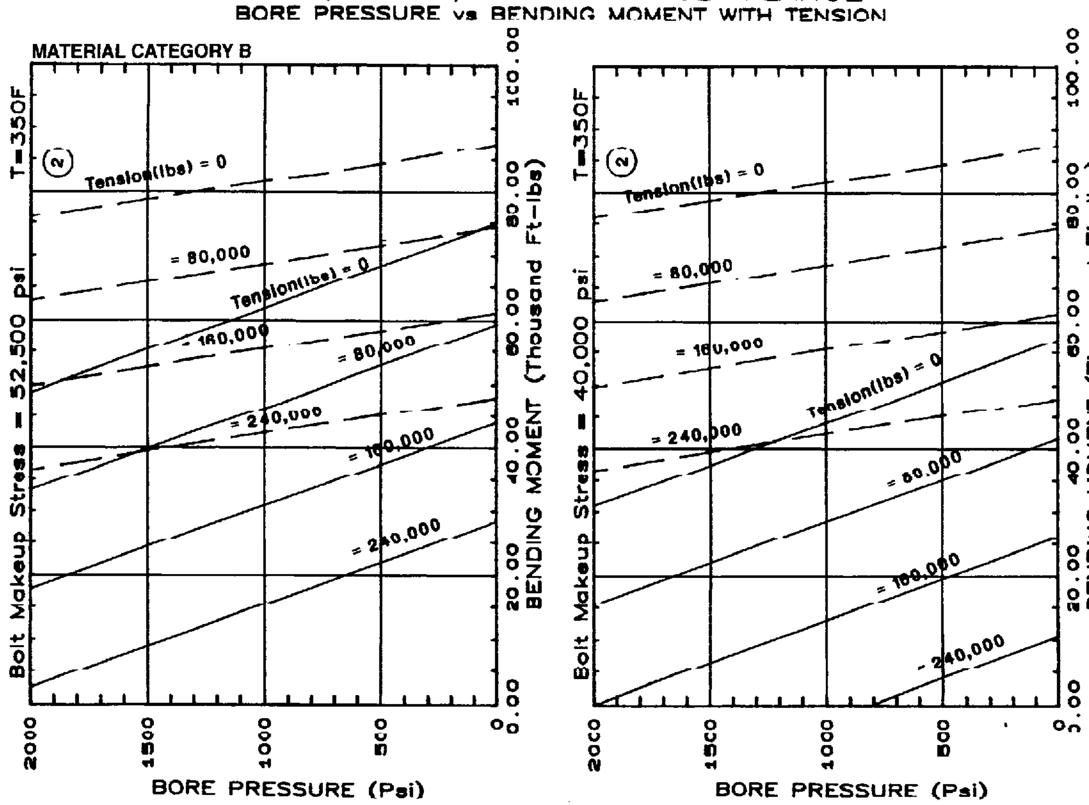
5-1/8"-2,000 PSI API 6B-FLANGE

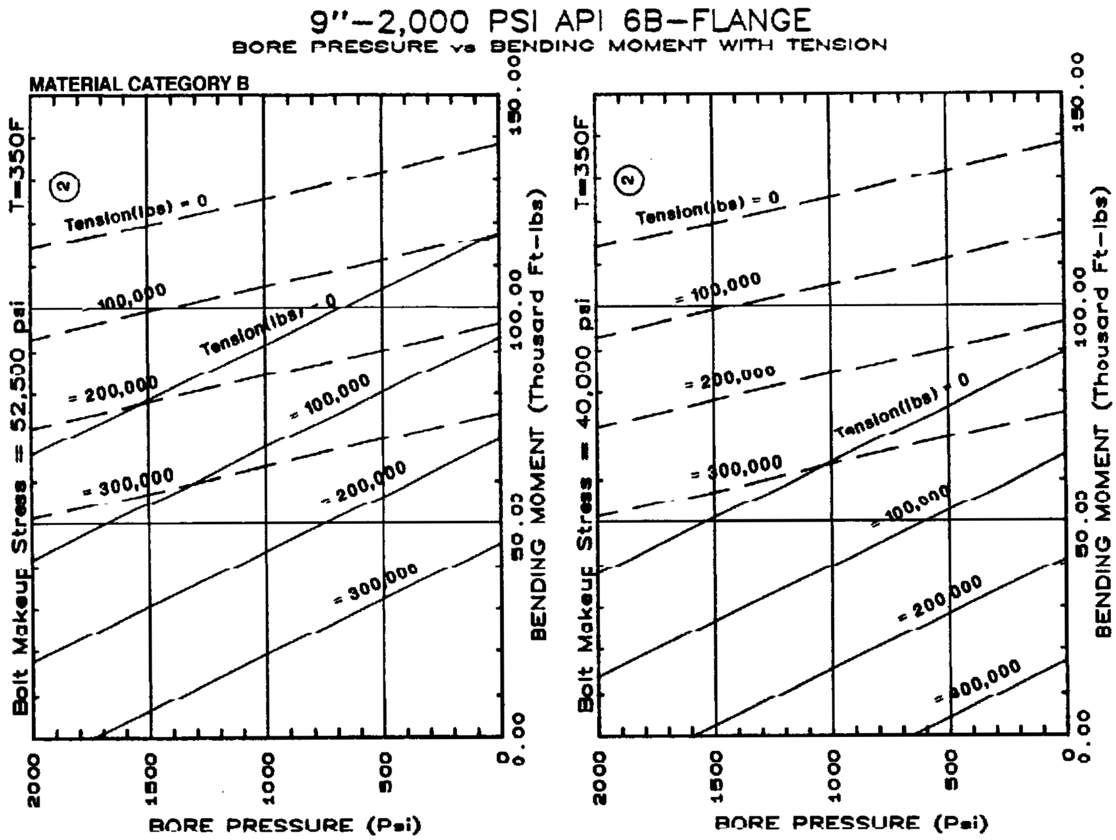
BORE PRESSURE vs BENDING MOMENT WITH TENSION

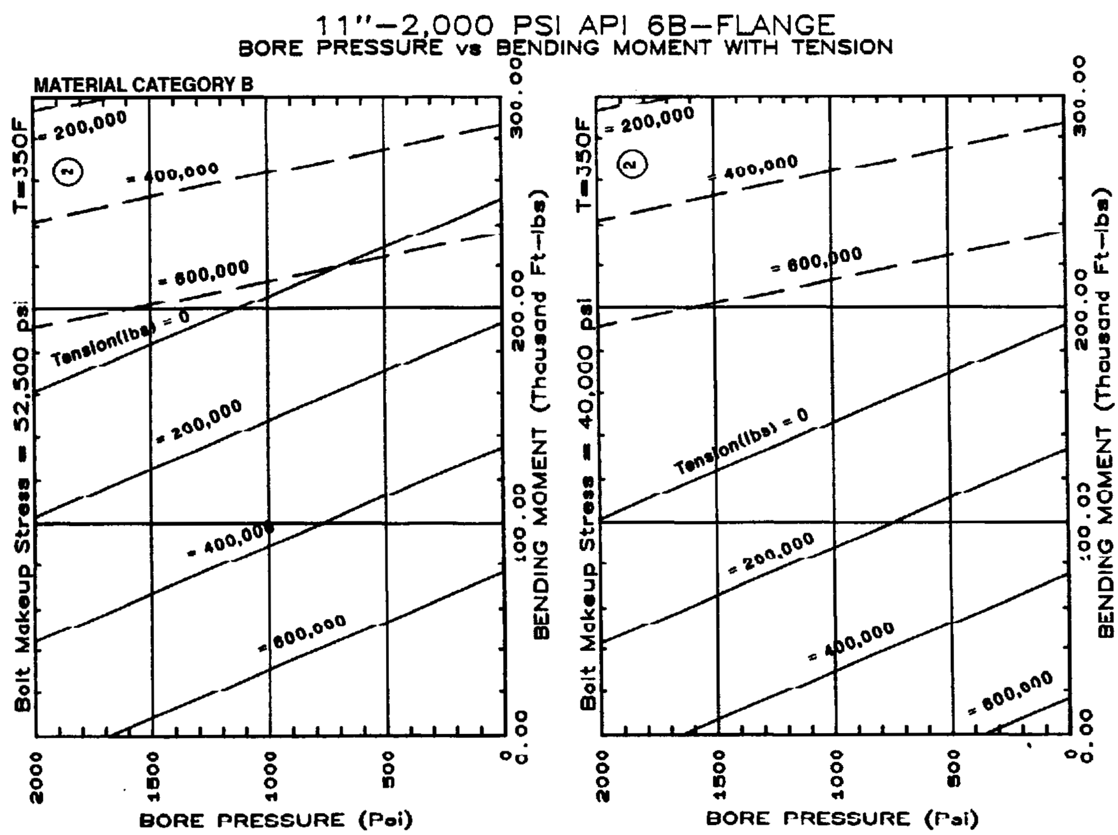


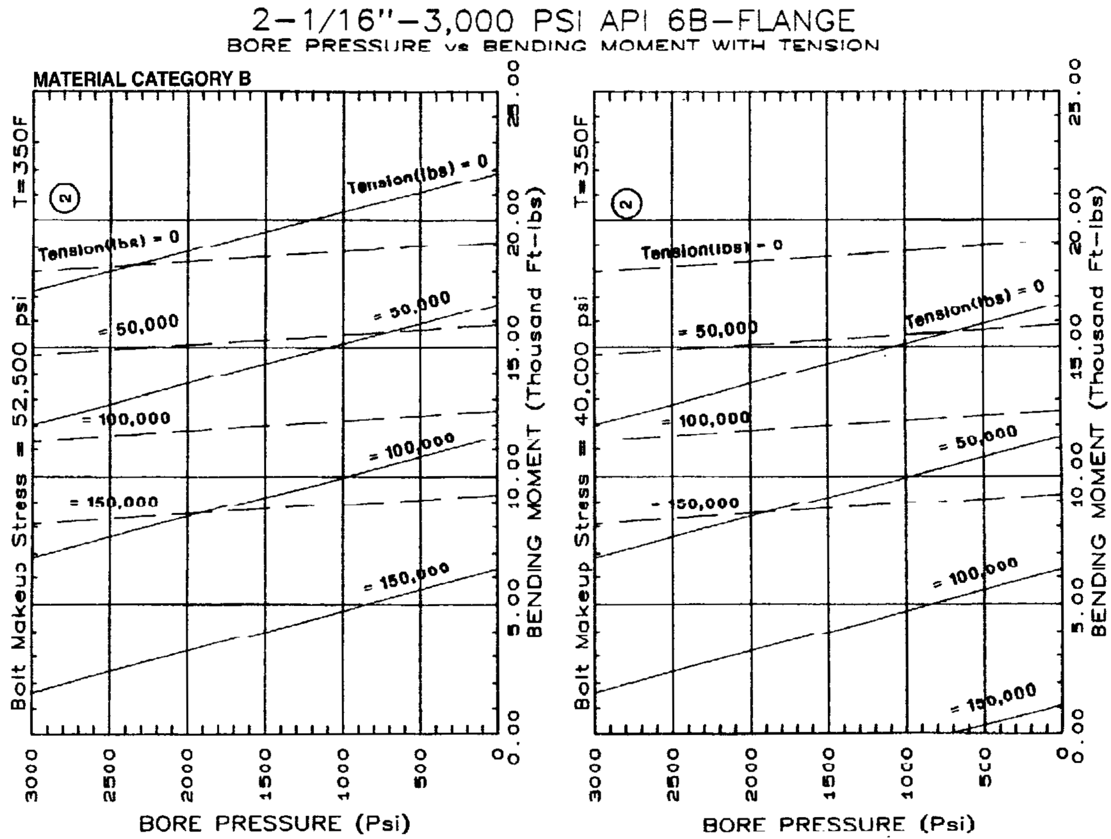
7-1/16"-2,000 PSI API 6B-FLANGE

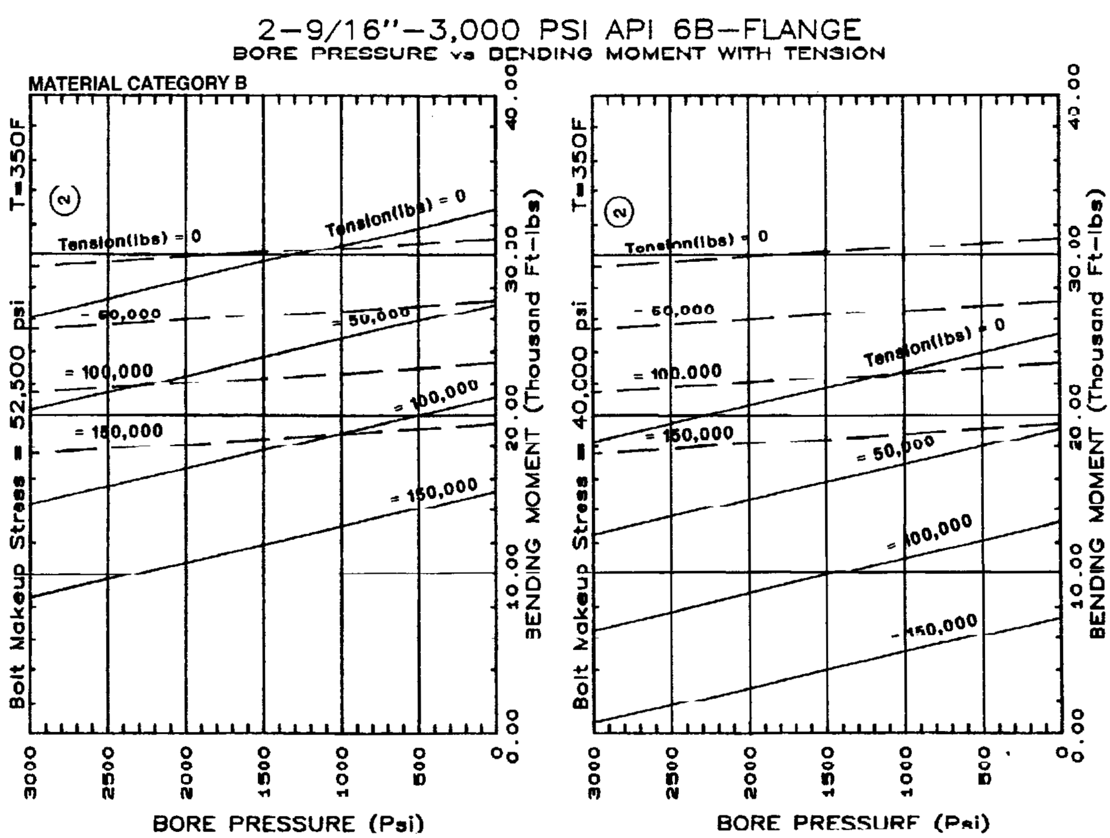
BORE PRESSURE vs BENDING MOMENT WITH TENSION



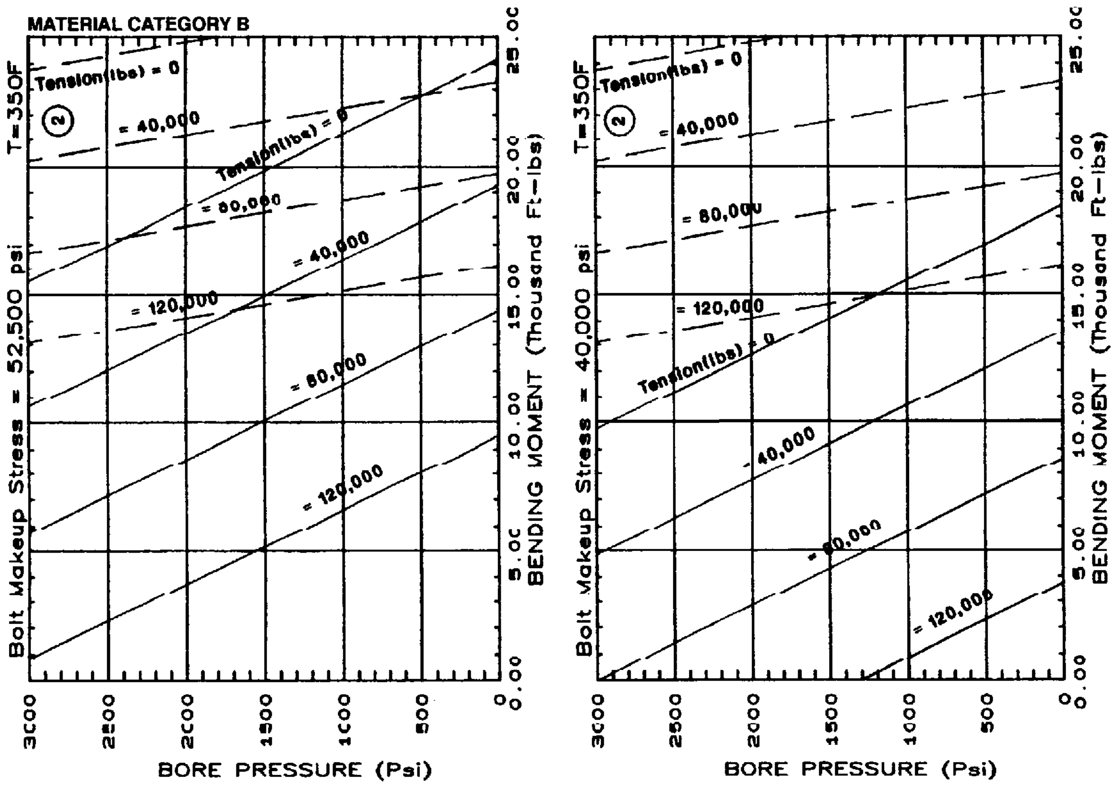

9"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
100,000
200,000
300,000
BENDING MOMENT (Thousand Ft–lbs)
BORE PRESSURE (Psi)


11"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
200,000
400,000
600,000
BENDING MOMENT (Thousand Ft–lbs)
BORE PRESSURE (Psi)

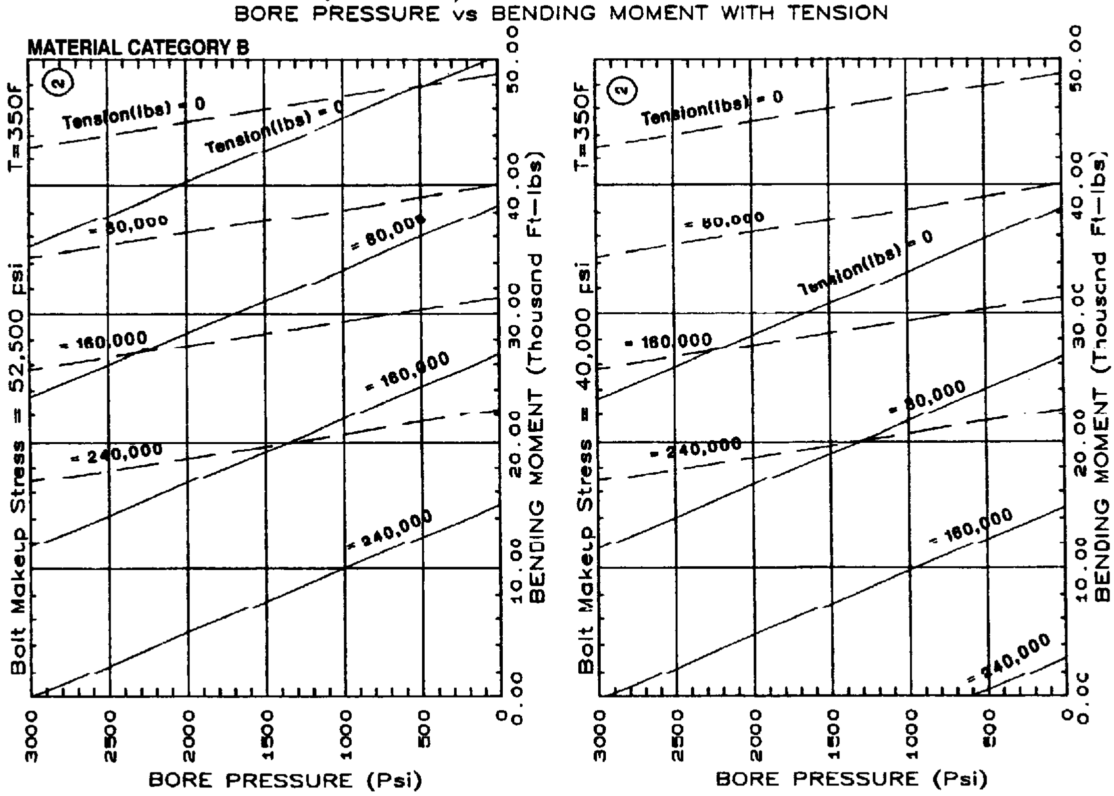

2-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 50,000
= 100,000
= 150,000


2-9/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 50,000
= 100,000
= 150,000

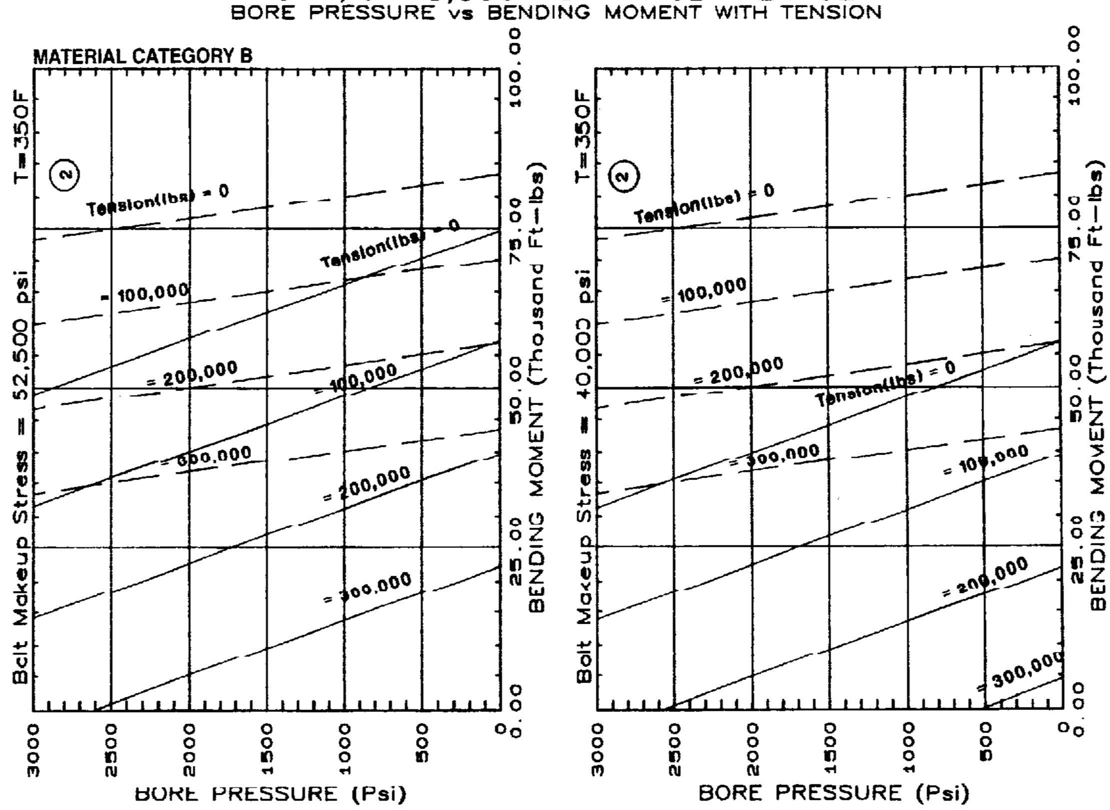
3-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



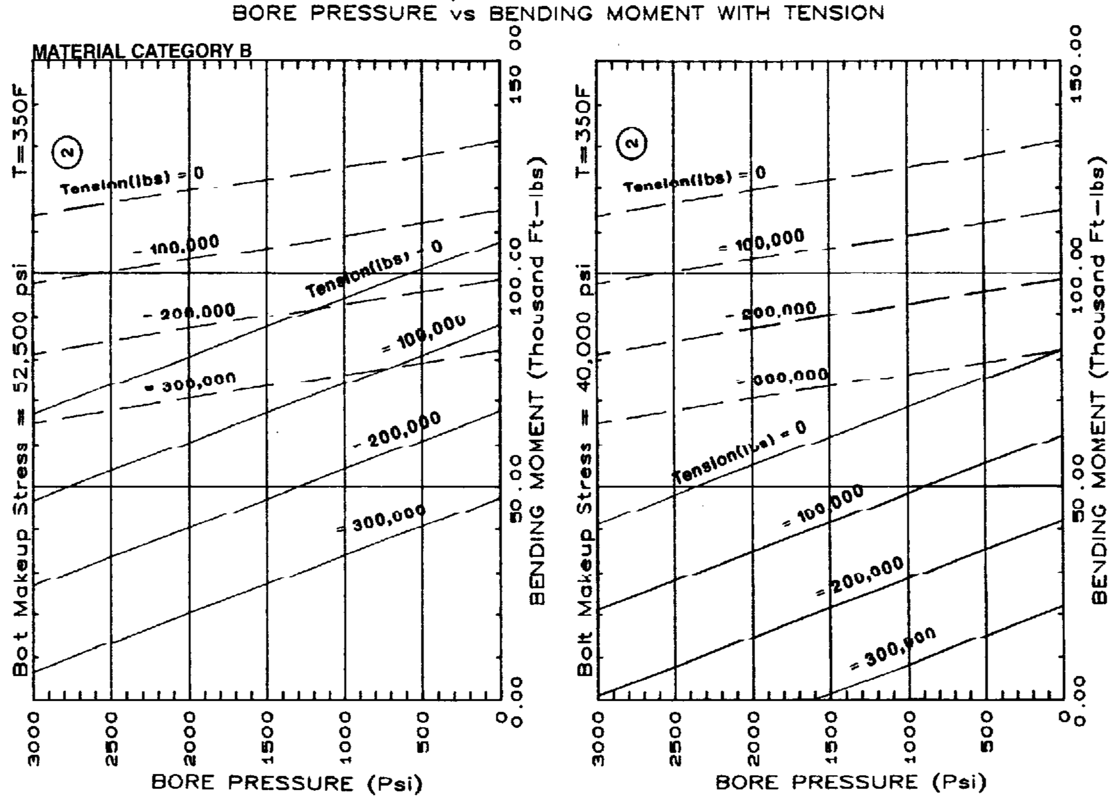
4-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

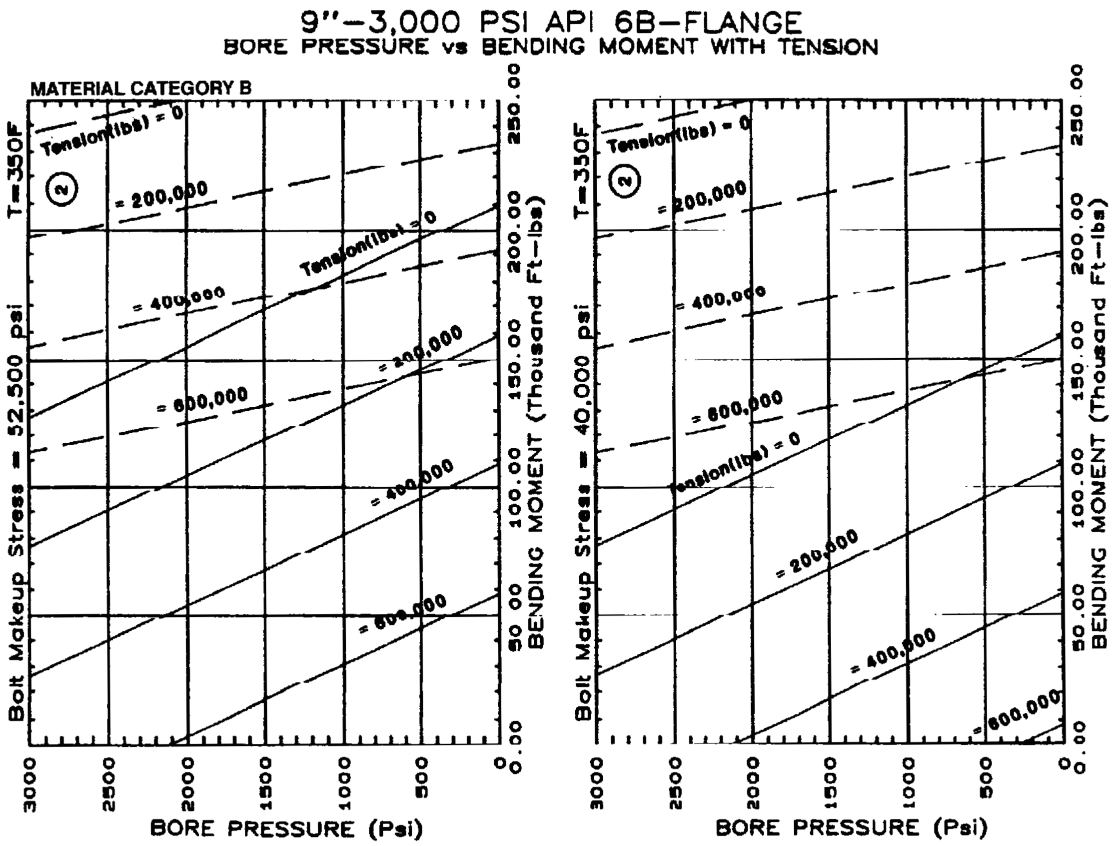


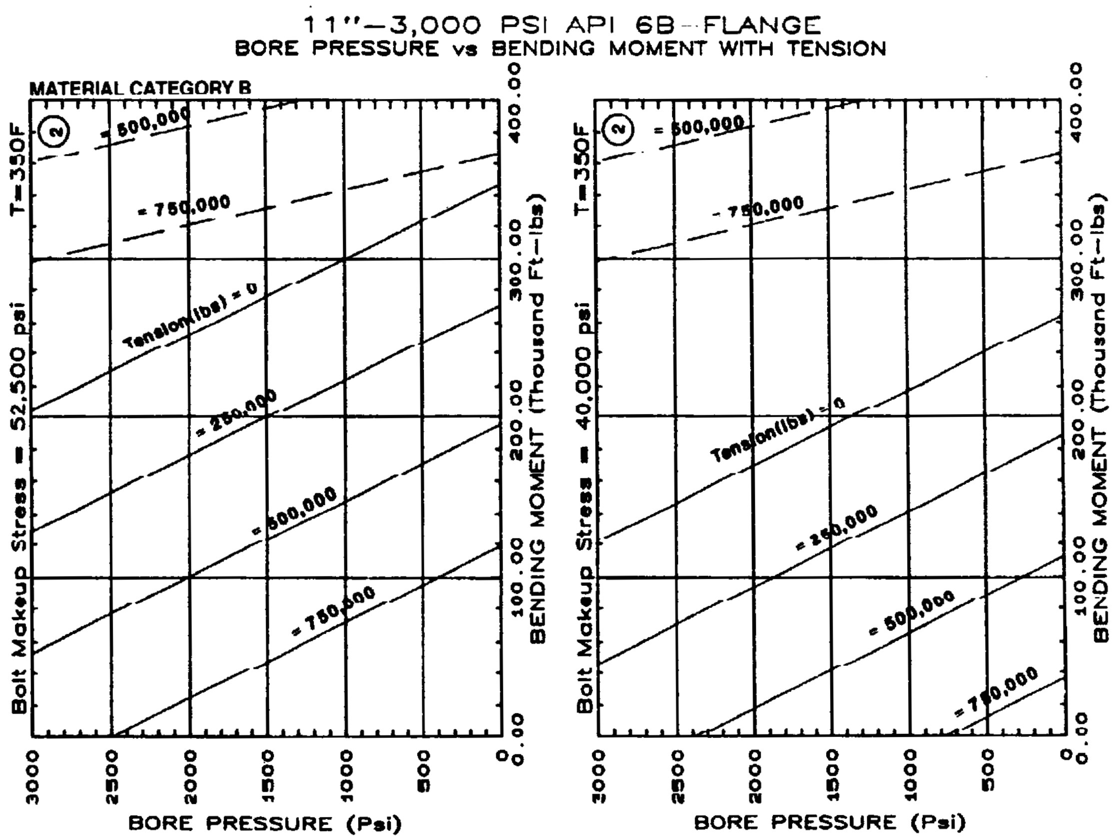
5-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



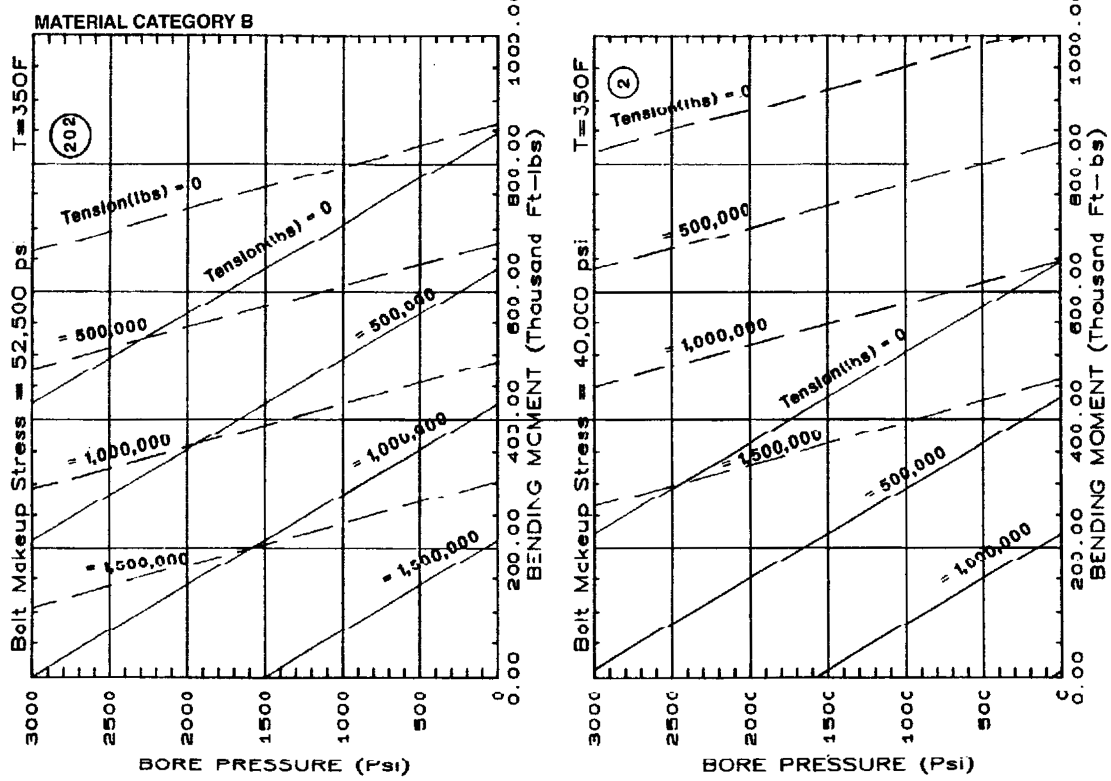
7-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



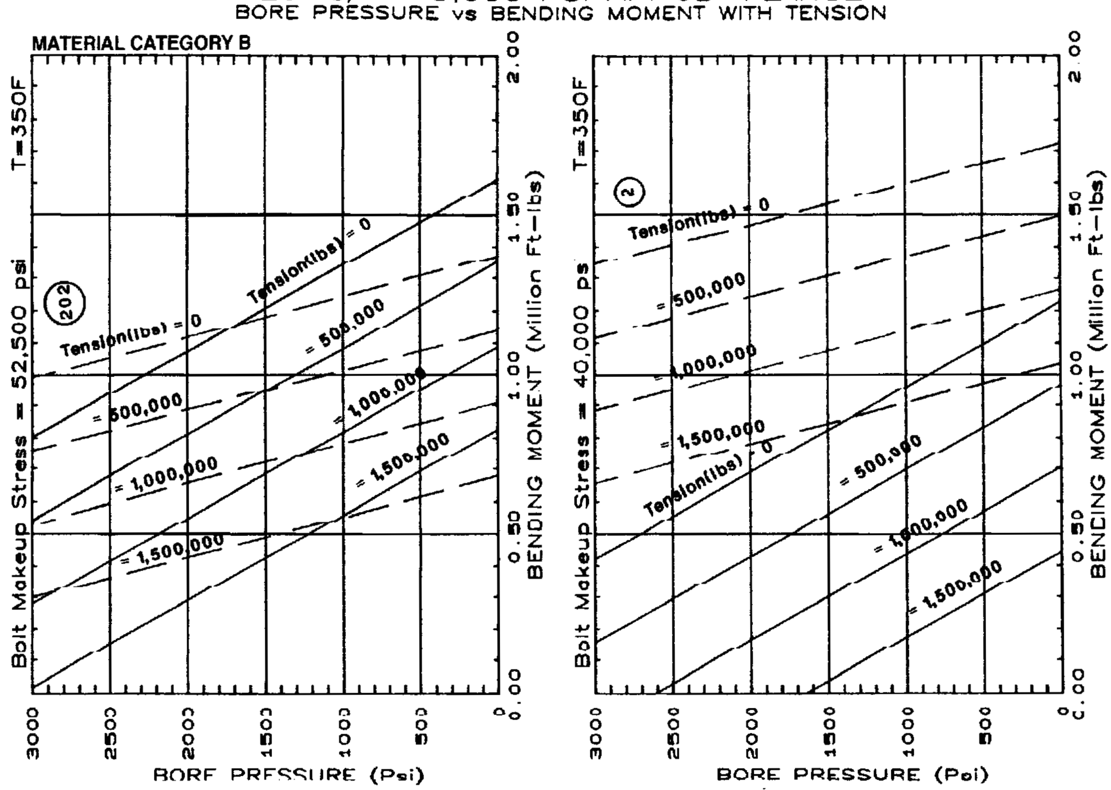

9"—3,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
= 200,000
= 400,000
= 600,000
BENDING MOMENT (Thousand Ft—lbs)
BORE PRESSURE (Psi)


11"—3,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
Tension(lbs) = 0
= 250,000
= 500,000
= 750,000
BENDING MOMENT (Thousand Ft—lbs)
BORE PRESSURE (Psi)

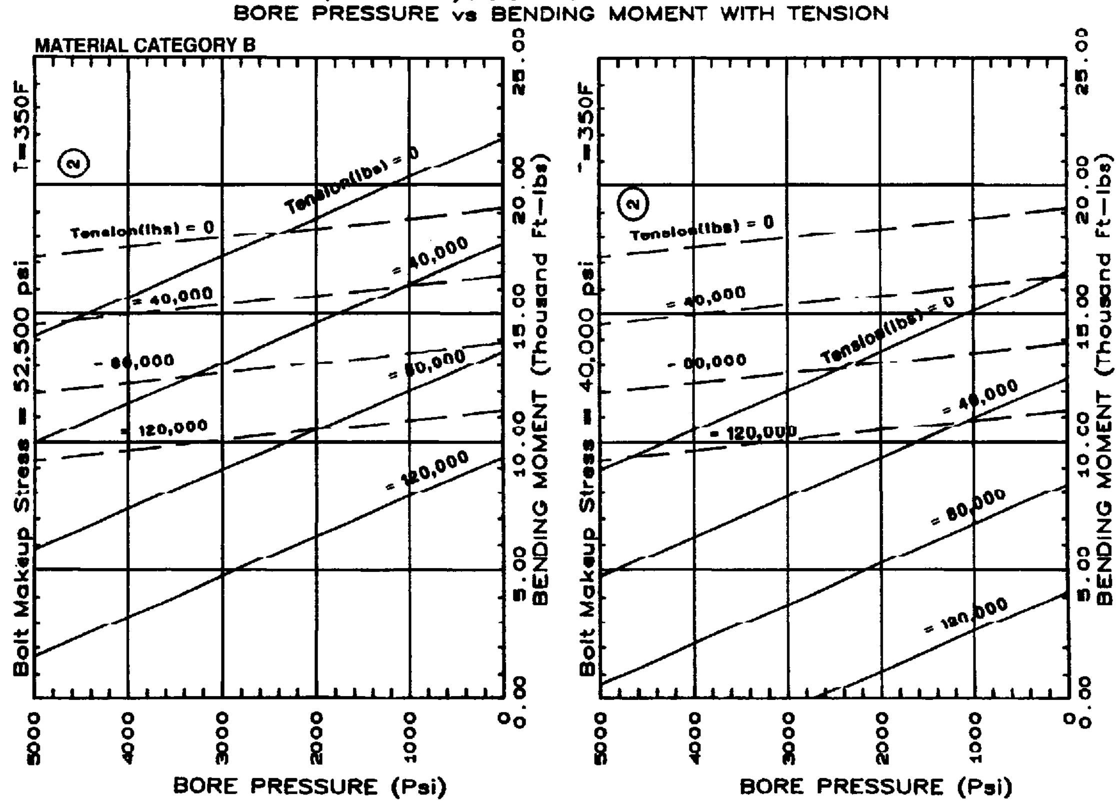
16–3/4"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



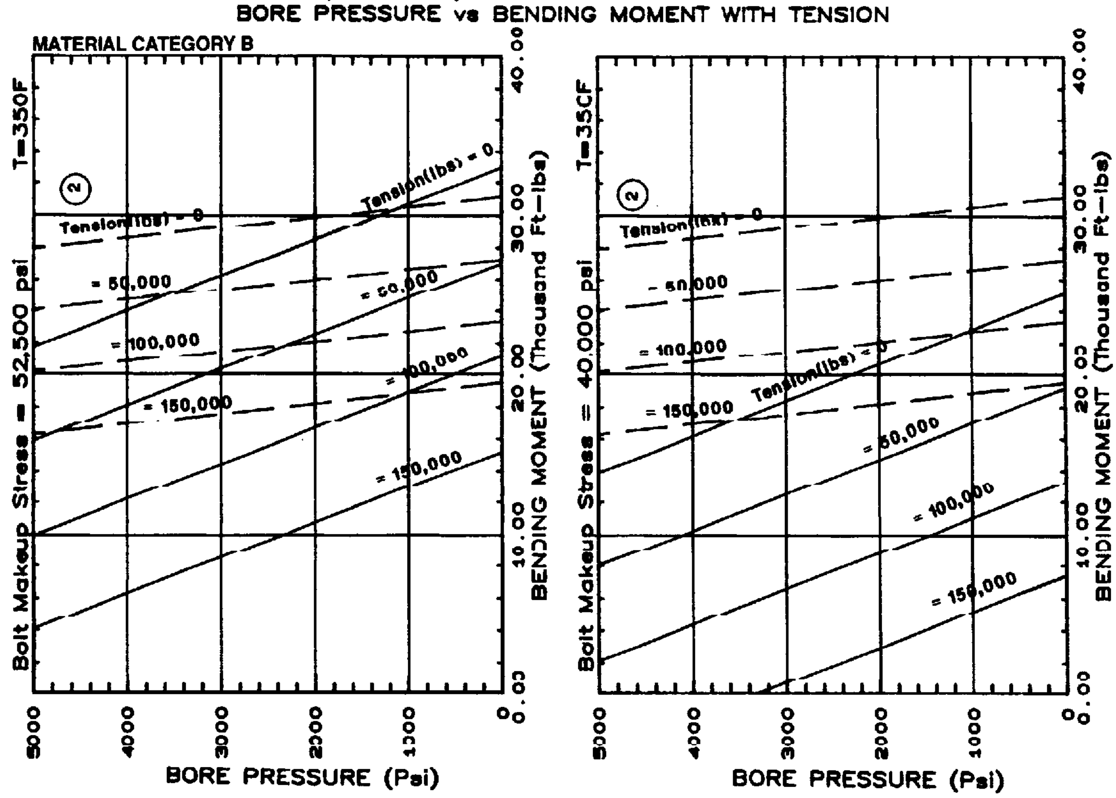
20–3/4"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



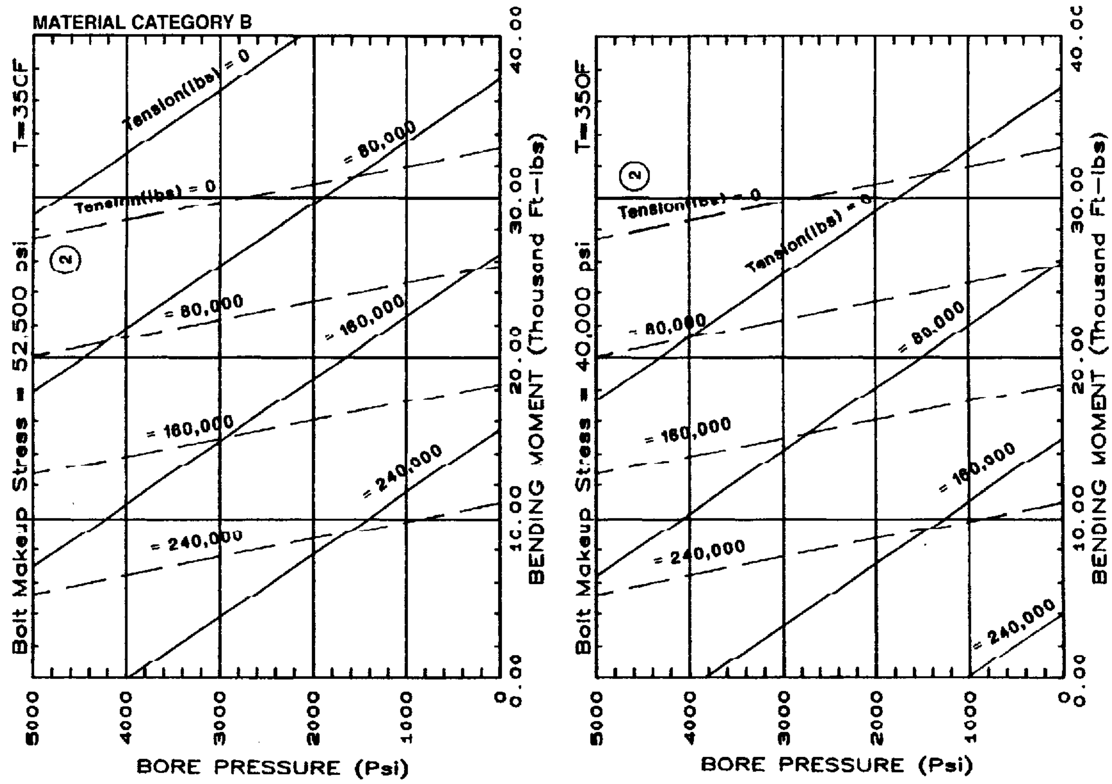
2-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



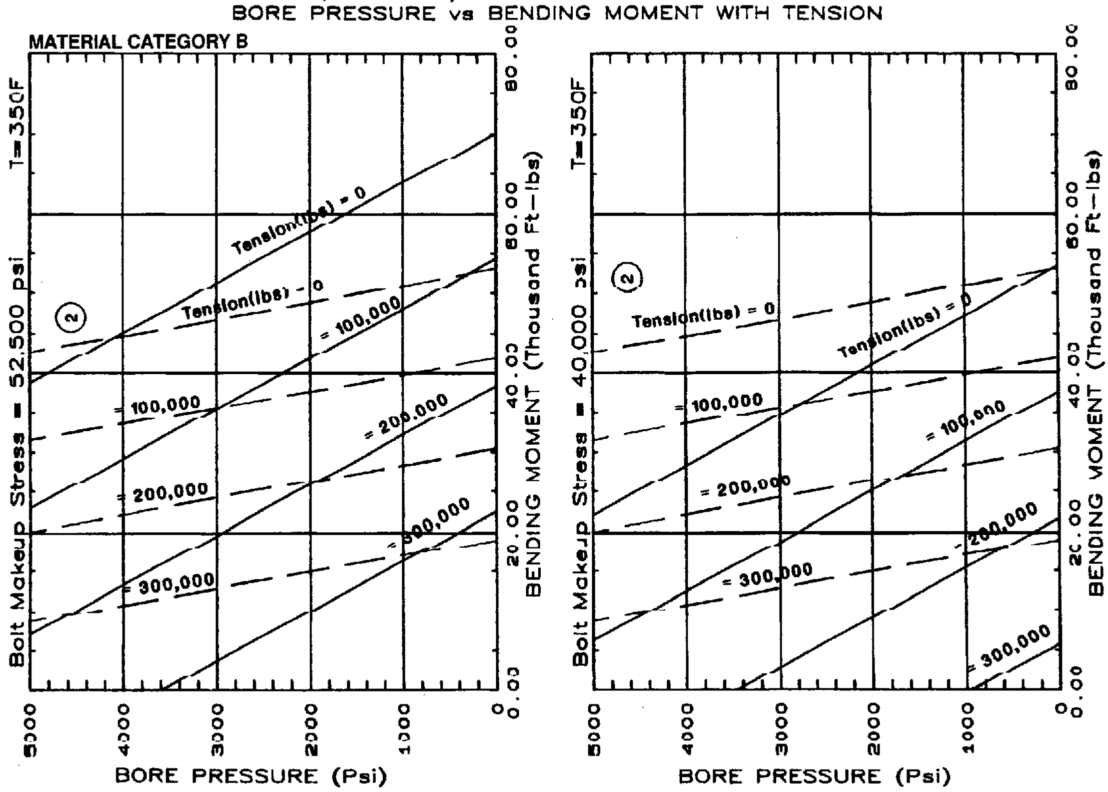
2-9/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



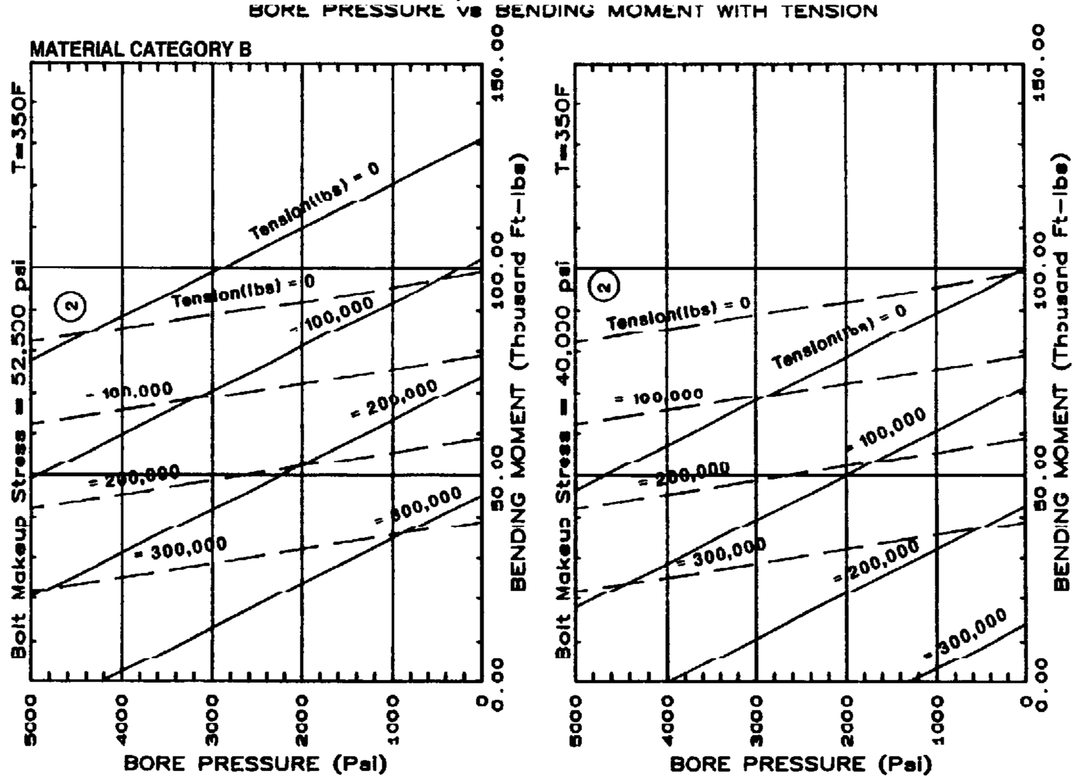
3-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



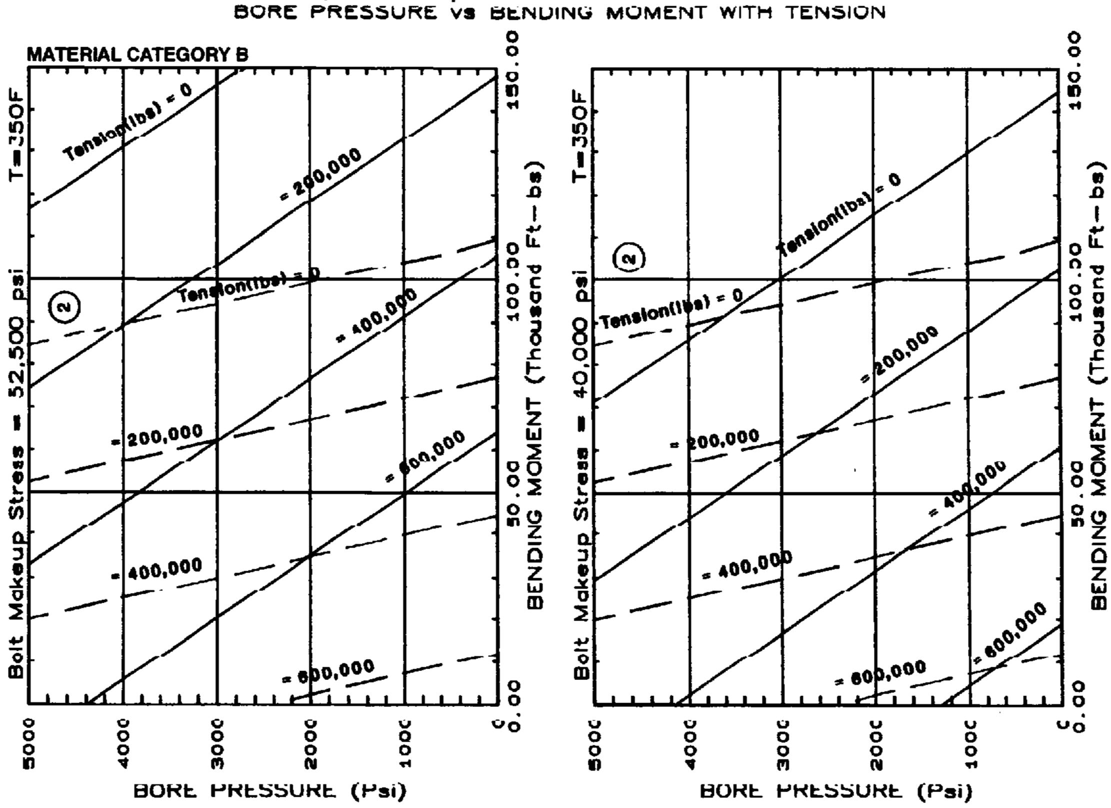
4-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



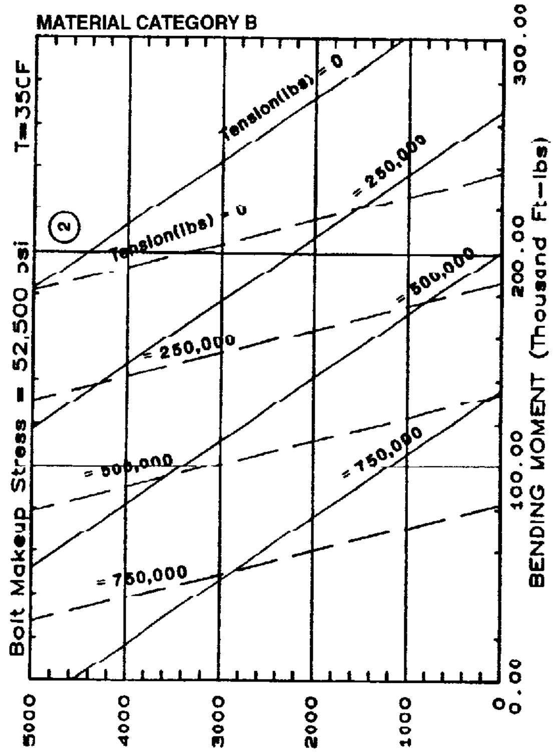
5-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

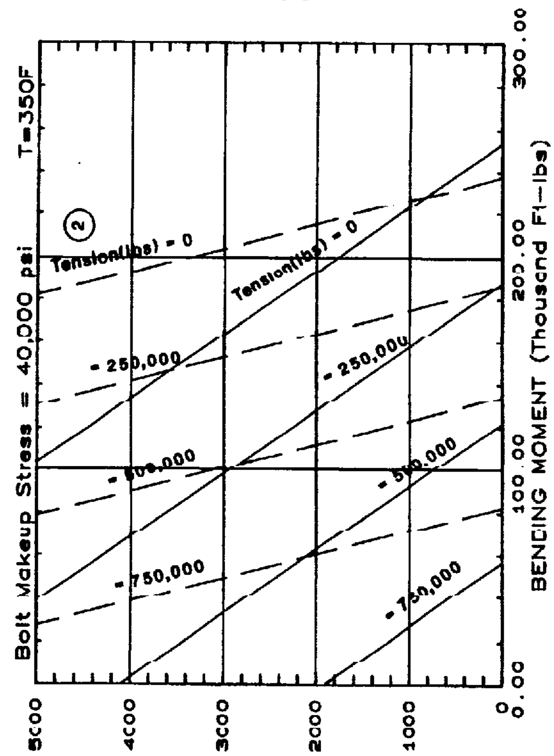


7-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

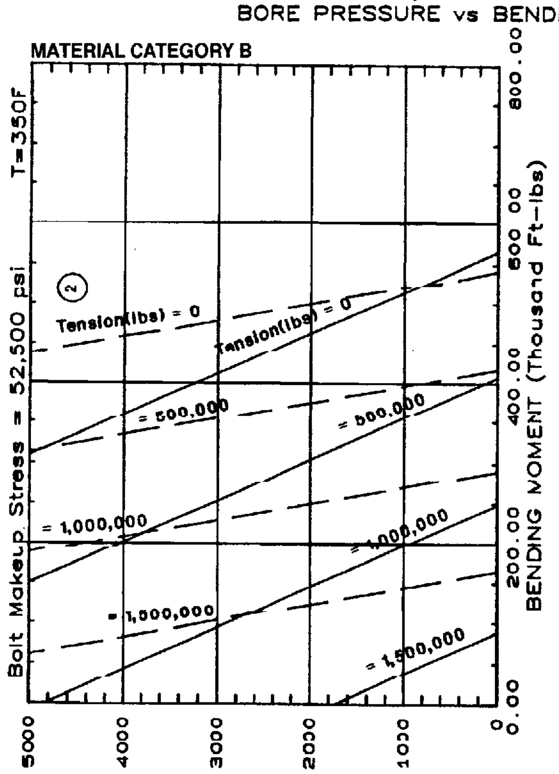


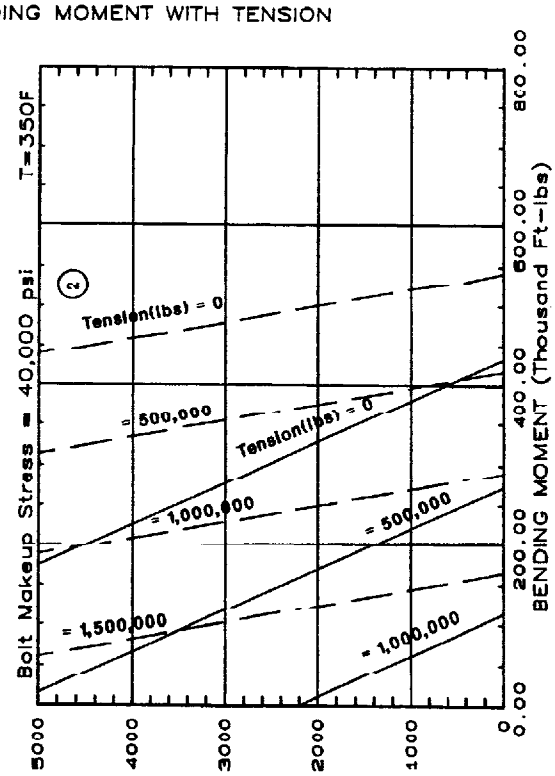
9"–5,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





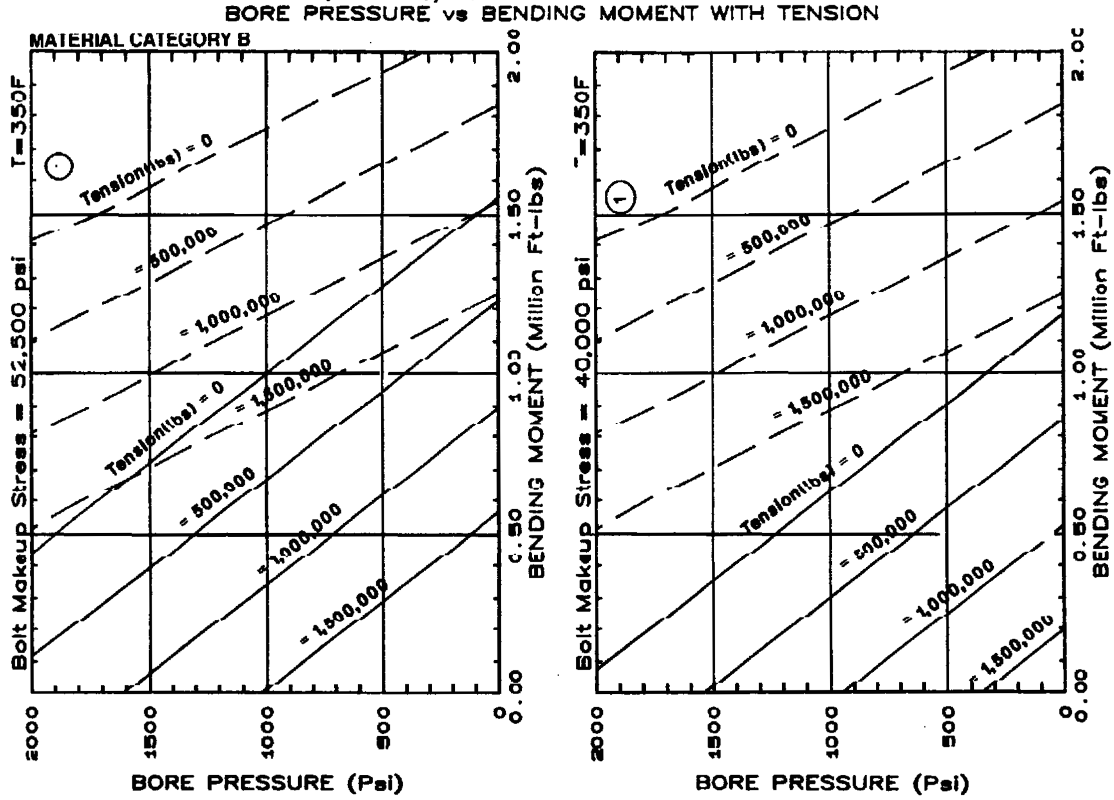
11"–5,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





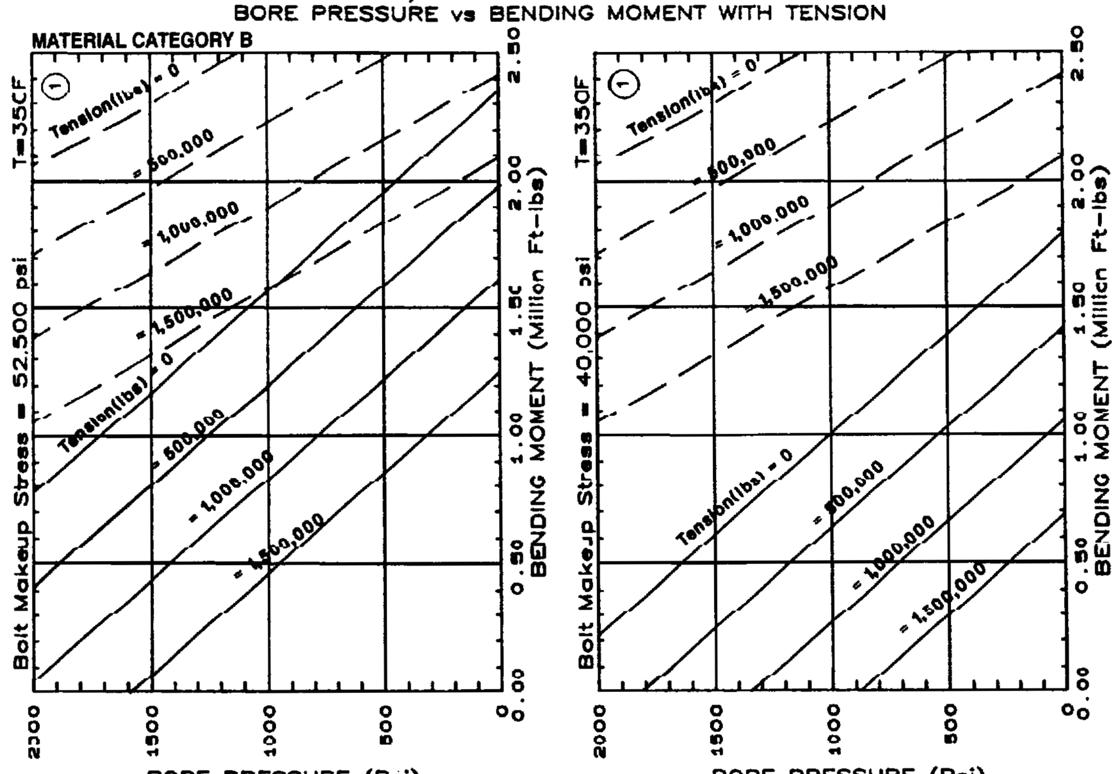
26-3/4"-2,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



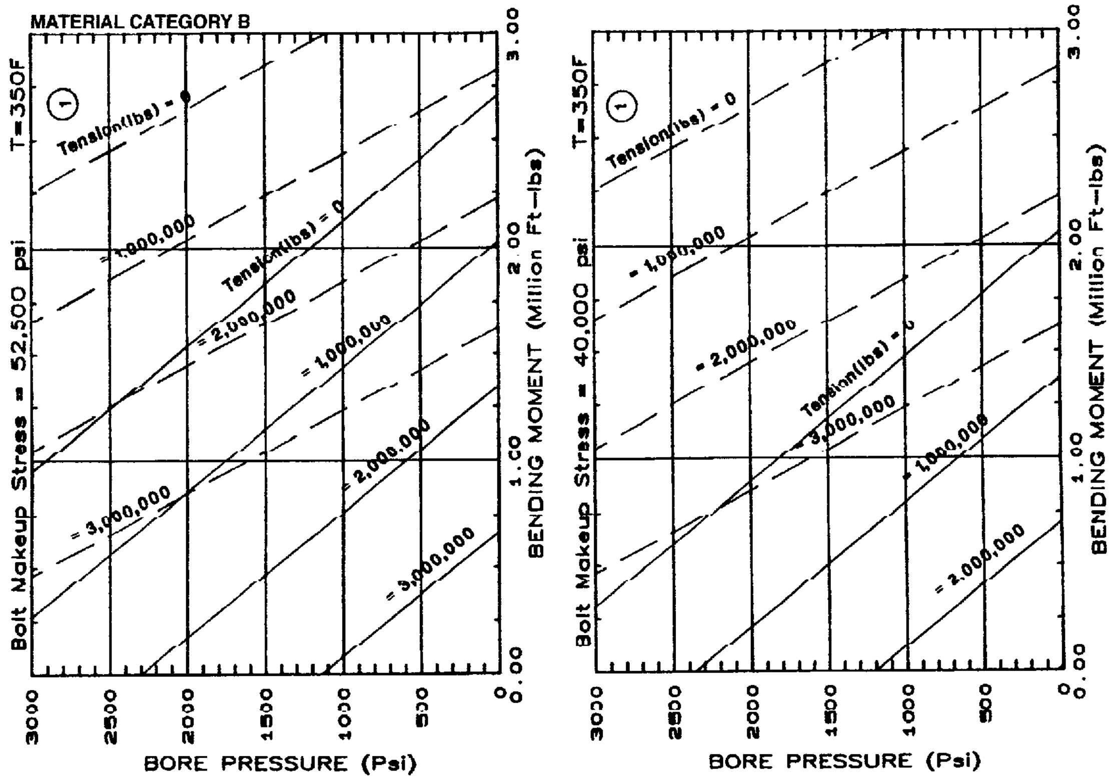
30"-2,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



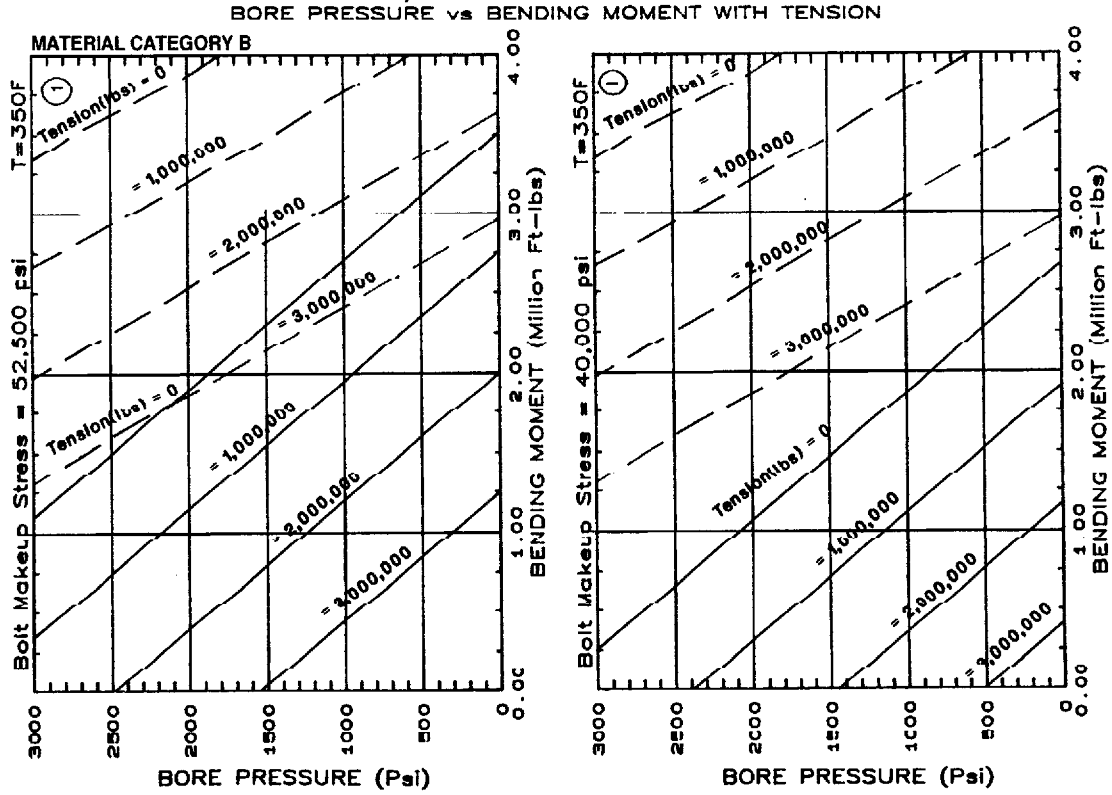
26-3/4"-3,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



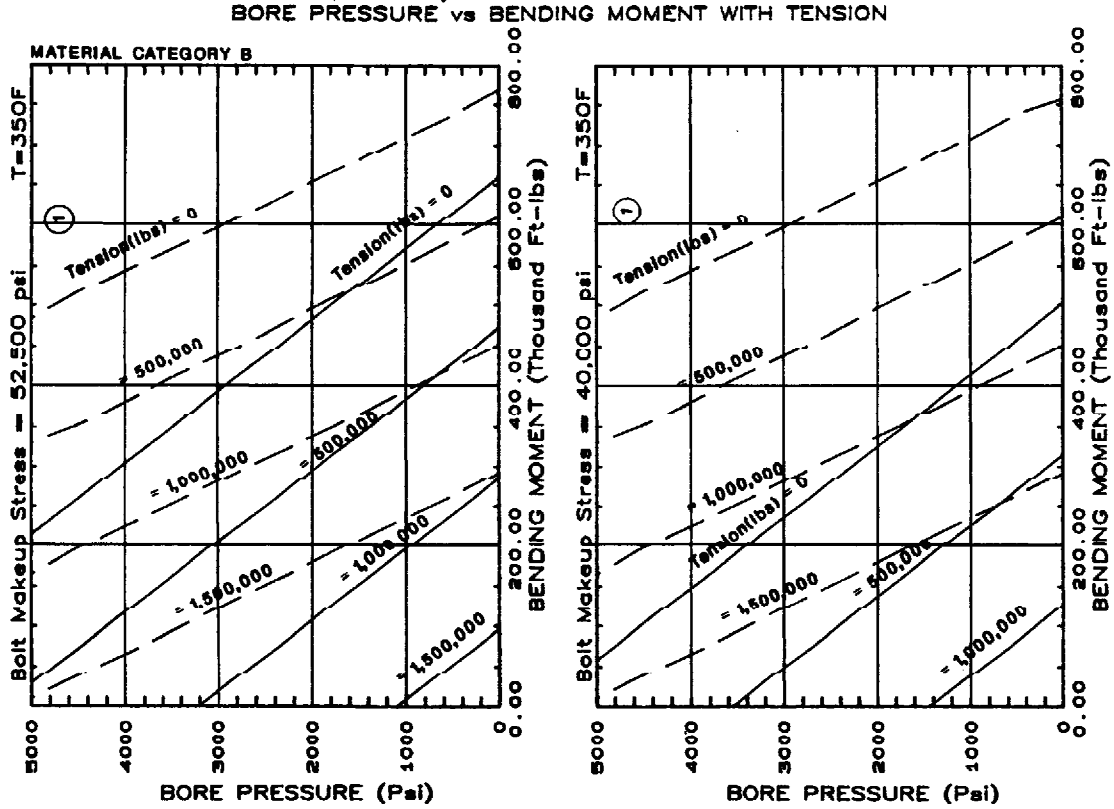
30"-3,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



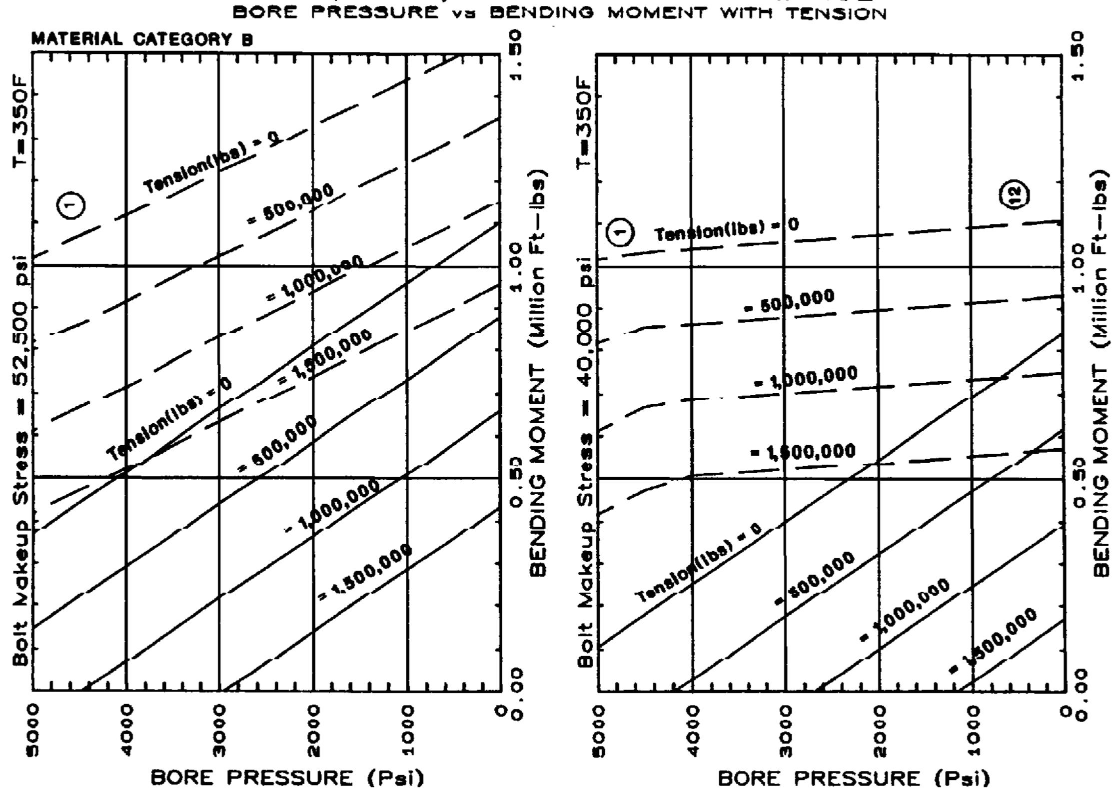
13-5/8"-5,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



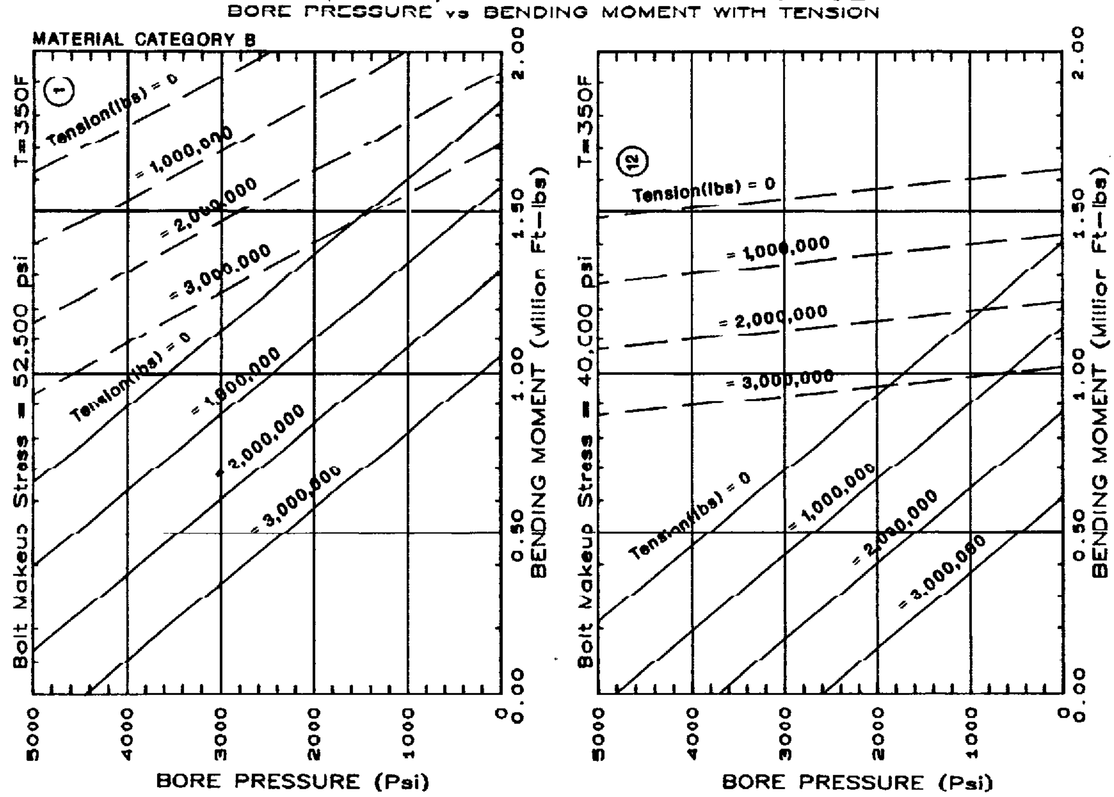
16-3/4"-5,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



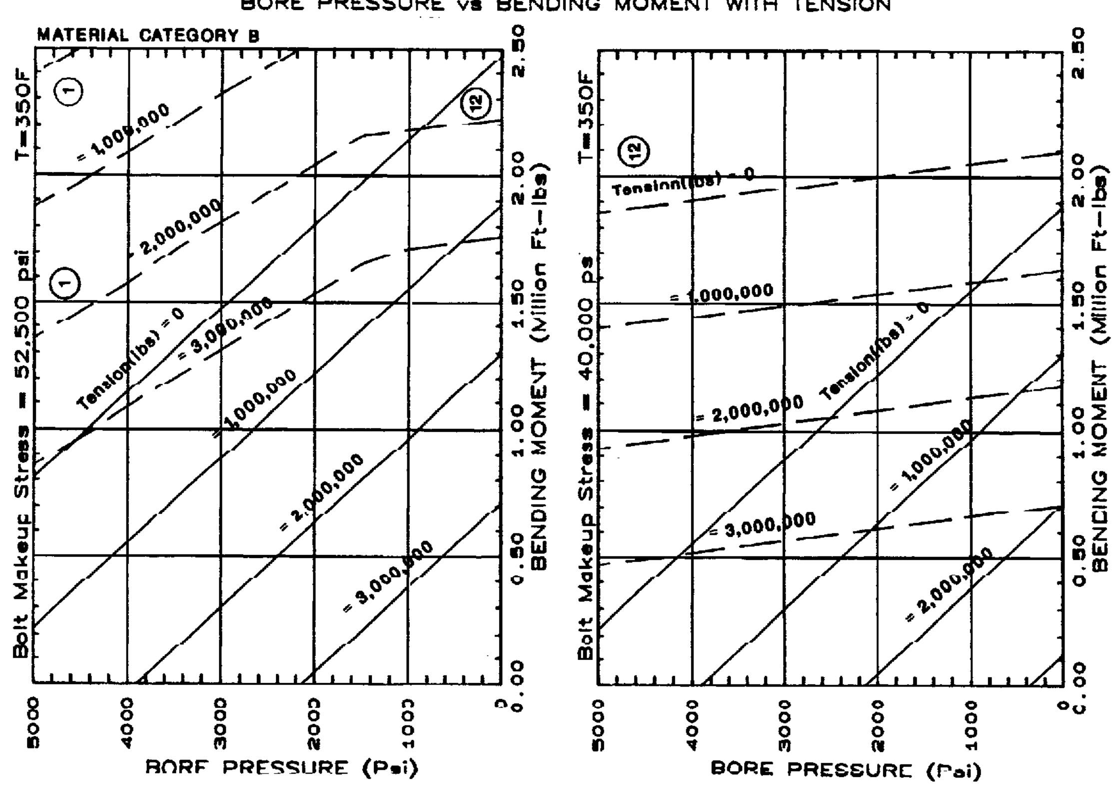
18-3/4"-5,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

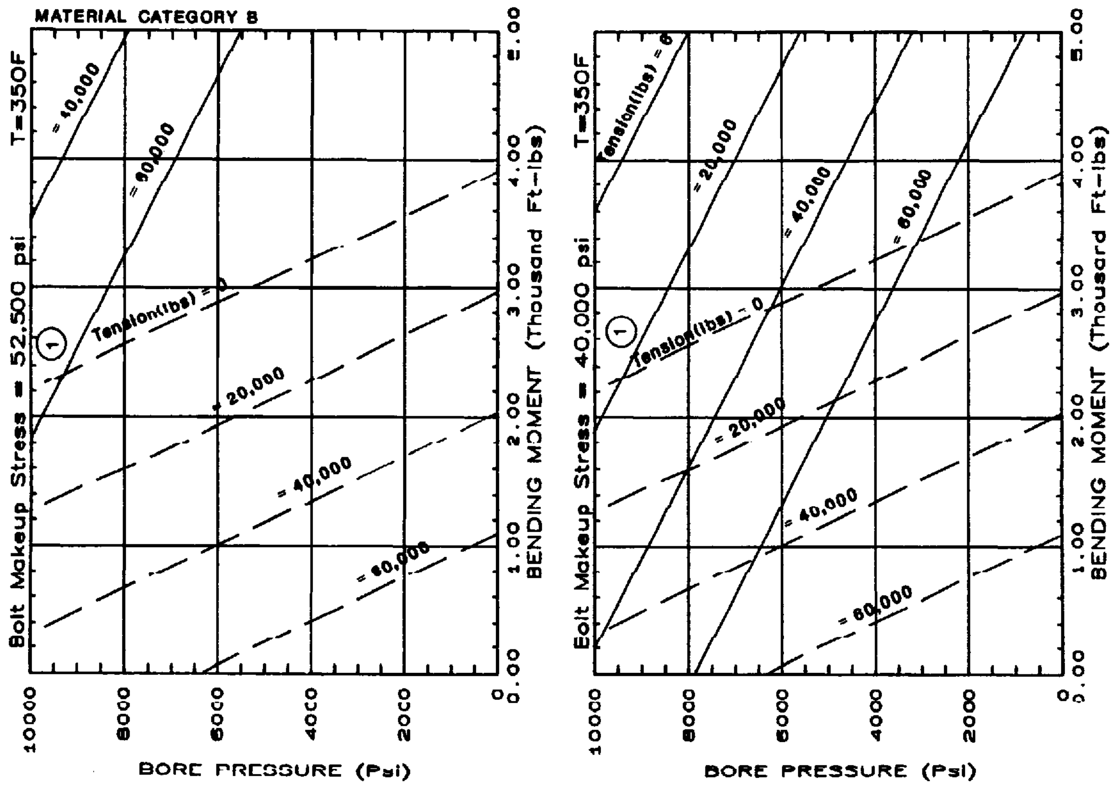


21-1/4"-5,000 PSI API 6BX-FLANGE

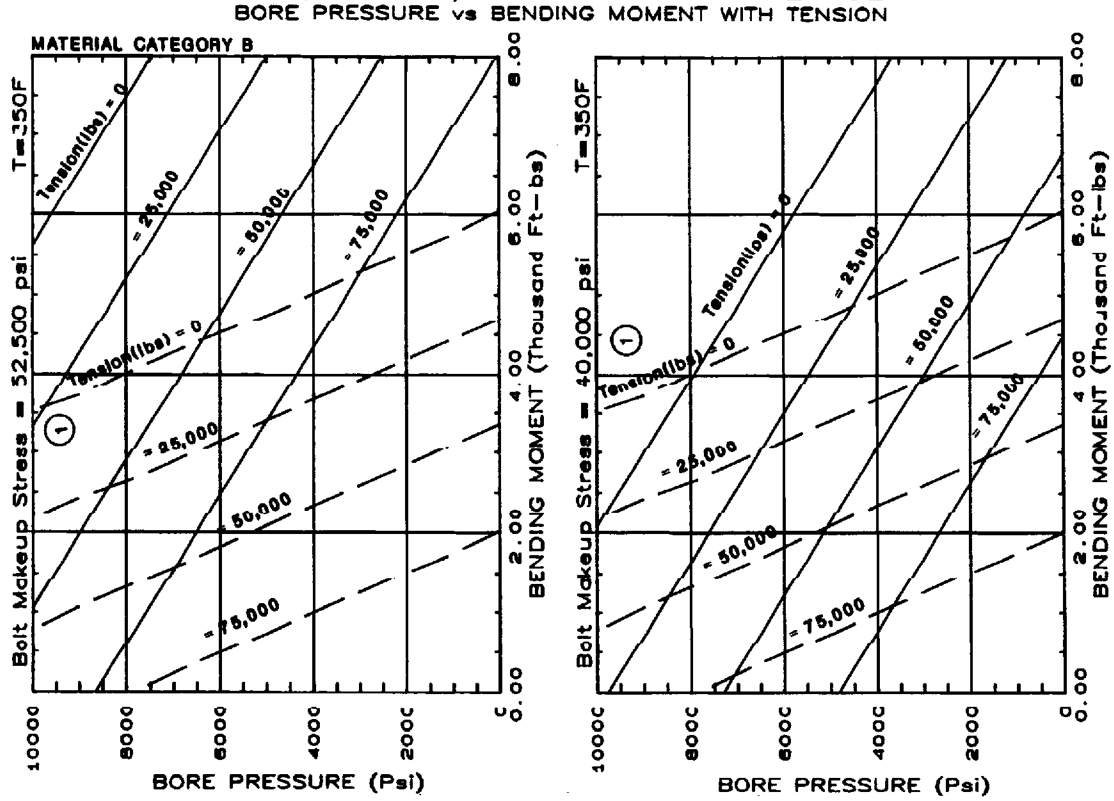
BORE PRESSURE vs BENDING MOMENT WITH TENSION



1-13/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

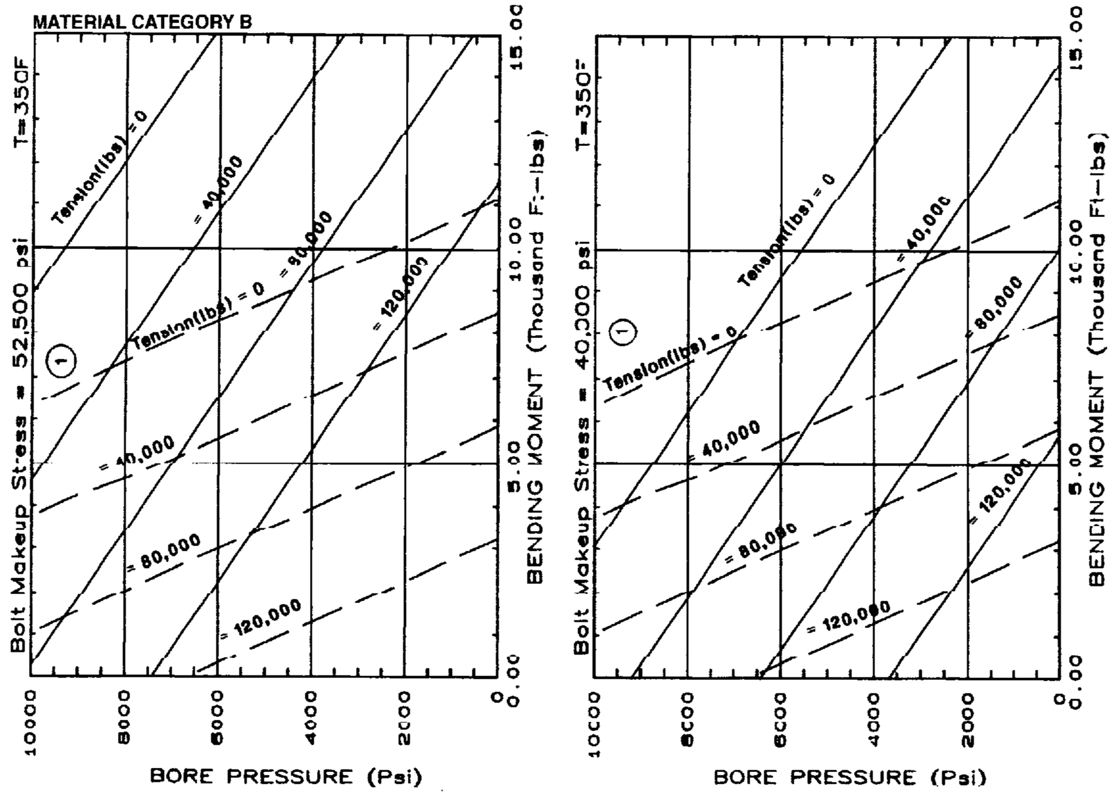


2-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



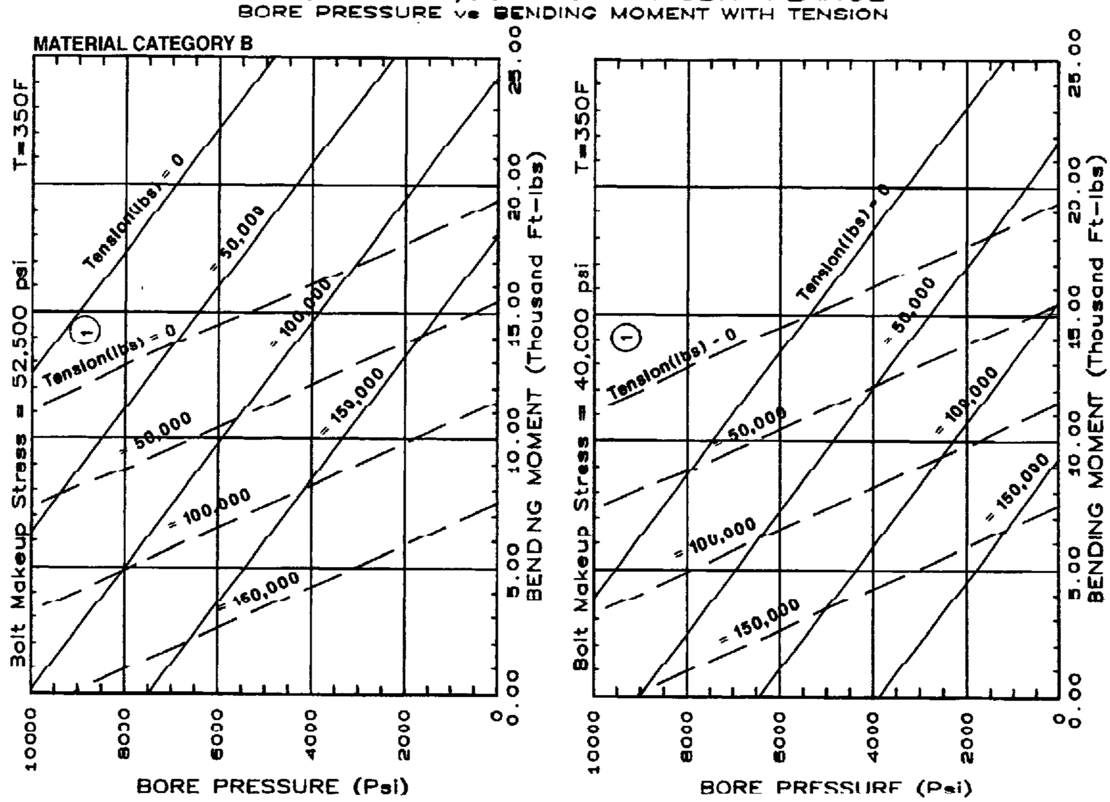
2-9/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



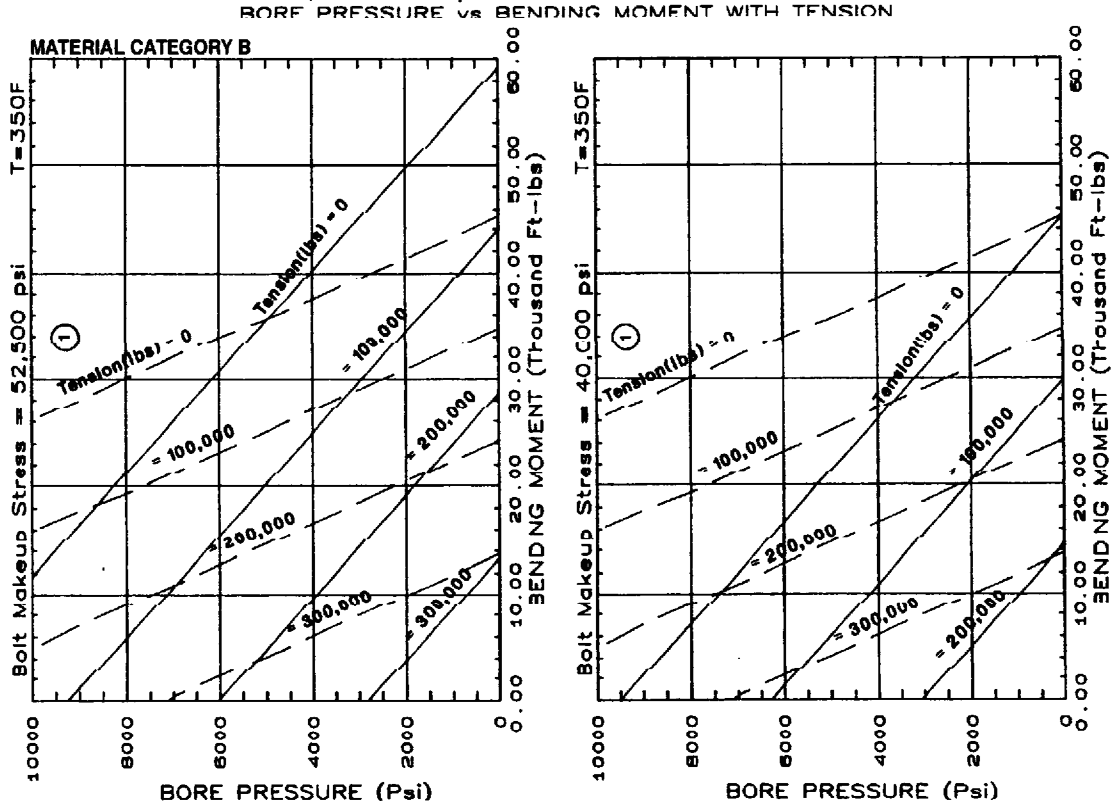
3-1/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



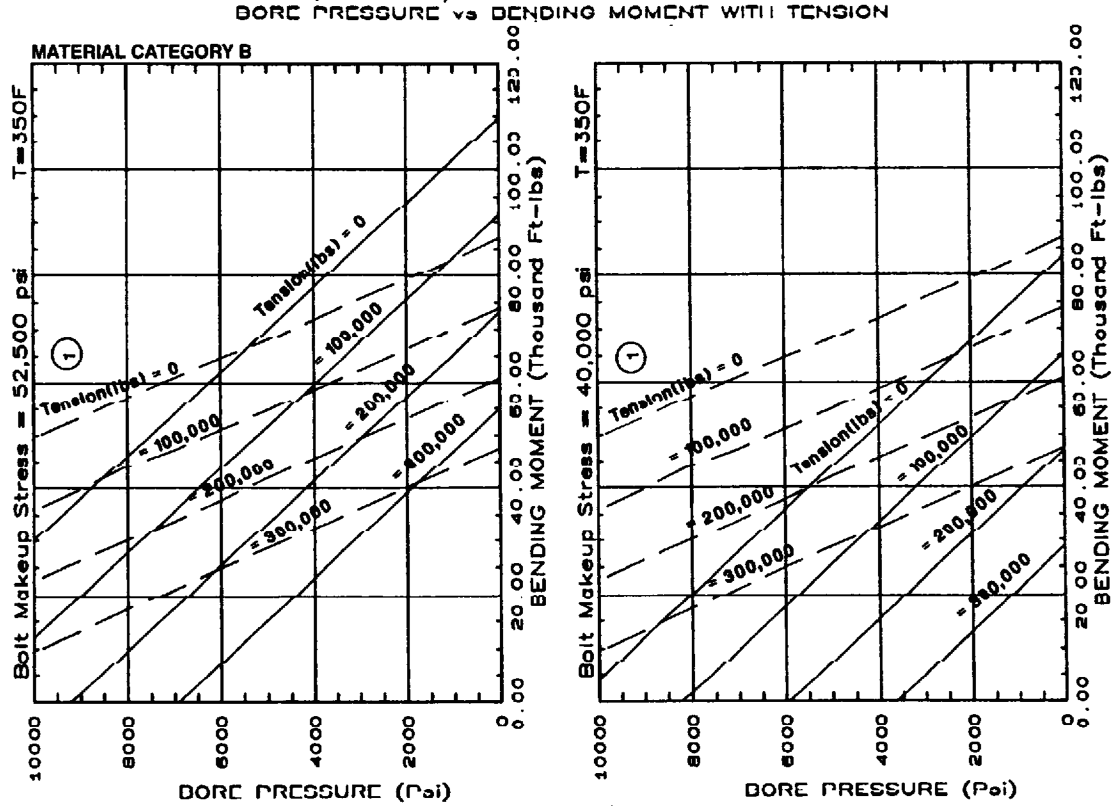
4-1/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

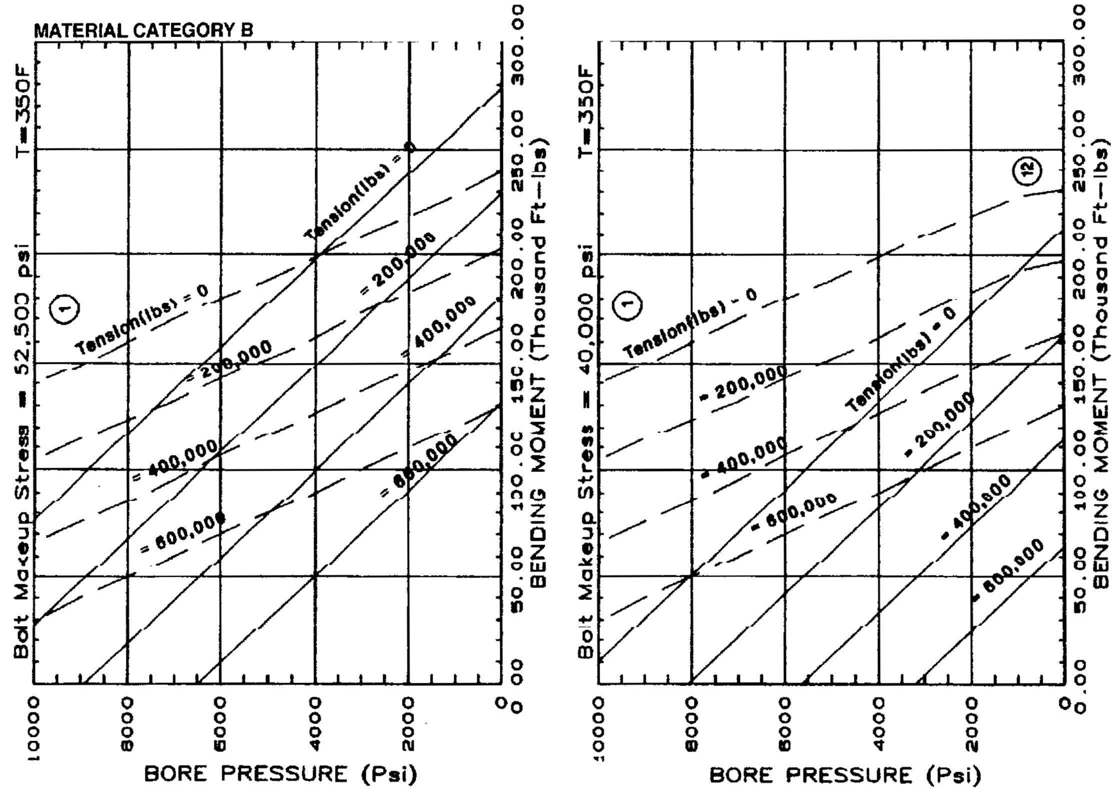


5-1/8"-10,000 PSI API 6BX-FLANGE

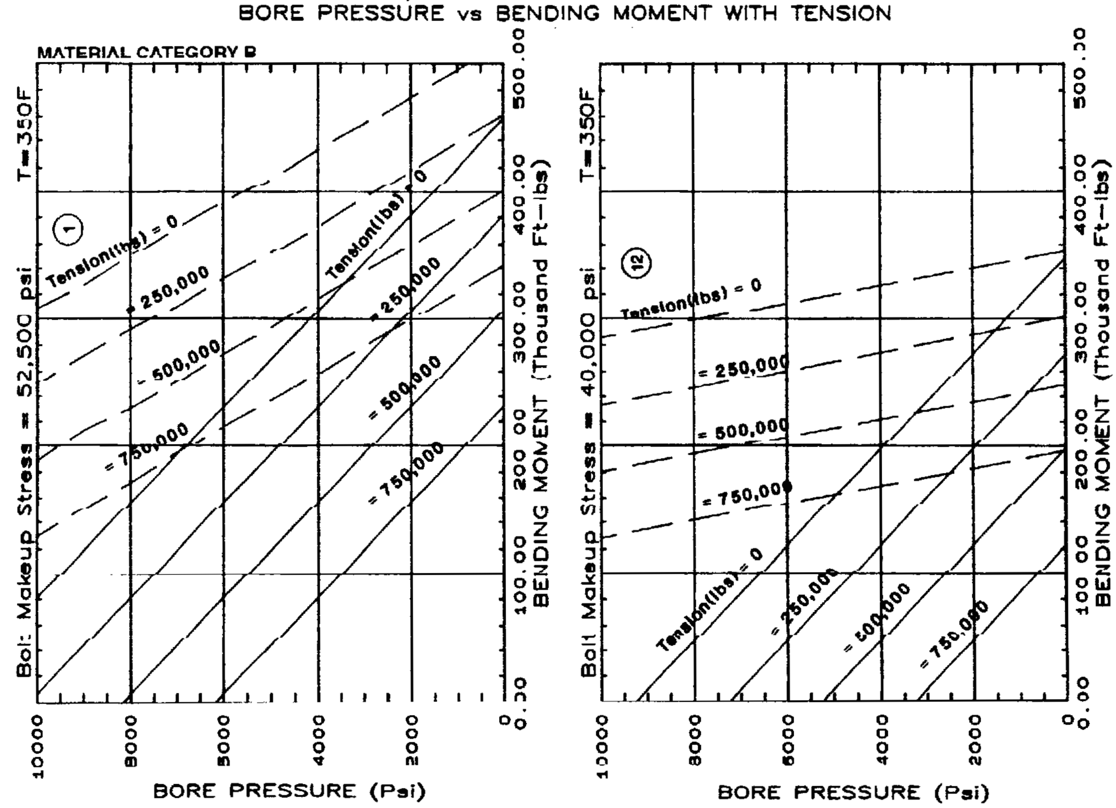
BORE PRESSURE vs BENDING MOMENT WITH TENSION

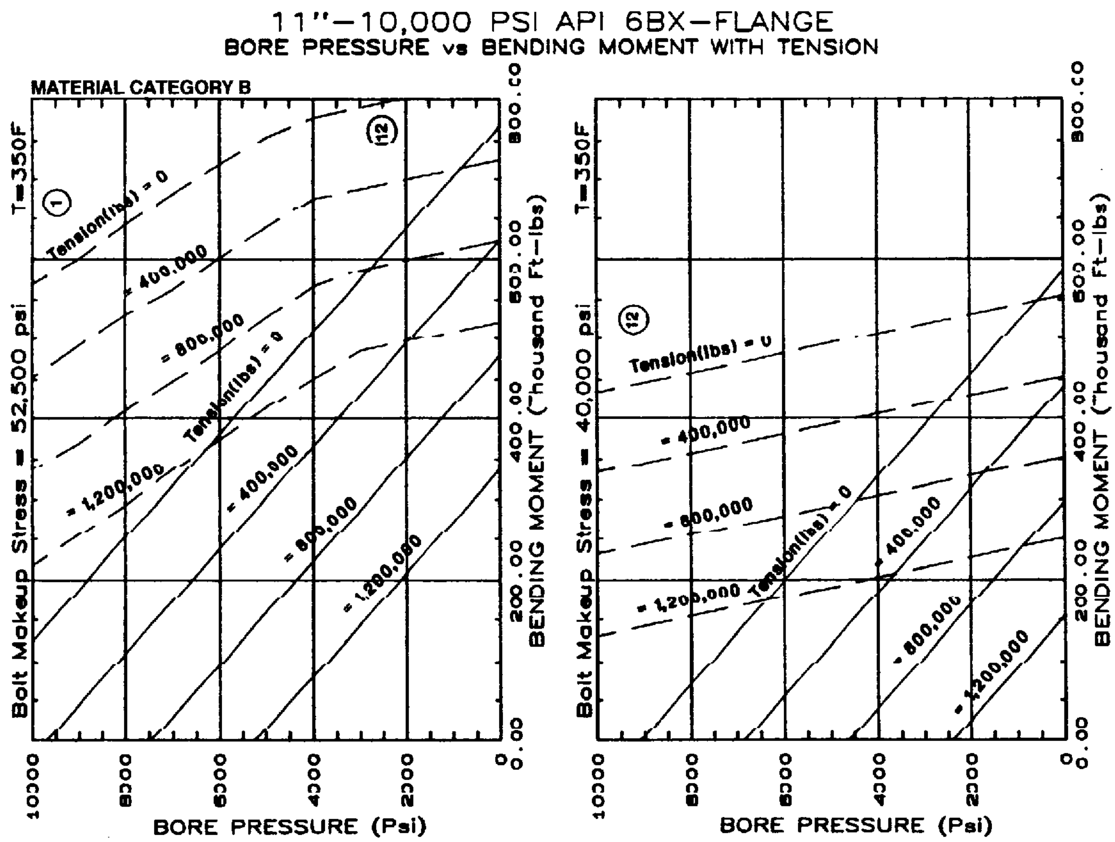


7-1/16"-10.000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

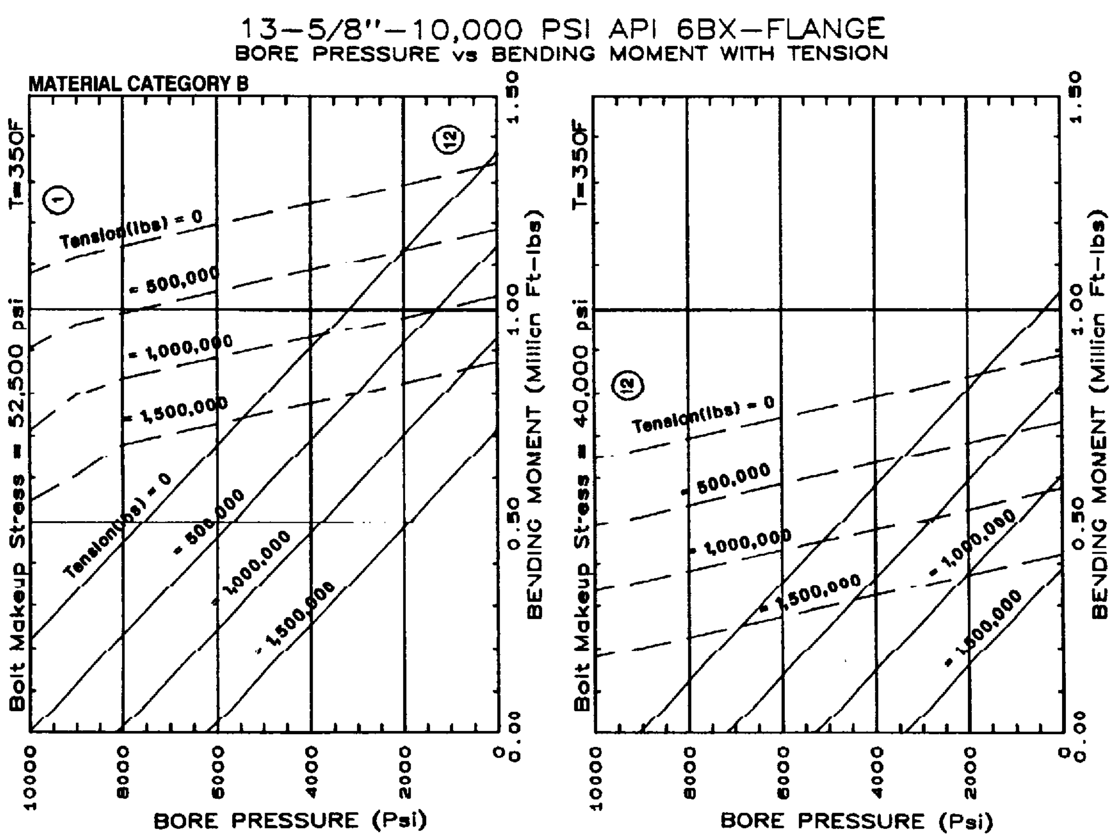


9"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



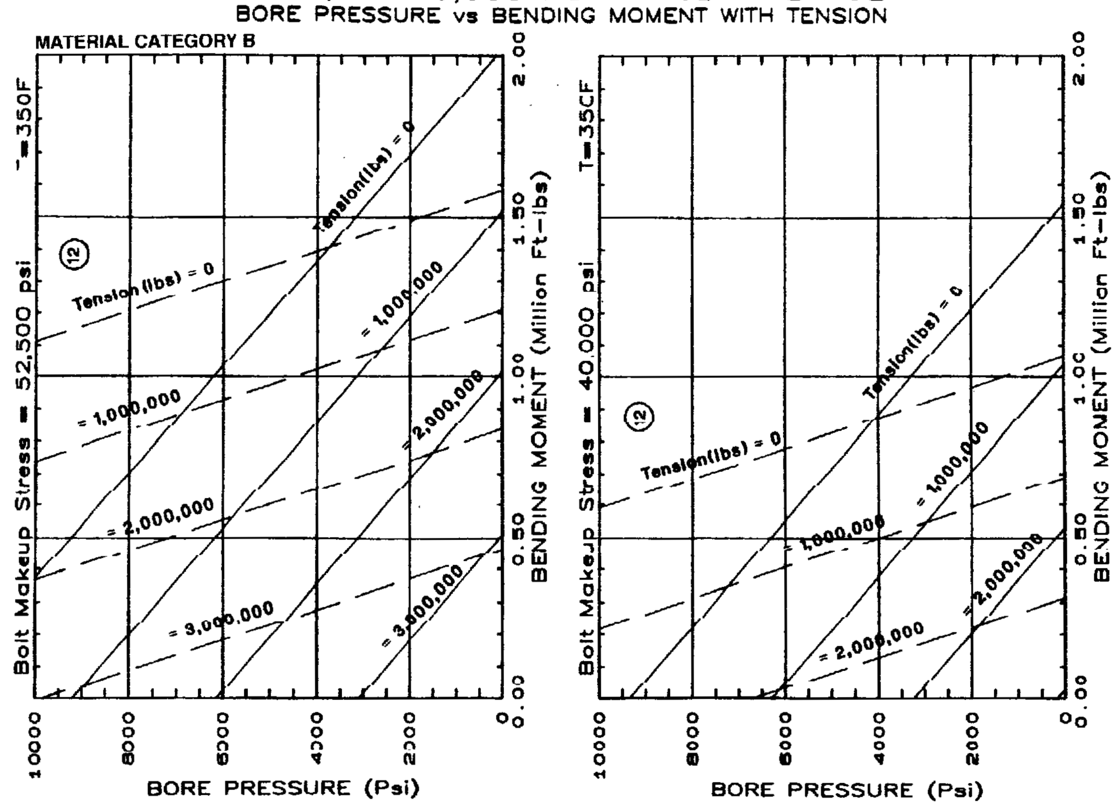


11"—10,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 400,000
= 800,000
= 1,200,000

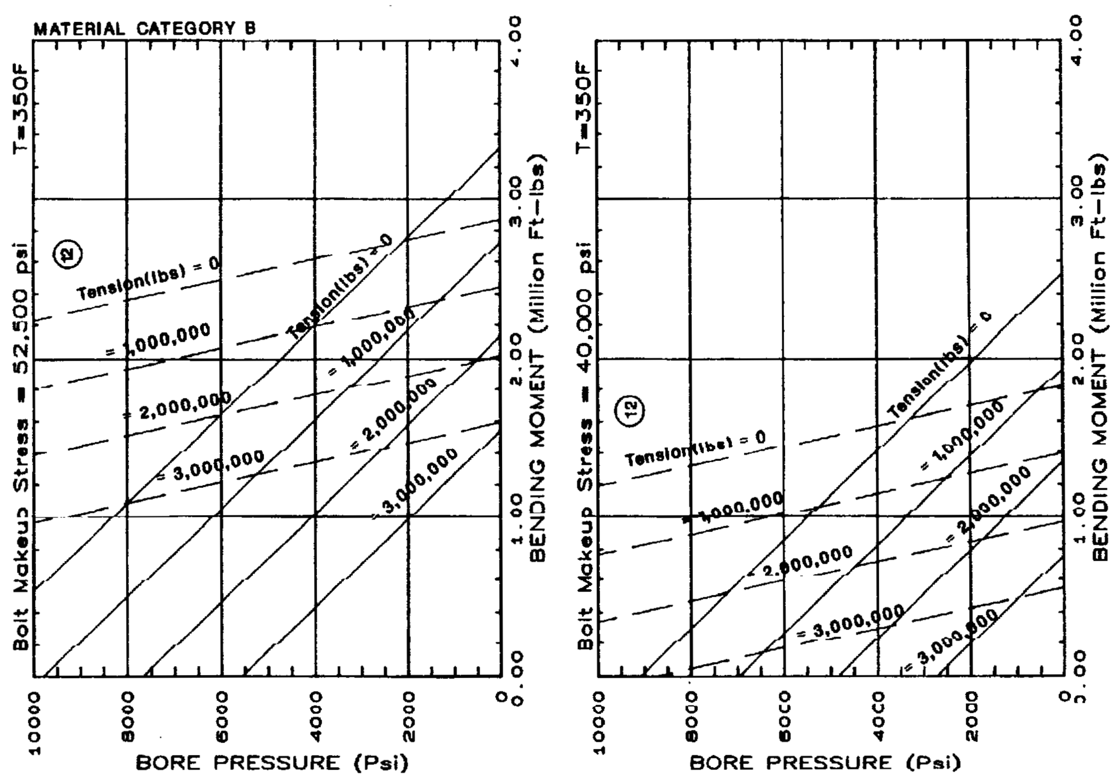


13-5/8"—10,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Million Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 500,000
= 1,000,000
= 1,500,000

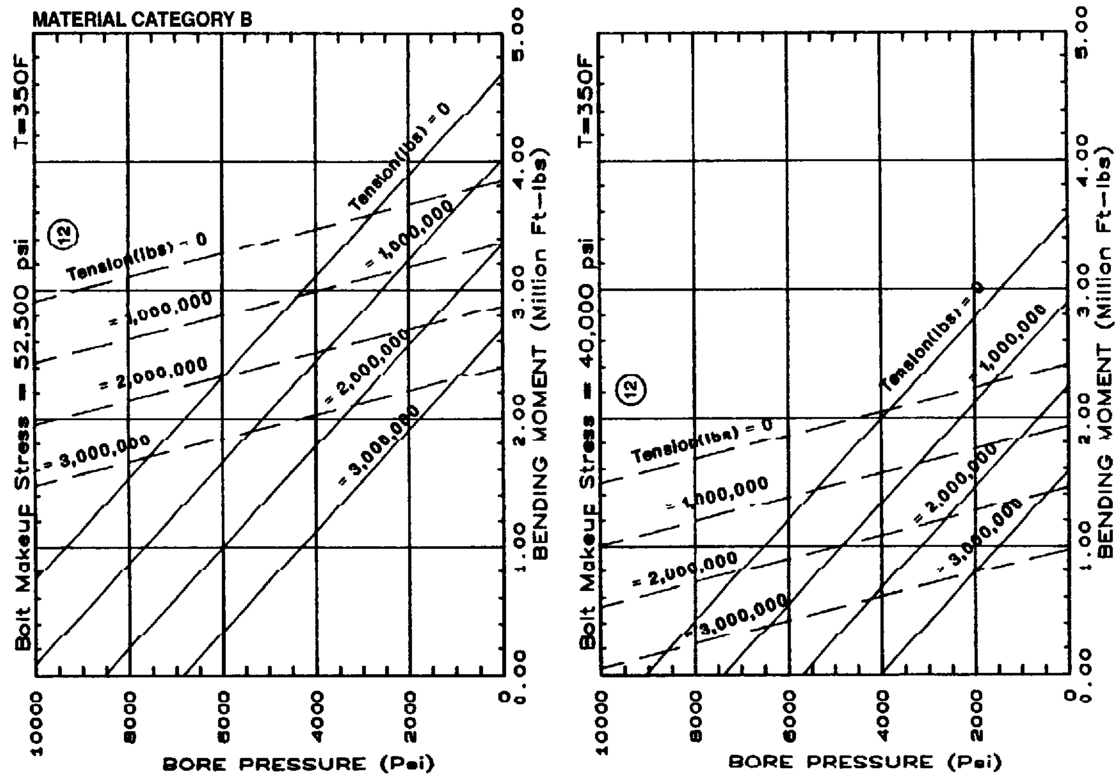
16-3/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



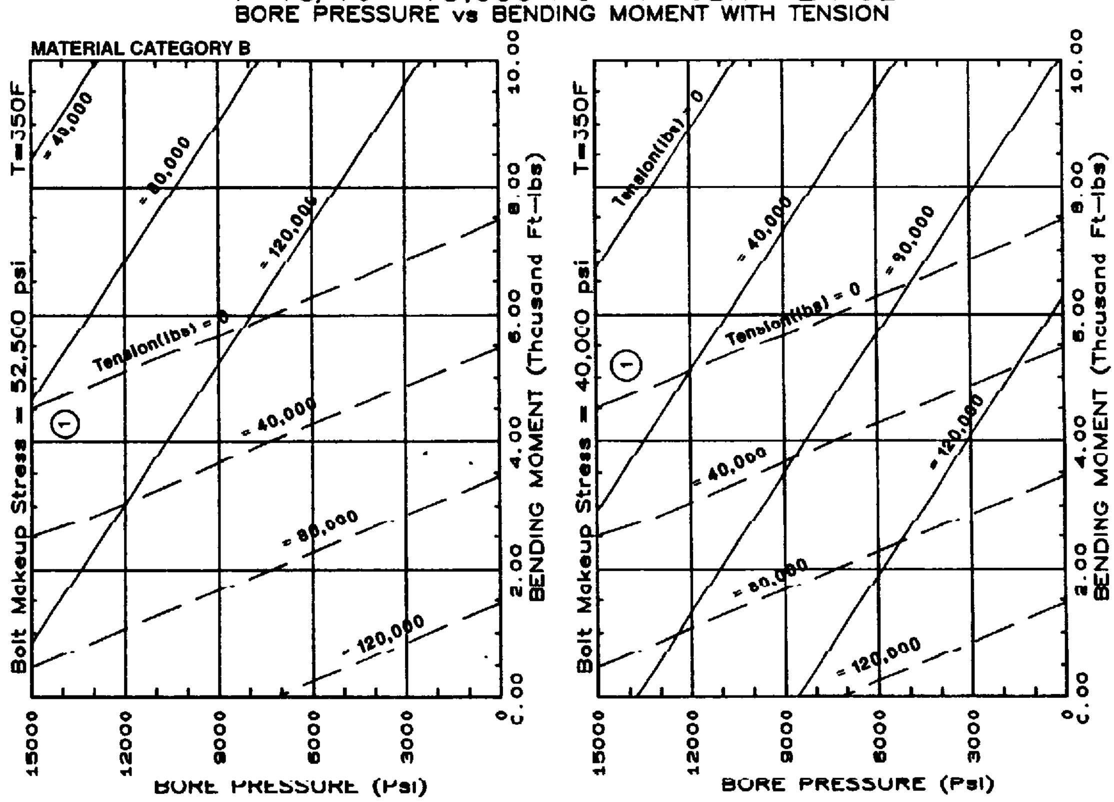
18-3/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



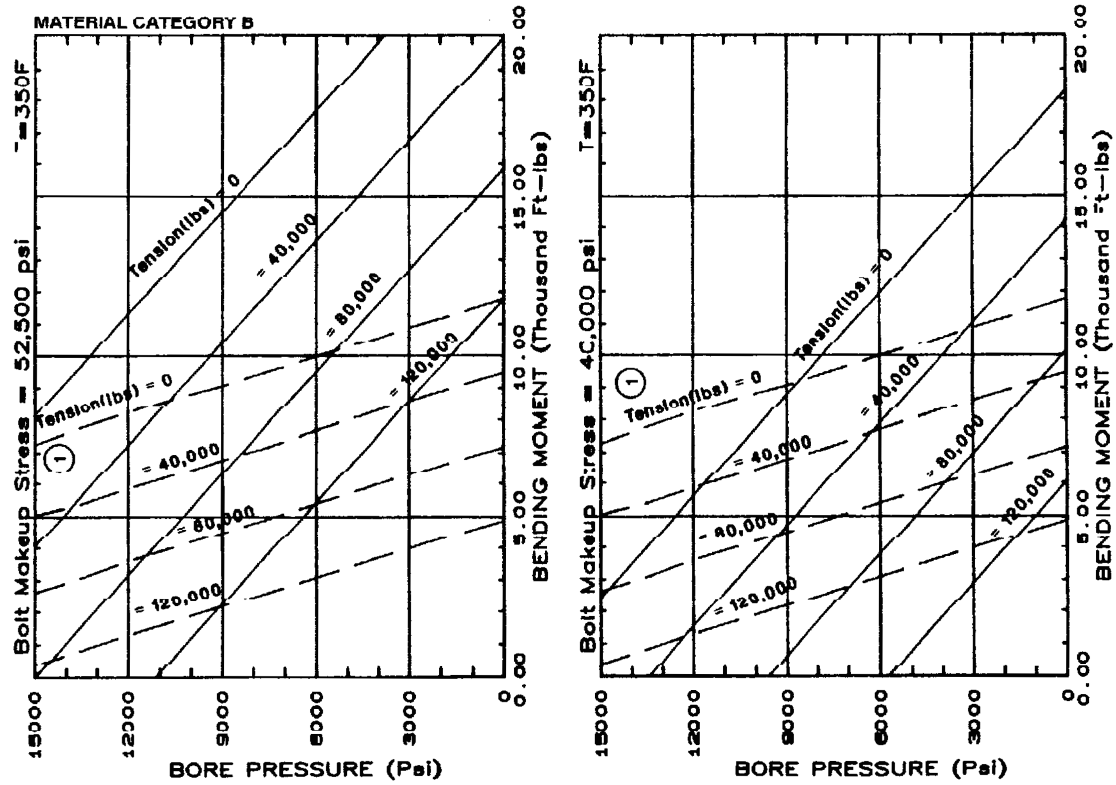
21-1/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



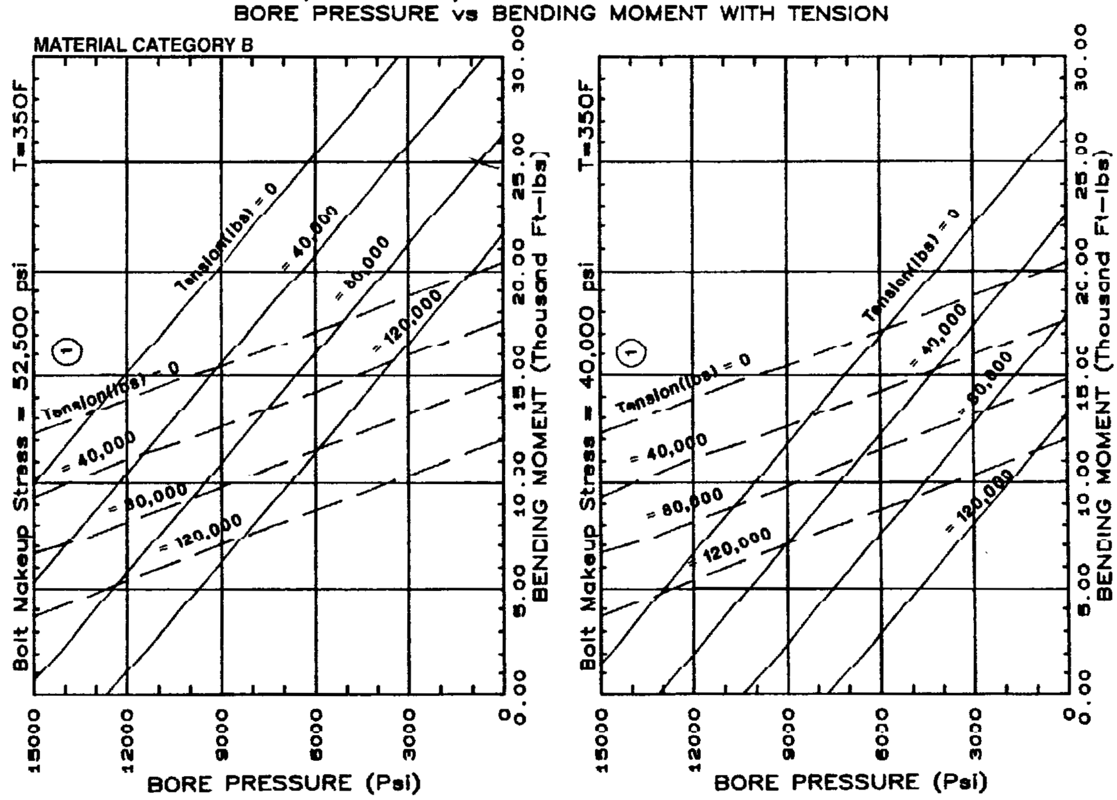
1-13/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



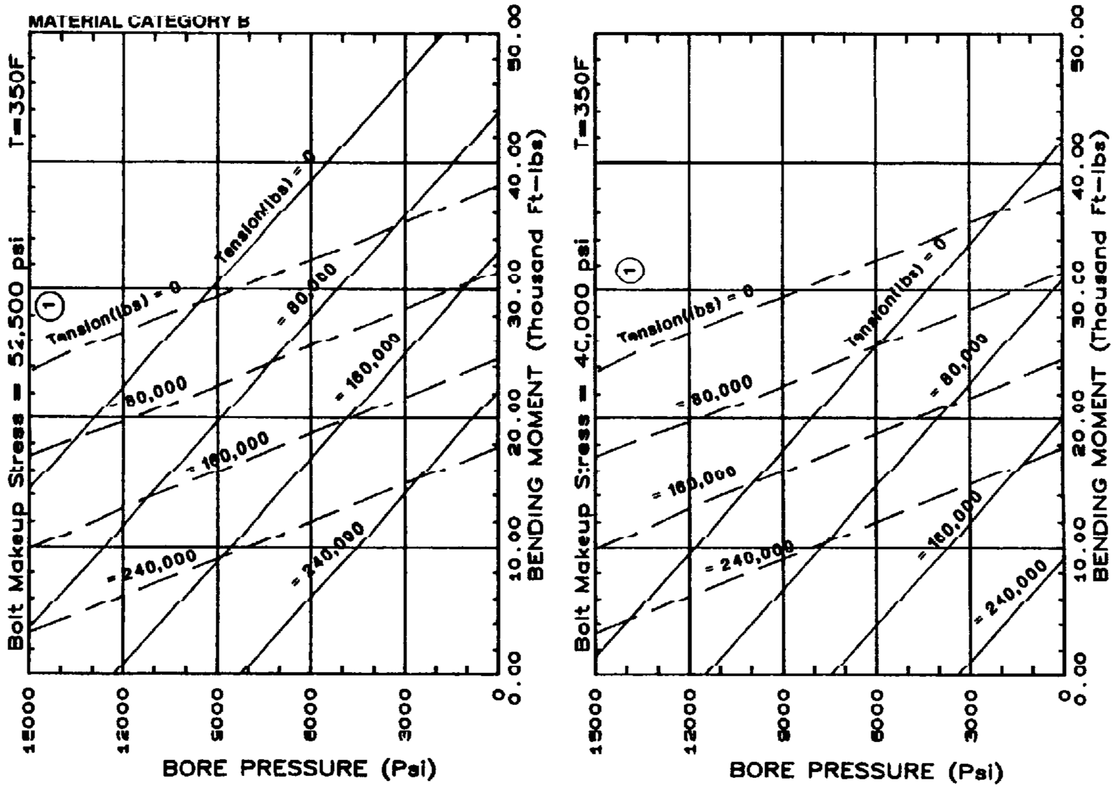
2-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



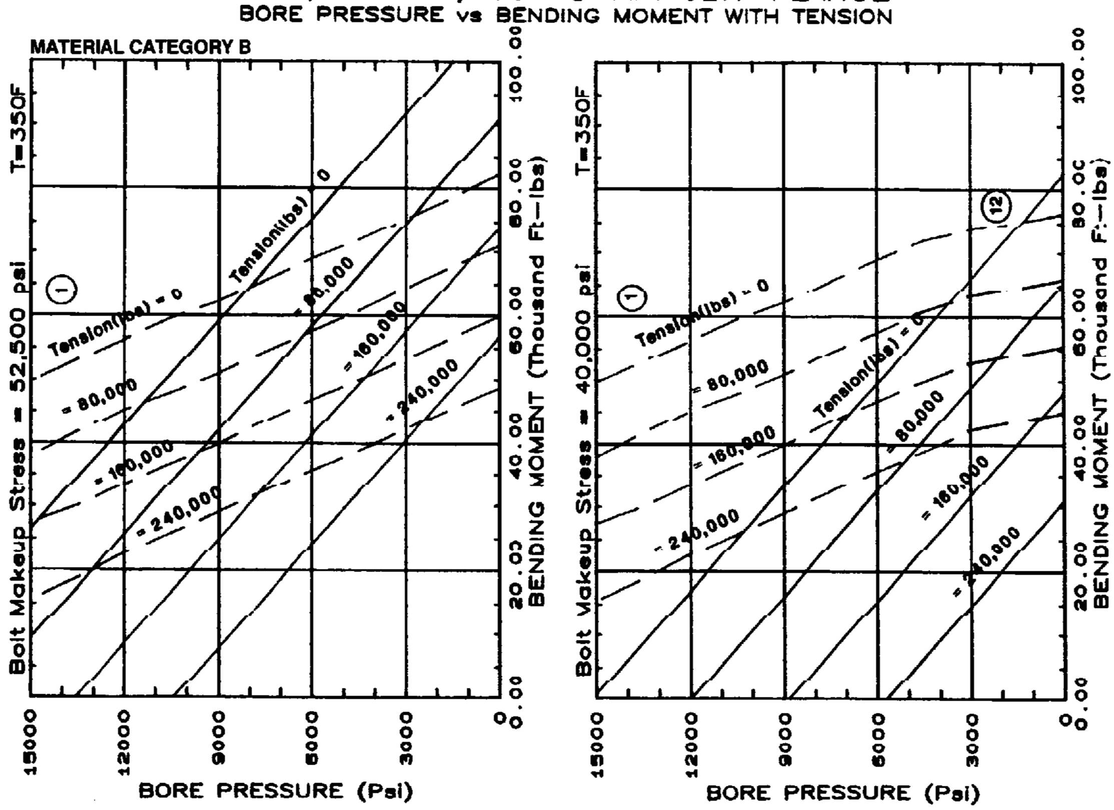
2-9/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

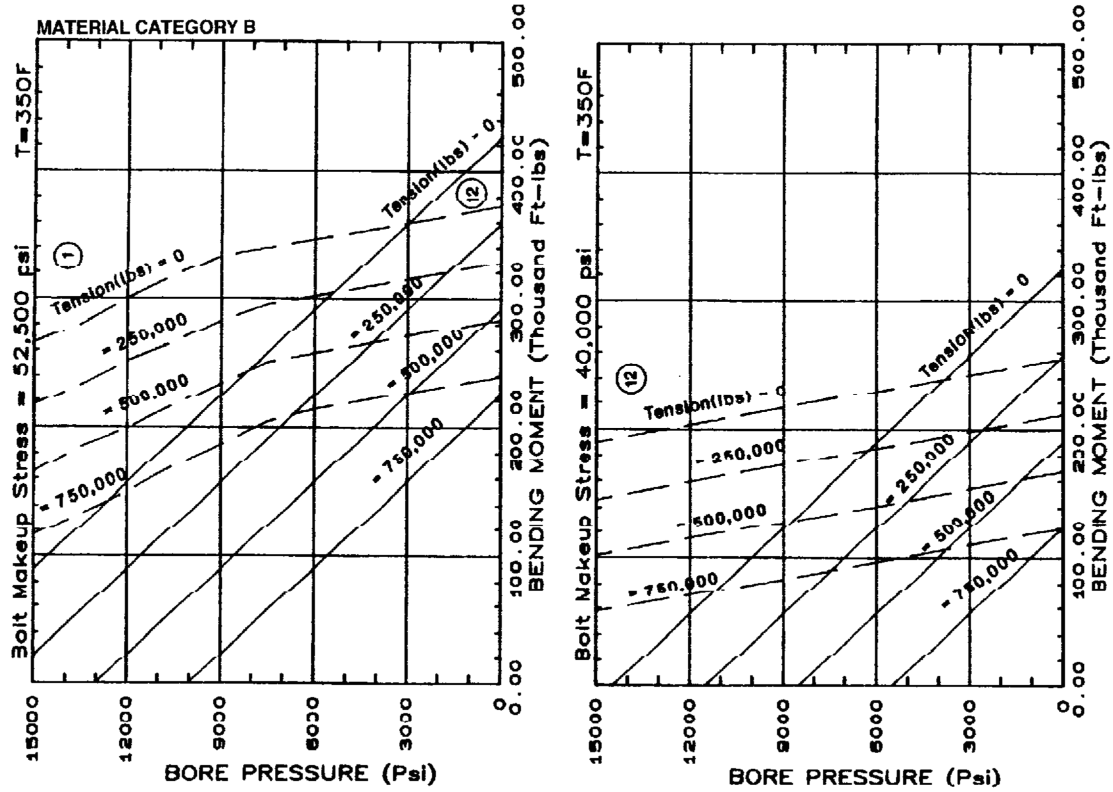


4-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



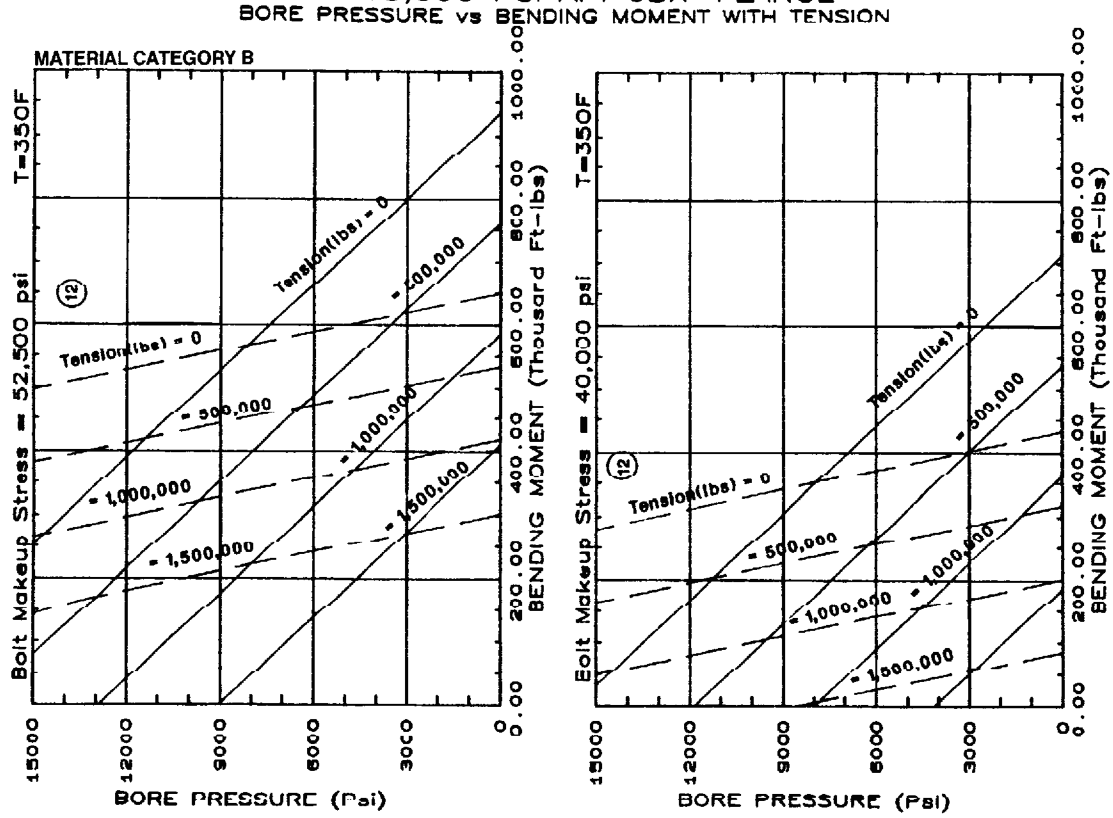
7-1/16"-15,000 PSI API 6BX-FLANGE

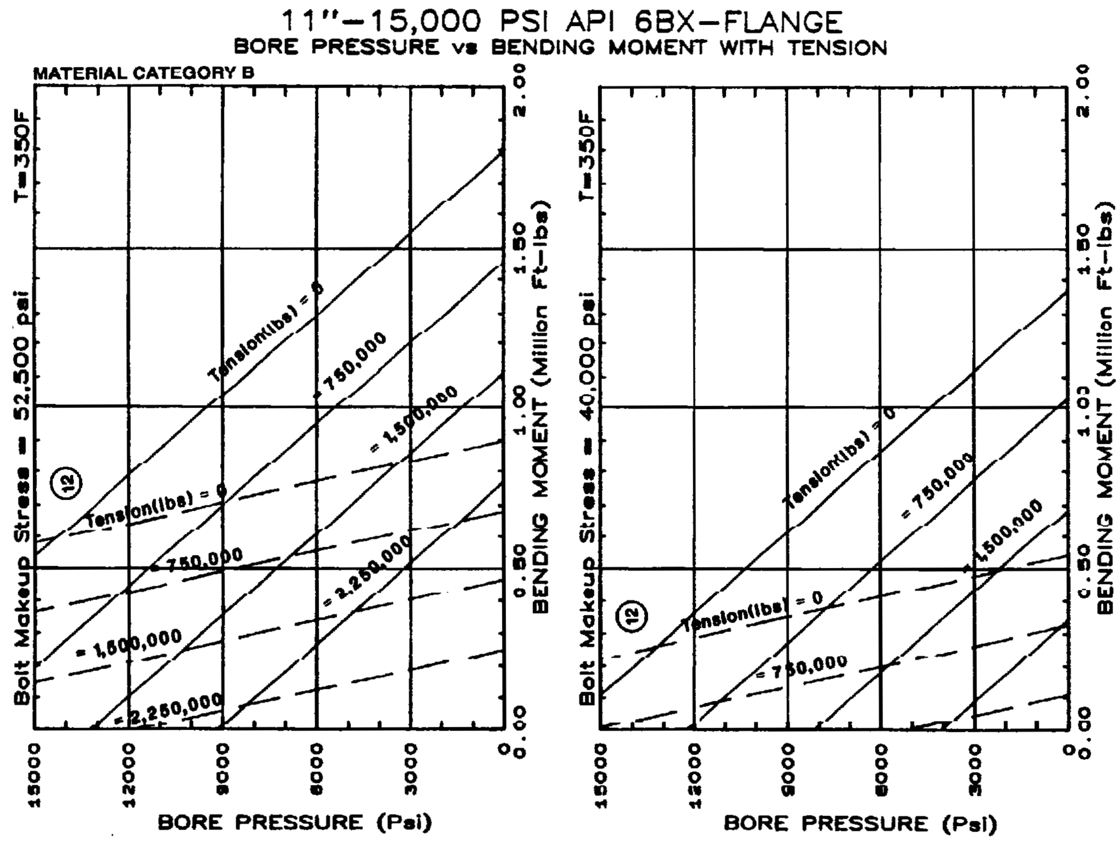
BORE PRESSURE vs BENDING MOMENT WITH TENSION

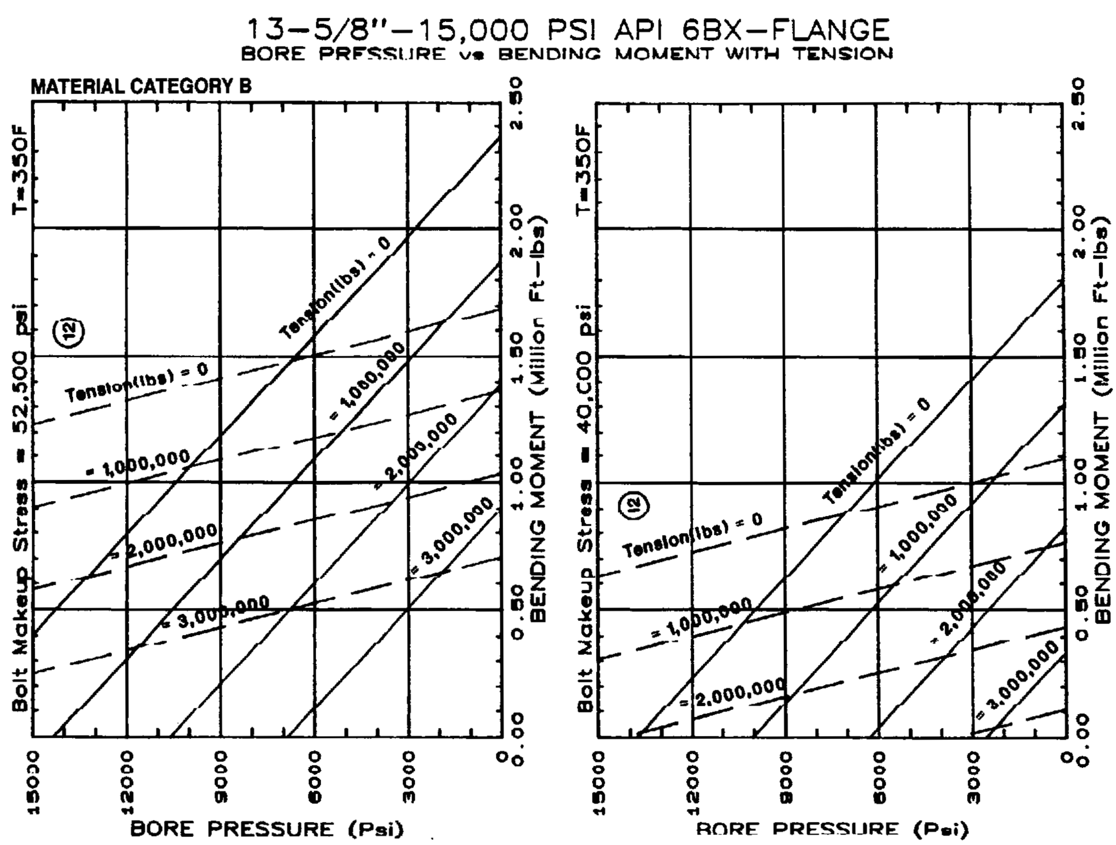


9"-15,000 PSI API 6BX-FLANGE

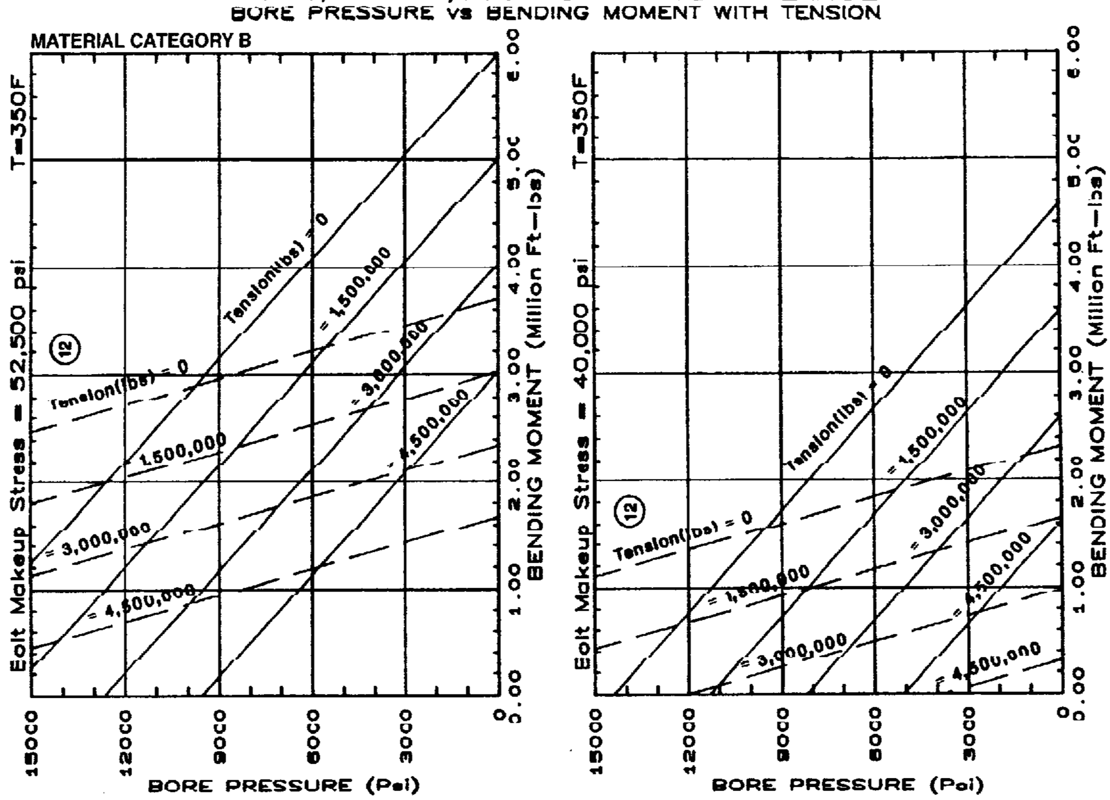
BORE PRESSURE vs BENDING MOMENT WITH TENSION



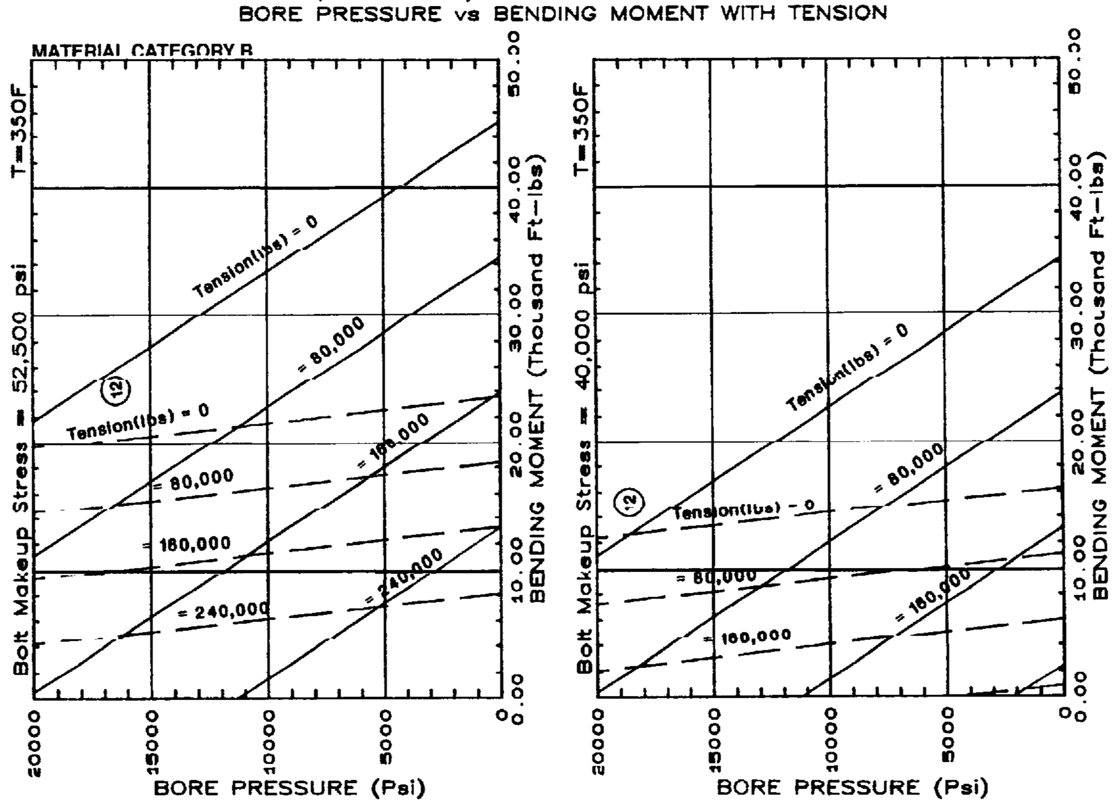

11"—15,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Million Ft—lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
750,000
1,500,000
2,250,000


13—5/8"—15,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=350F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Million Ft—lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
1,000,000
2,000,000
3,000,000

18-3/4"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

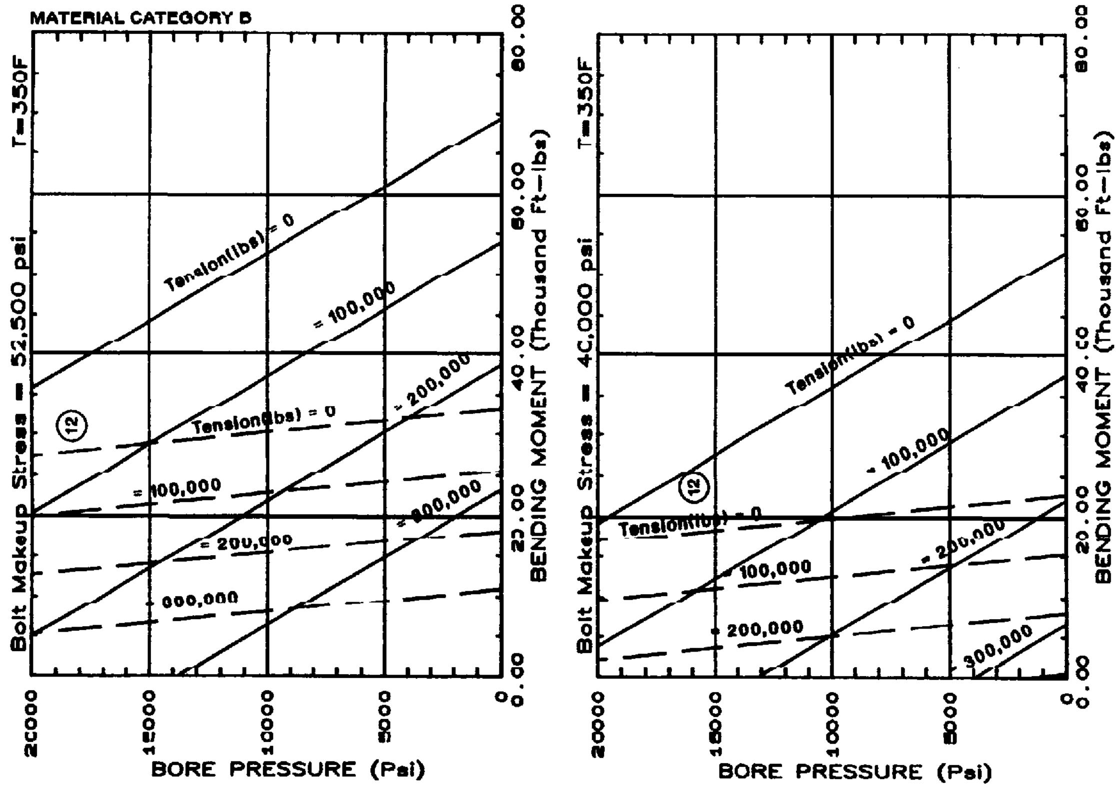


1-13/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



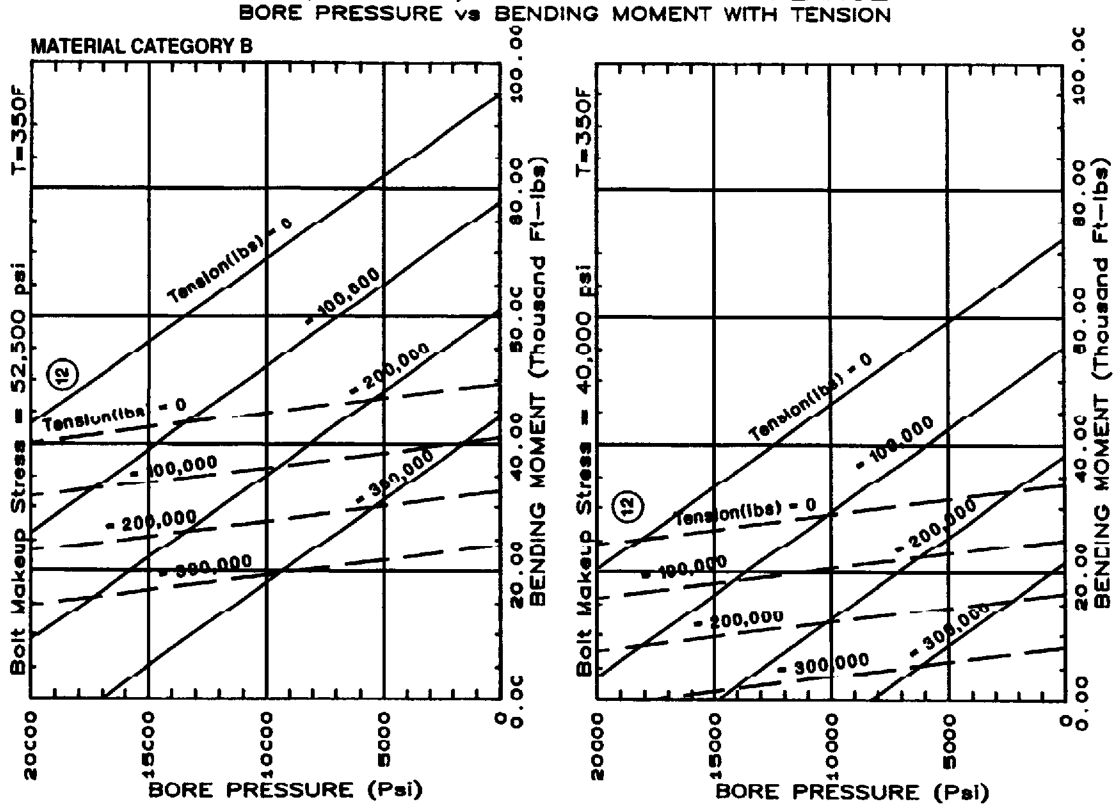
2-1/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

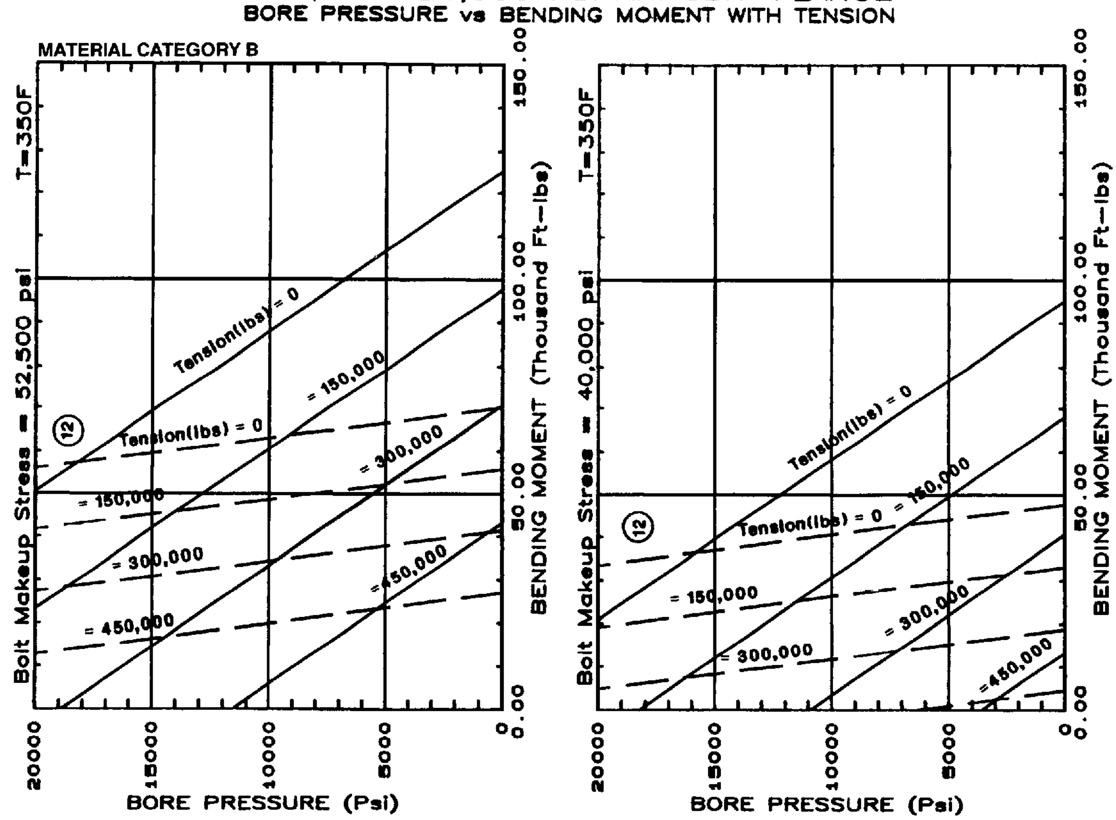


2-9/16"-20,000 PSI API 6BX-FLANGE

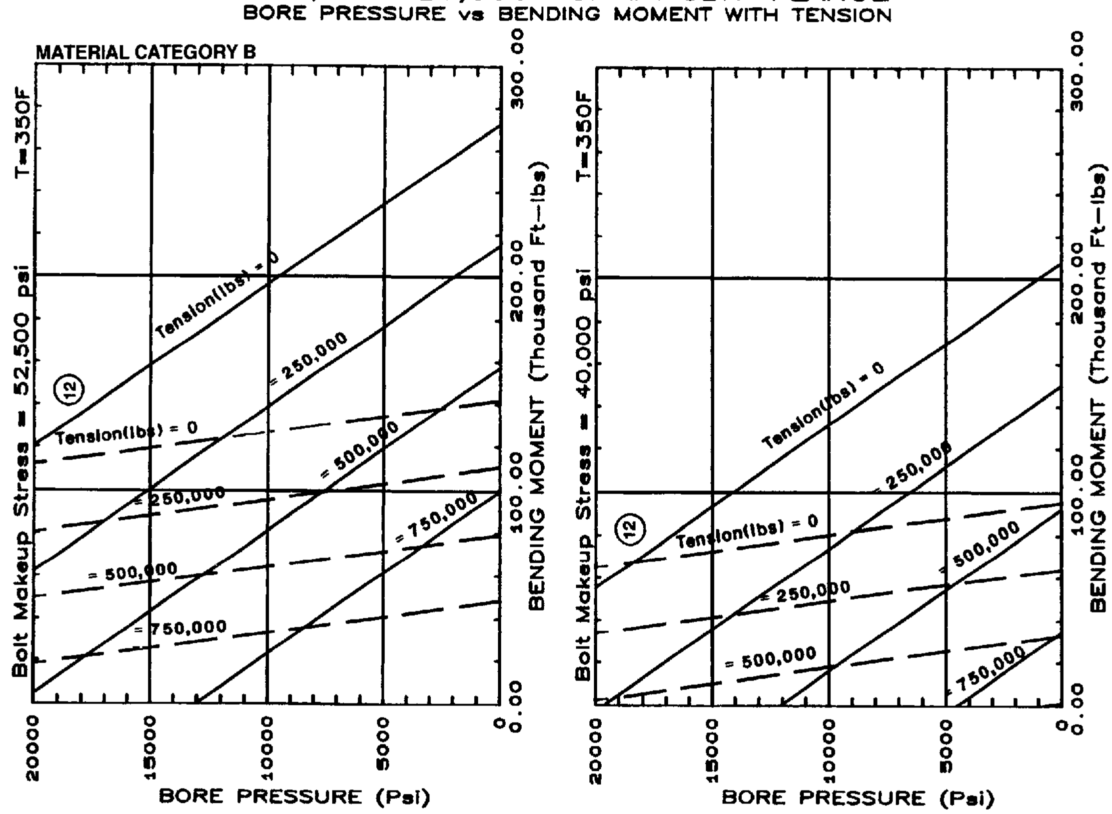
BORE PRESSURE vs BENDING MOMENT WITH TENSION



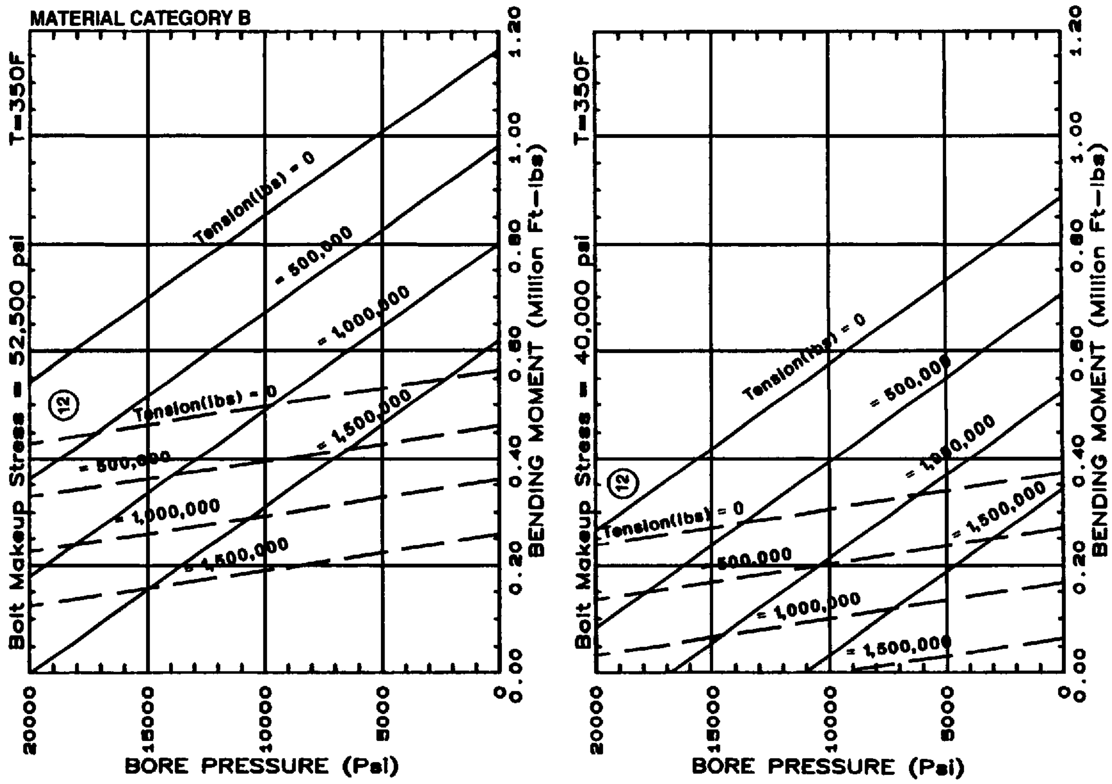
3-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



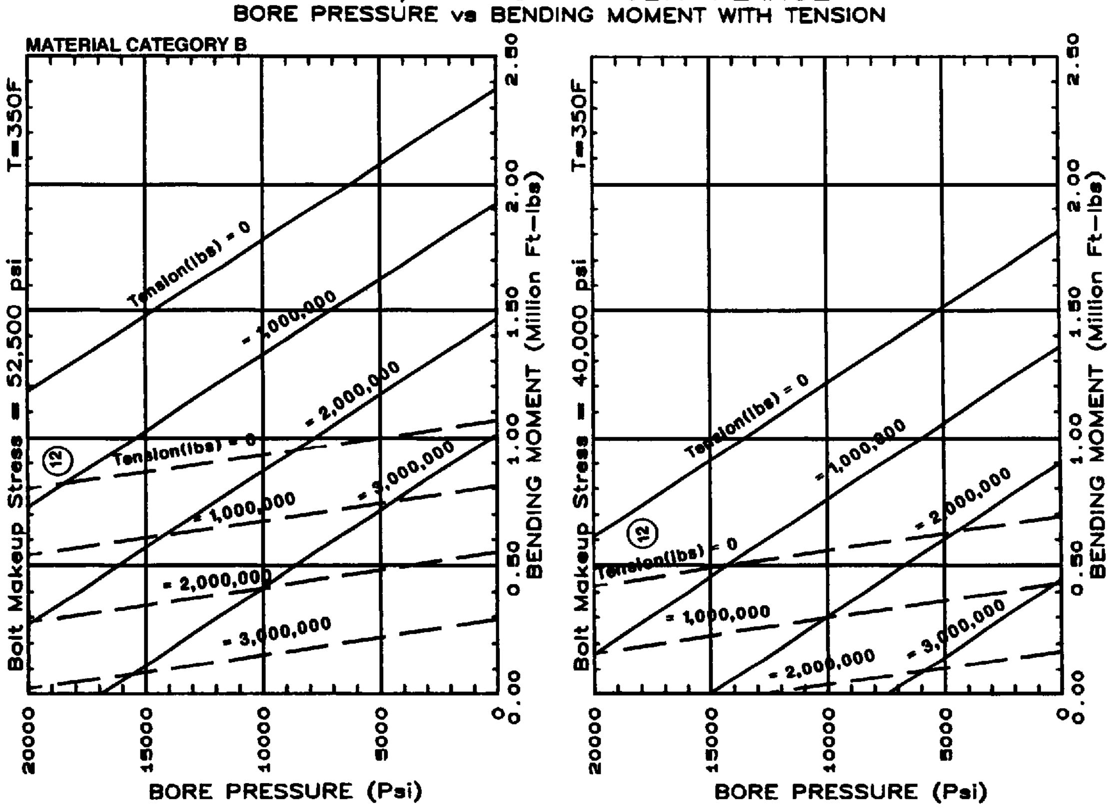
4-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



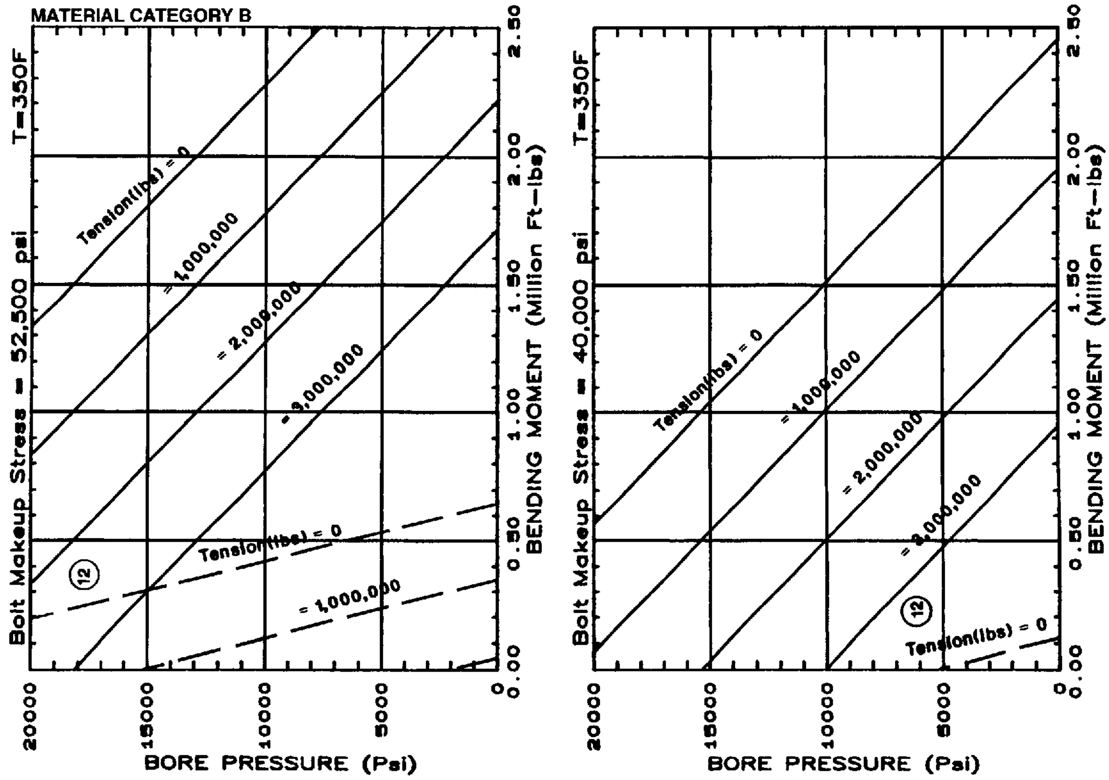
7-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



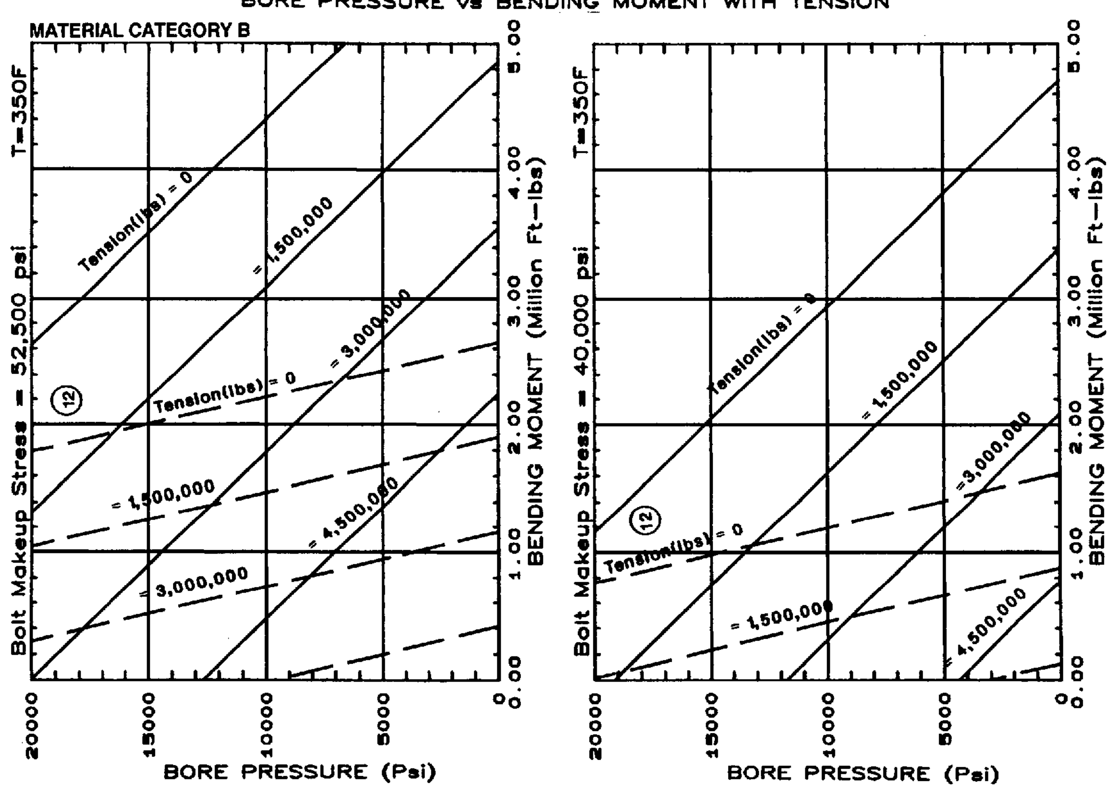
9"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



13–5/8"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



Material Category B
Bore Temperature—650°F

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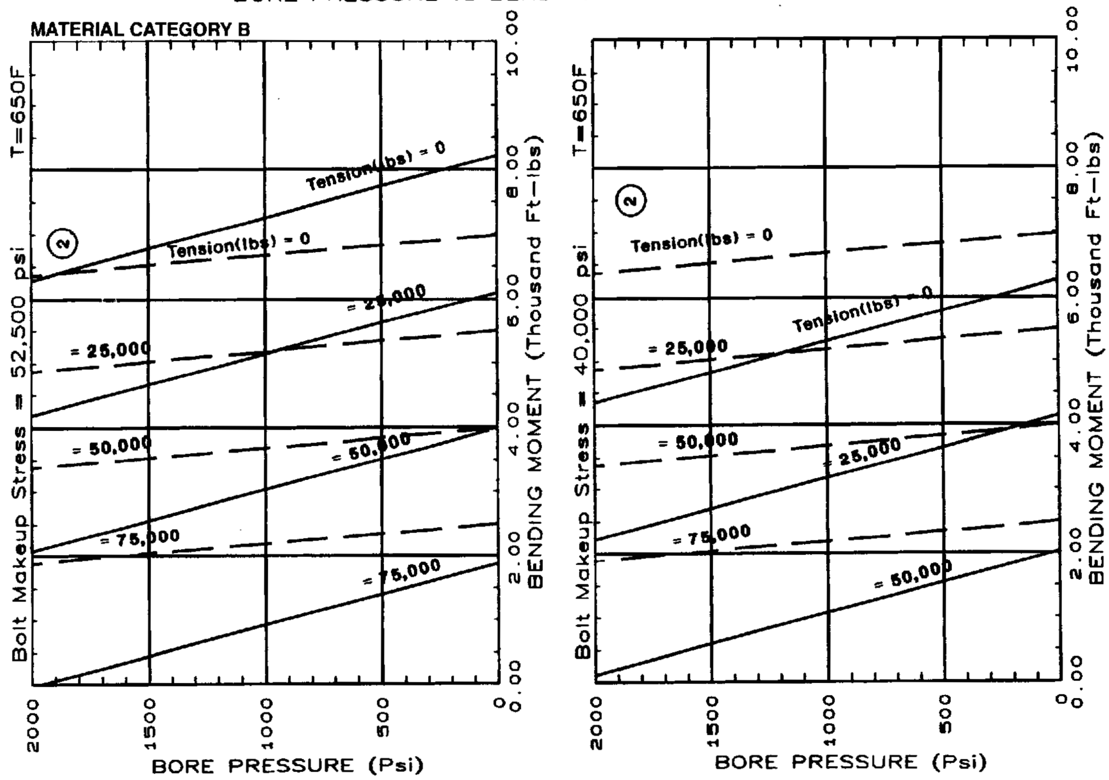
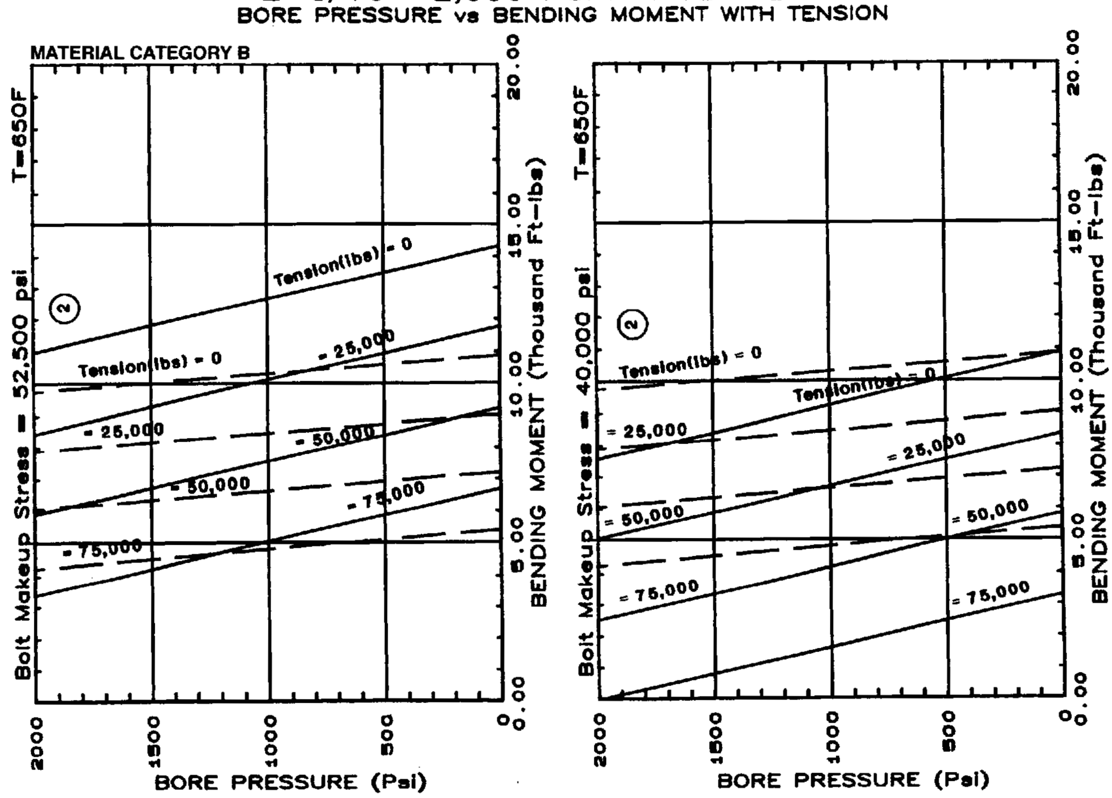
2-1/16"-2,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



2-9/16"-2,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



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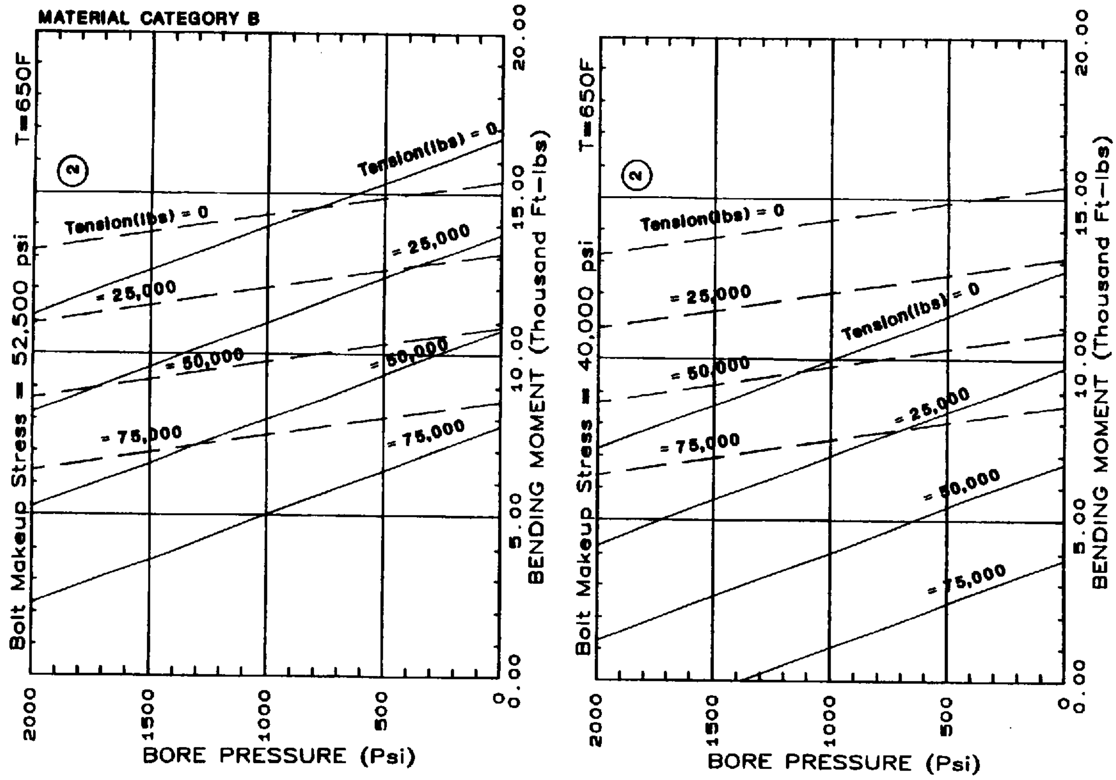
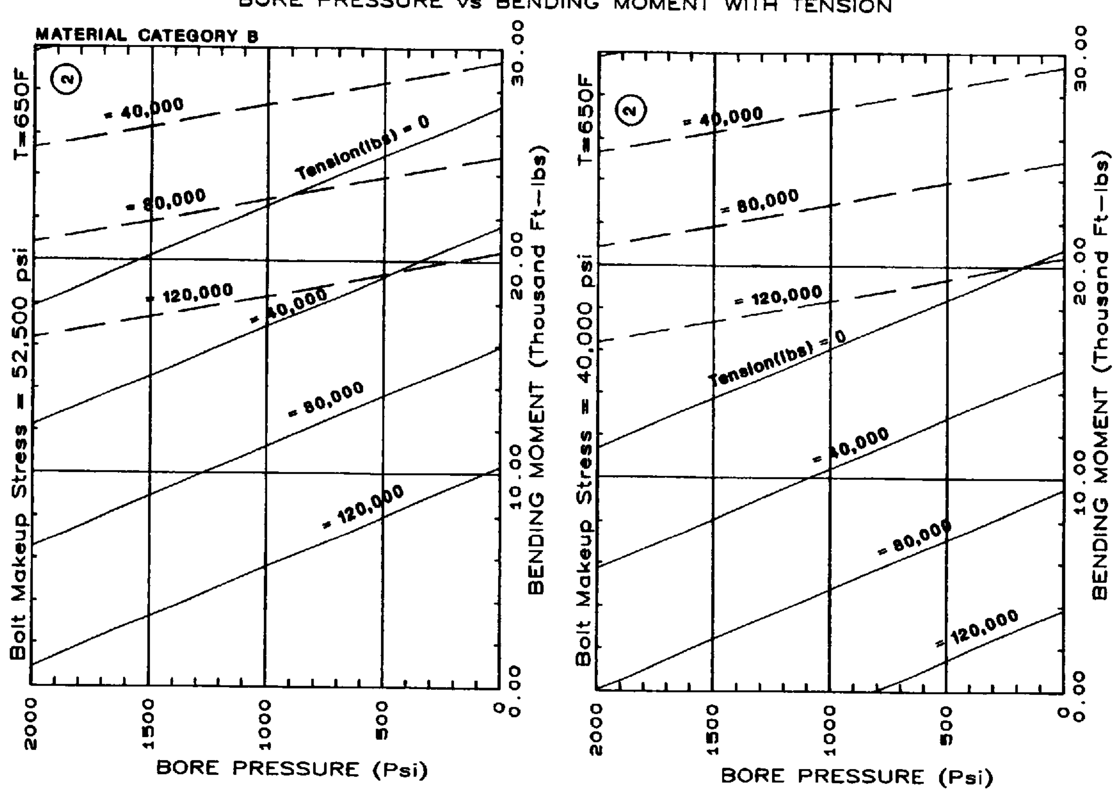
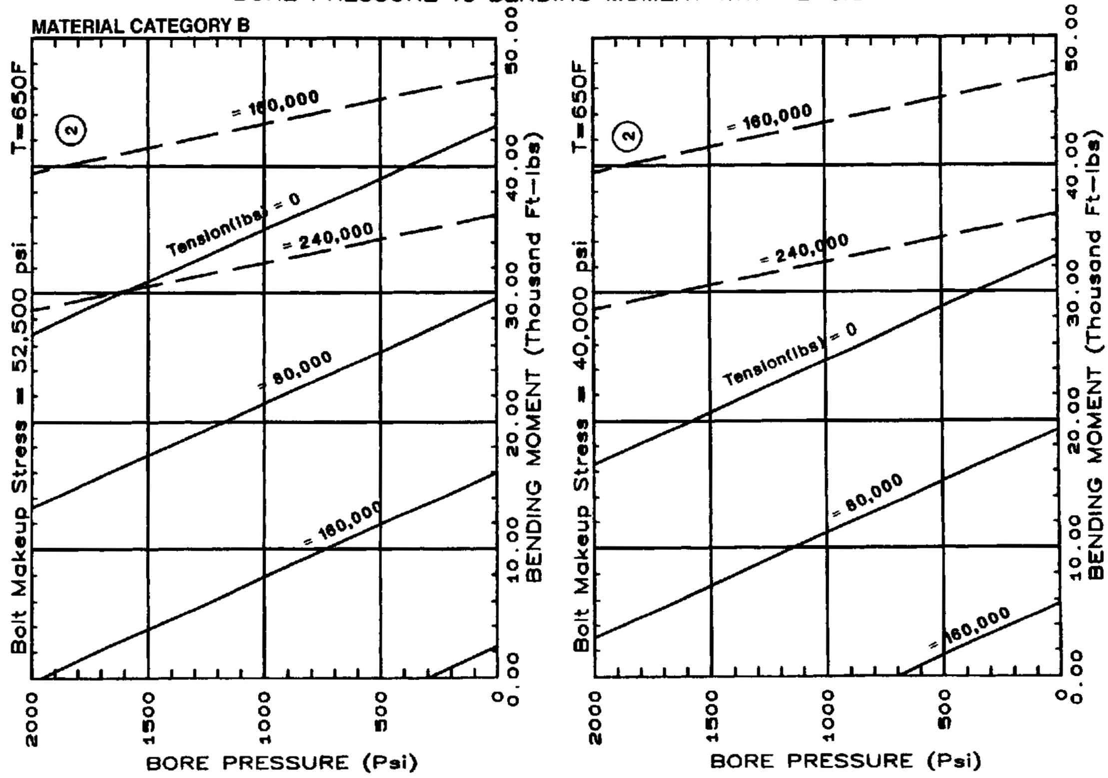
3-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



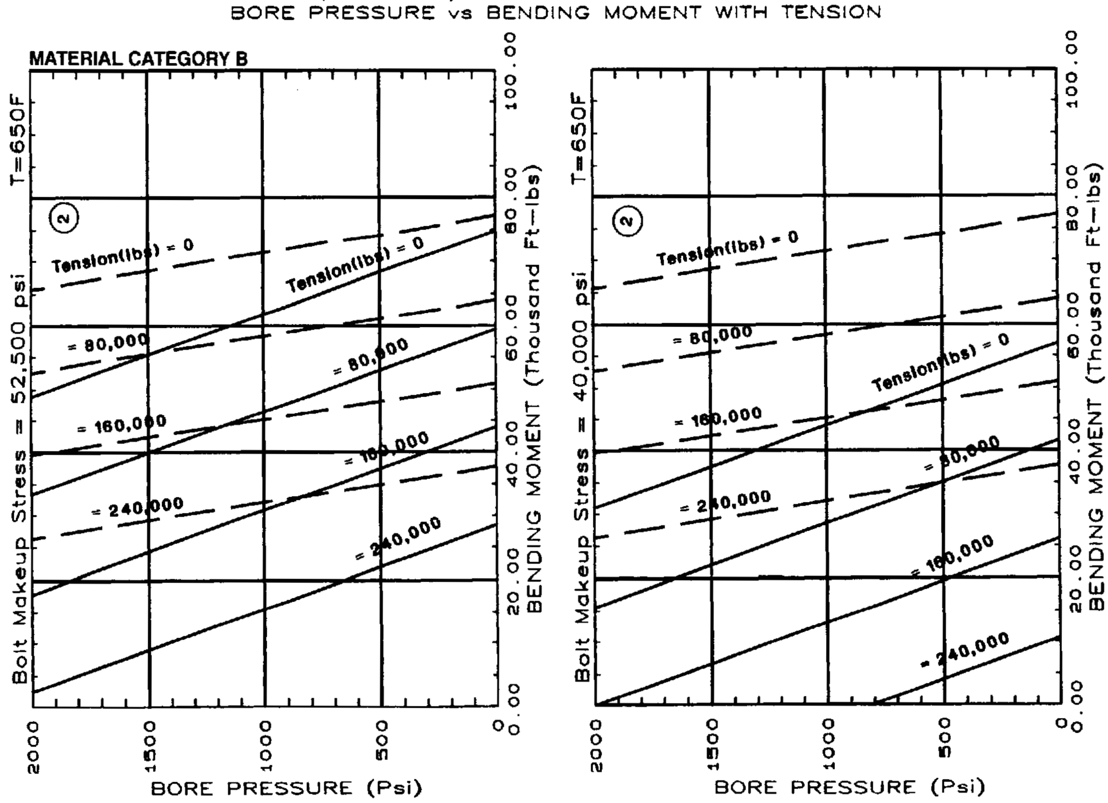
4-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



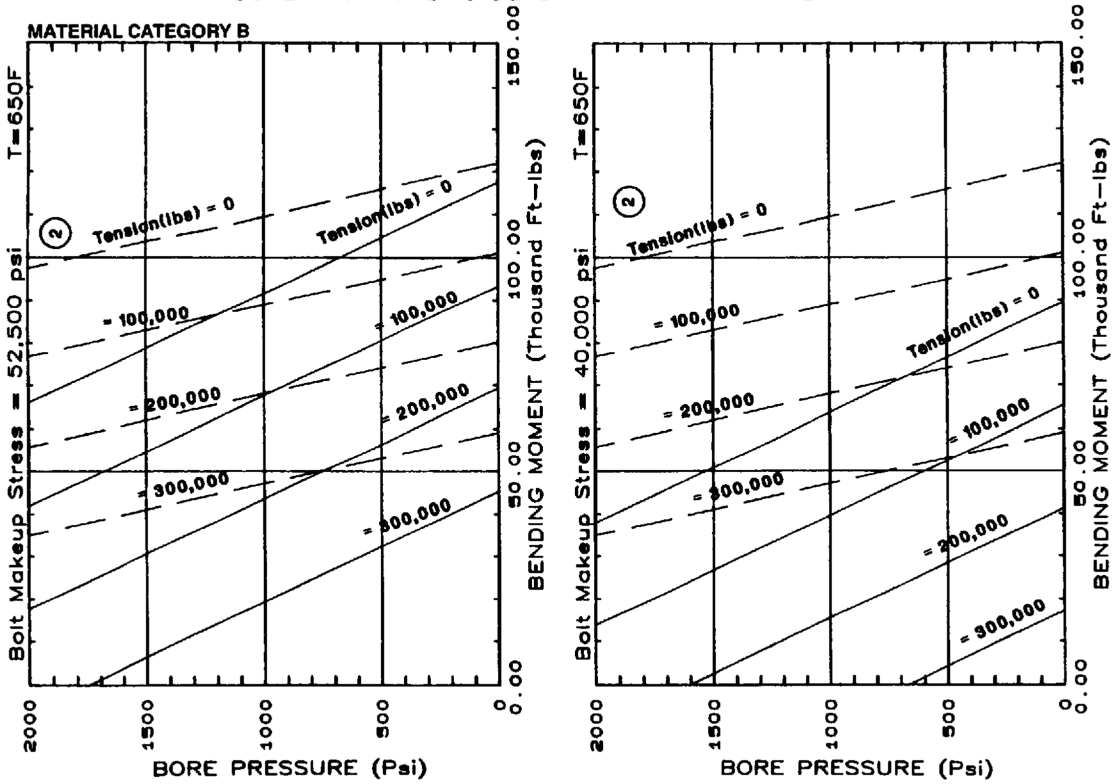
5-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



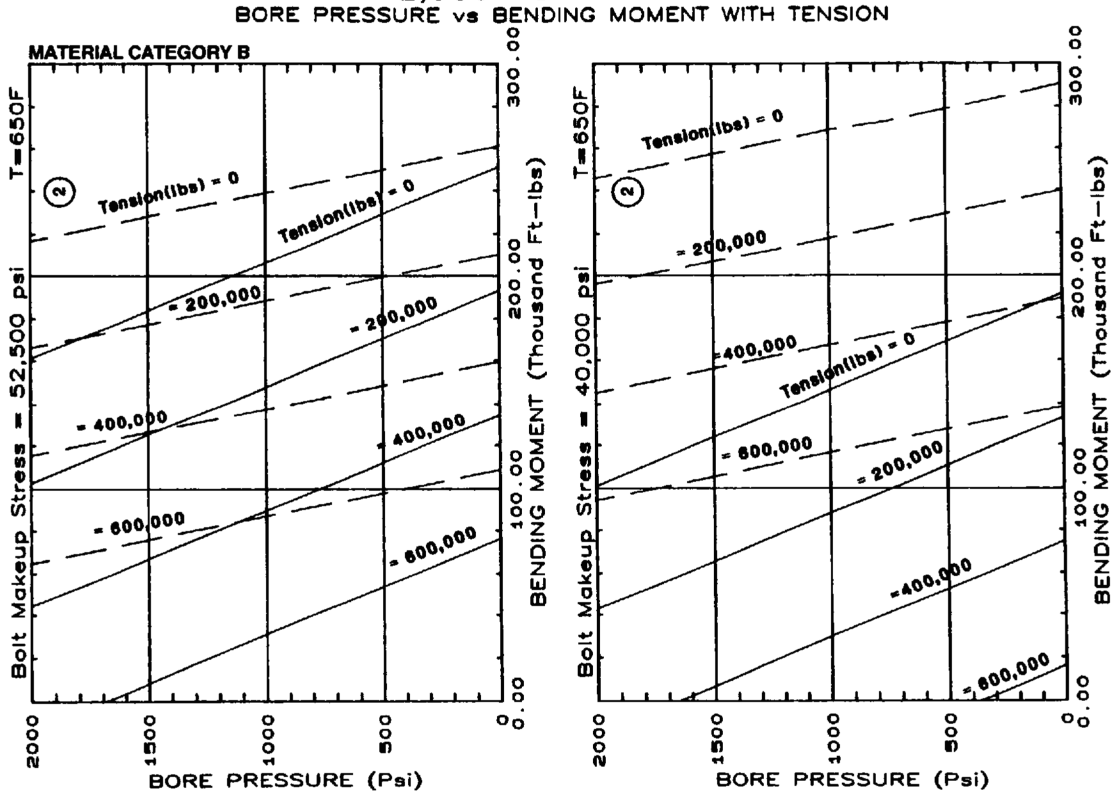
7-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



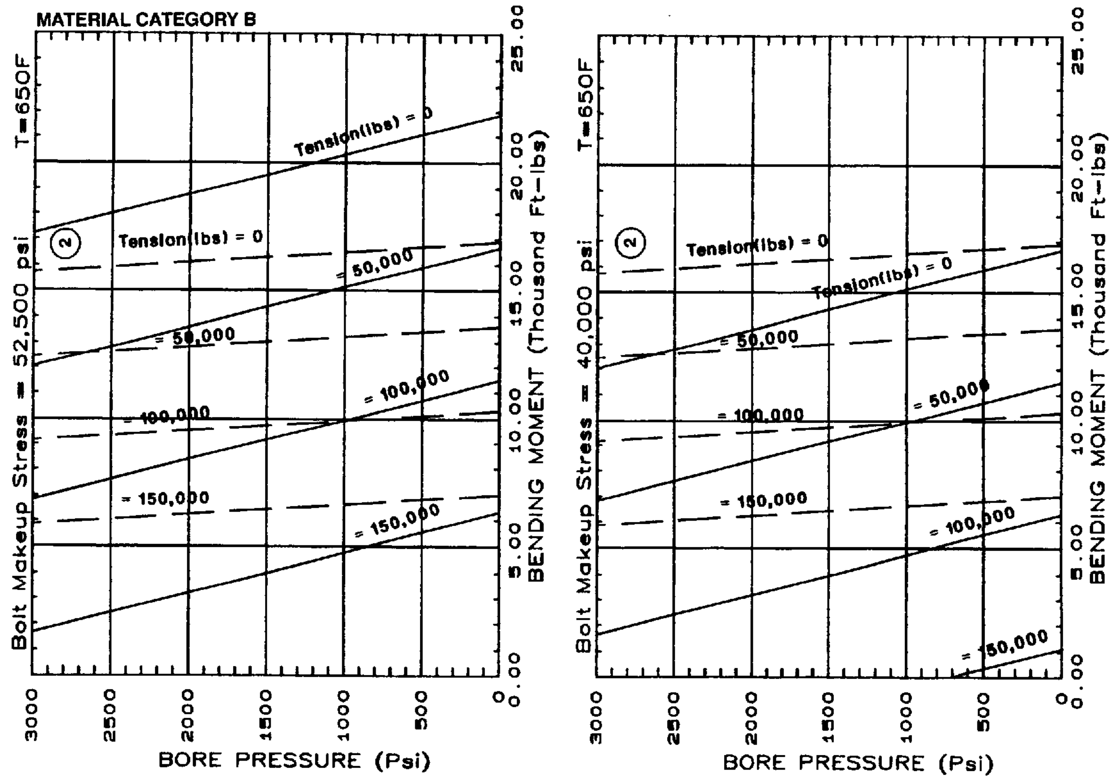
9"—2,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



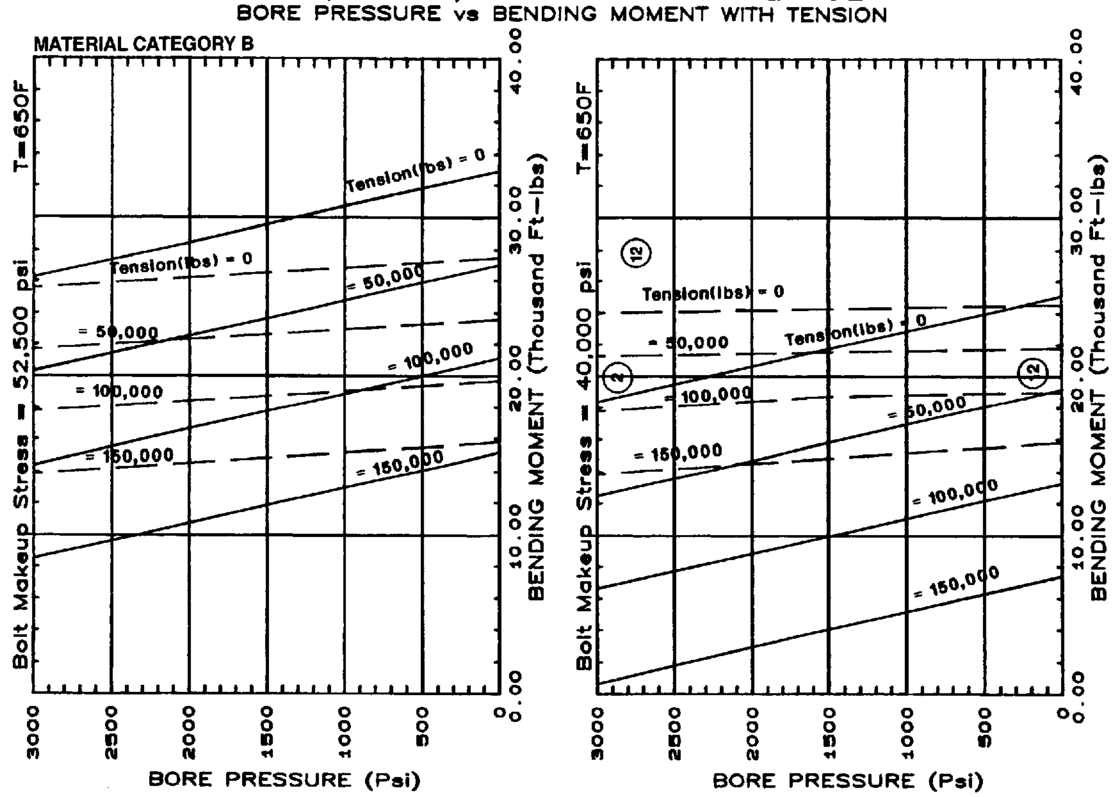
11"—2,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



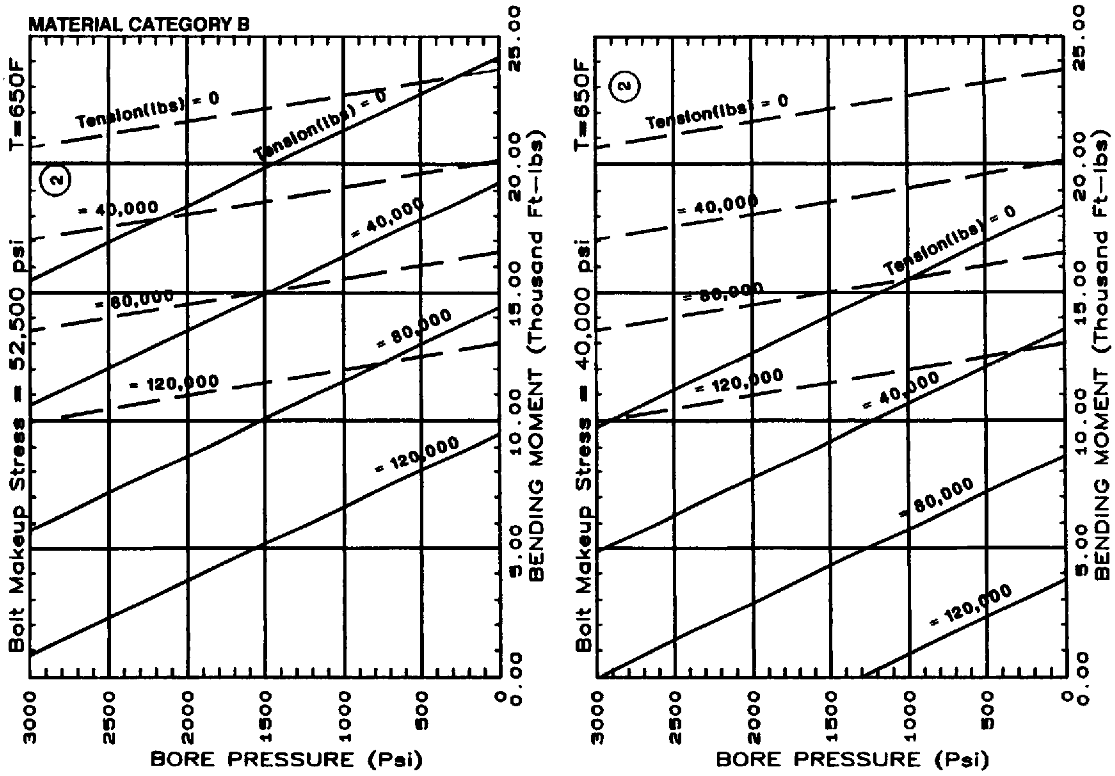
2-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



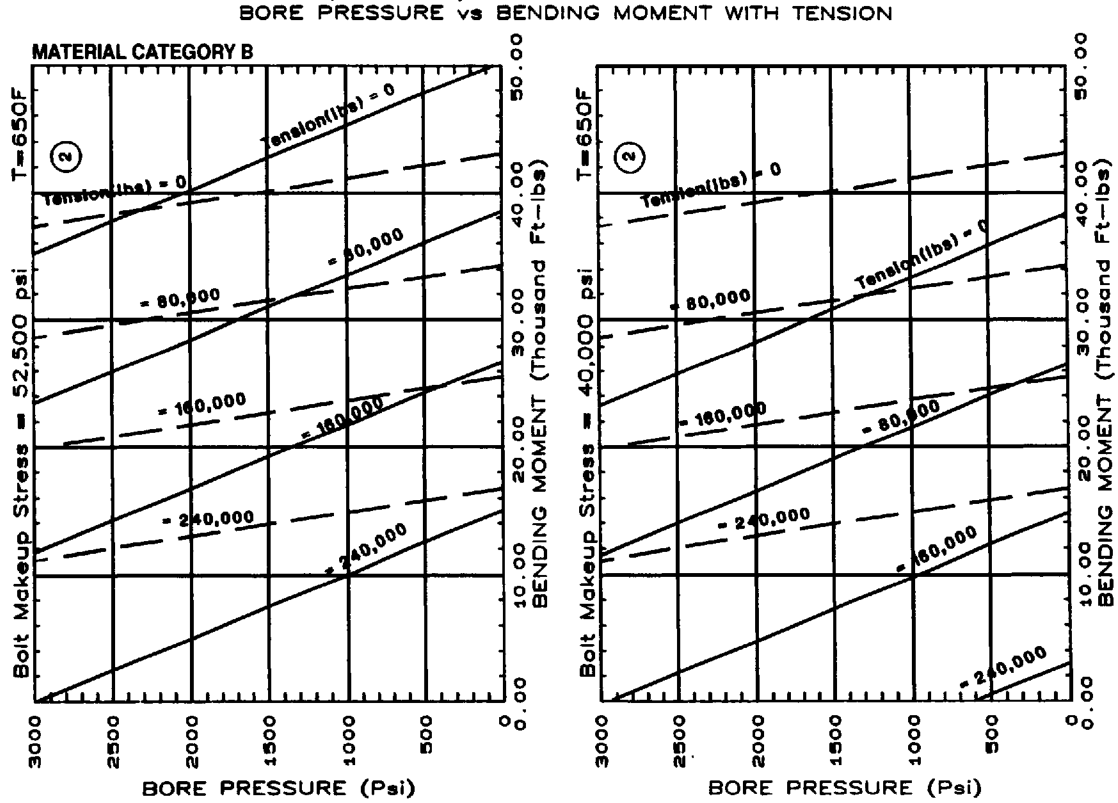
2-9/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



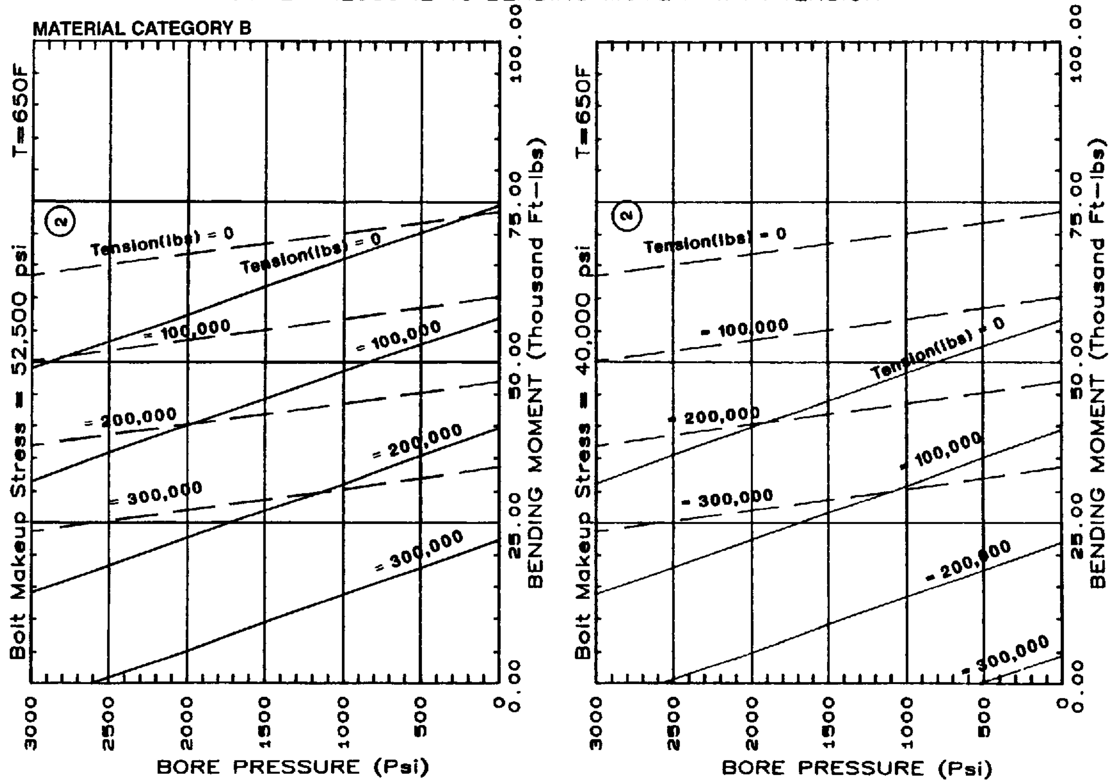
4-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



STD.API/PETRO TR 6AF1-ENGL 1998 0732290 0613536 852

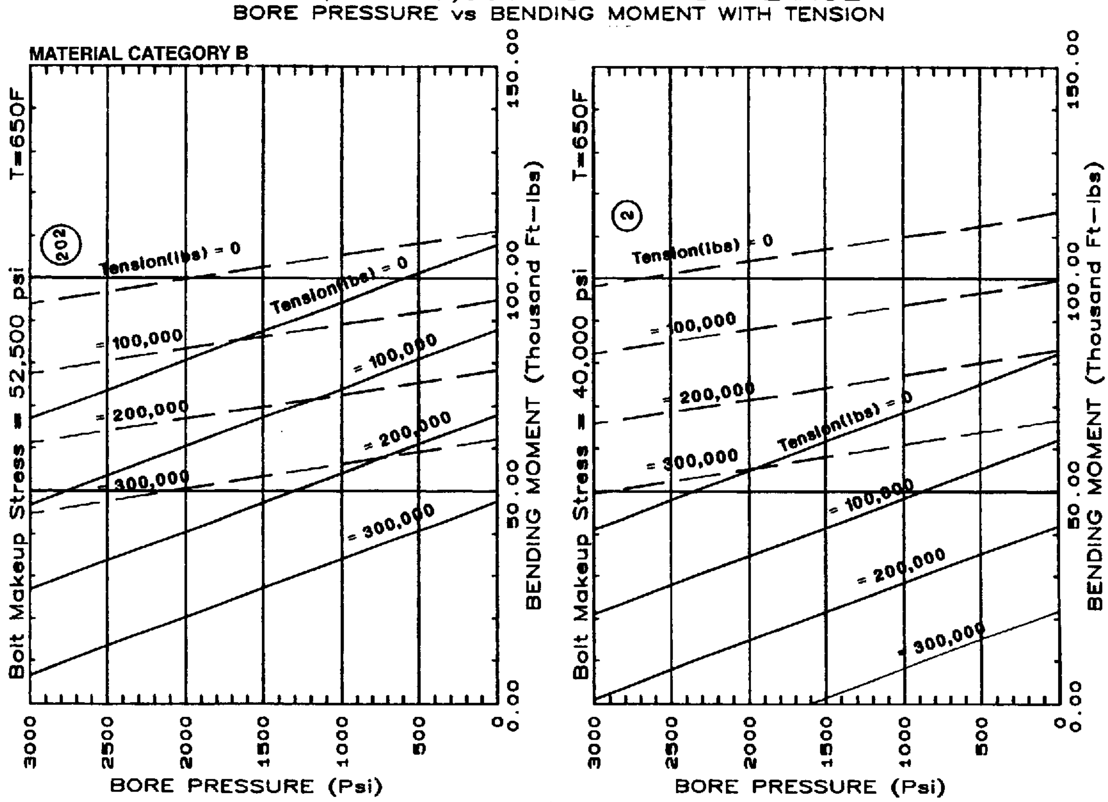
5-1/8"-3,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

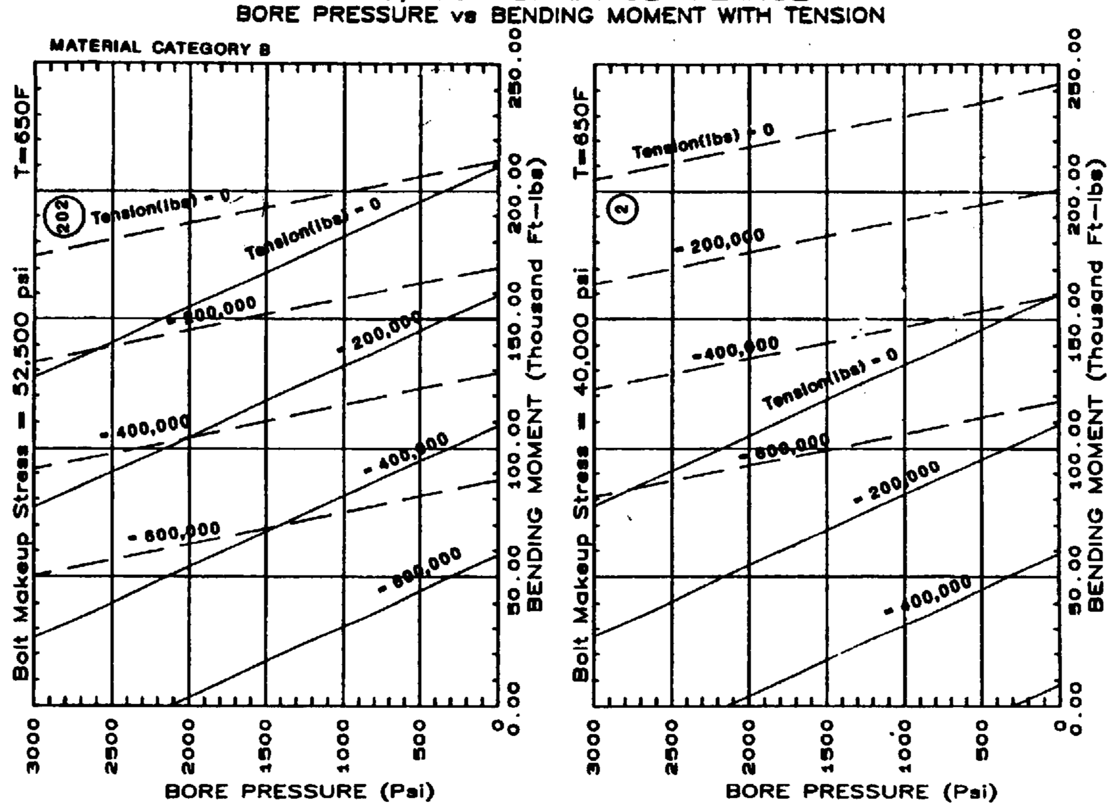


7-1/16"-3,000 PSI API 6B-FLANGE

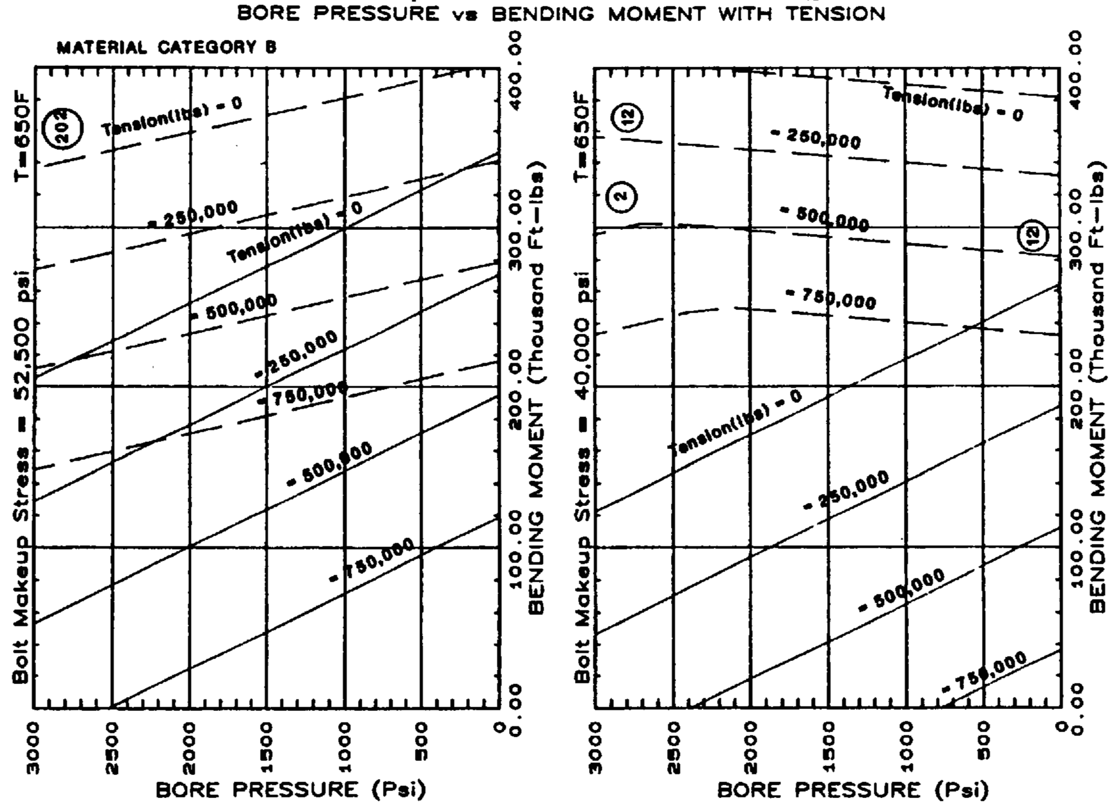
BORE PRESSURE vs BENDING MOMENT WITH TENSION



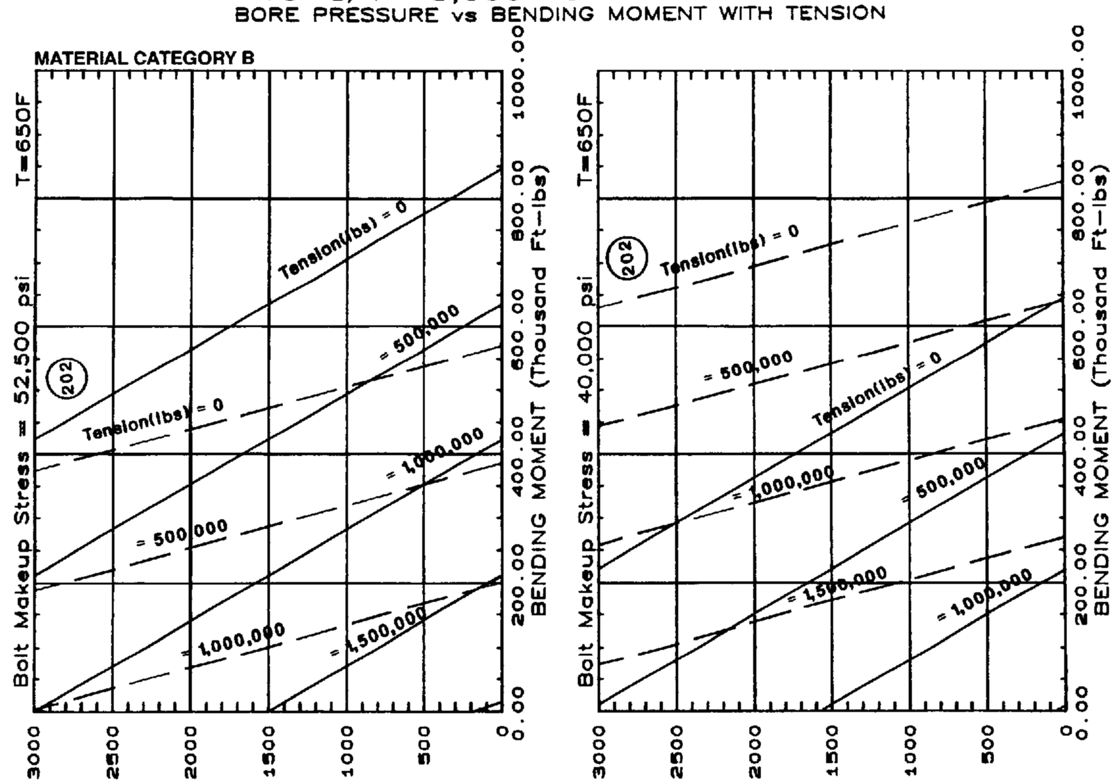
9"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



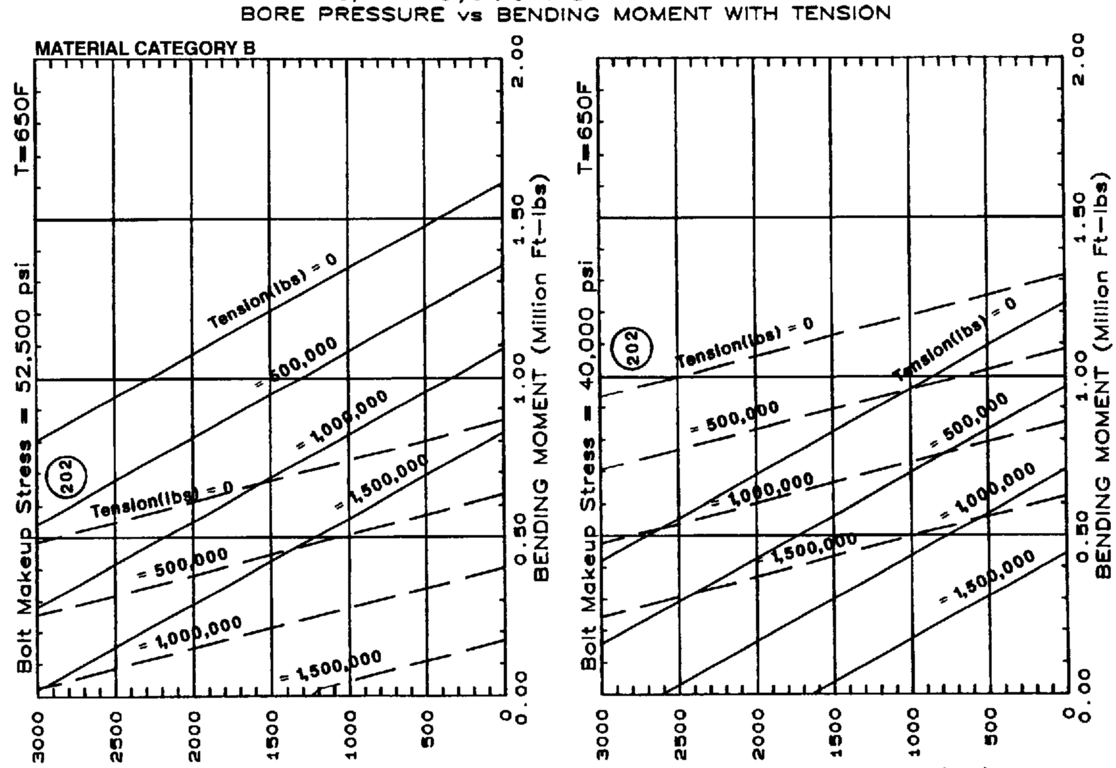
11"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



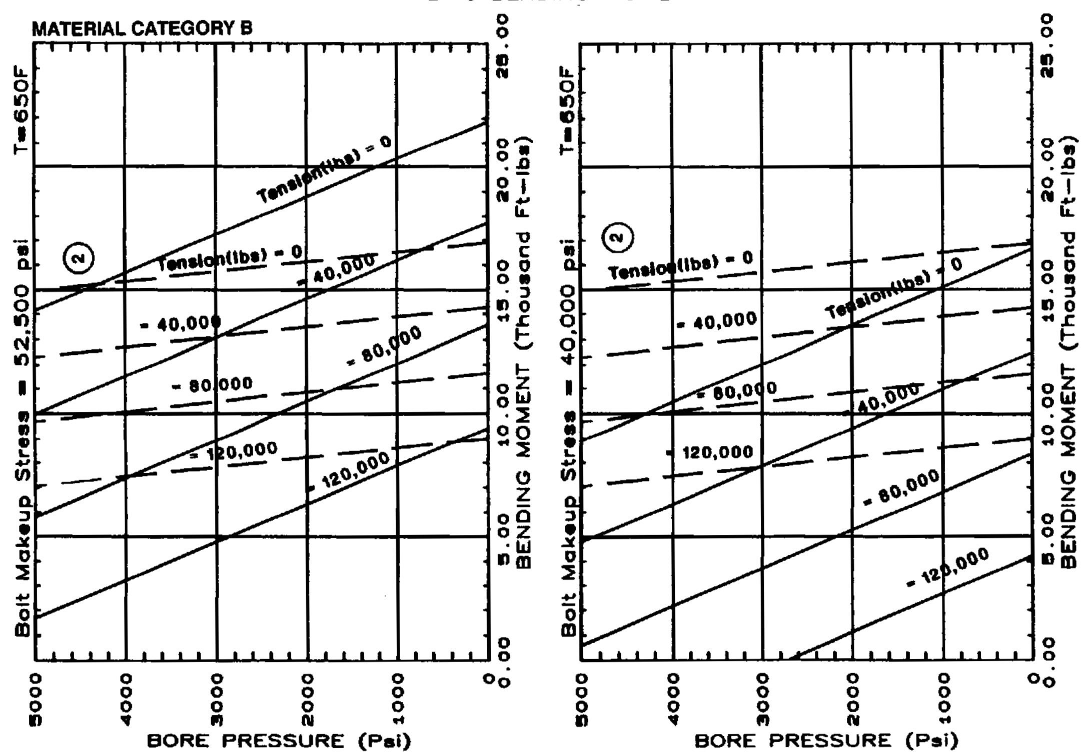
16-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



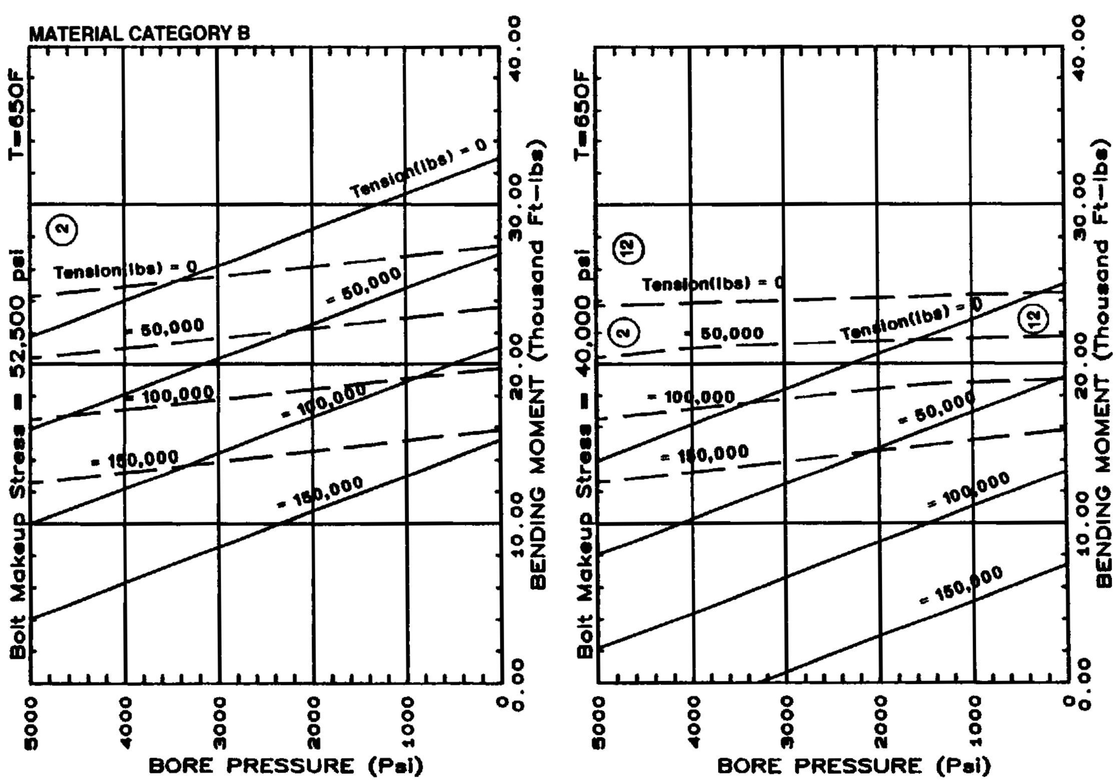
20-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



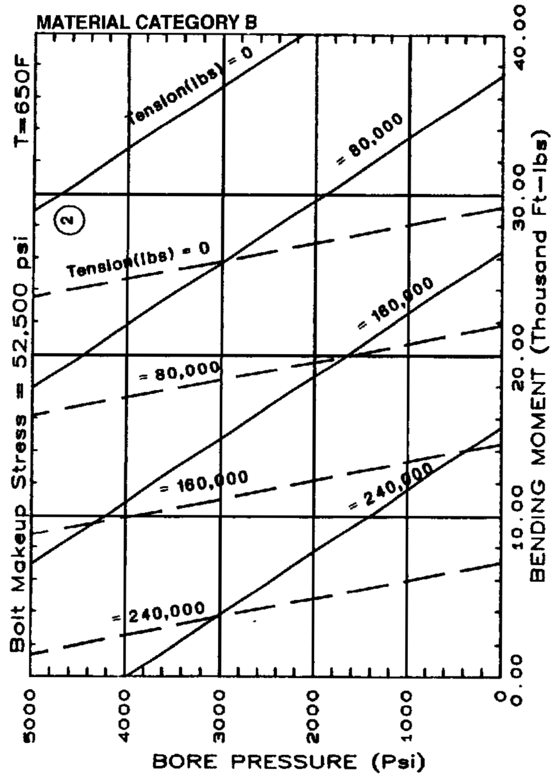
2-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

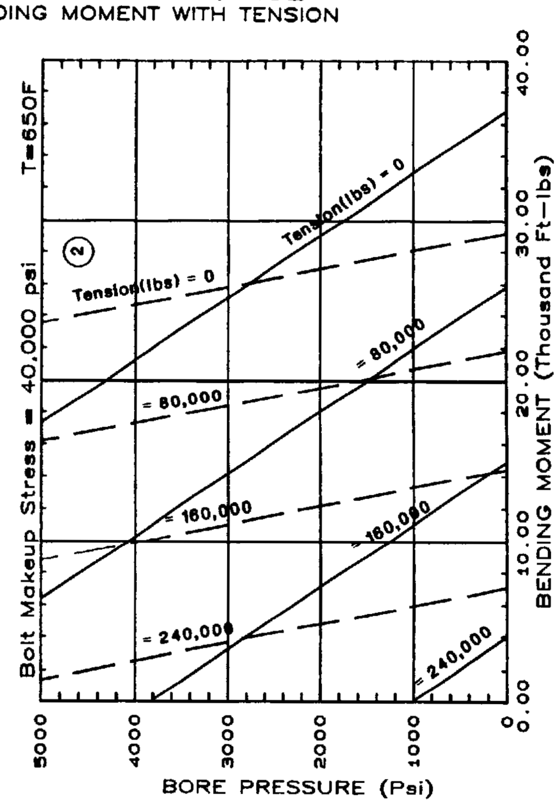


2-9/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

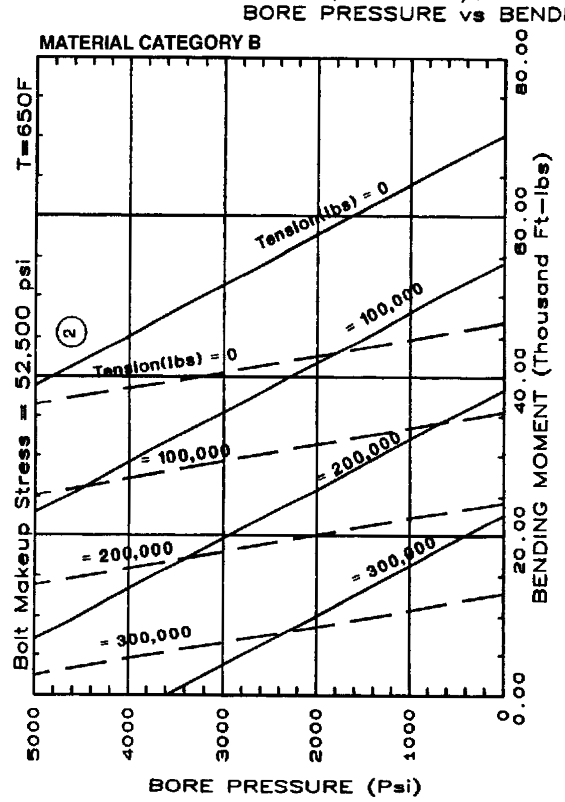


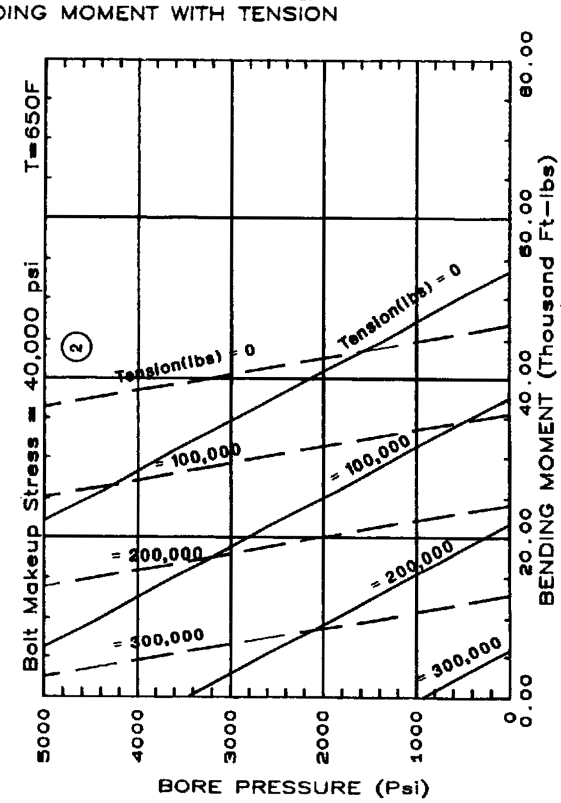
3-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





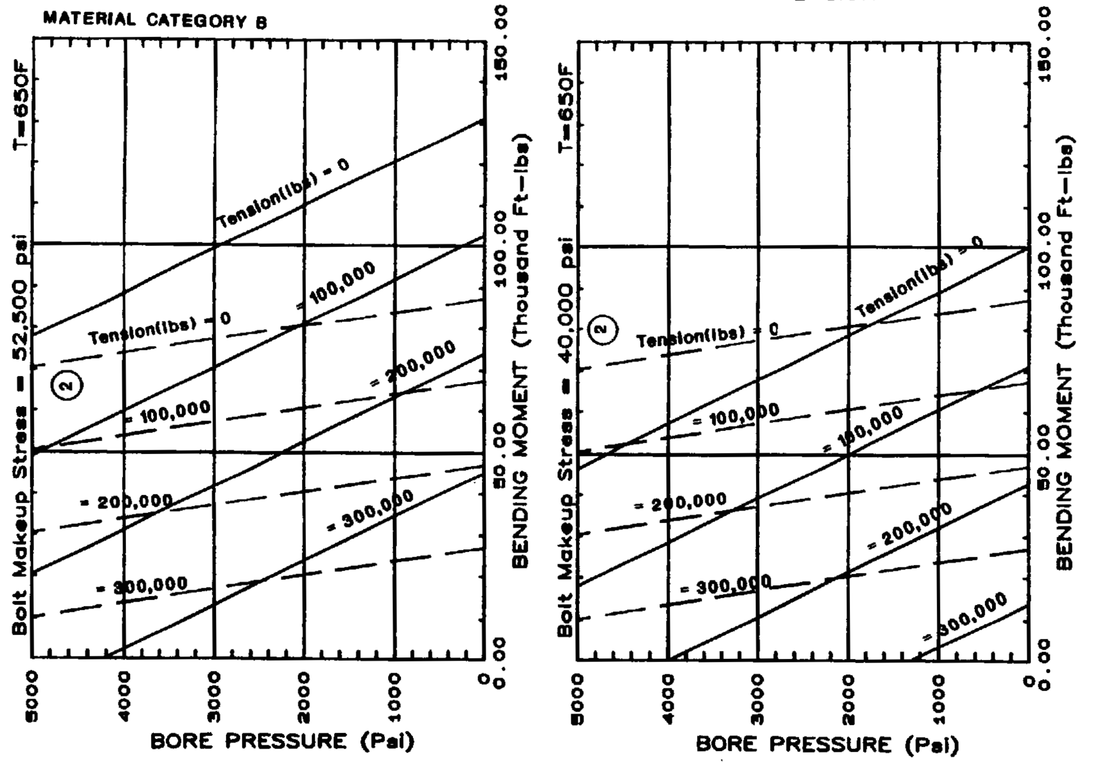
4-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





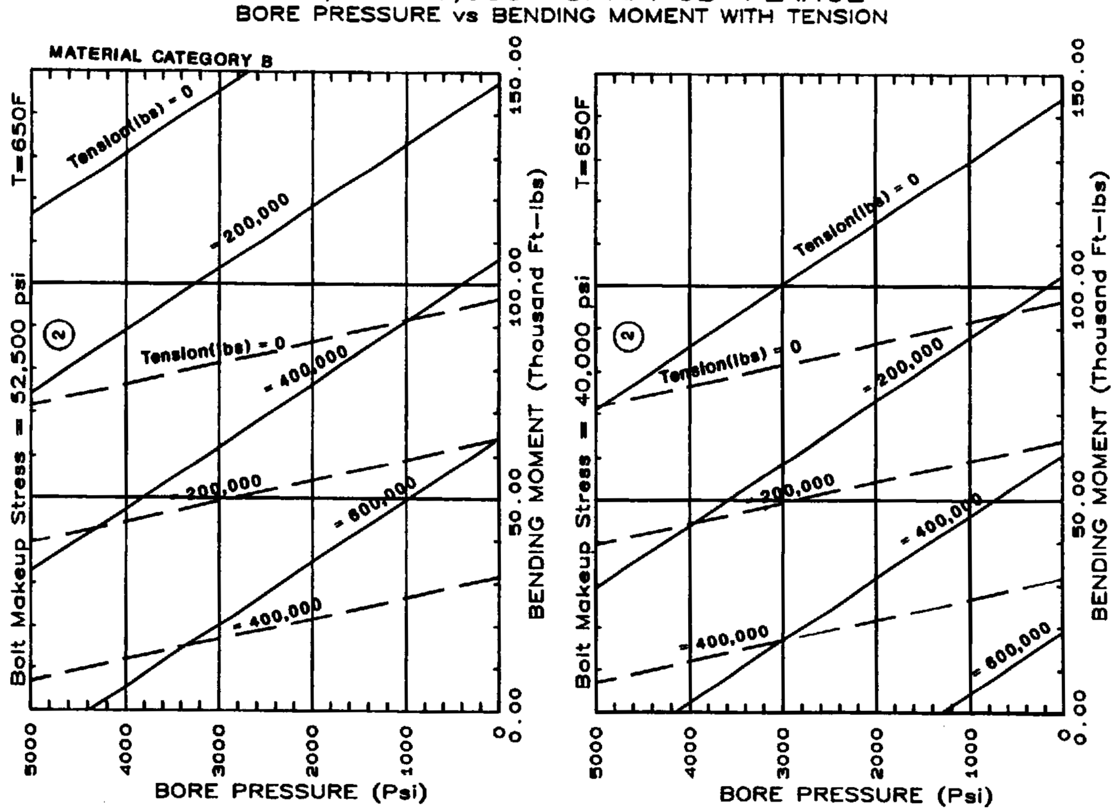
5-1/8"-5,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

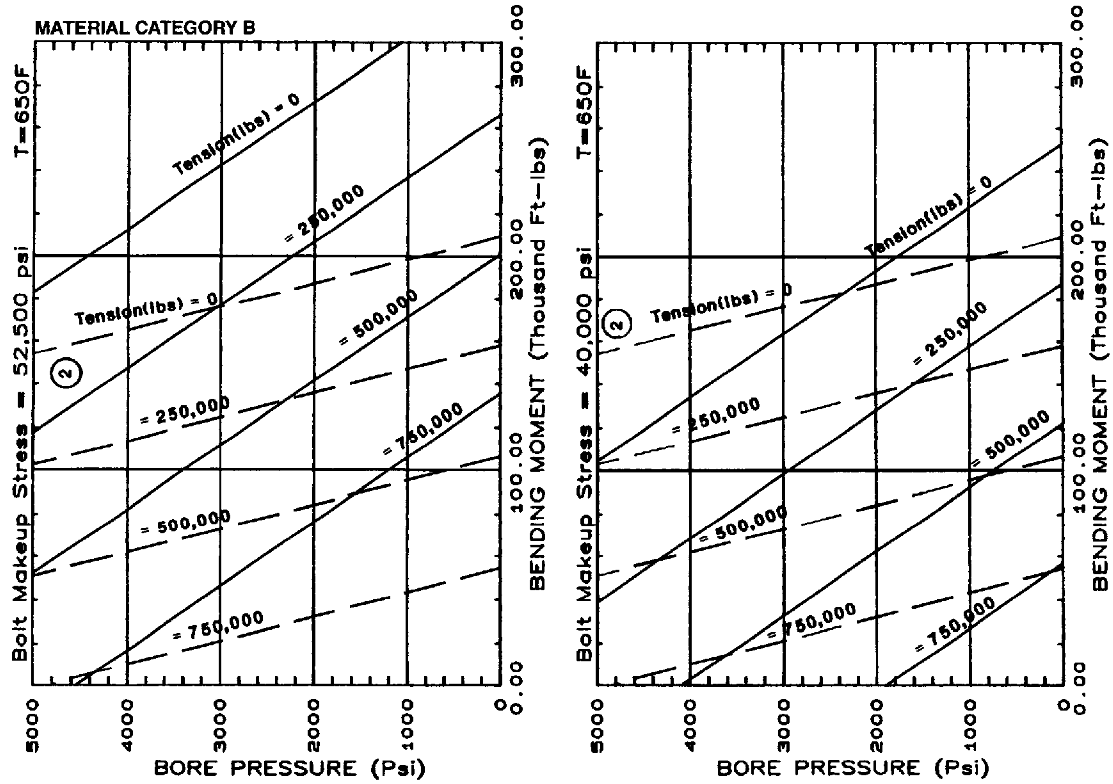


7-1/16"-5,000 PSI API 6B-FLANGE

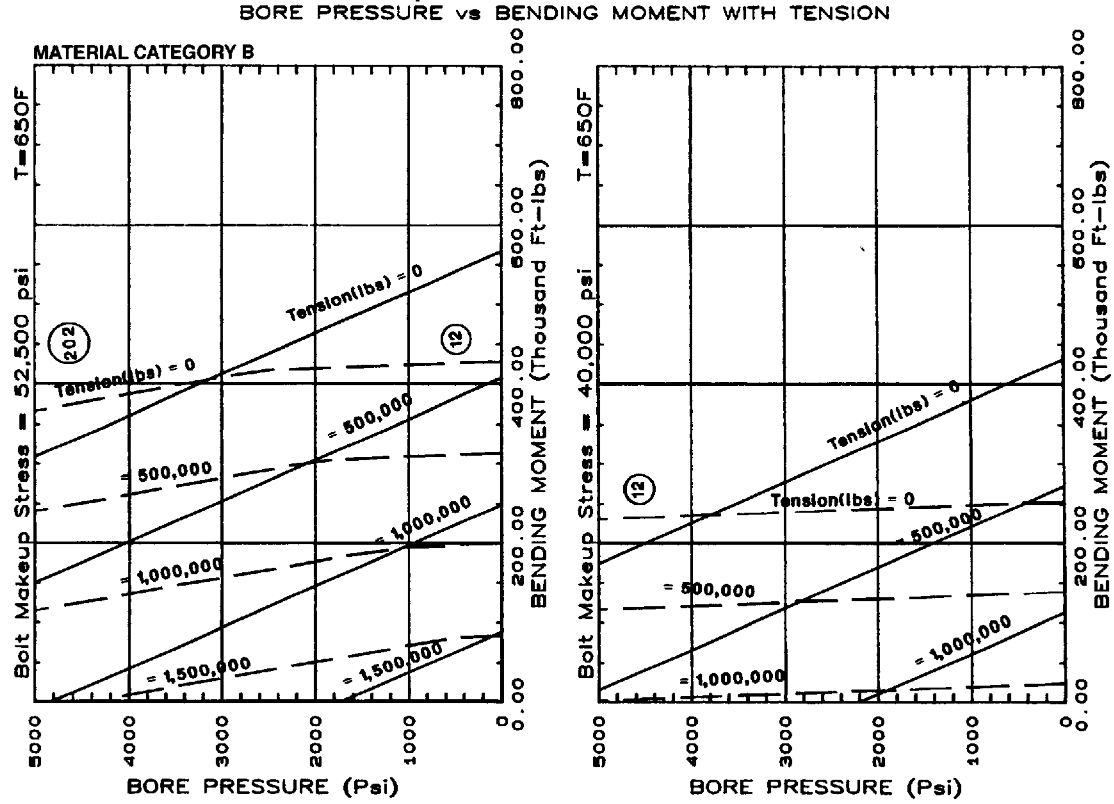
BORE PRESSURE vs BENDING MOMENT WITH TENSION



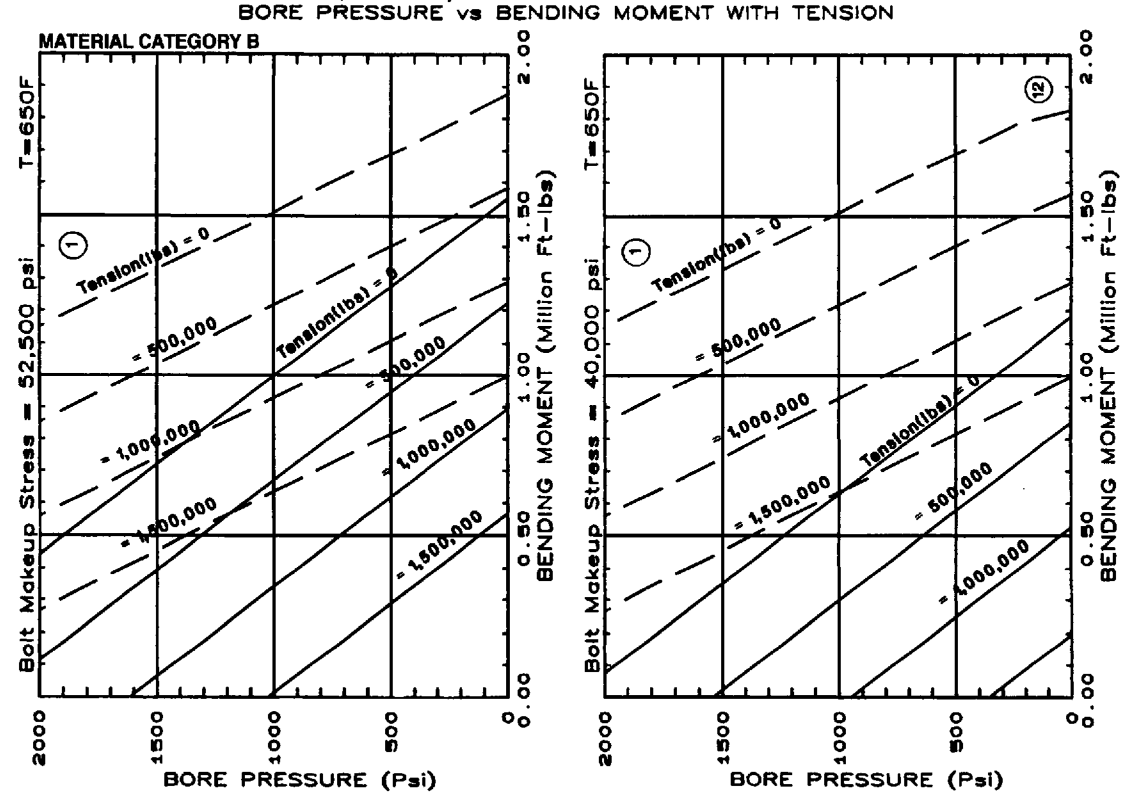
9"—5,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



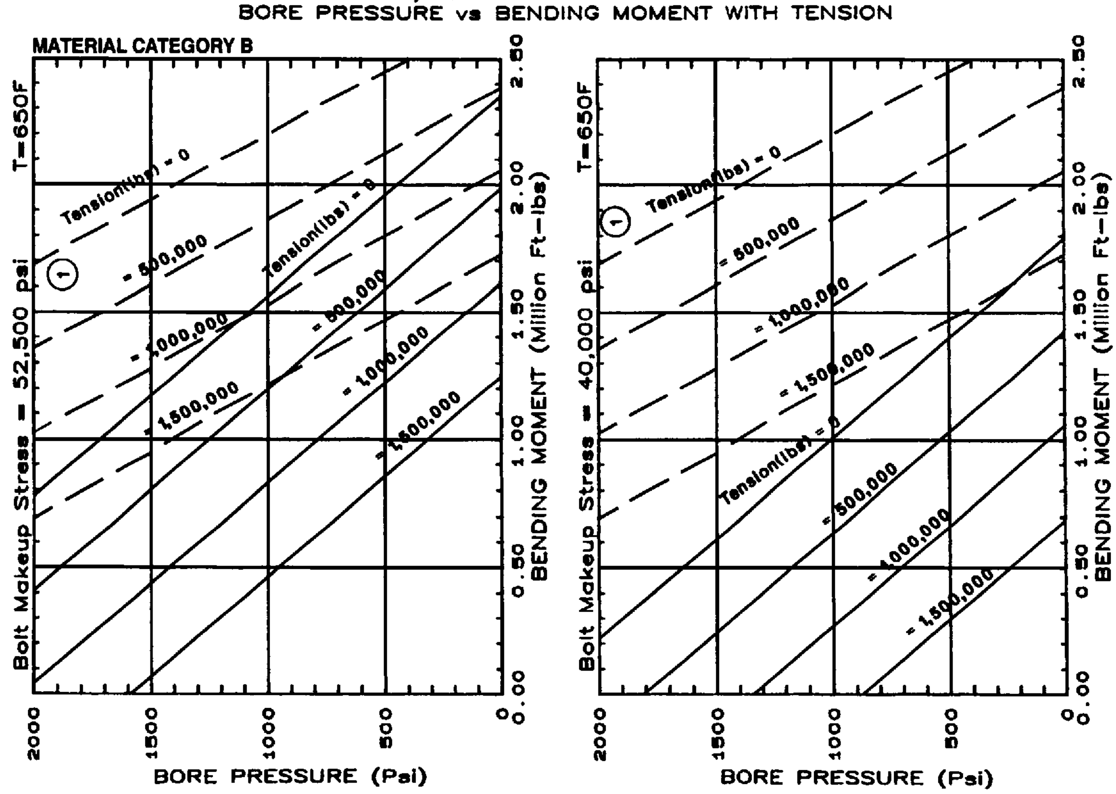
11"—5,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



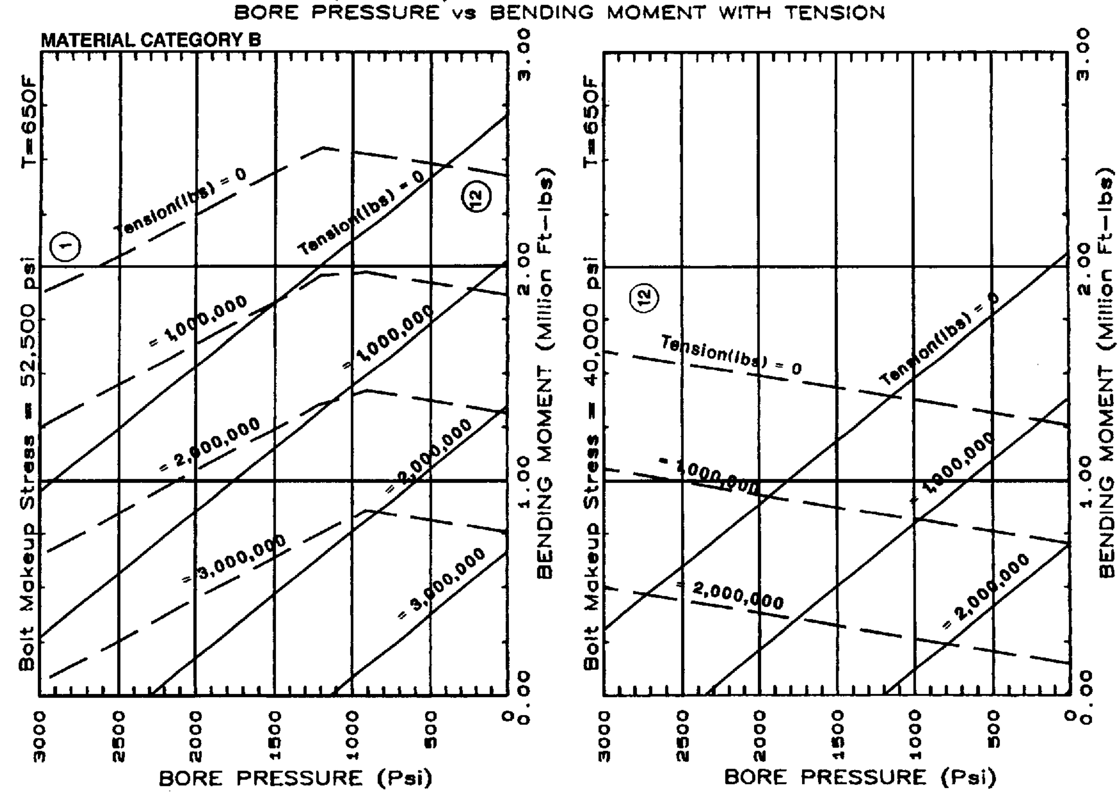
26-3/4"-2,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



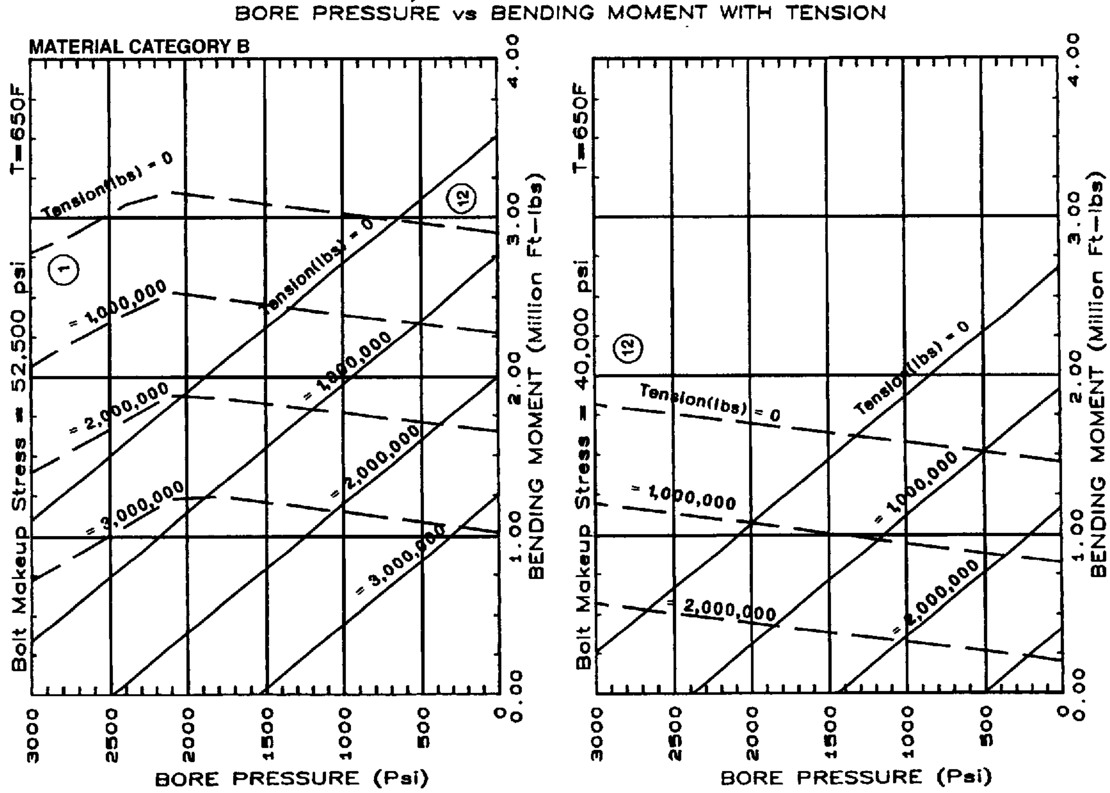
30"-2,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



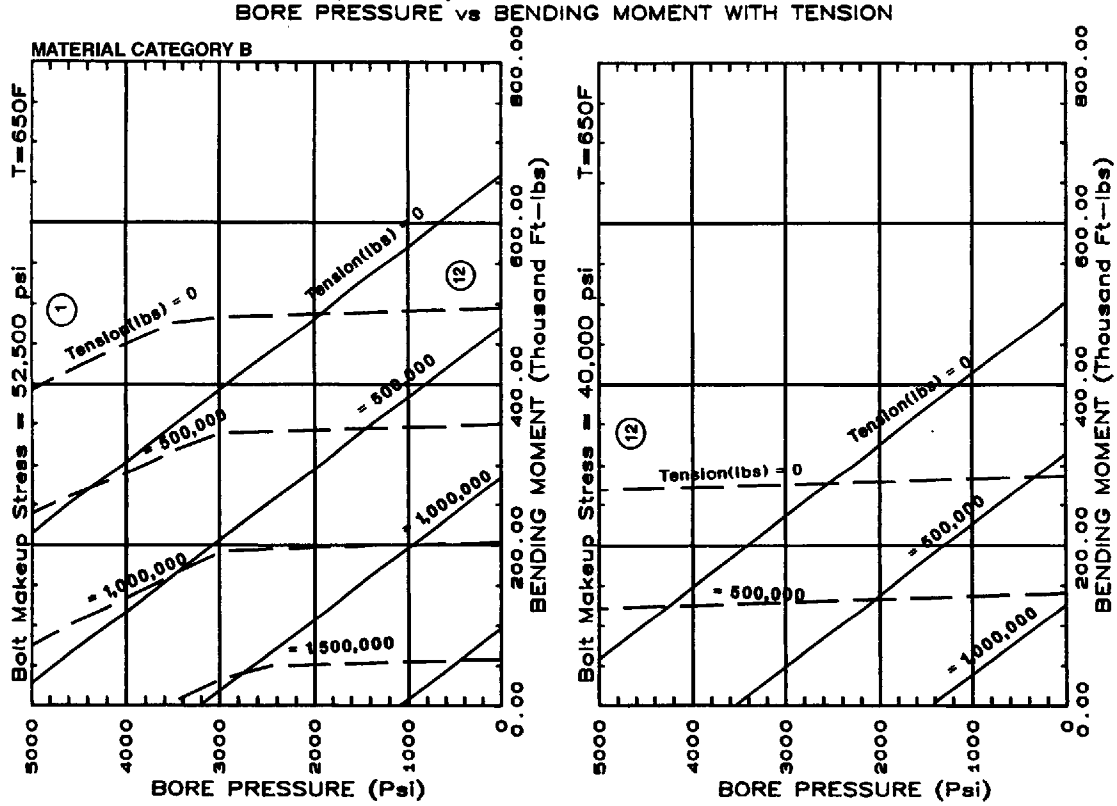
26-3/4"-3,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



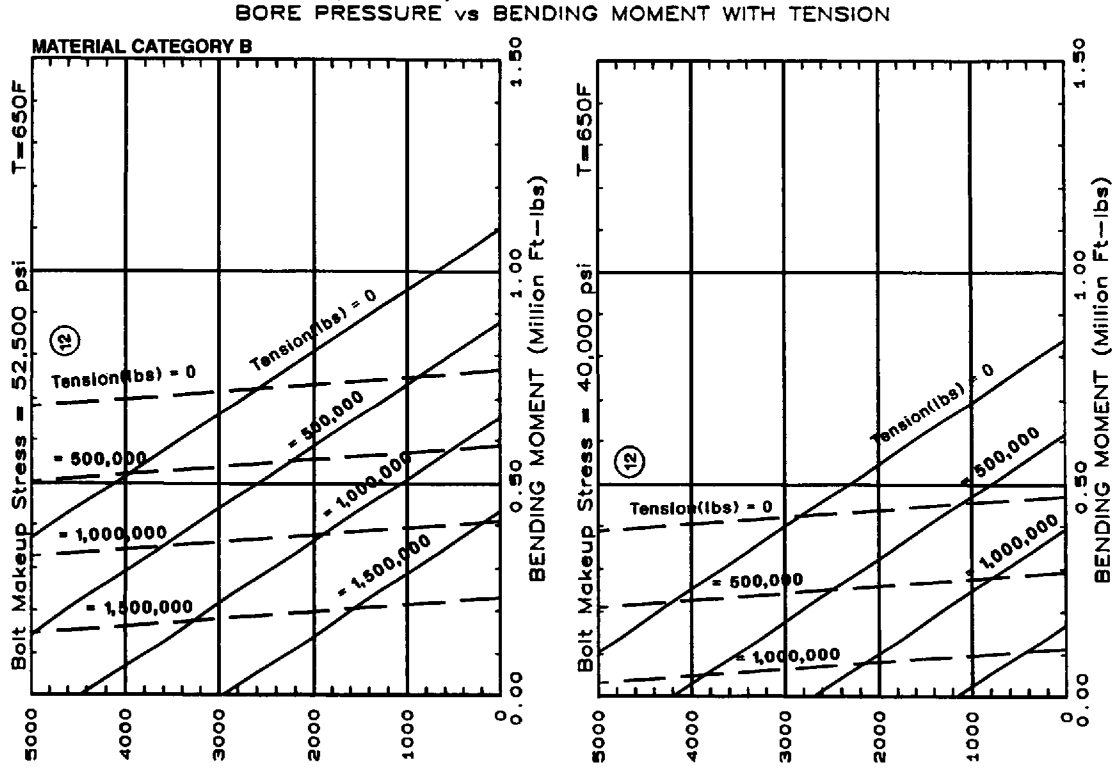
30"-3,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



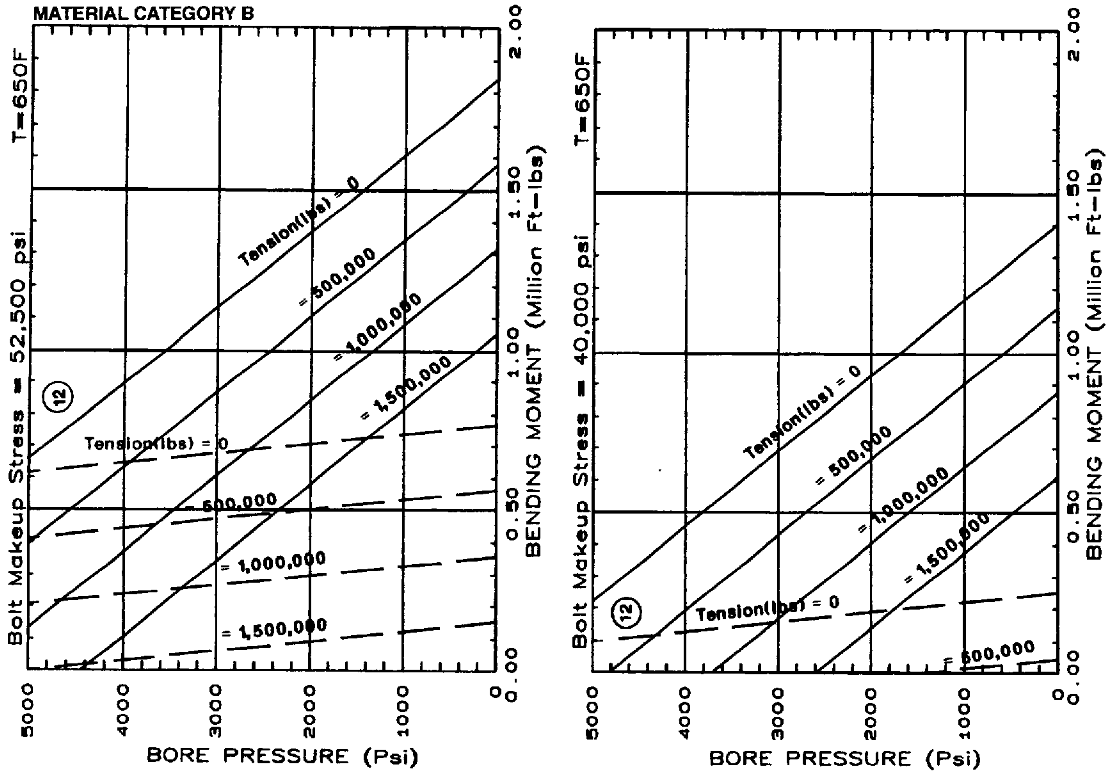
13-5/8"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



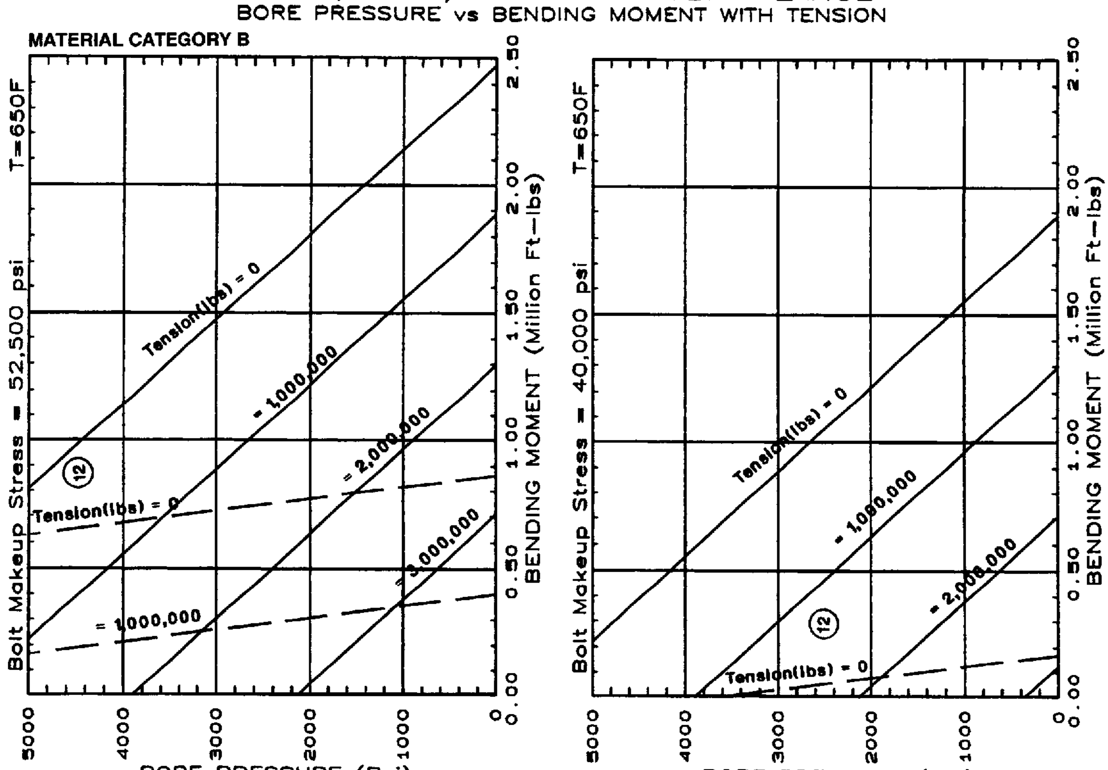
16-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



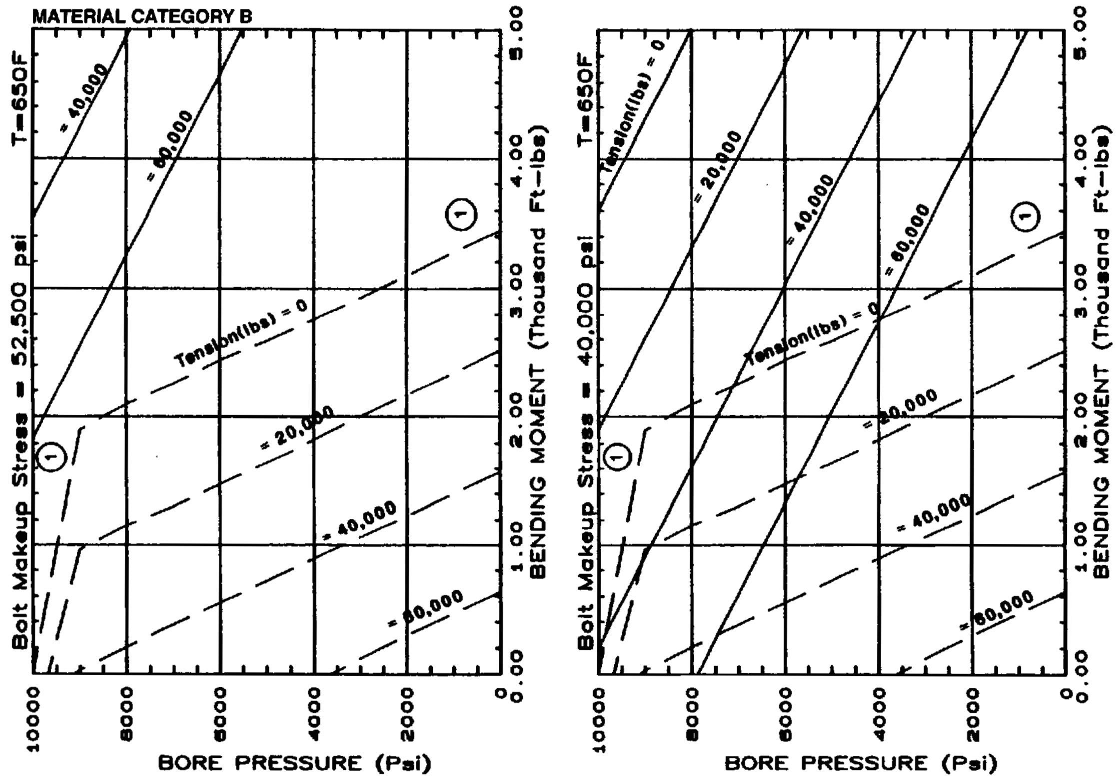
18–3/4"–5,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



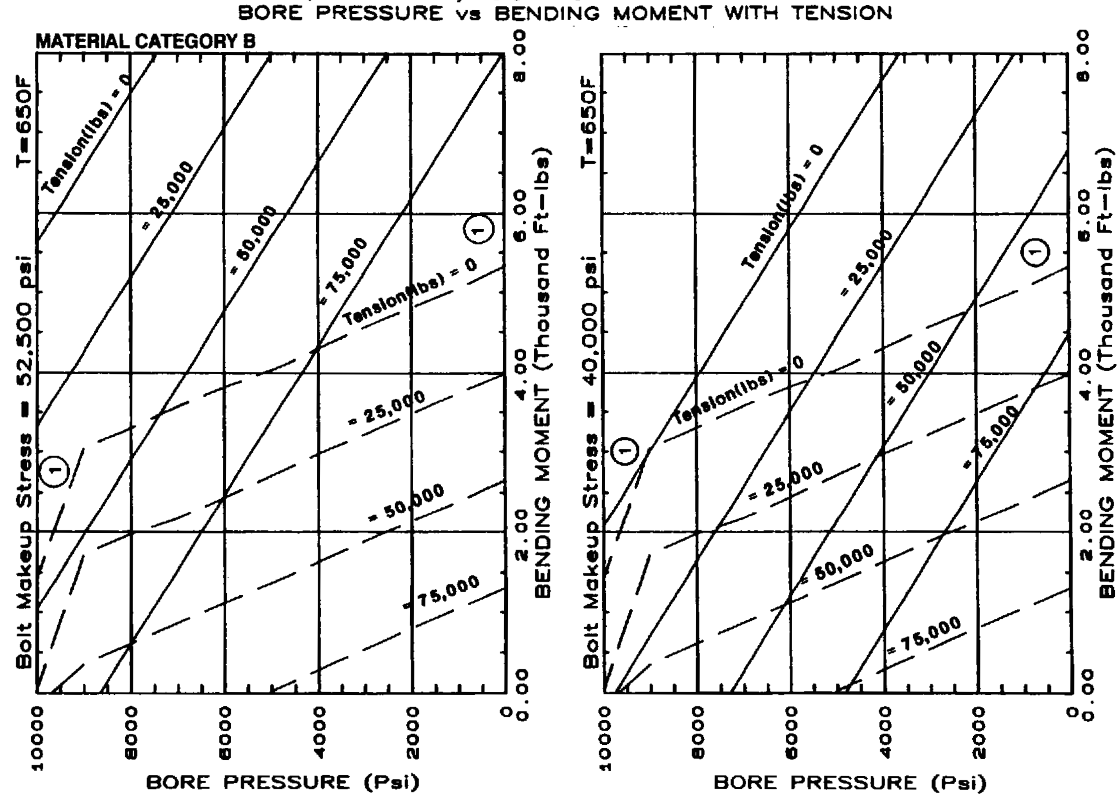
21–1/4"–5,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



1–13/16"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

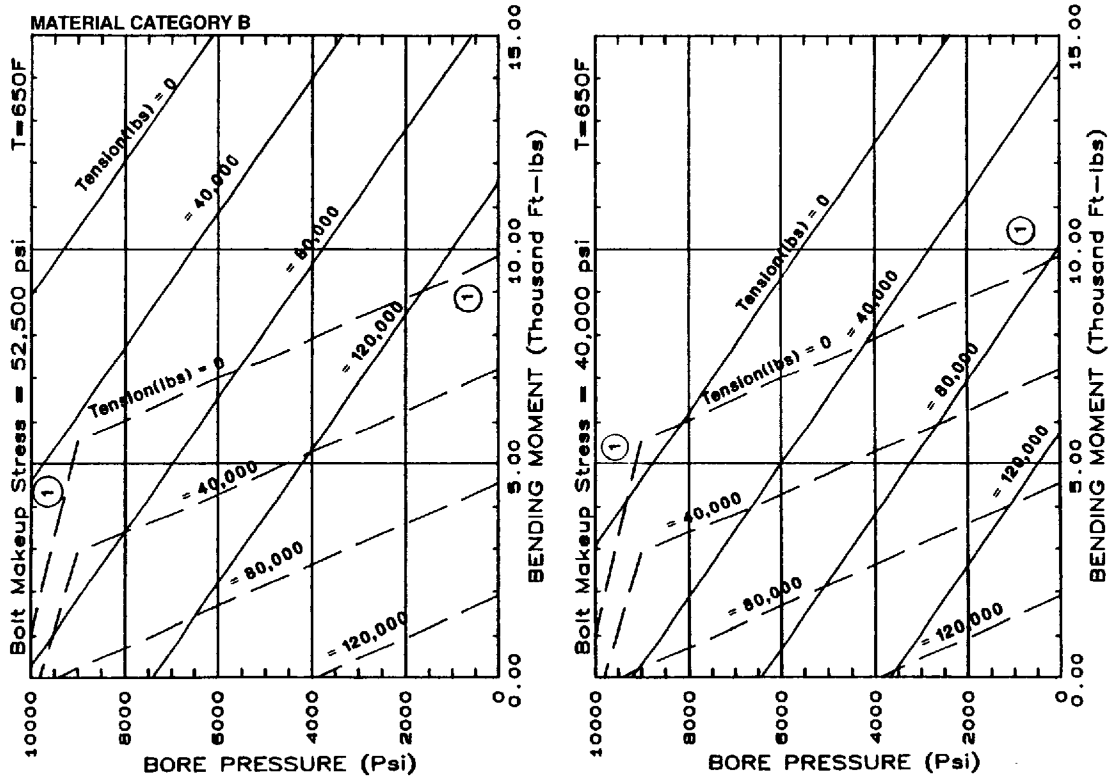


2–1/16"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



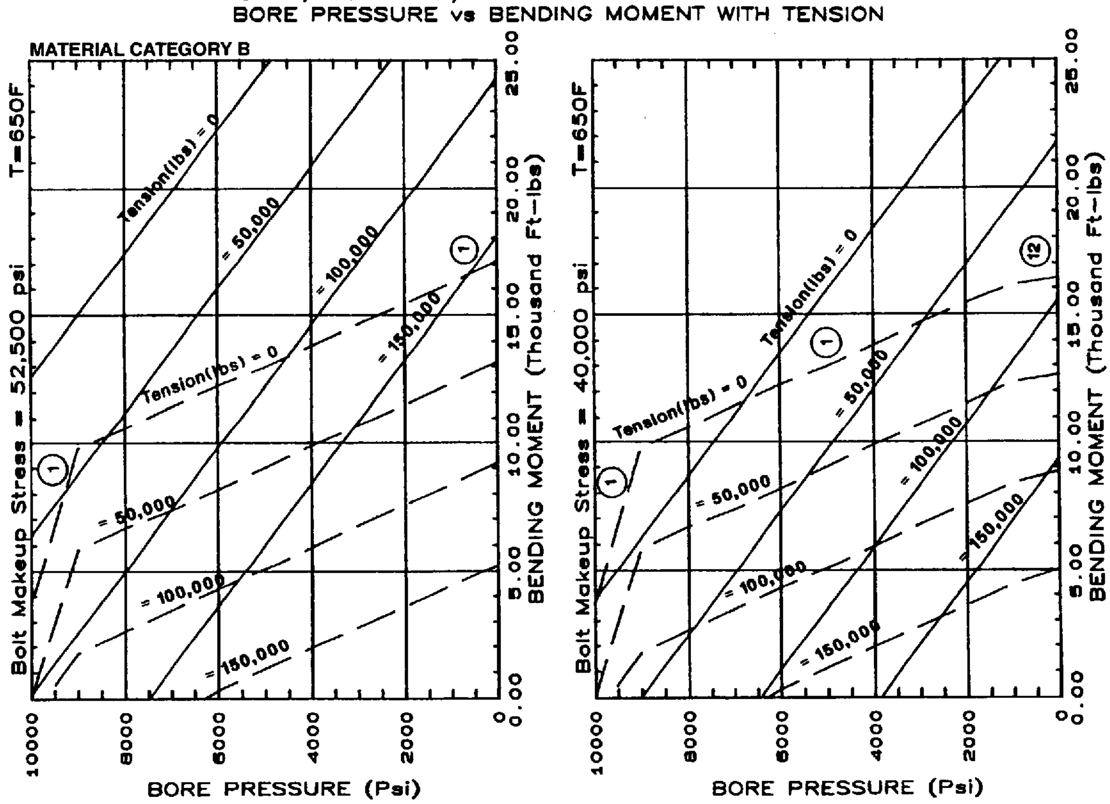
2-9/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

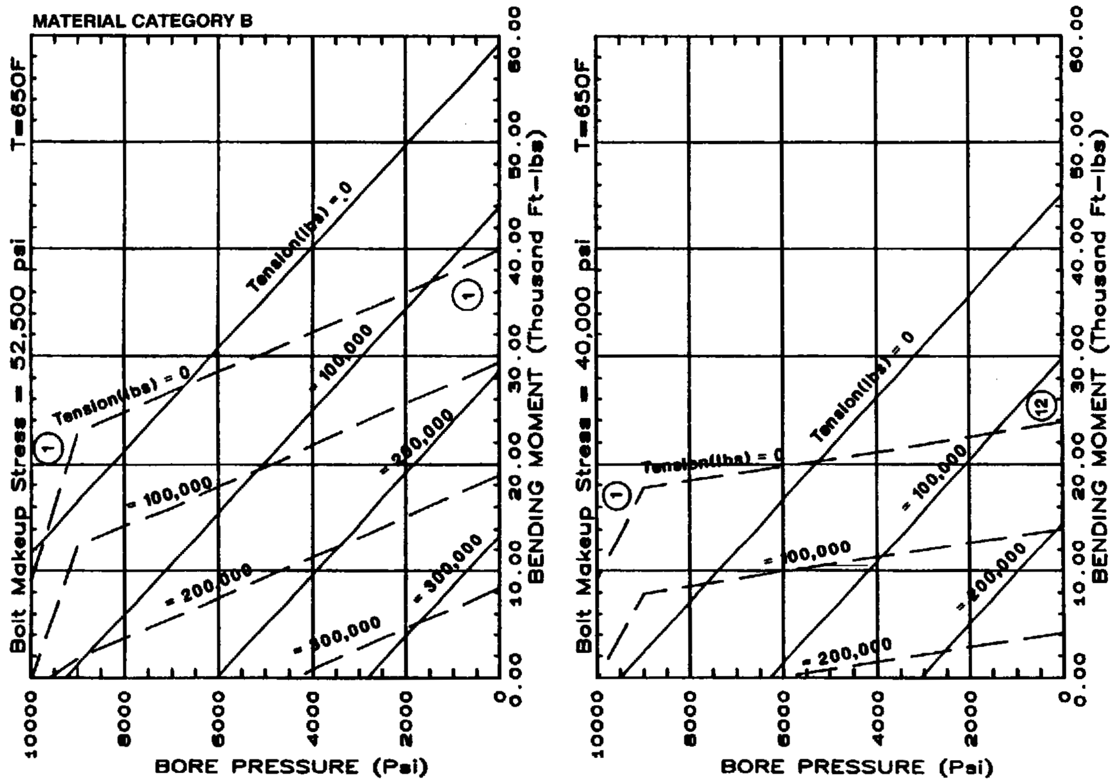


3-1/16"-10,000 PSI API 6BX-FLANGE

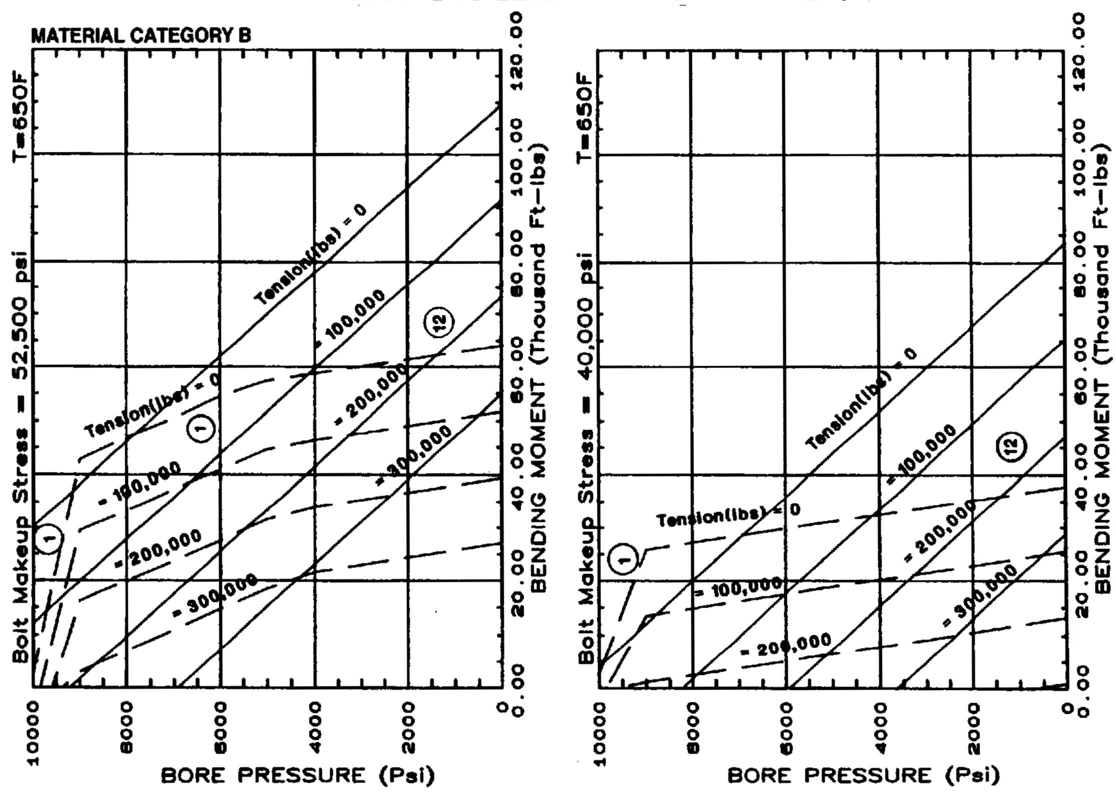
BORE PRESSURE vs BENDING MOMENT WITH TENSION

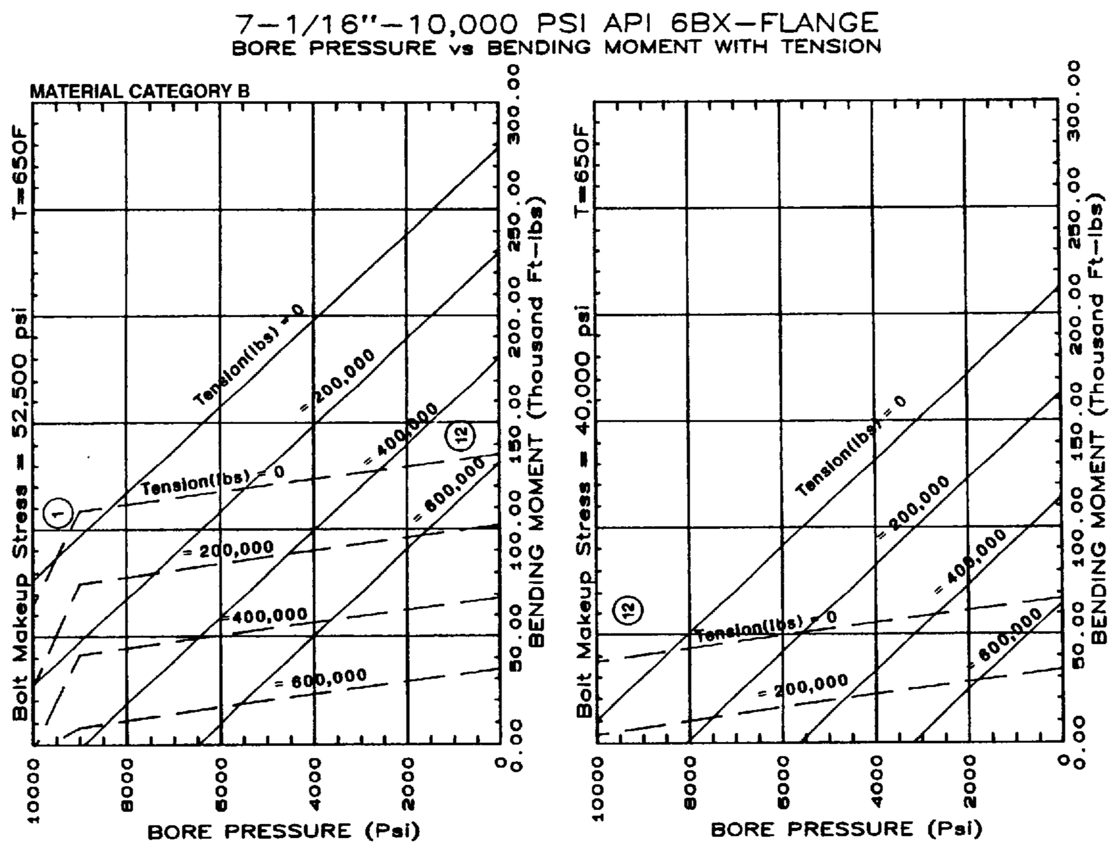


4-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

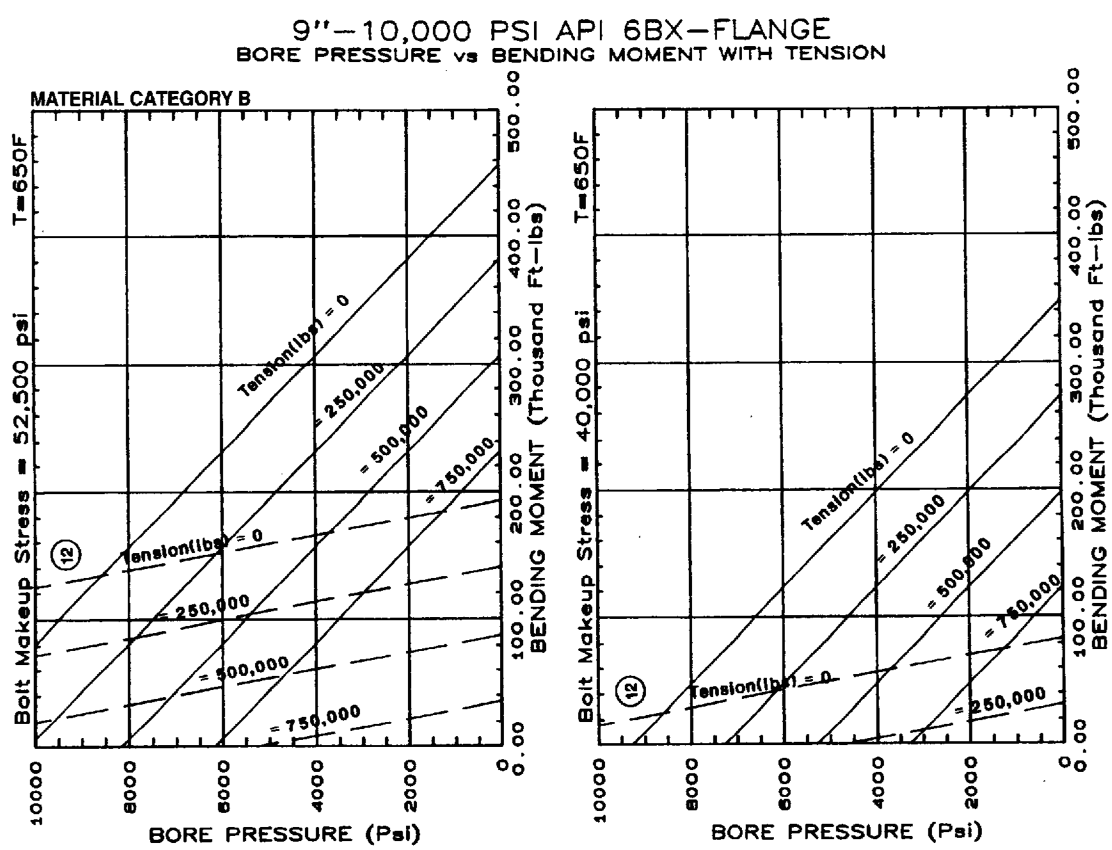


5-1/8"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





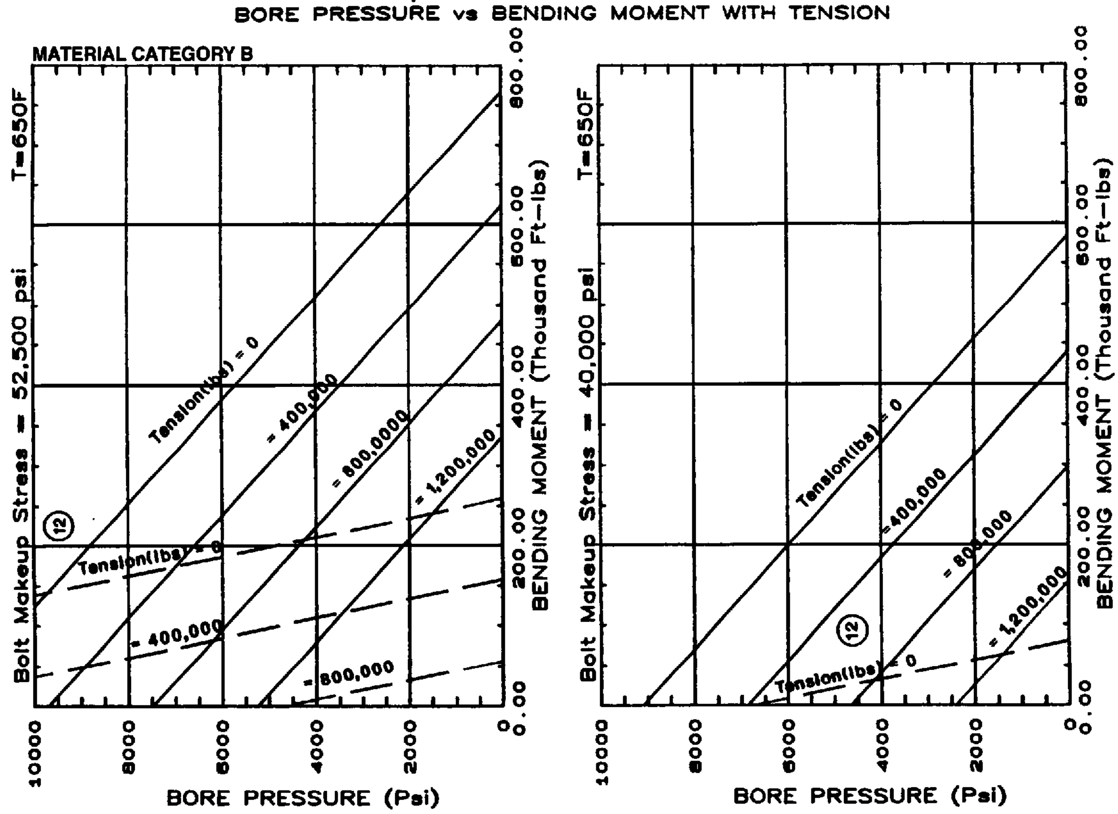
7-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=650F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 200,000
= 400,000
= 600,000



9"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY B
T=650F
Bolt Makeup Stress = 52,500 psi
Bolt Makeup Stress = 40,000 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 250,000
= 500,000
= 750,000

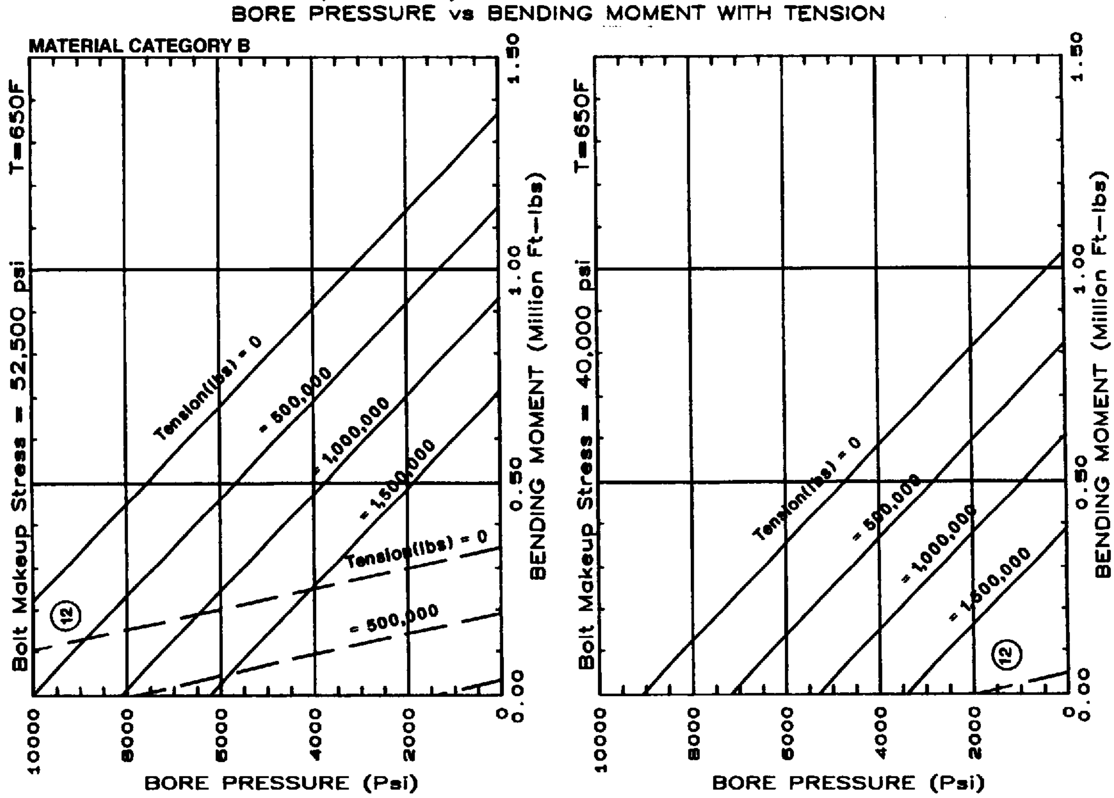
11"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

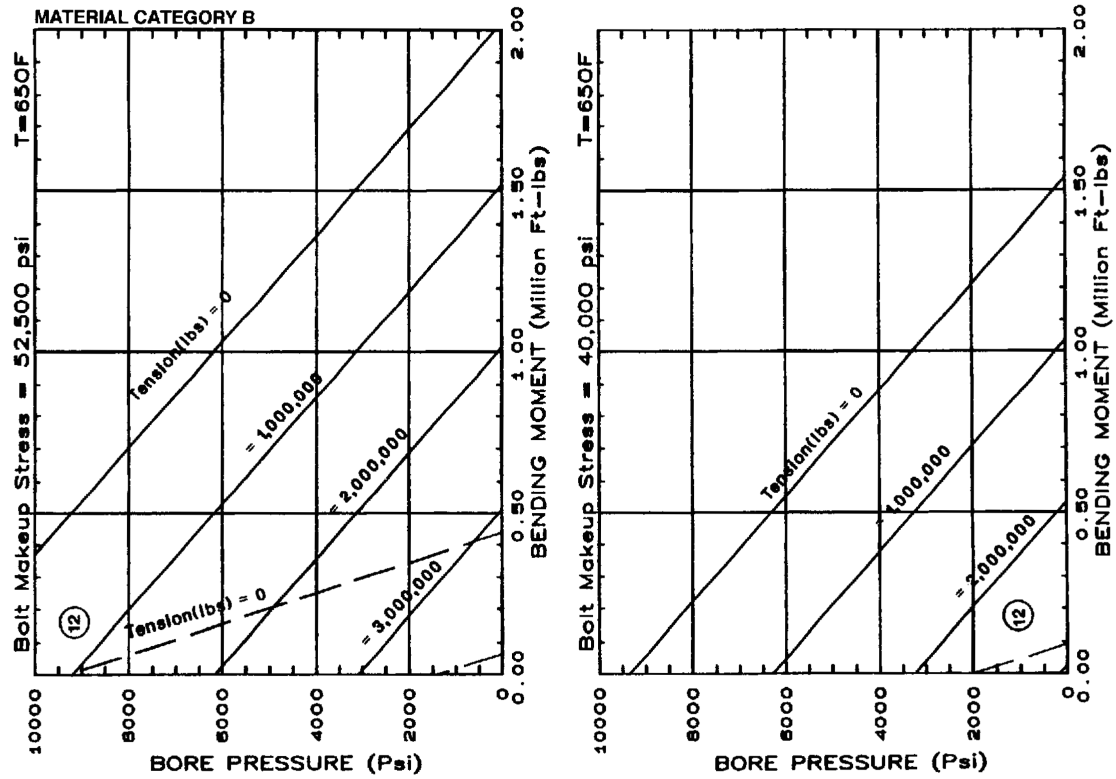


13-5/8"-10,000 PSI API 6BX-FLANGE

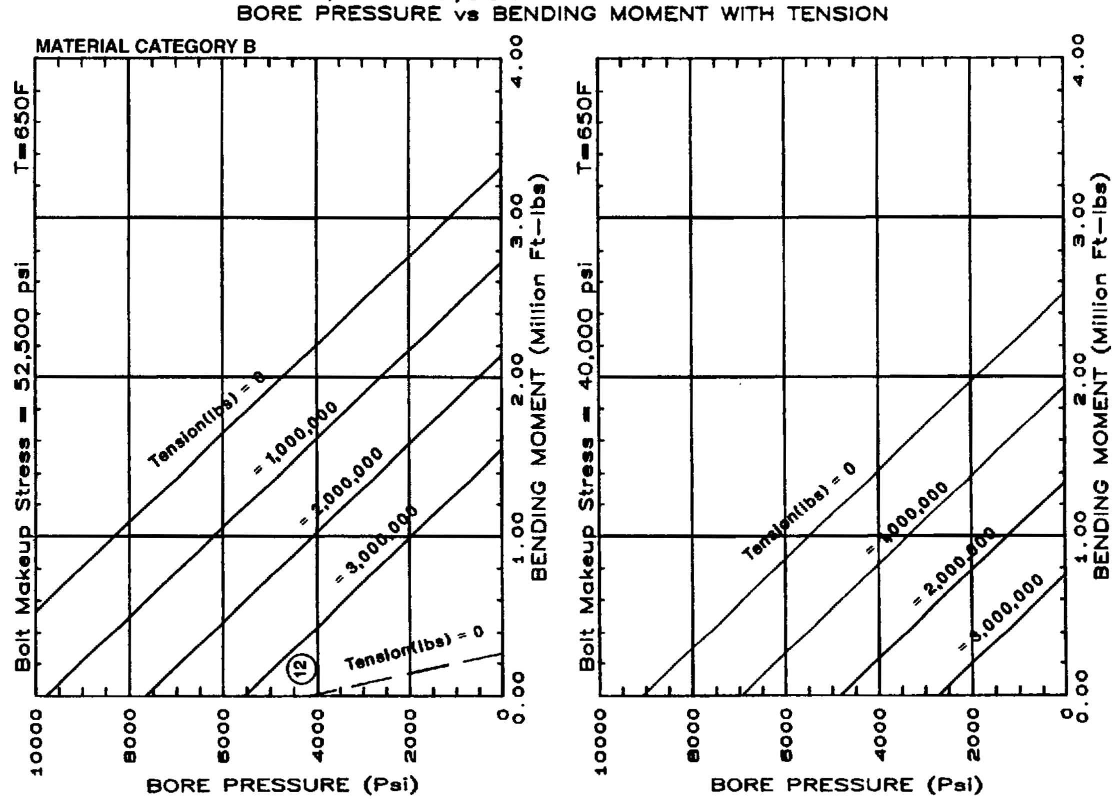
BORE PRESSURE vs BENDING MOMENT WITH TENSION



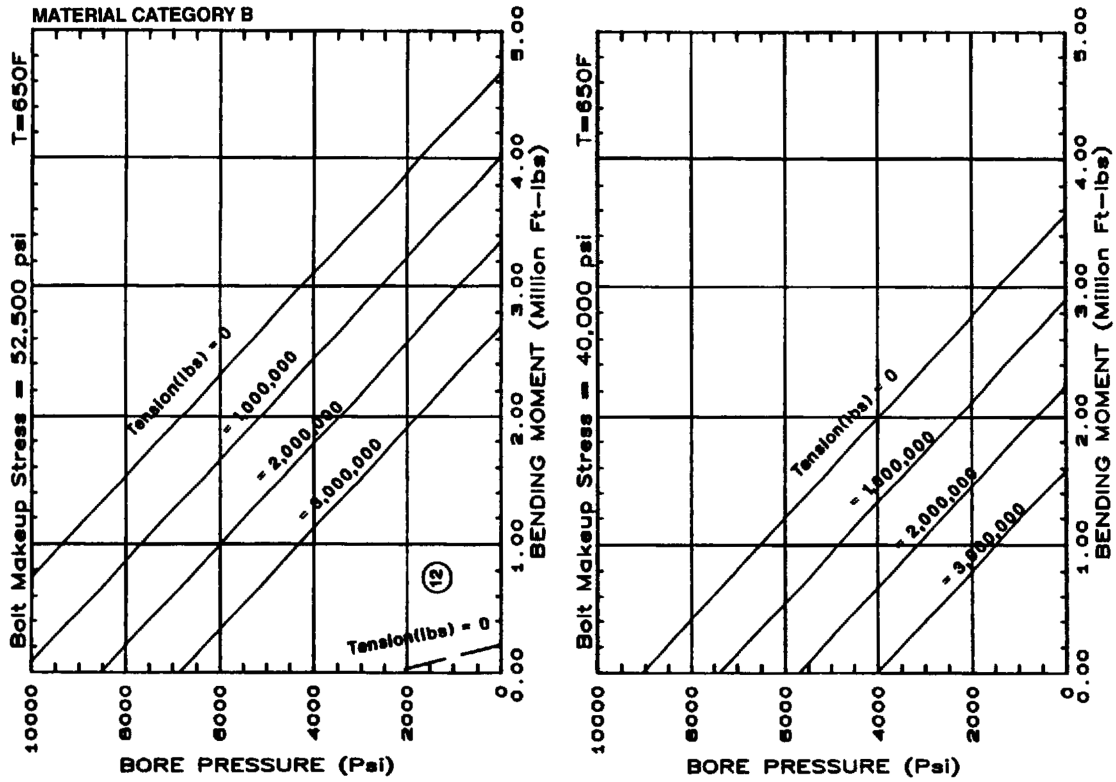
16–3/4"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



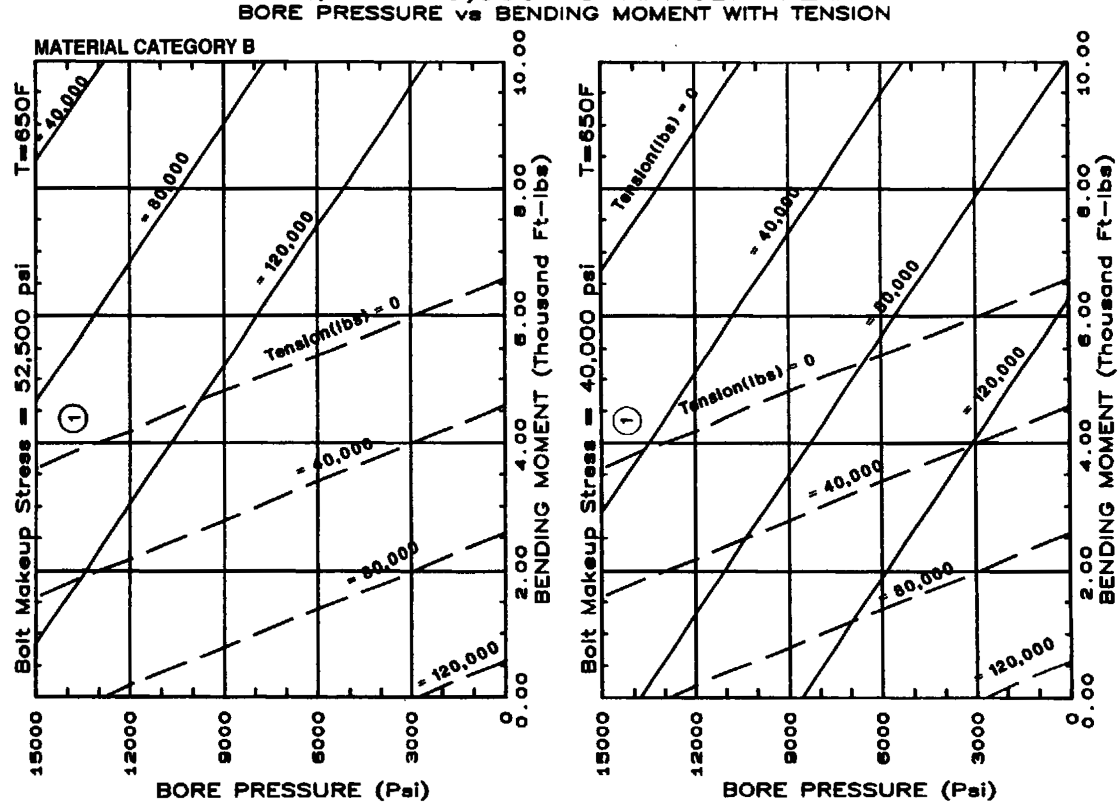
18–3/4"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



21-1/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

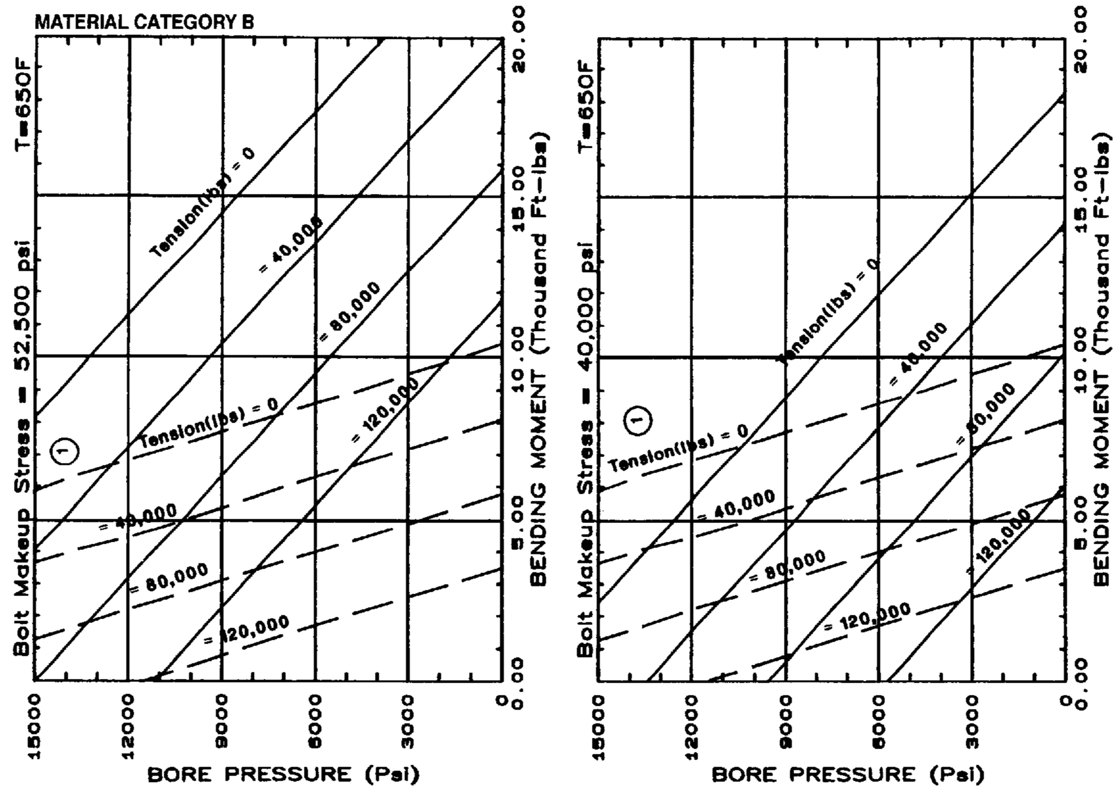


1-13/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



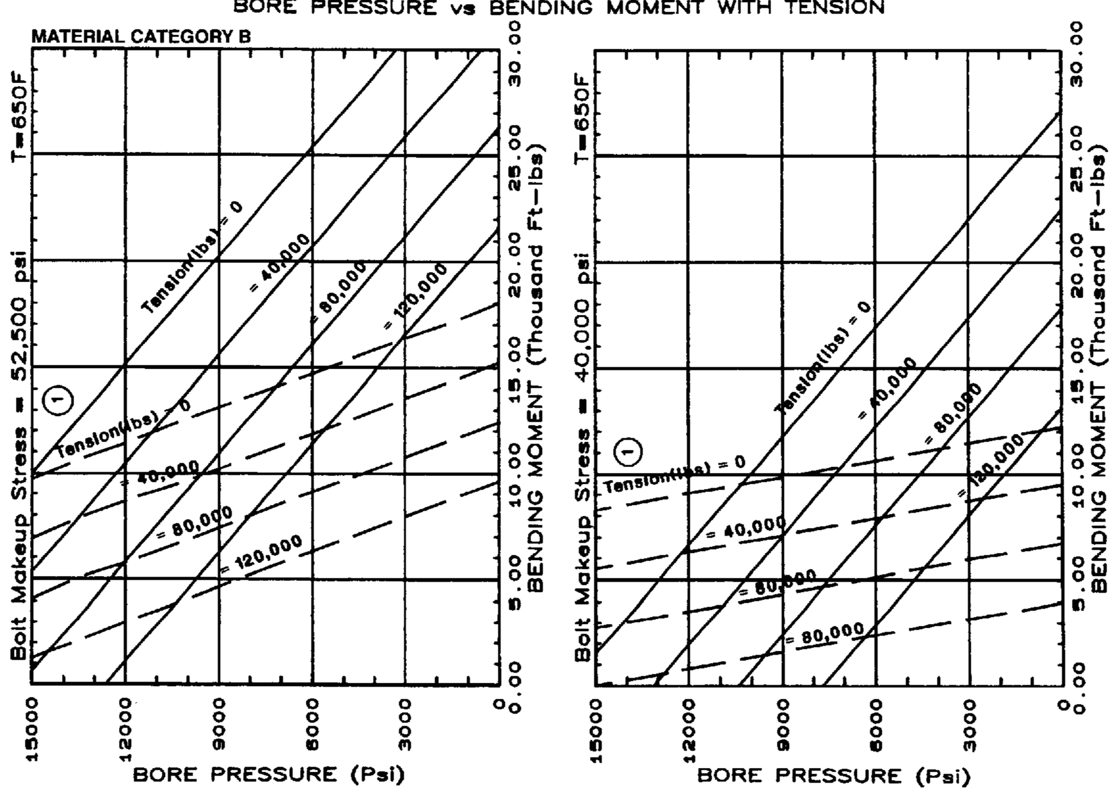
2-1/16"-15,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

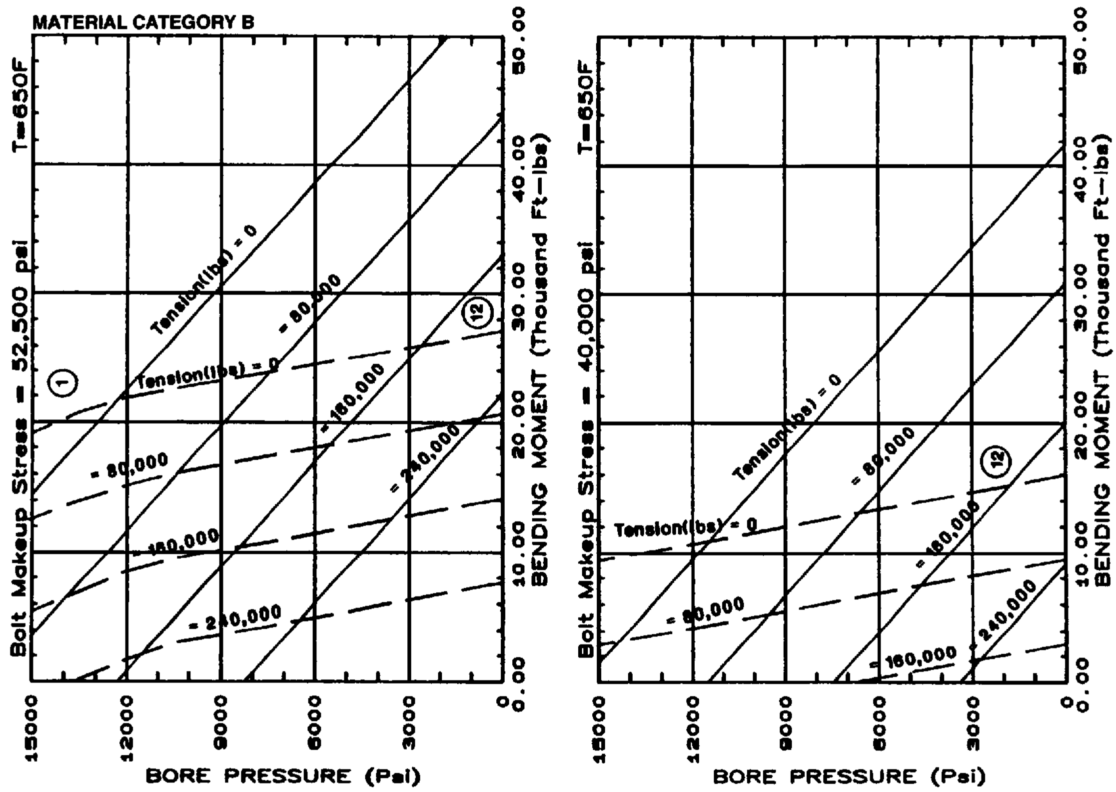


2-9/16"-15,000 PSI API 6BX-FLANGE

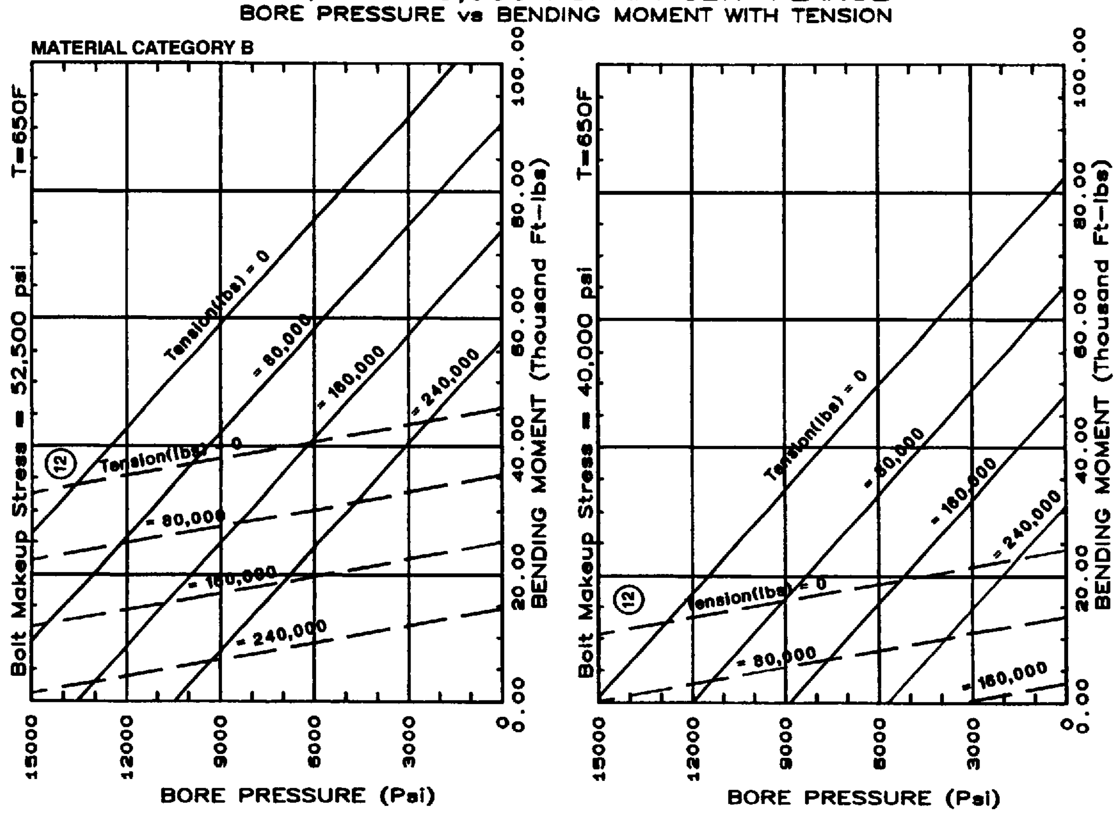
BORE PRESSURE vs BENDING MOMENT WITH TENSION



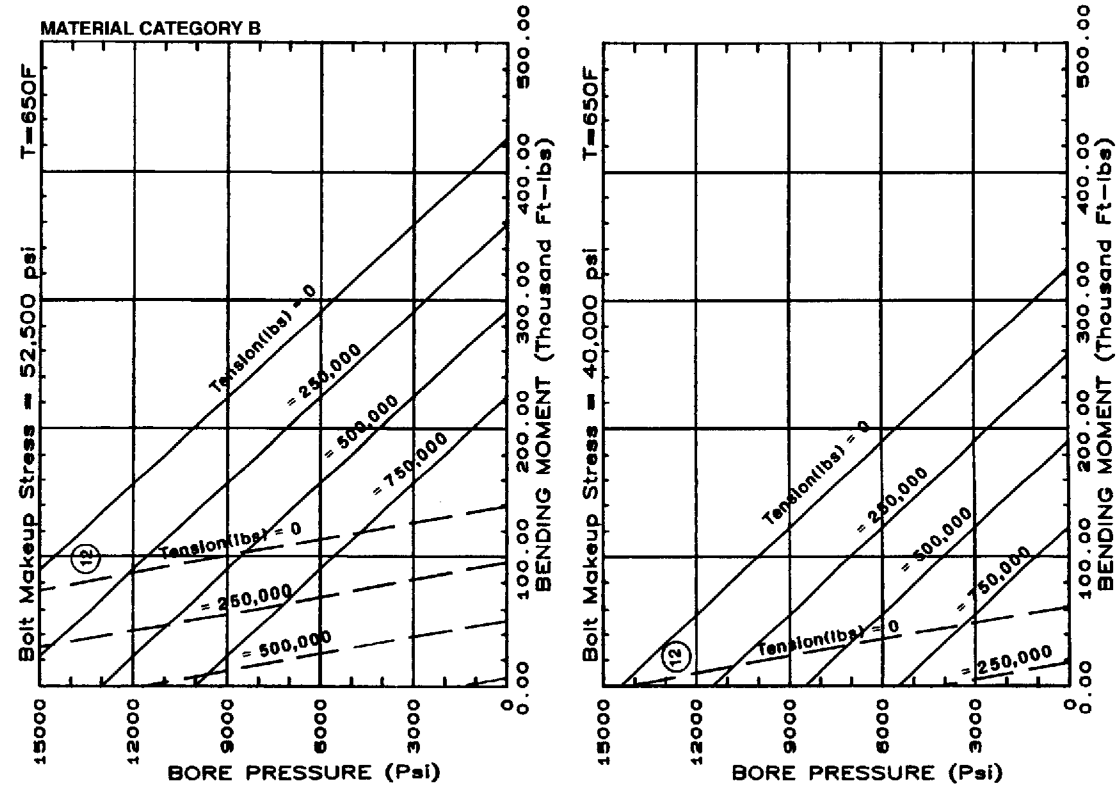
3-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



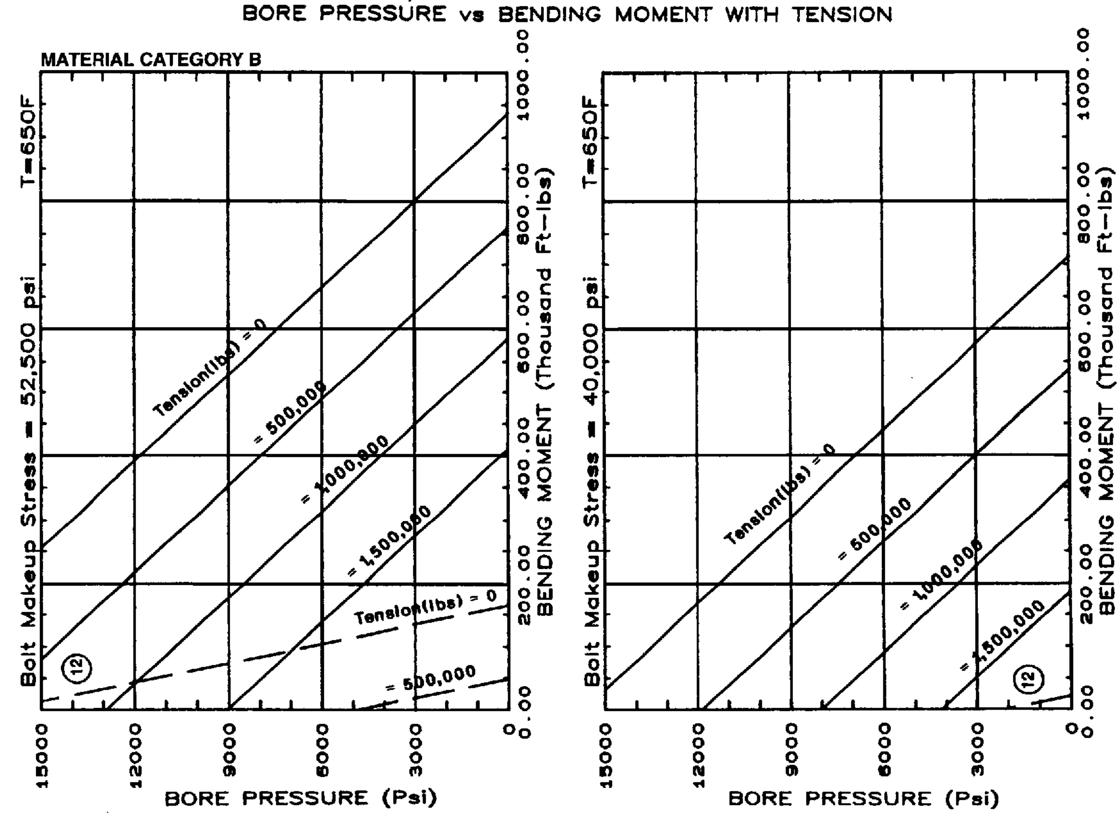
4-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



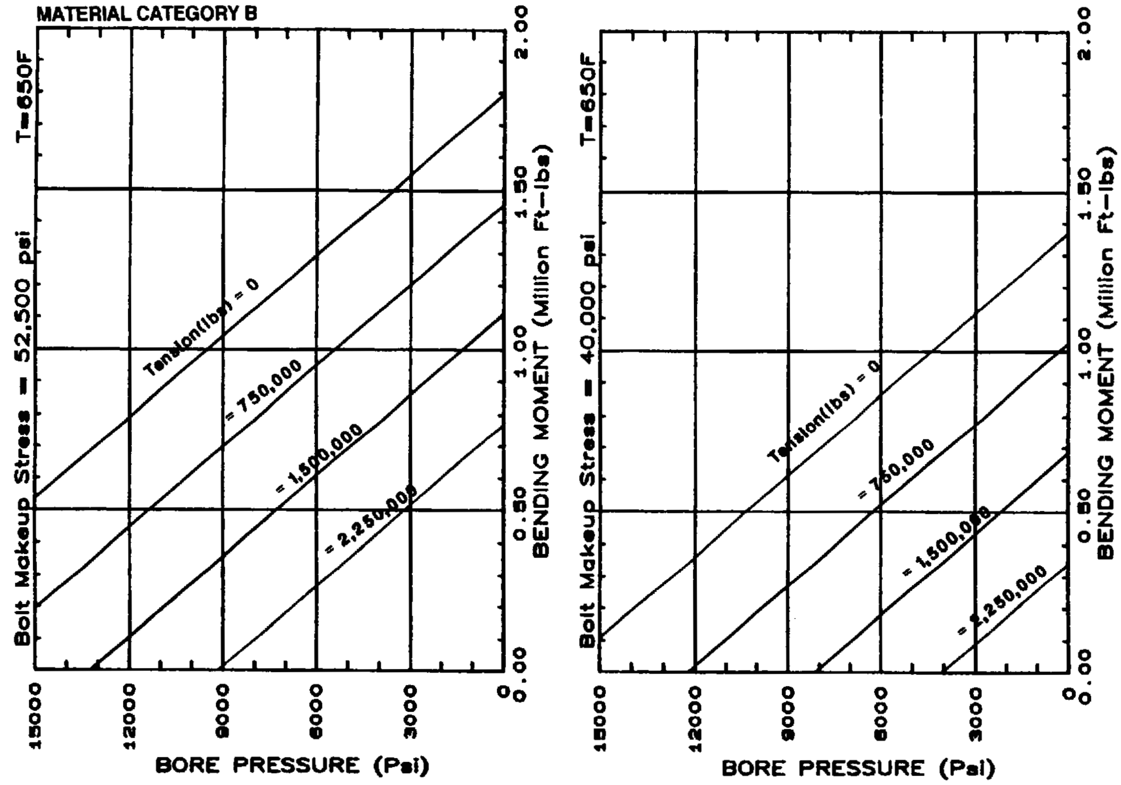
7-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



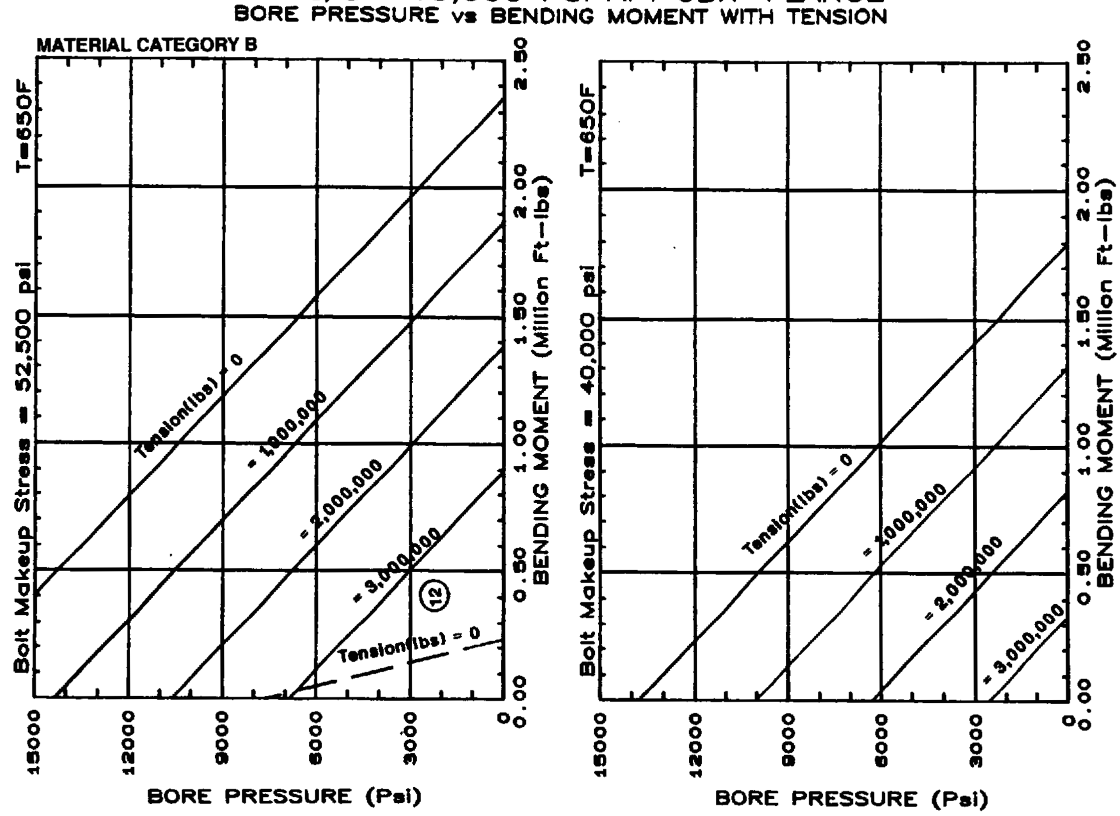
9"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



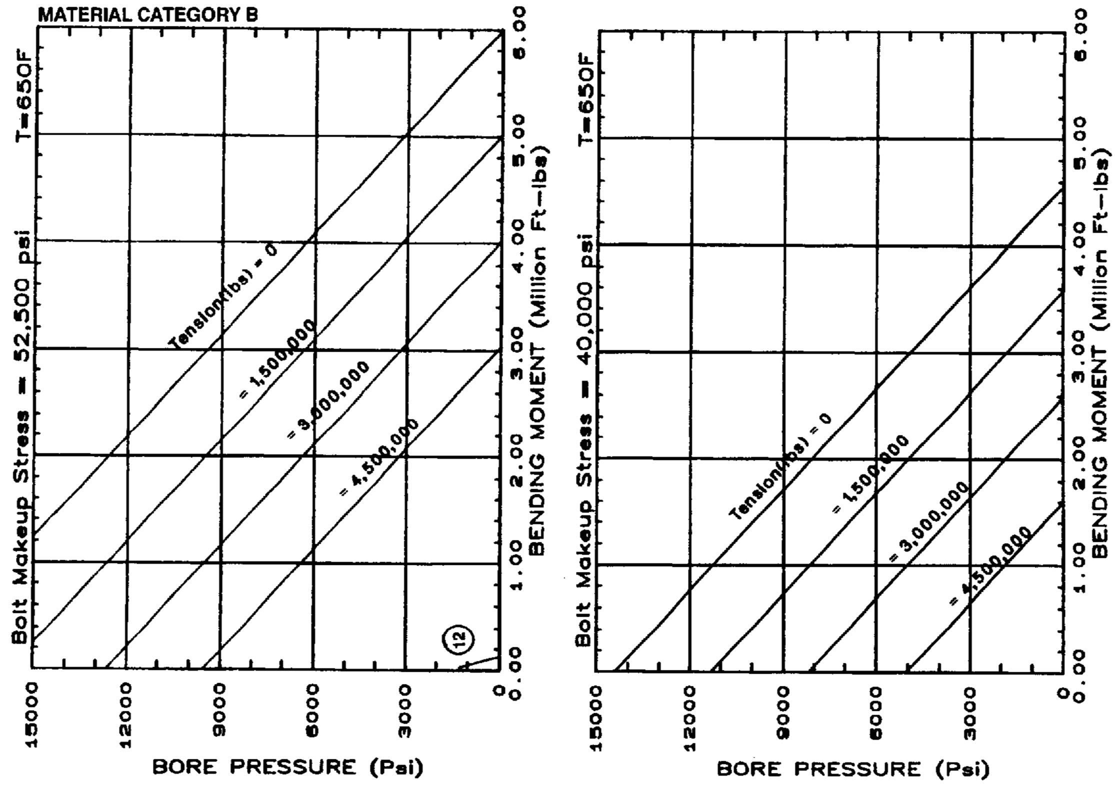
11"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



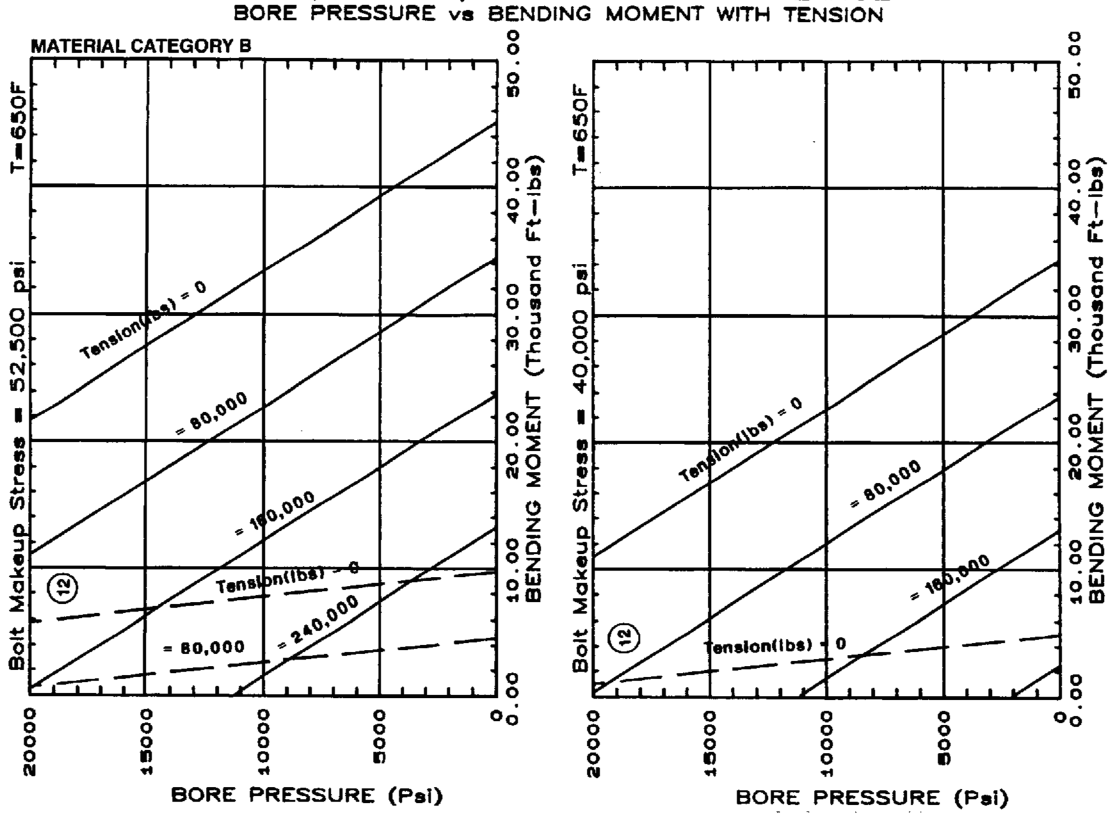
13–5/8"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



18-3/4"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

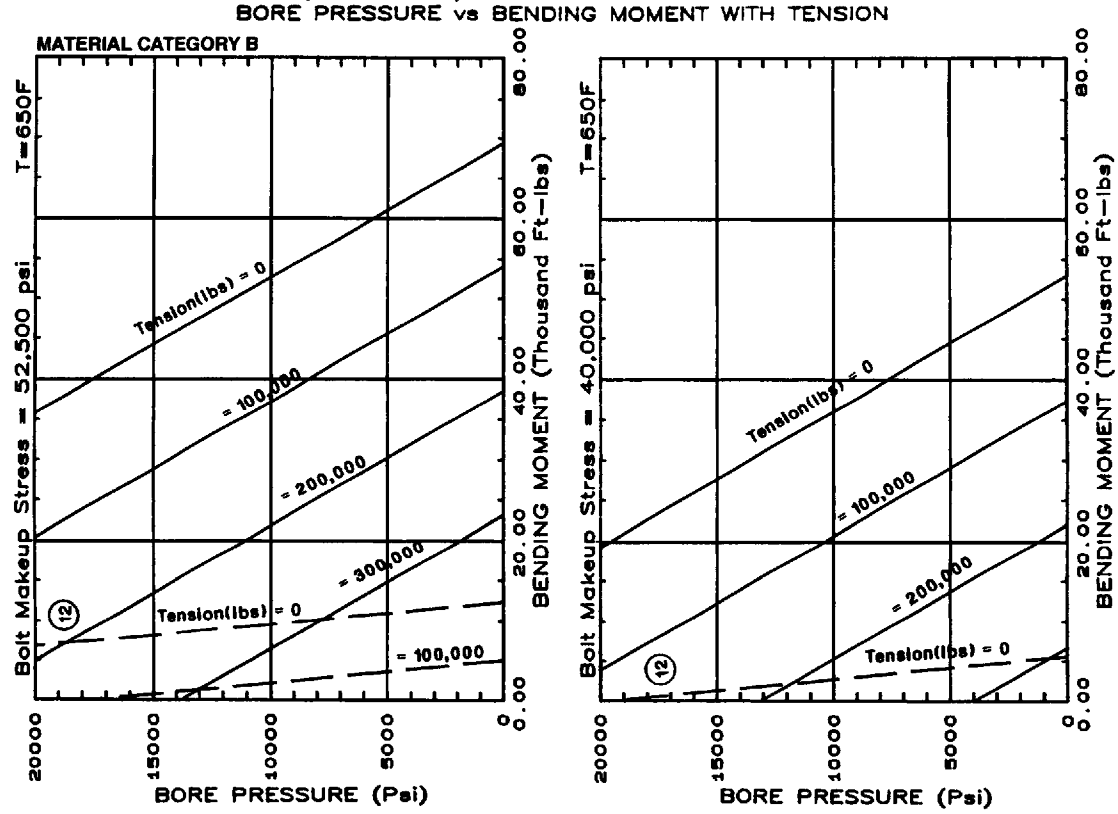


1-13/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



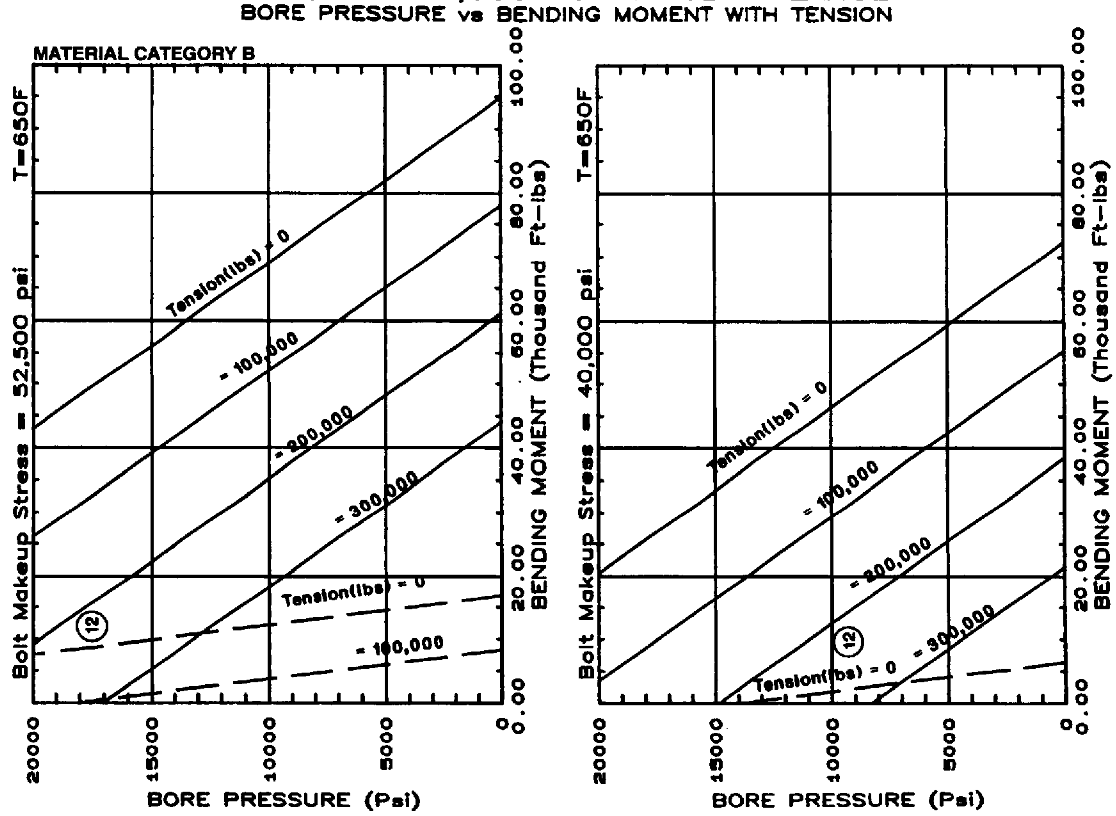
2-1/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

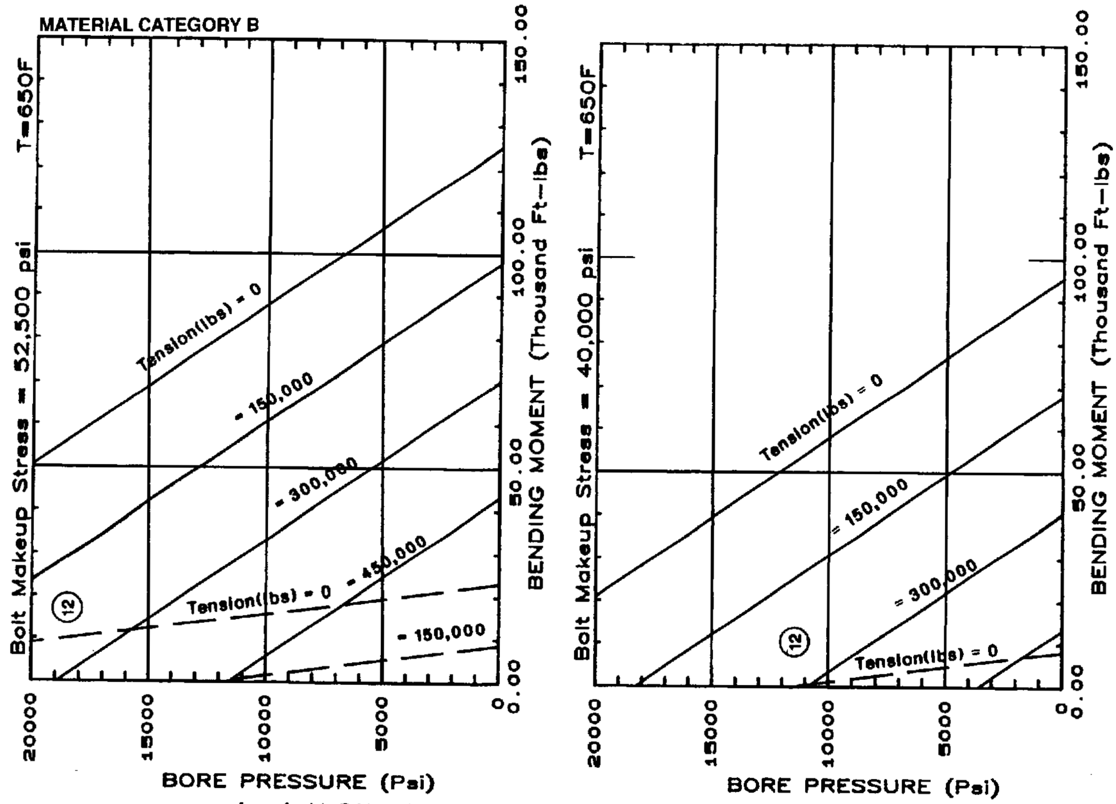


2-9/16"-20,000 PSI API 6BX-FLANGE

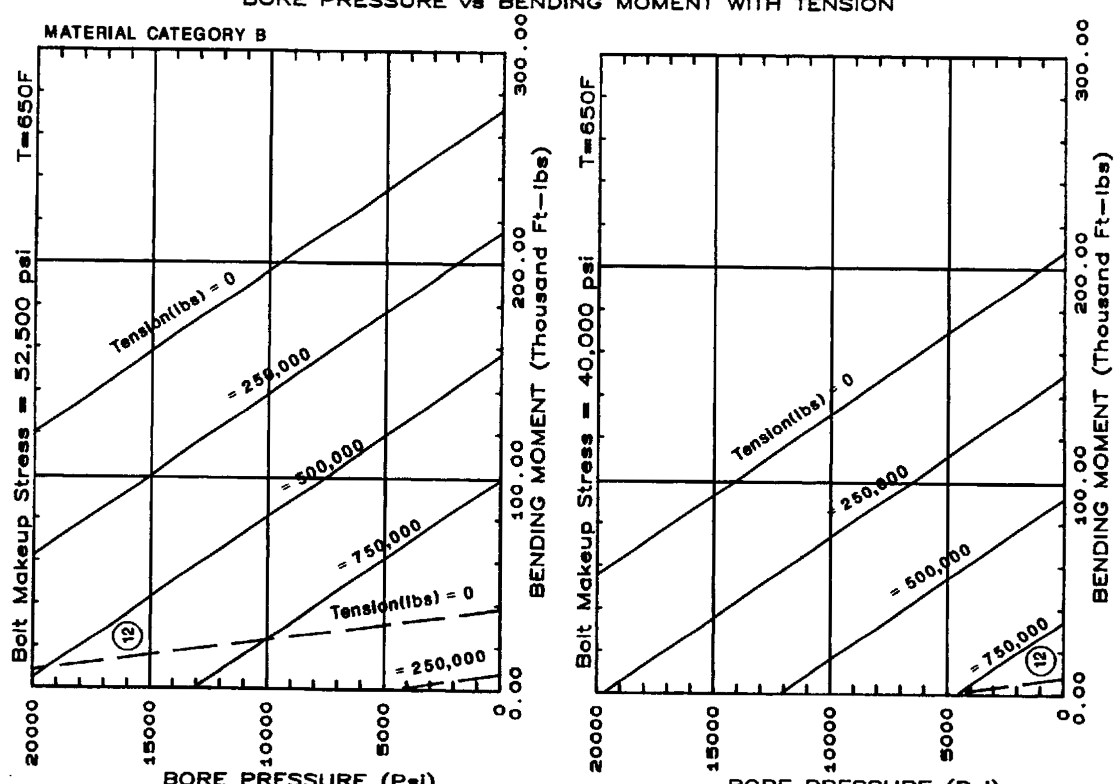
BORE PRESSURE vs BENDING MOMENT WITH TENSION



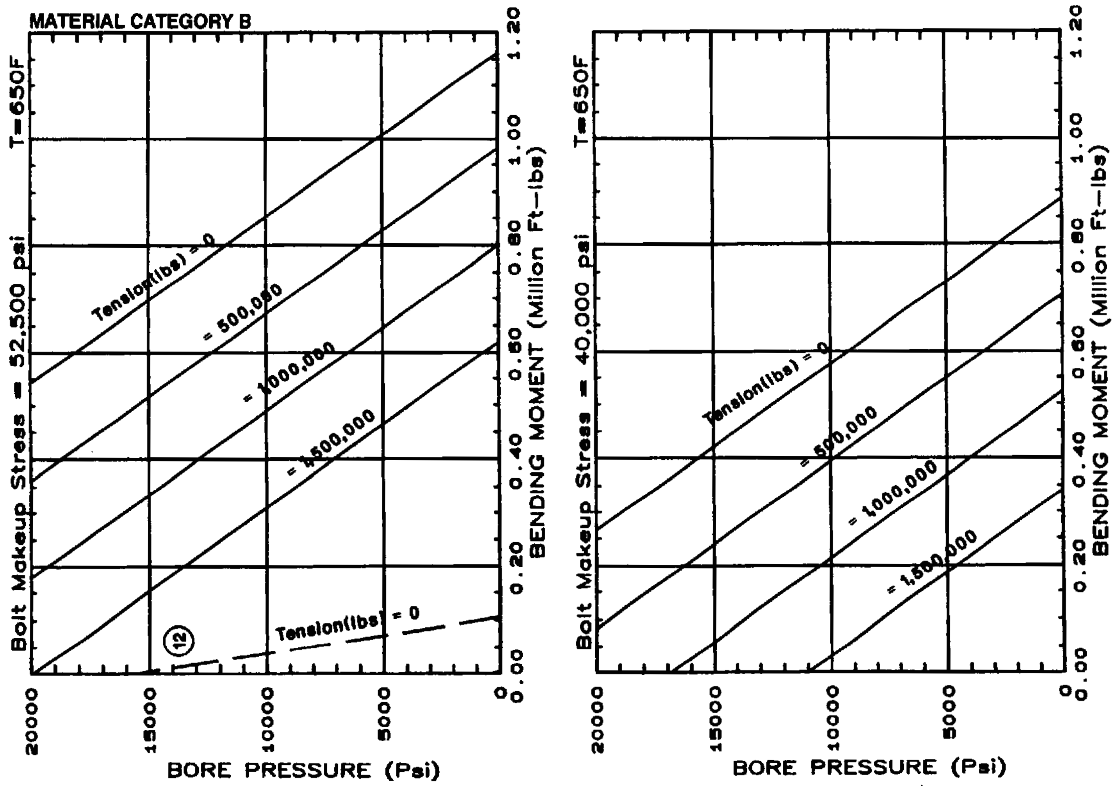
3-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



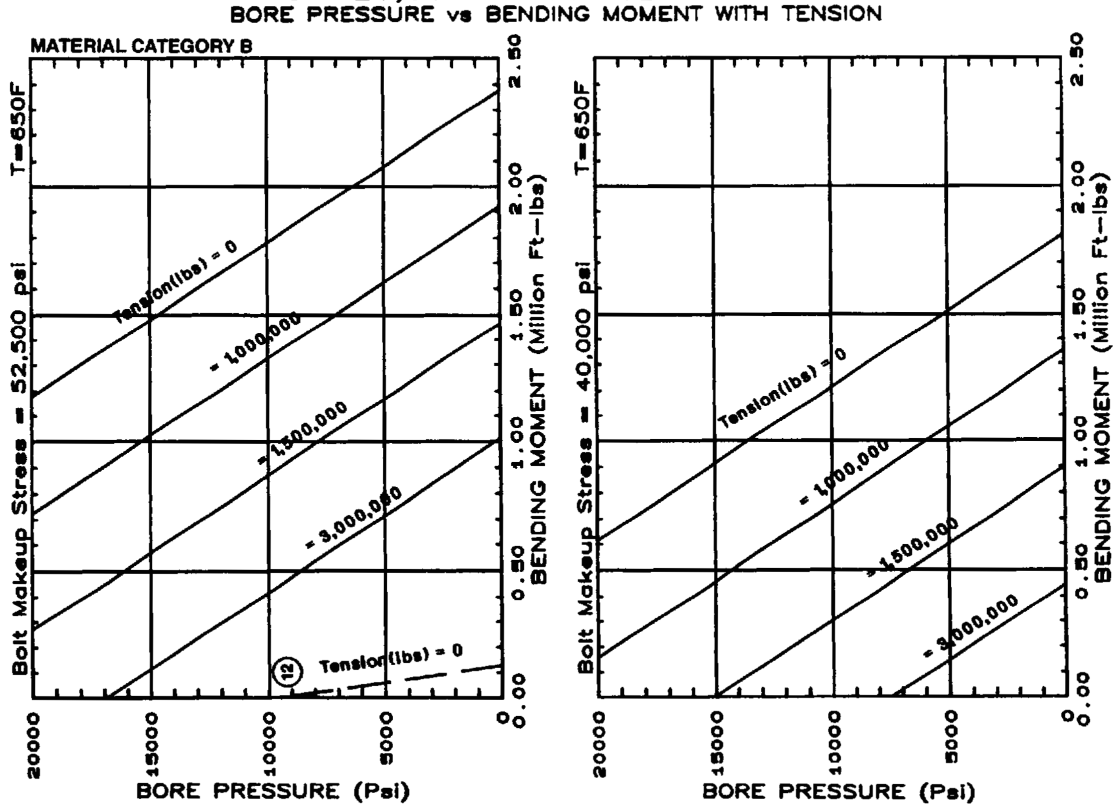
4-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



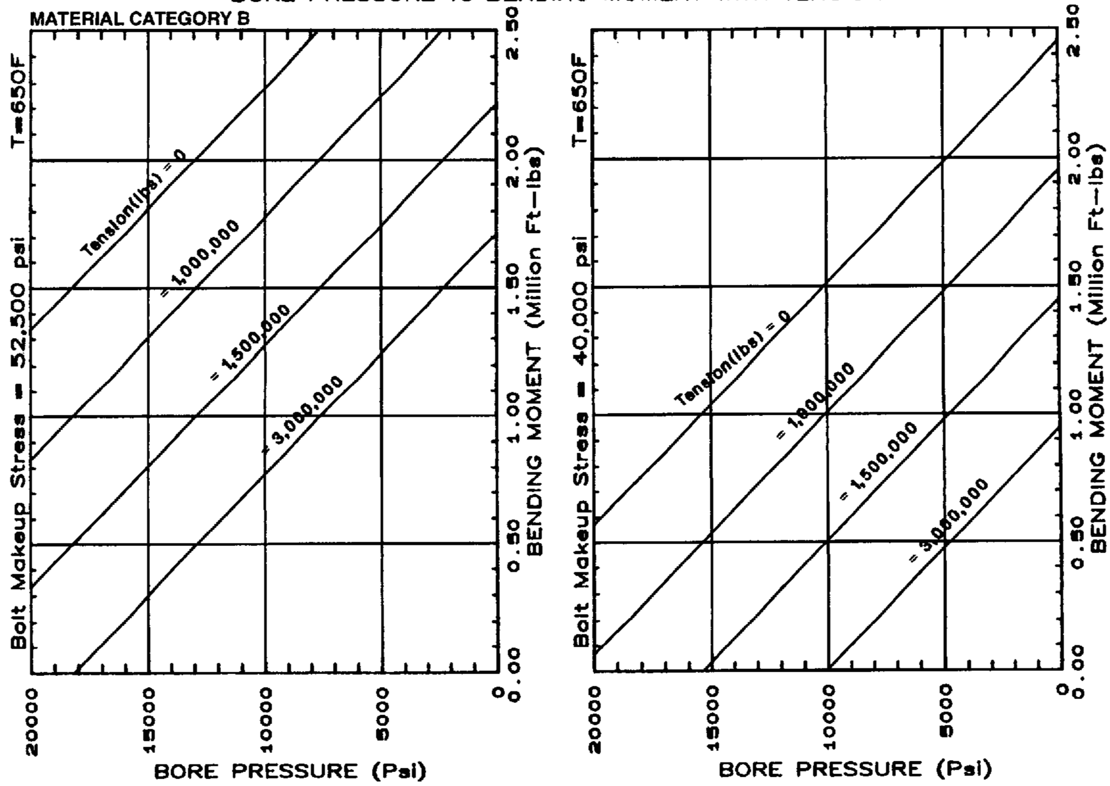
7–1/16"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



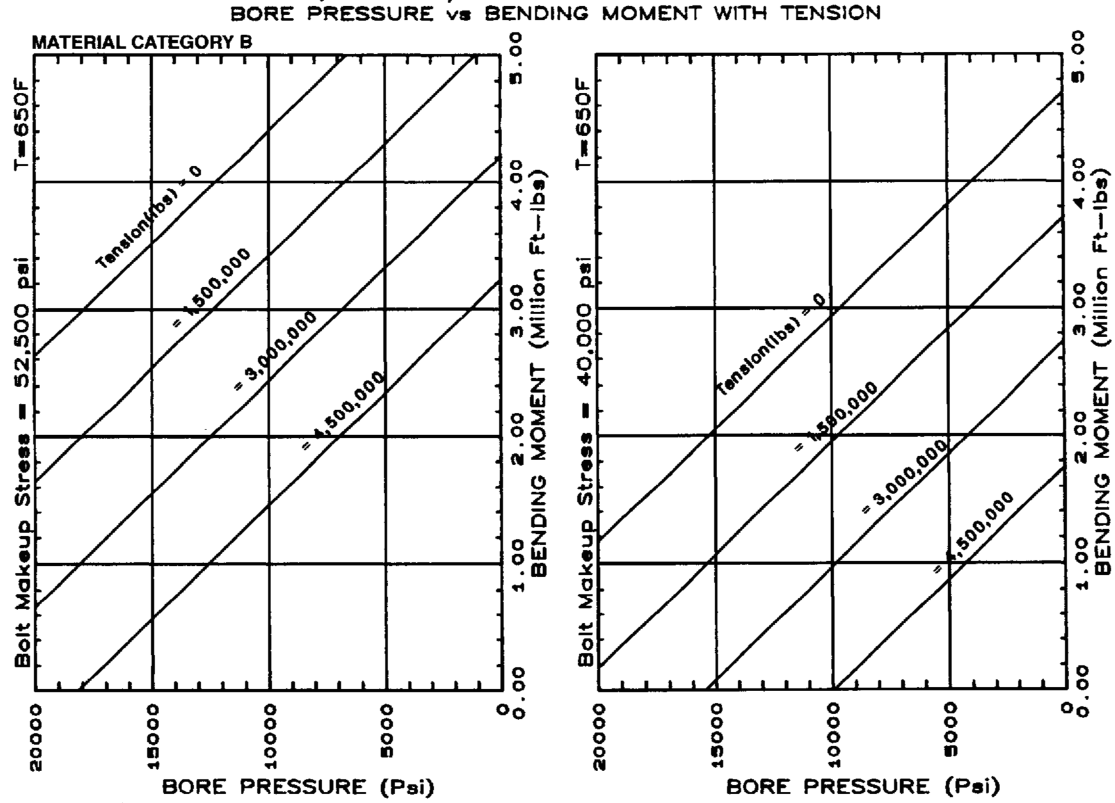
9"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

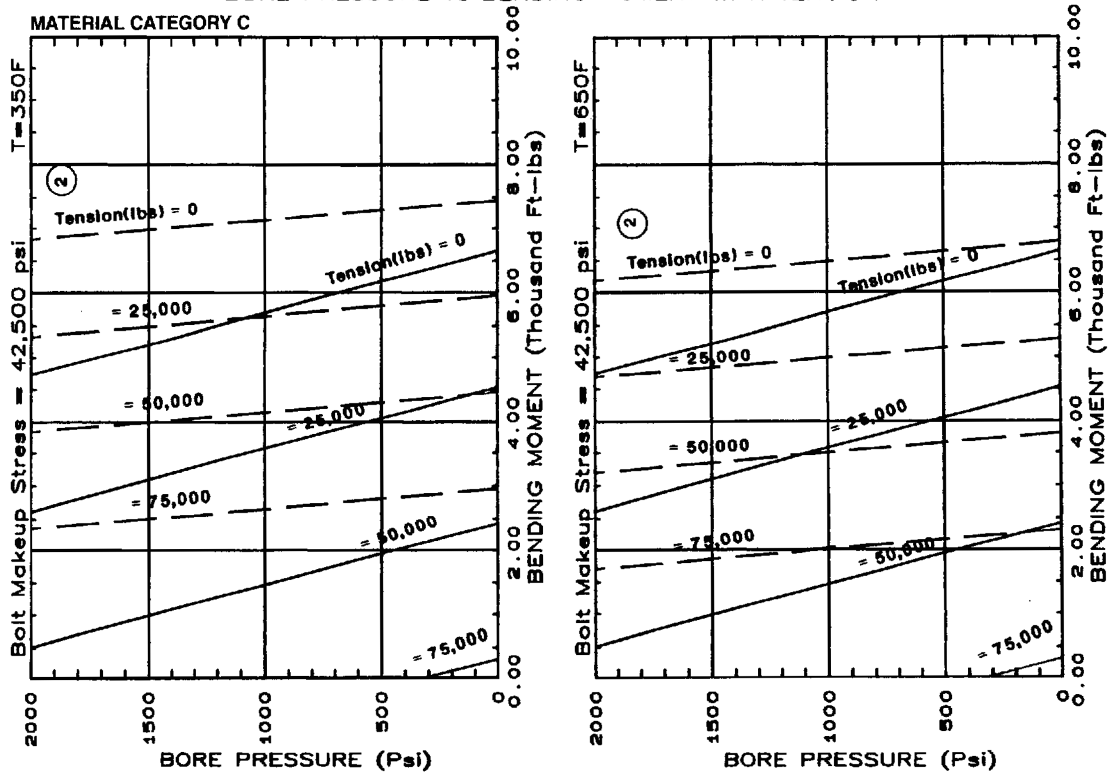


13-5/8"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

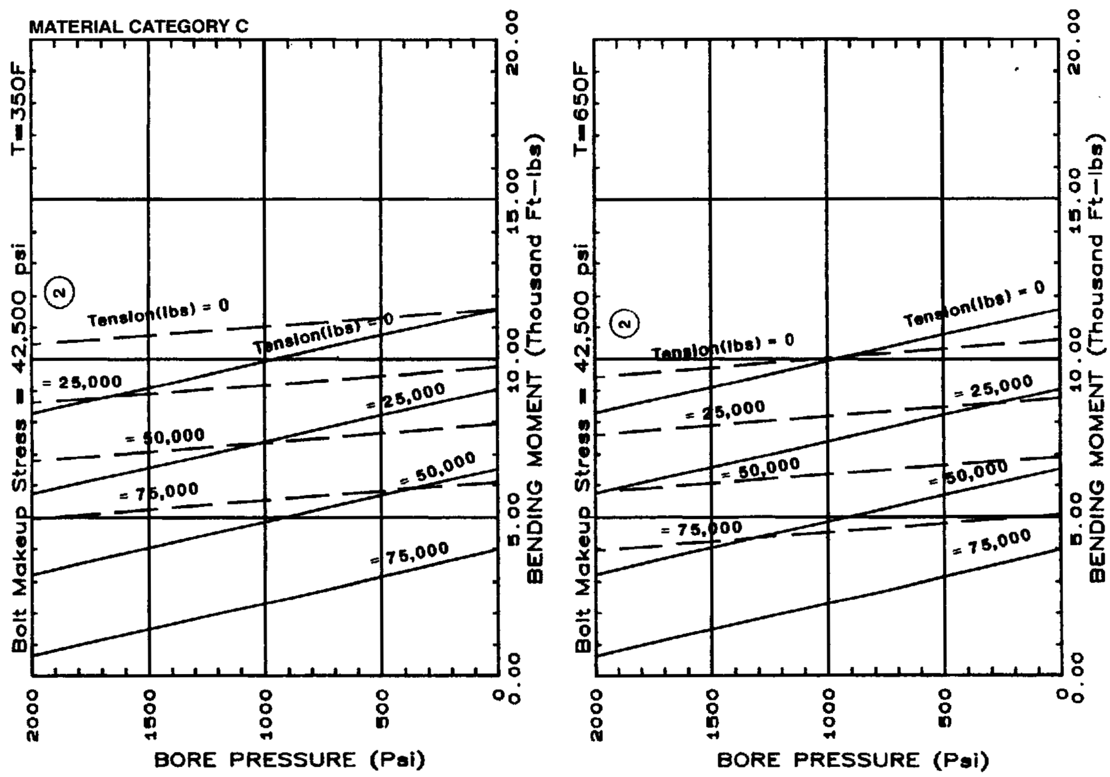


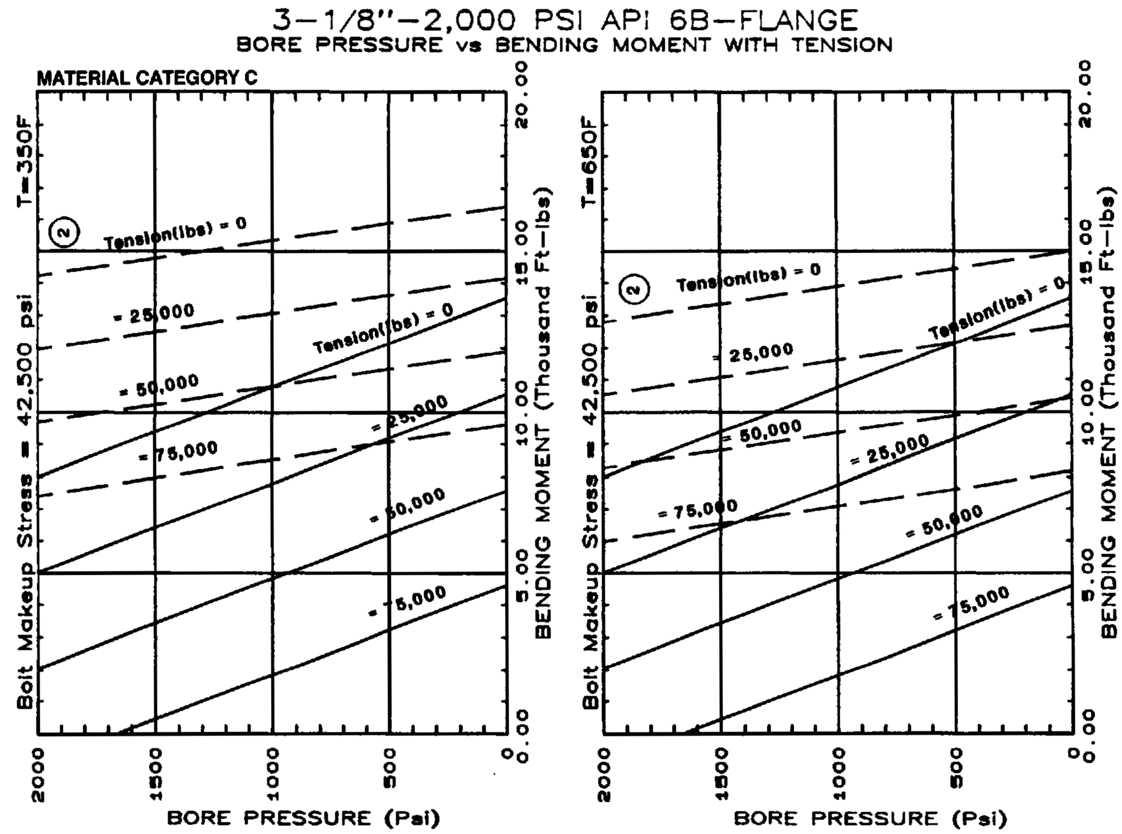
APPENDIX C—MATERIAL CATEGORY C

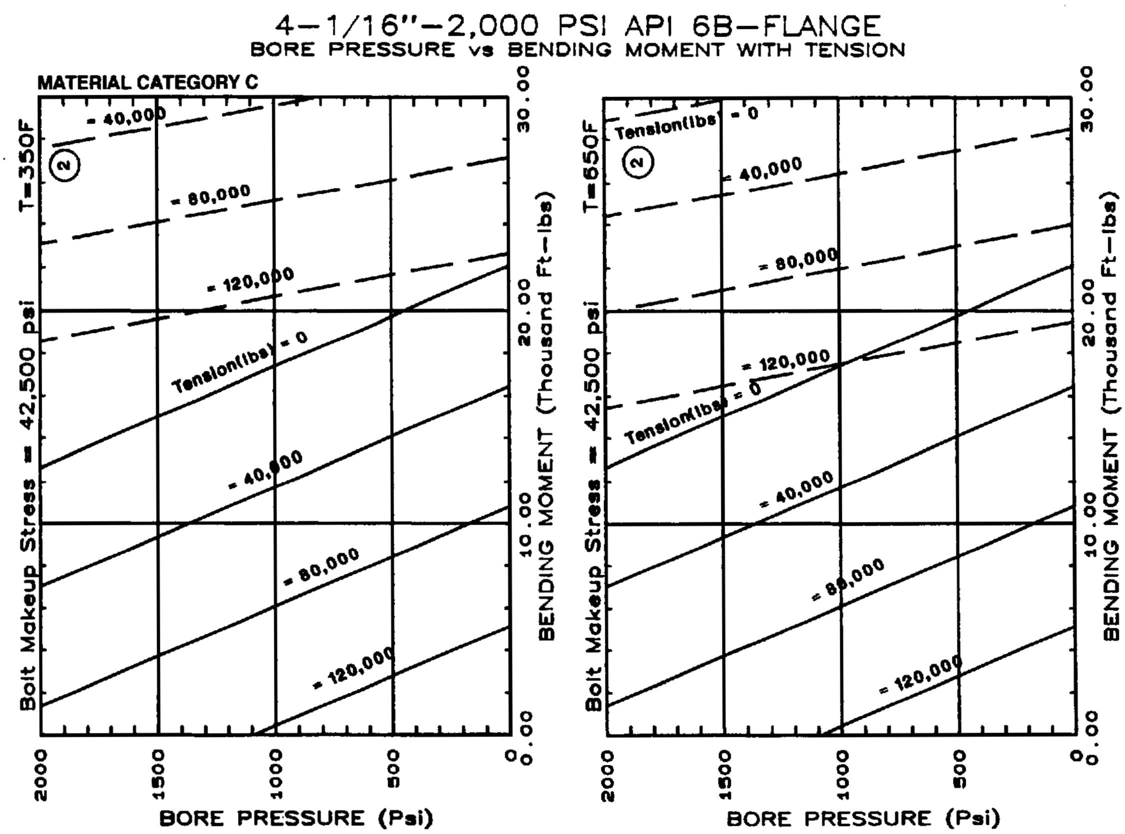
2–1/16"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



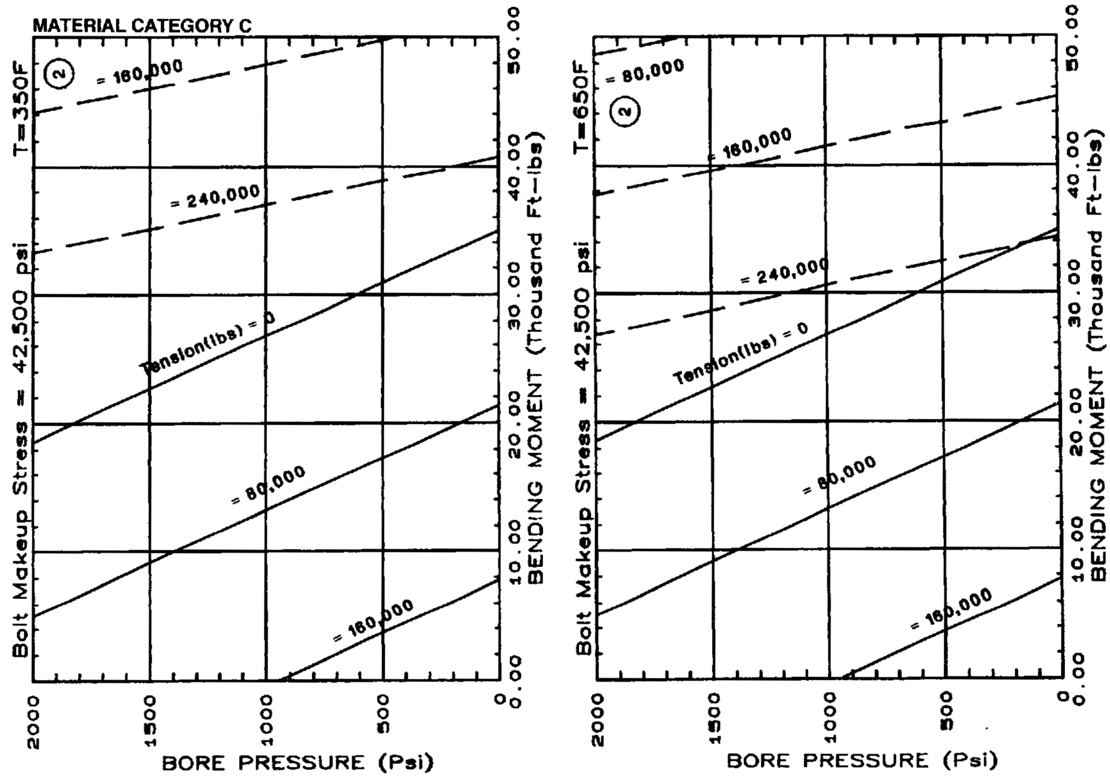
2–9/16"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



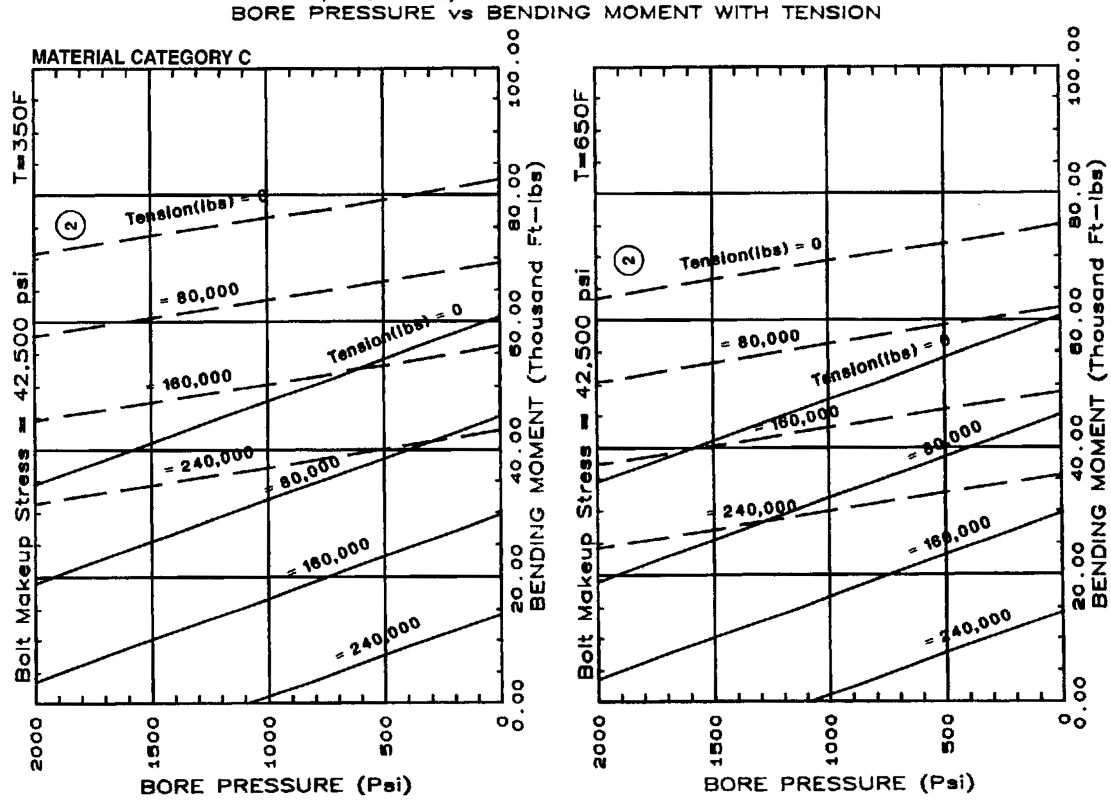

3-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY C
T=350F
T=650F
Bolt Makeup Stress = 42,500 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 25,000
= 50,000
= 75,000
2000
1500
1000
500
0
0.00
5.00
10.00
15.00
20.00


4-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY C
T=350F
T=650F
Bolt Makeup Stress = 42,500 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 40,000
= 80,000
= 120,000
2000
1500
1000
500
0
0.00
10.00
20.00
30.00

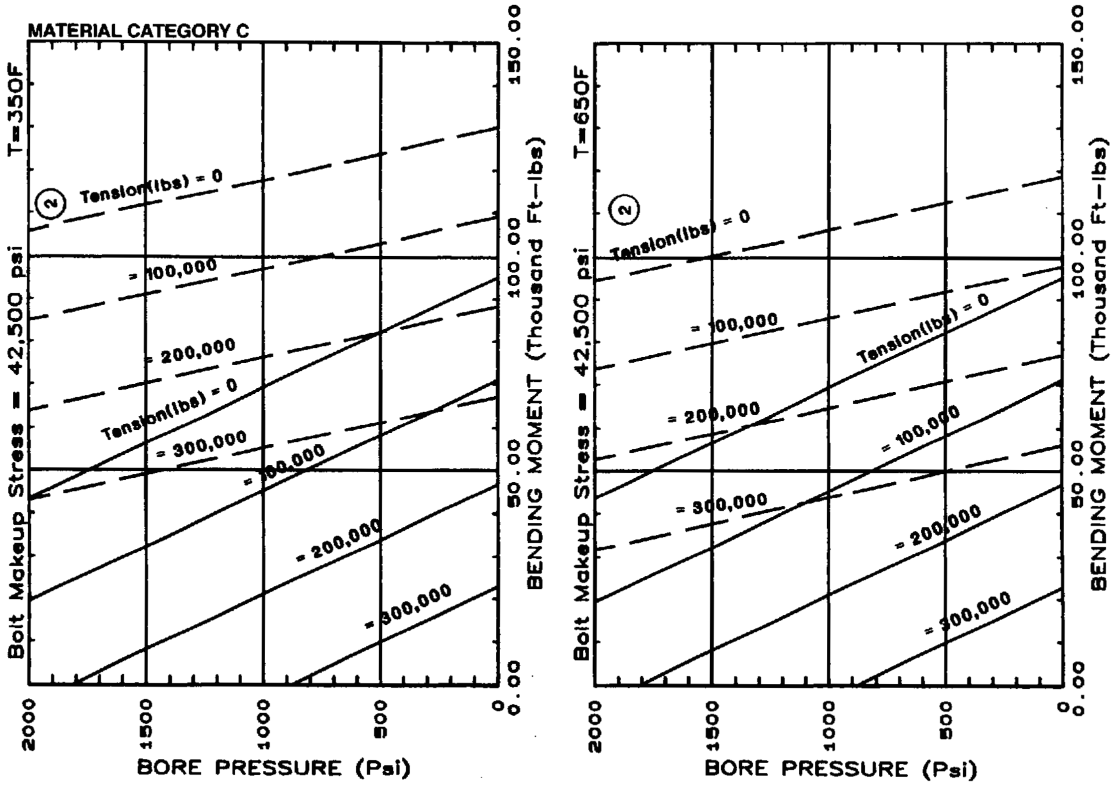
5-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



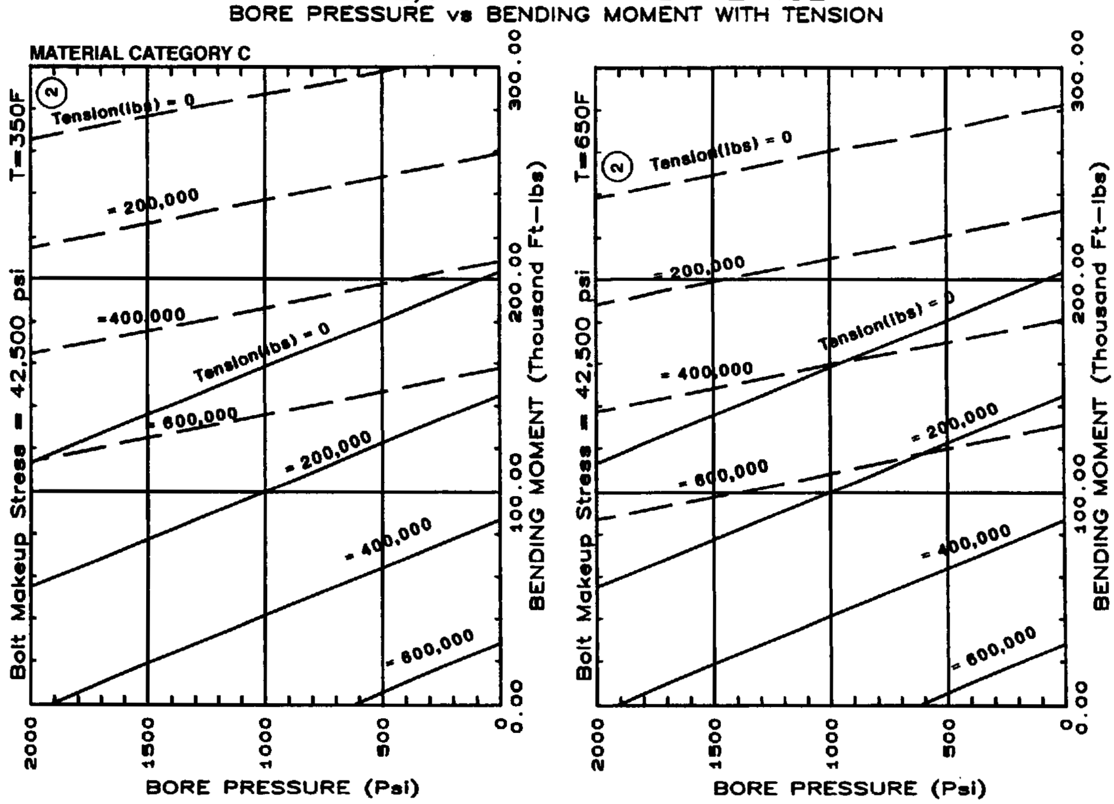
7-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



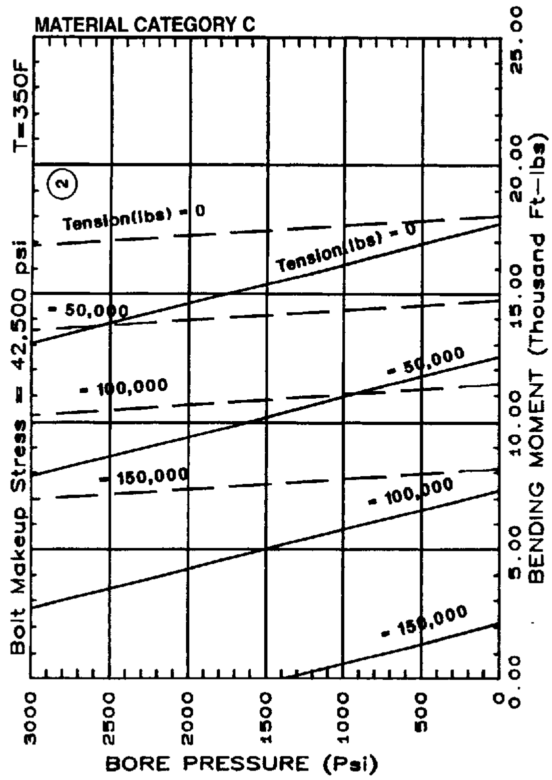
9"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

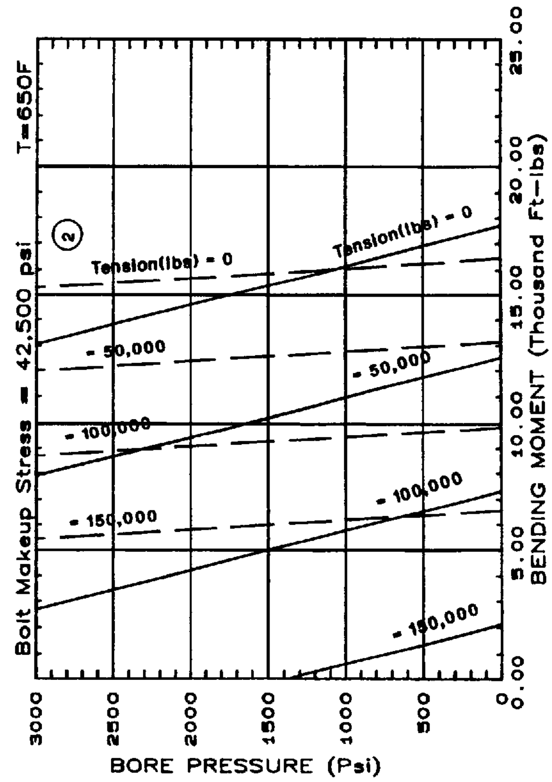


11"–2,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

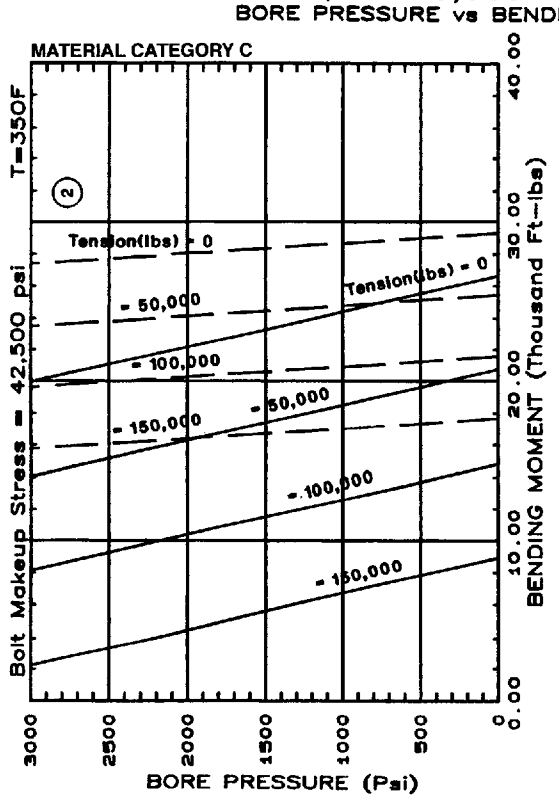


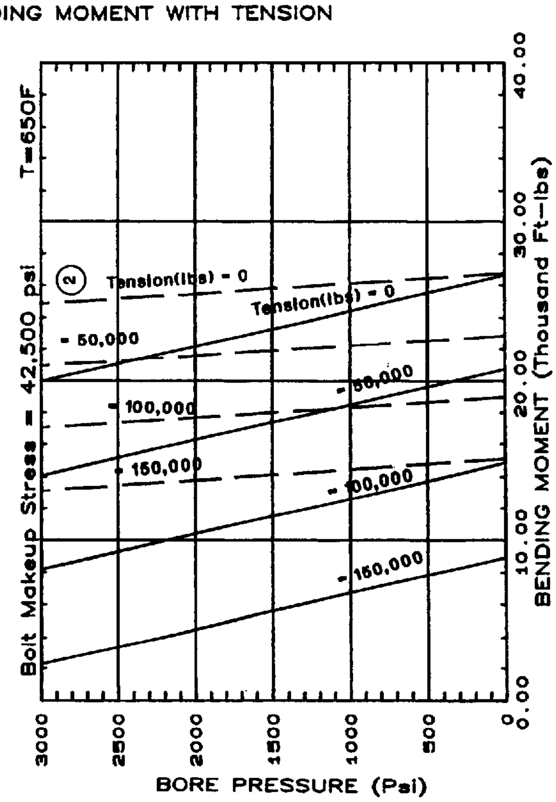
2-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



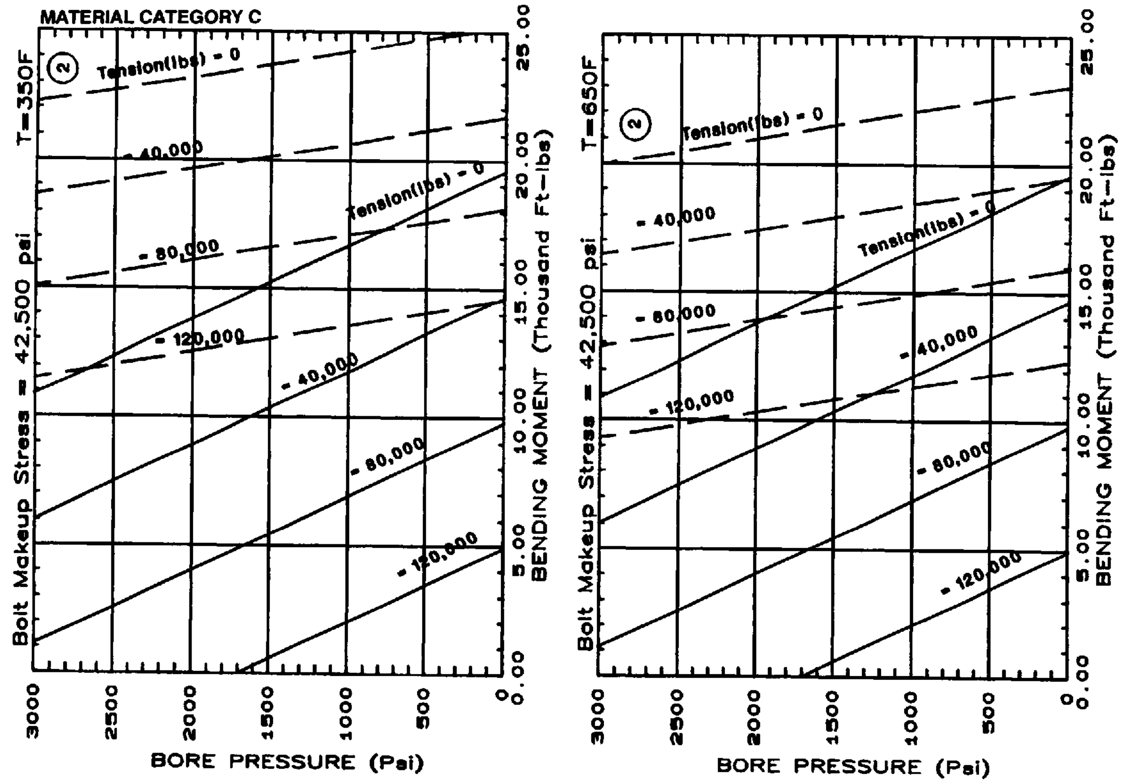


2-9/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

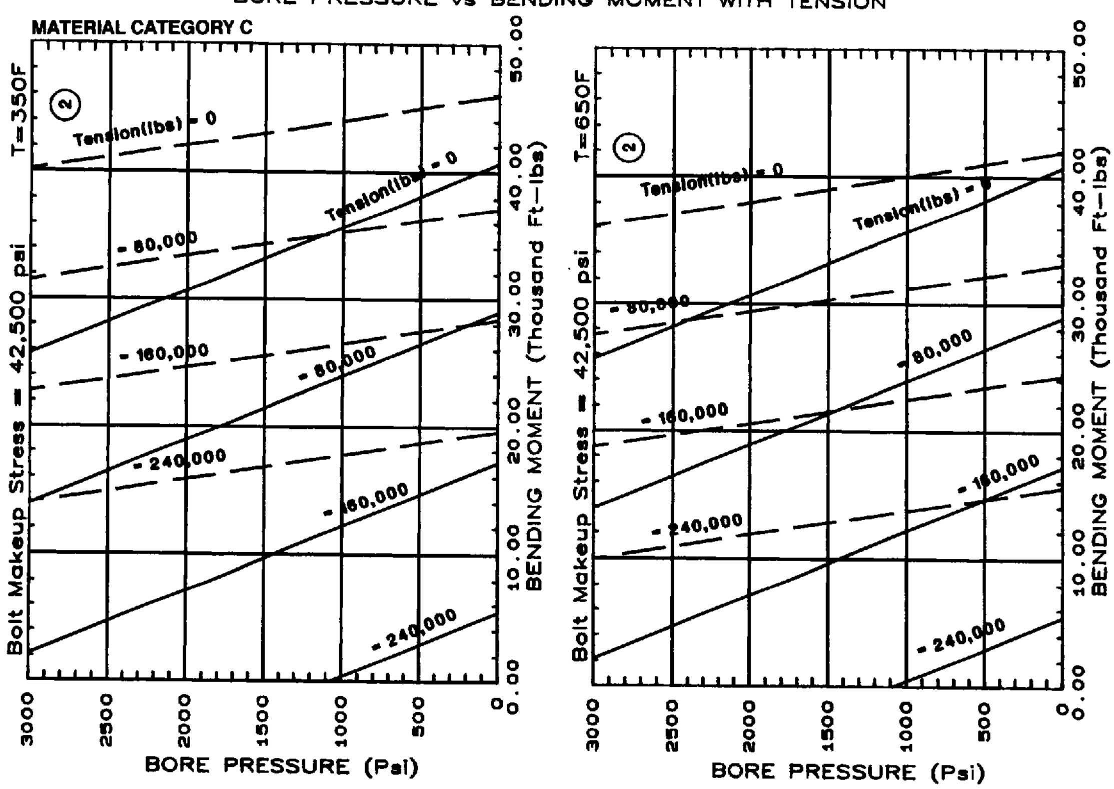




3-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

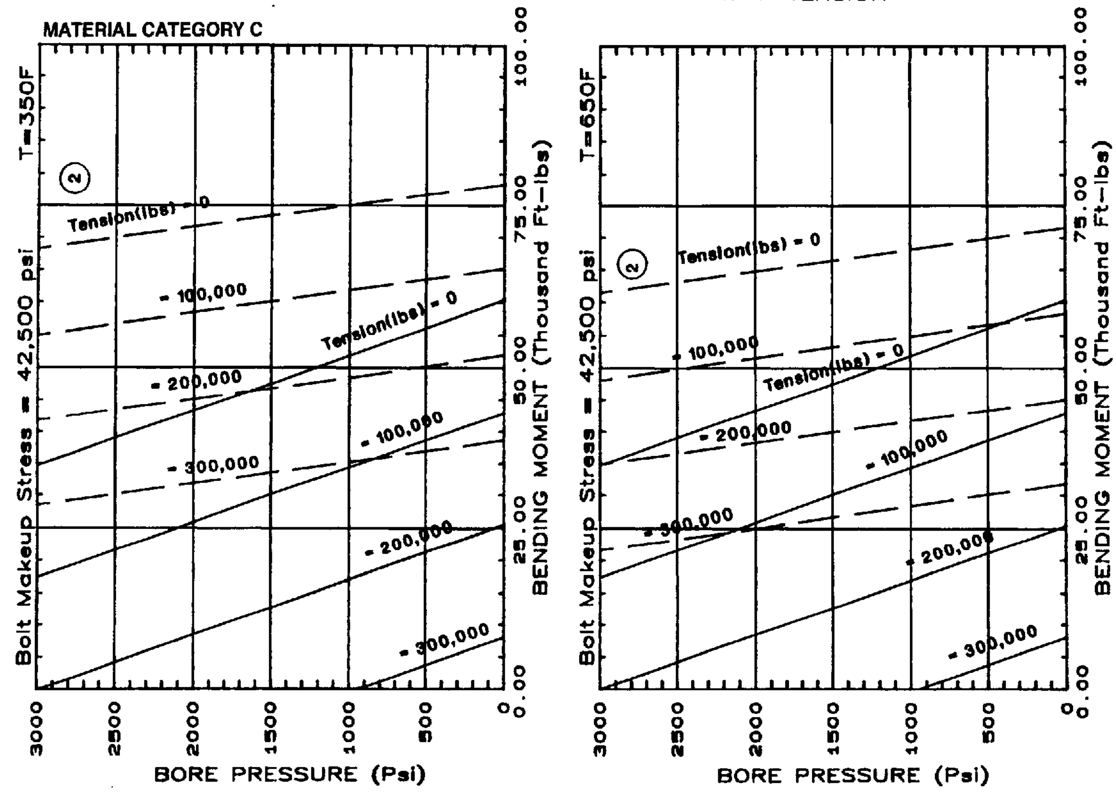


4-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



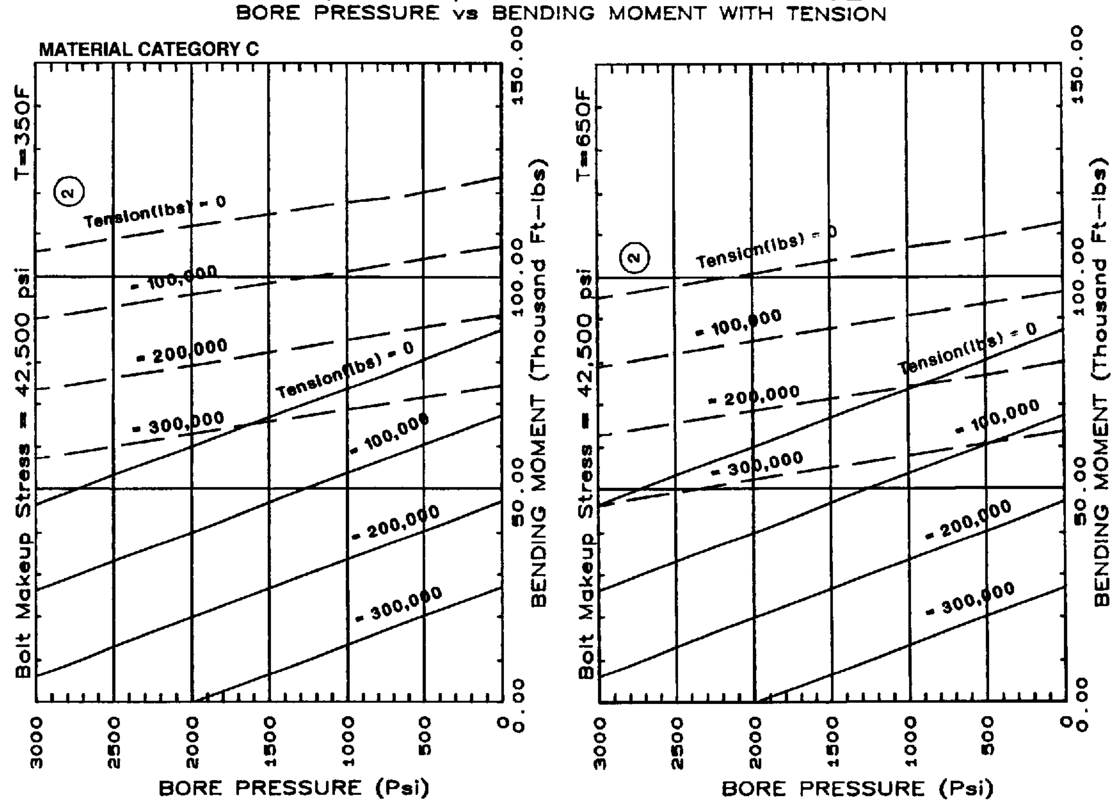
5-1/8"-3,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

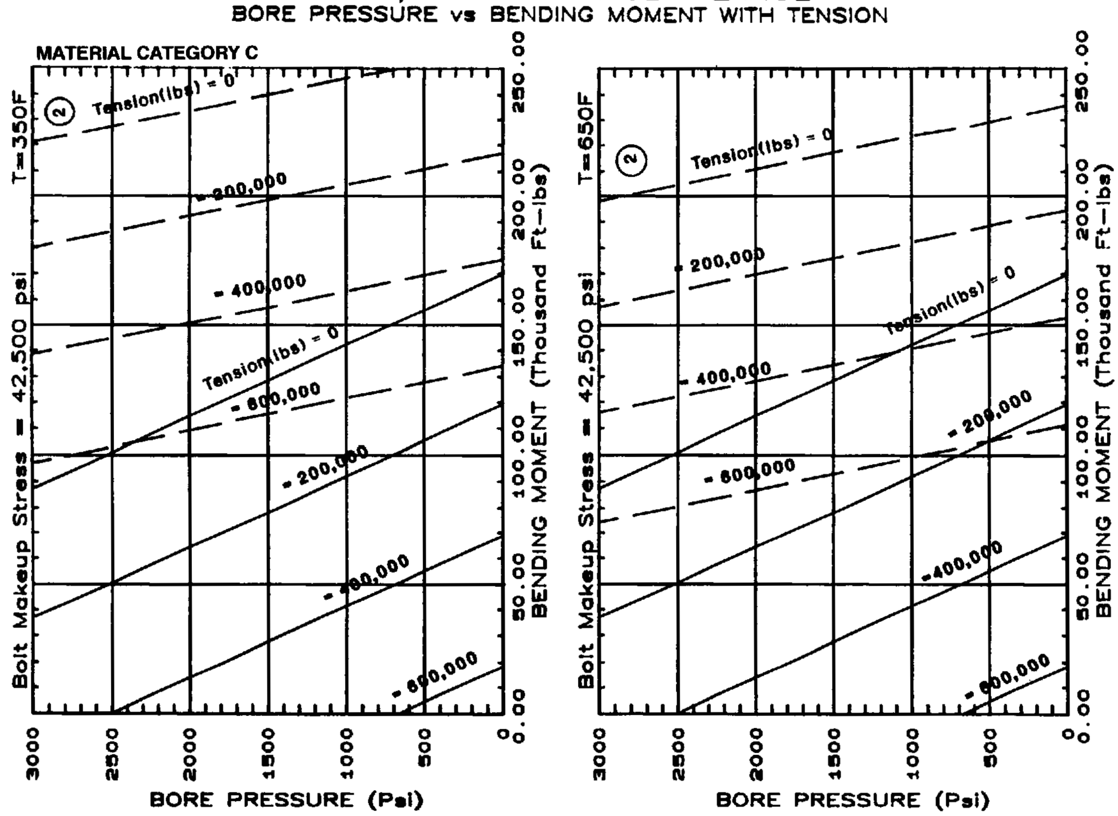


7-1/16"-3,000 PSI API 6B-FLANGE

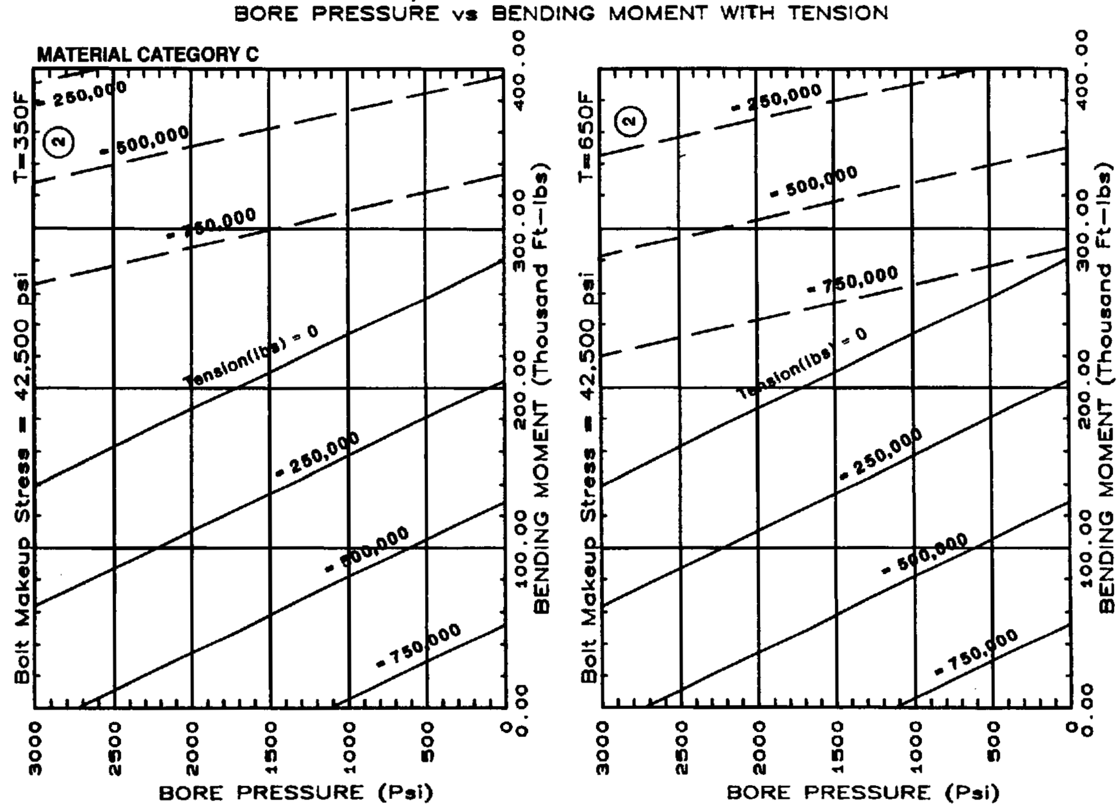
BORE PRESSURE vs BENDING MOMENT WITH TENSION

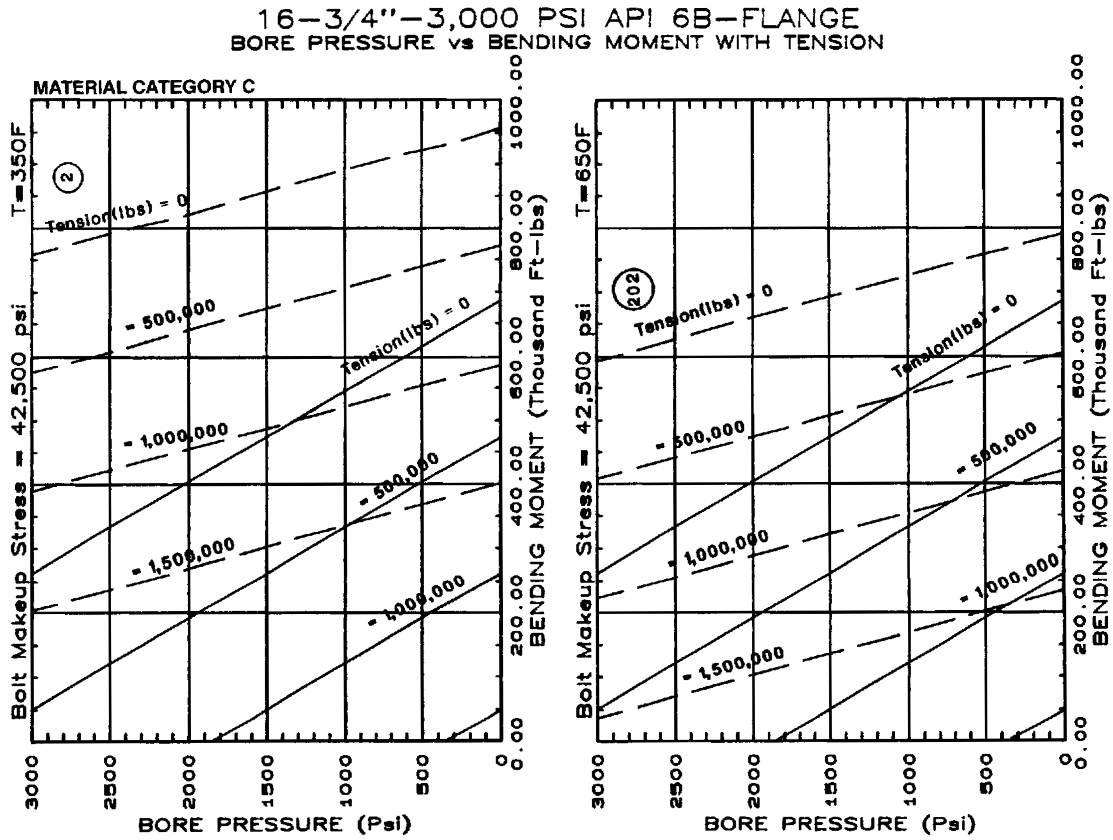


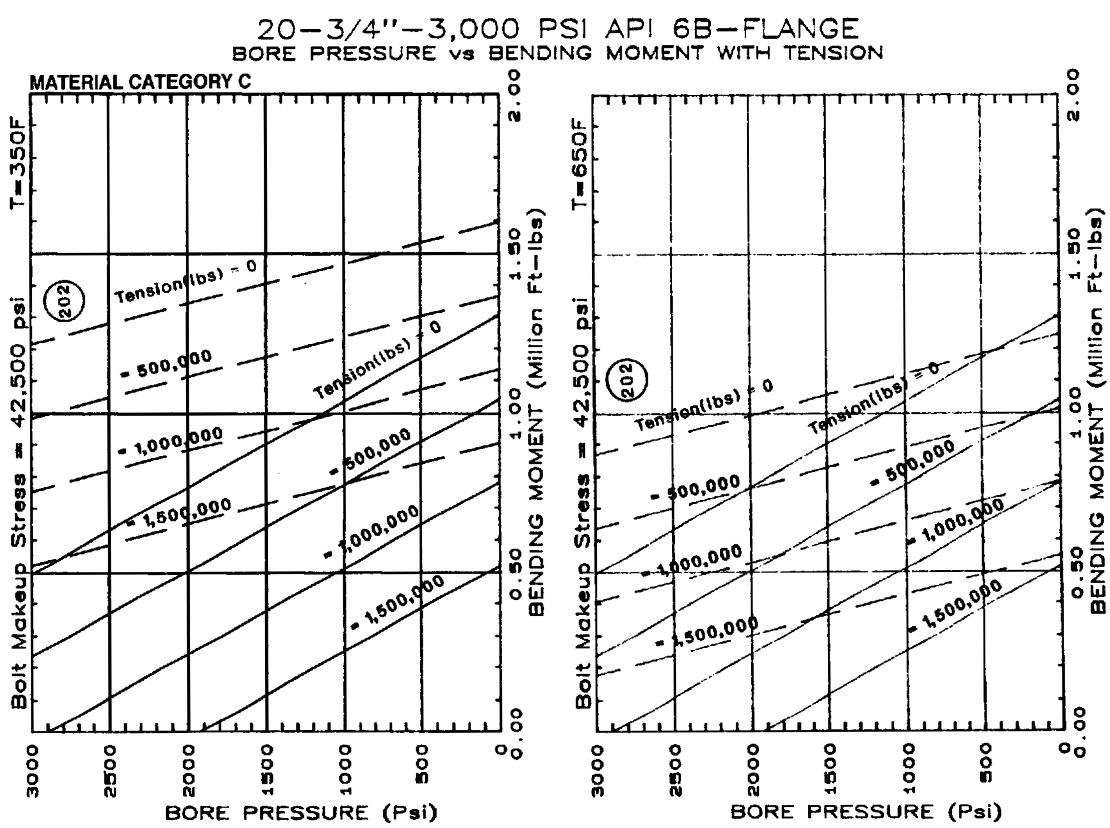
9"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



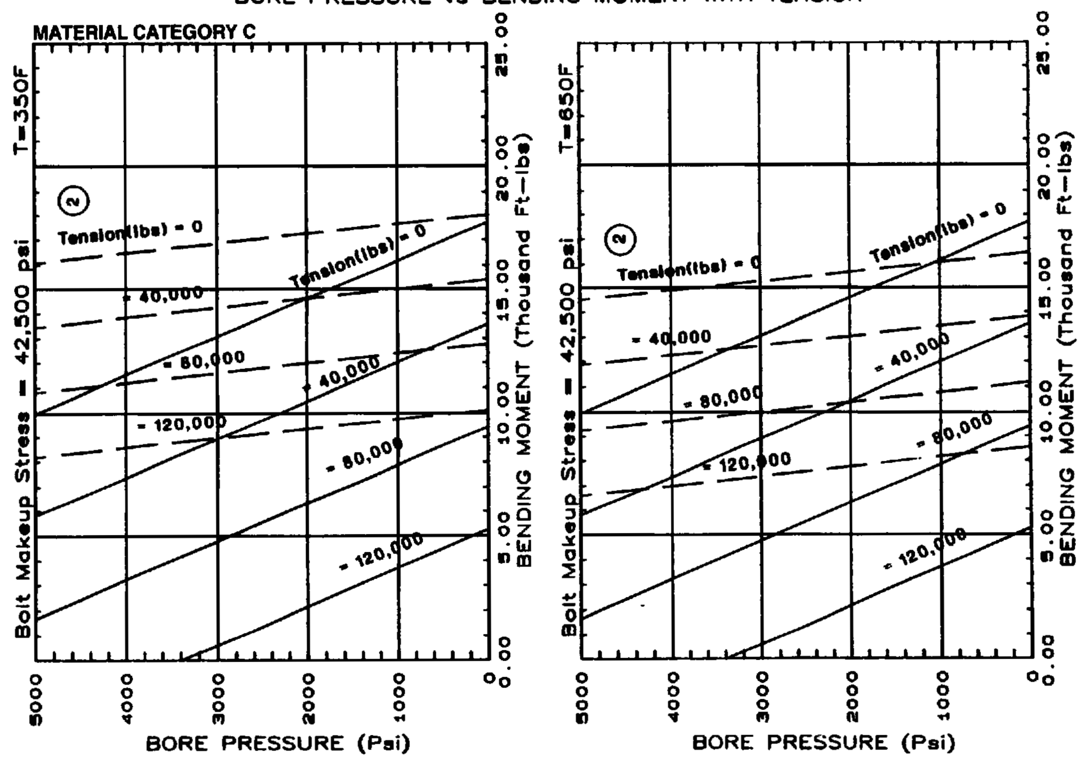
11"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



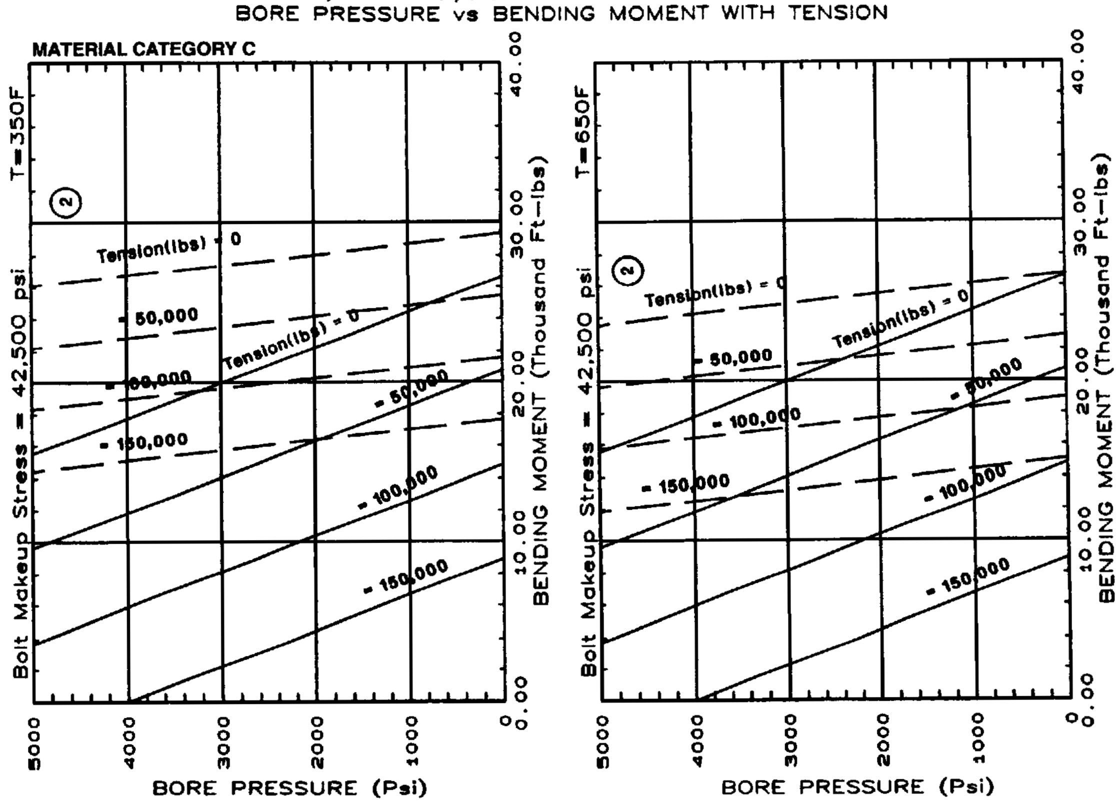

16-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY C
T=350F
T=650F
Bolt Makeup Stress = 42,500 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 500,000
= 1,000,000
= 1,500,000


20-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY C
T=350F
T=650F
Bolt Makeup Stress = 42,500 psi
BENDING MOMENT (Million Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 500,000
= 1,000,000
= 1,500,000

2-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

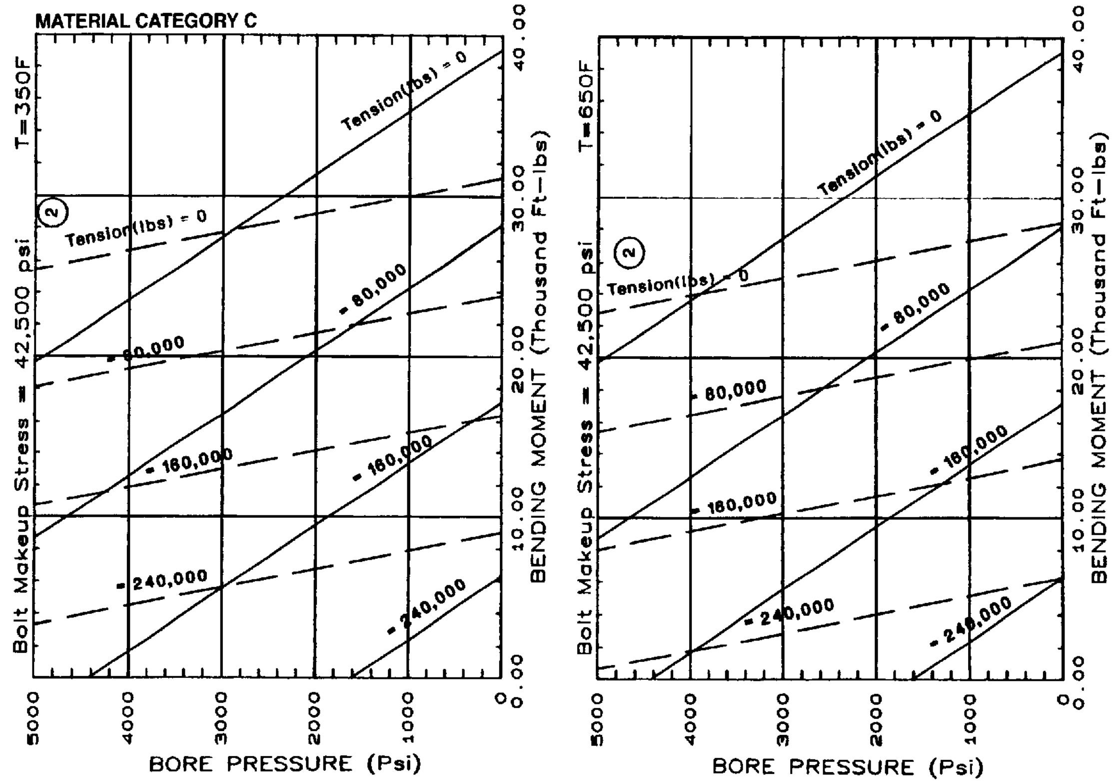


2-9/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



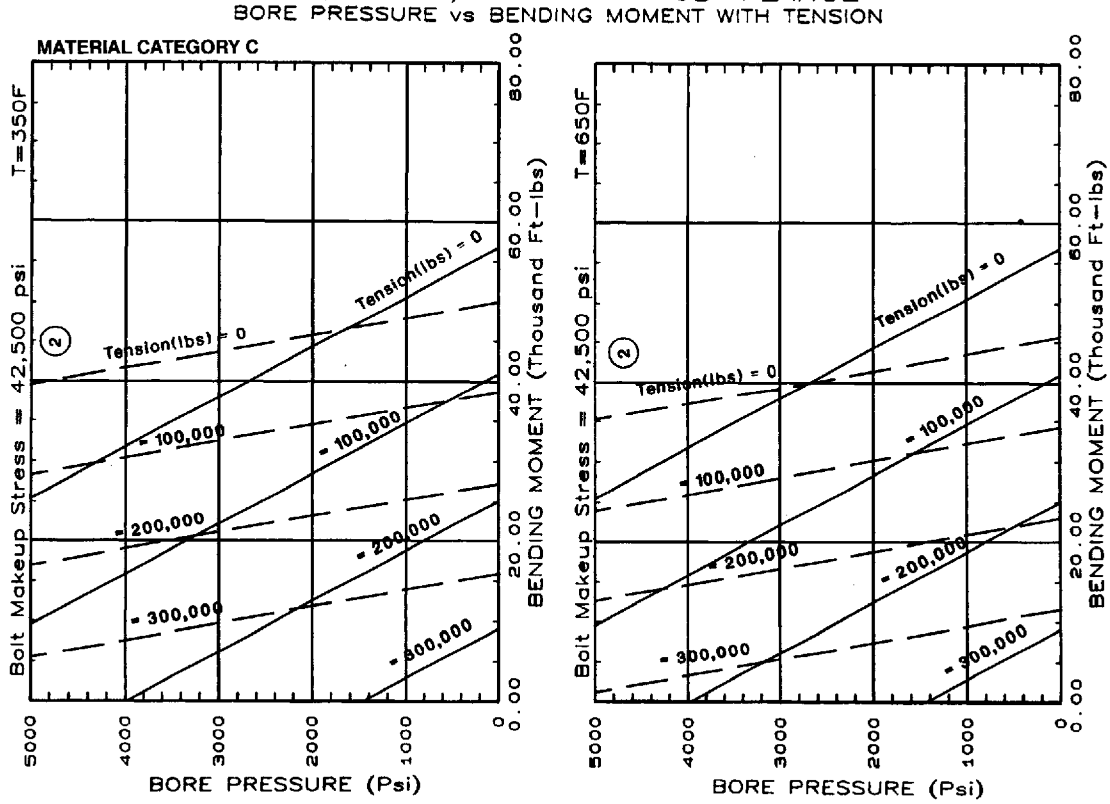
3-1/8"-5,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

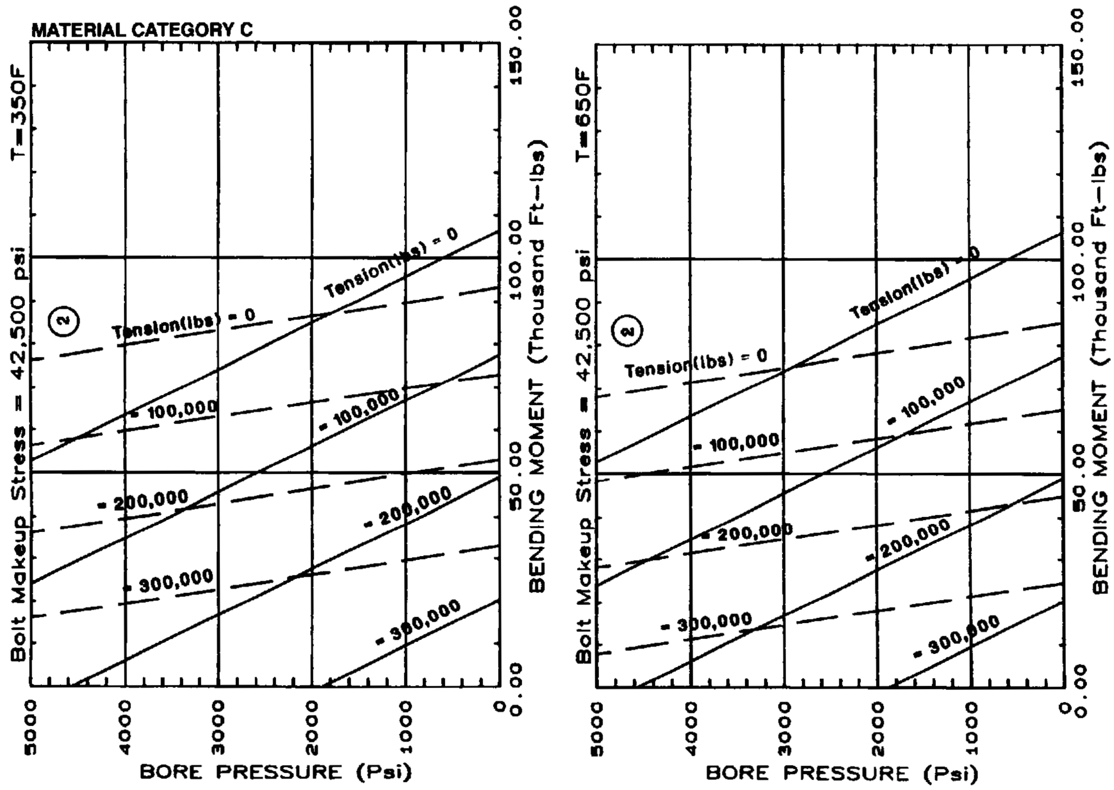


4-1/16"-5,000 PSI API 6B-FLANGE

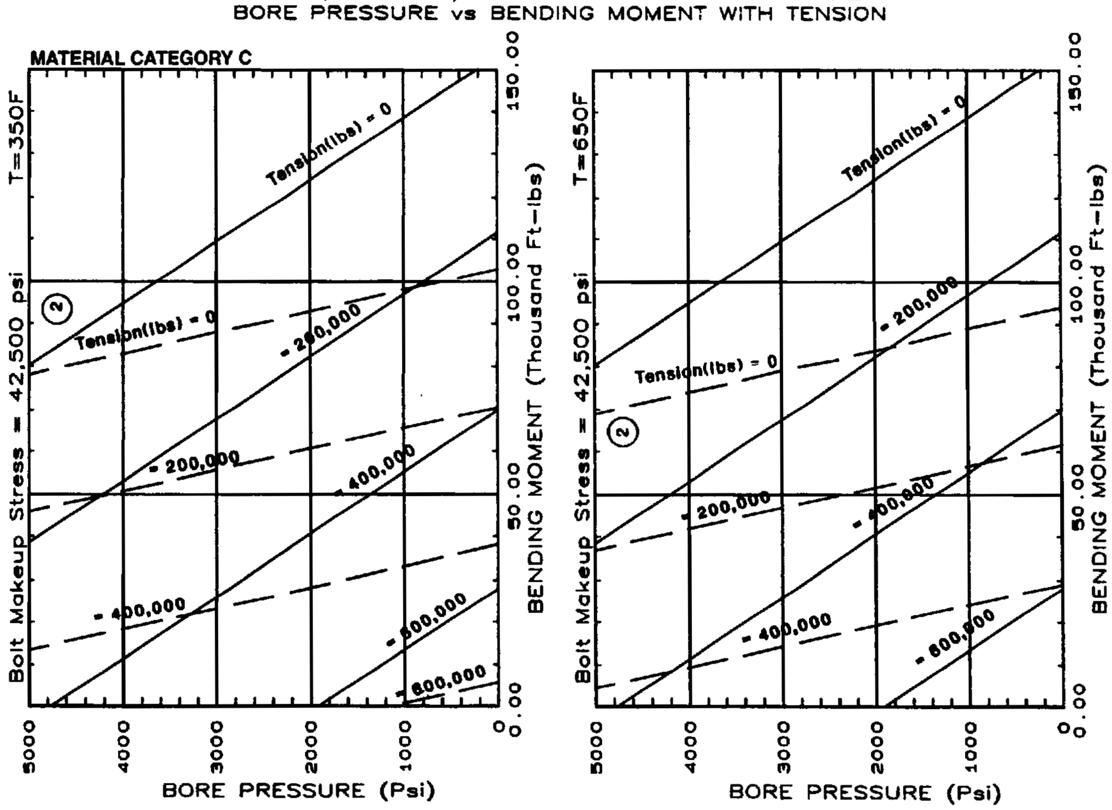
BORE PRESSURE vs BENDING MOMENT WITH TENSION



5-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

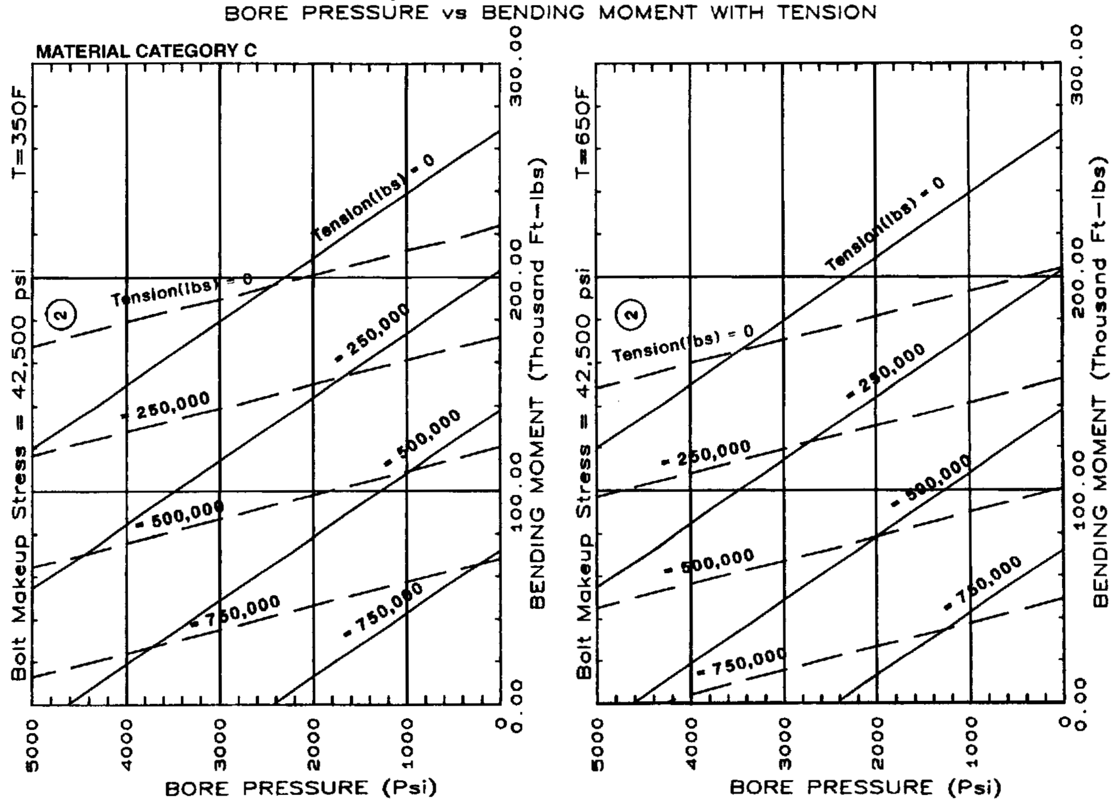


7-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



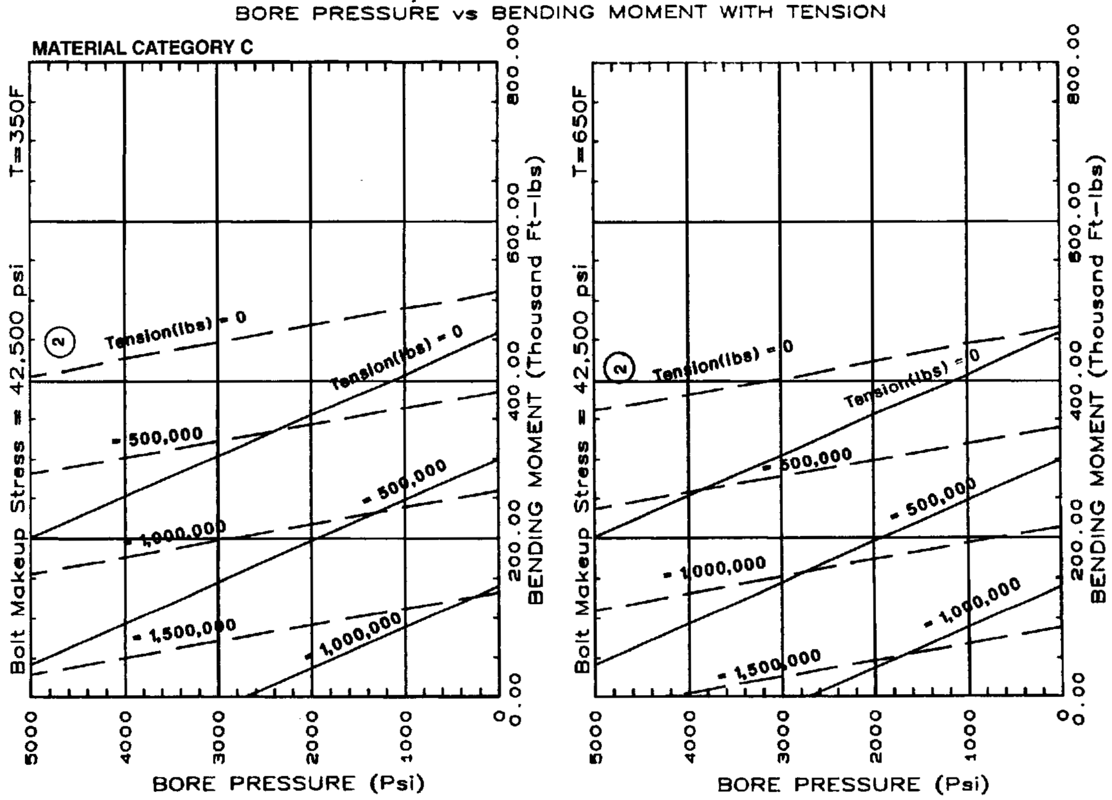
9"–5,000 PSI API 6B–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



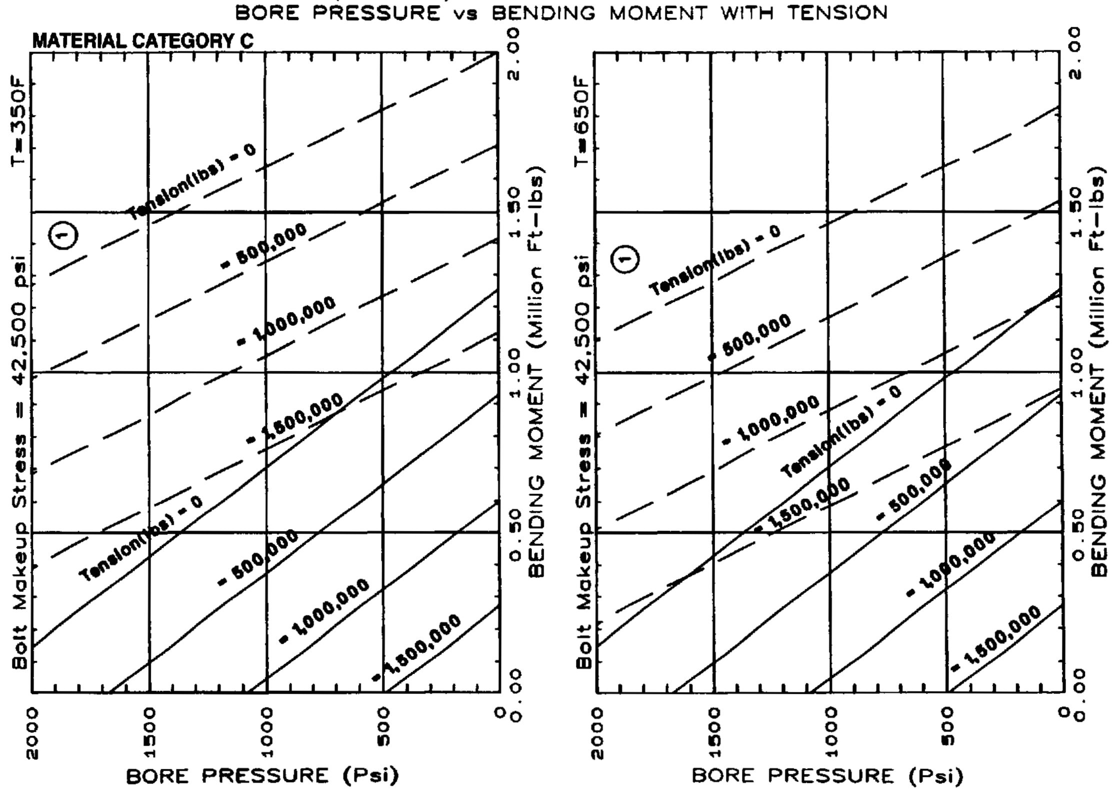
11"–5,000 PSI API 6B–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



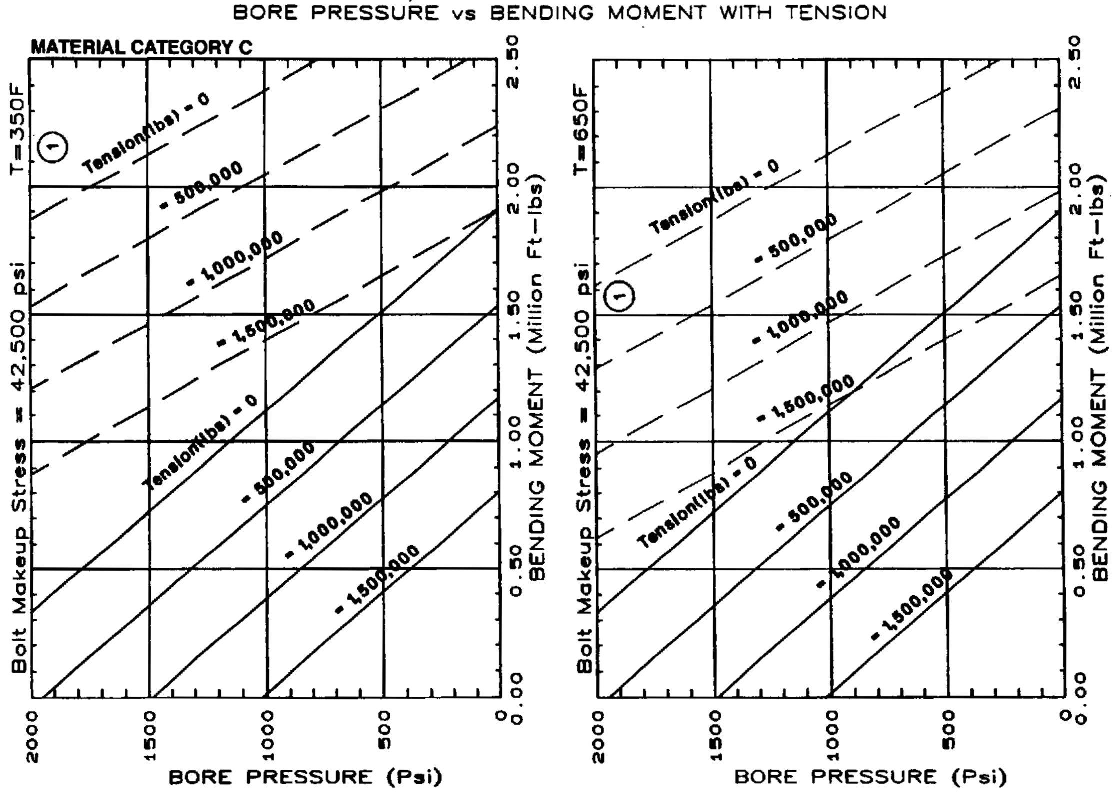
26-3/4"-2,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

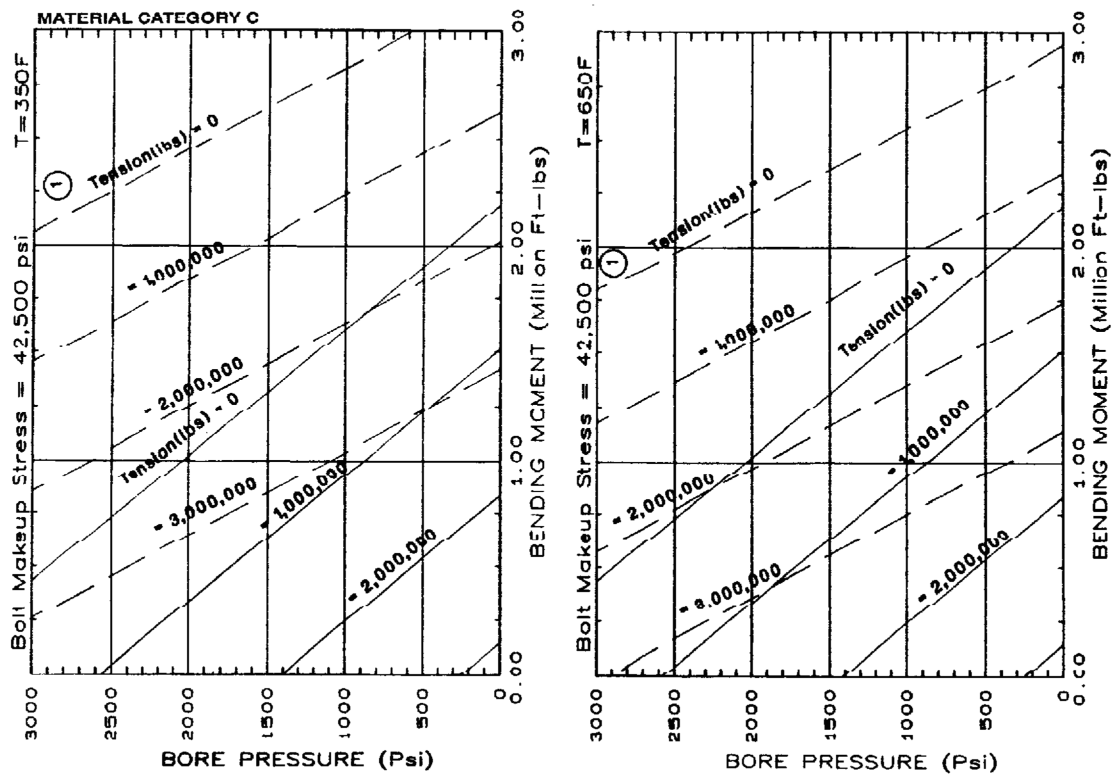


30"-2,000 PSI API 6BX-FLANGE

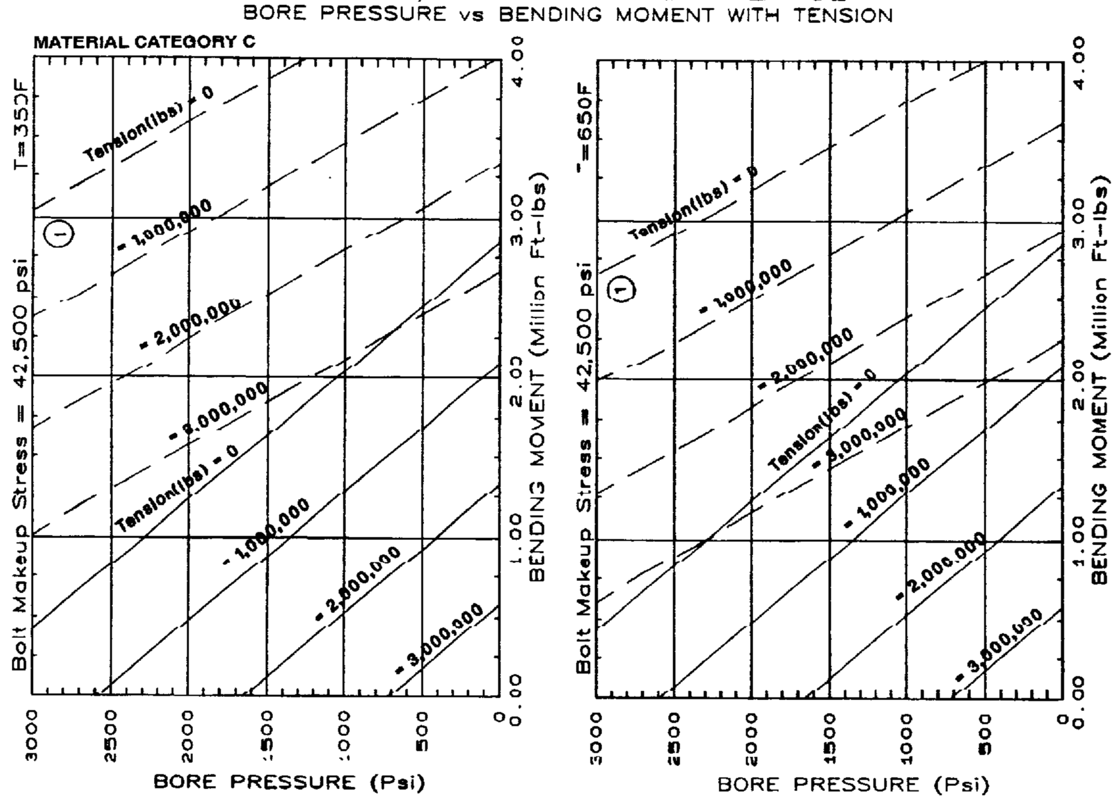
BORE PRESSURE vs BENDING MOMENT WITH TENSION



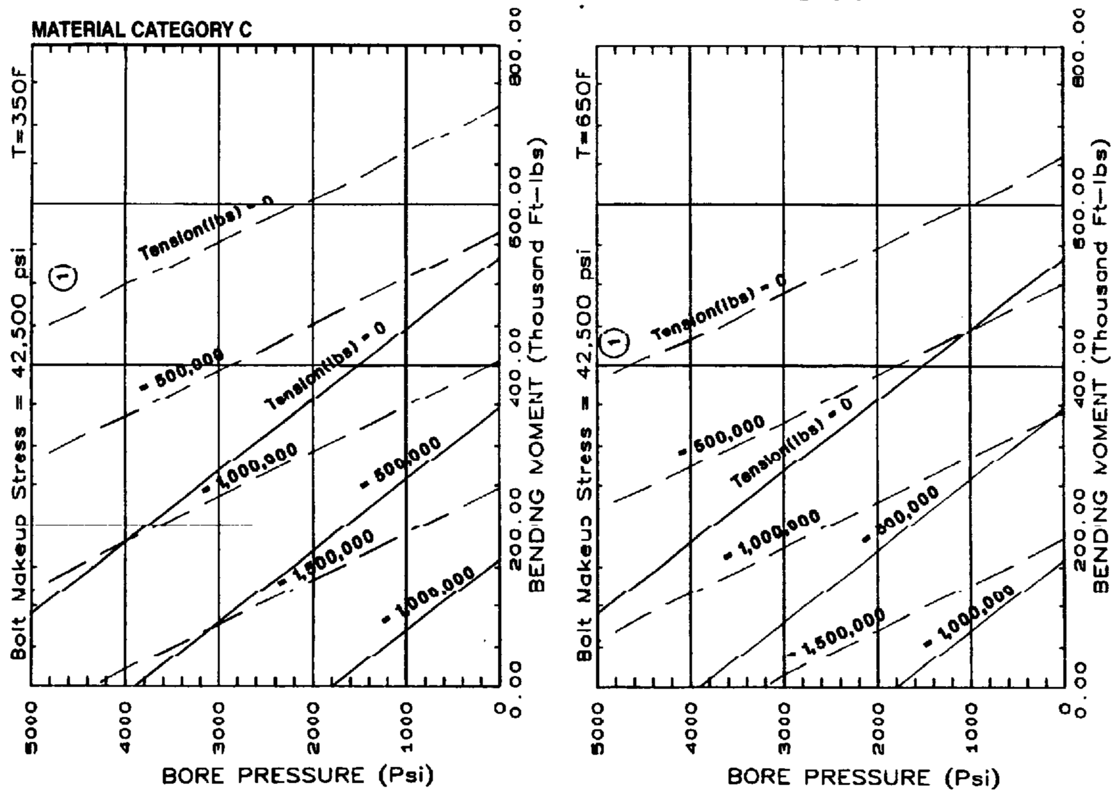
26–3/4"–3,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



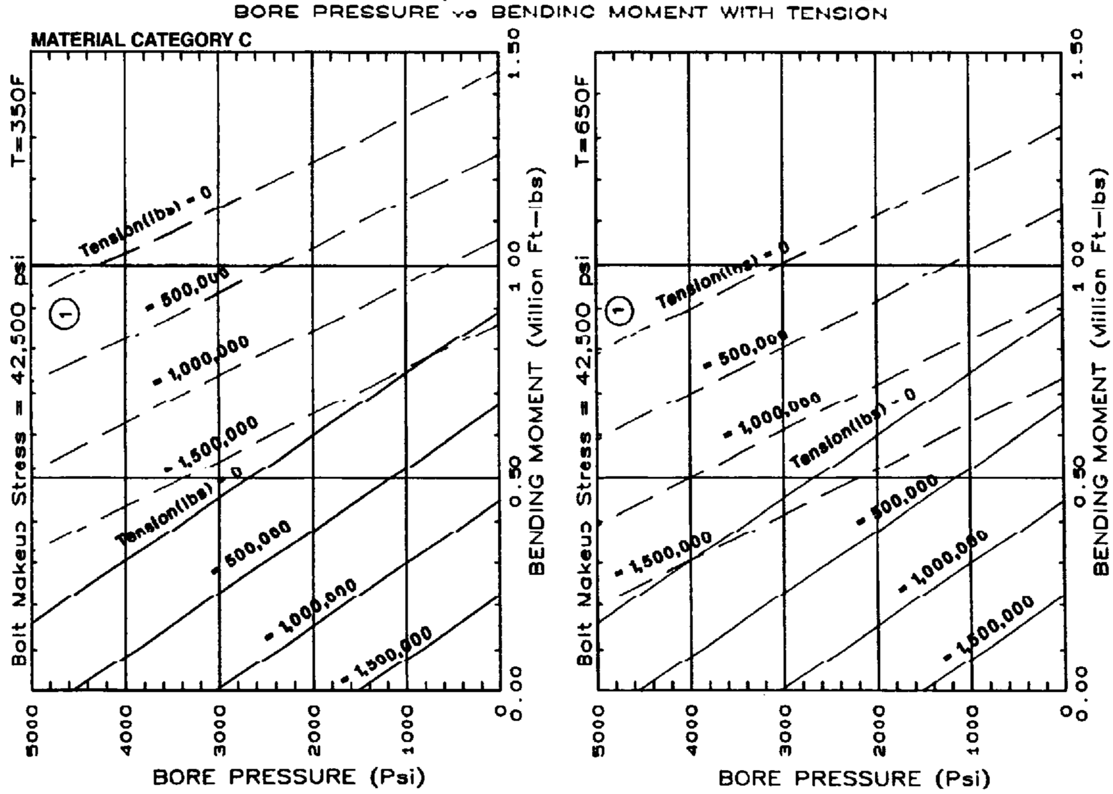
30"–3,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



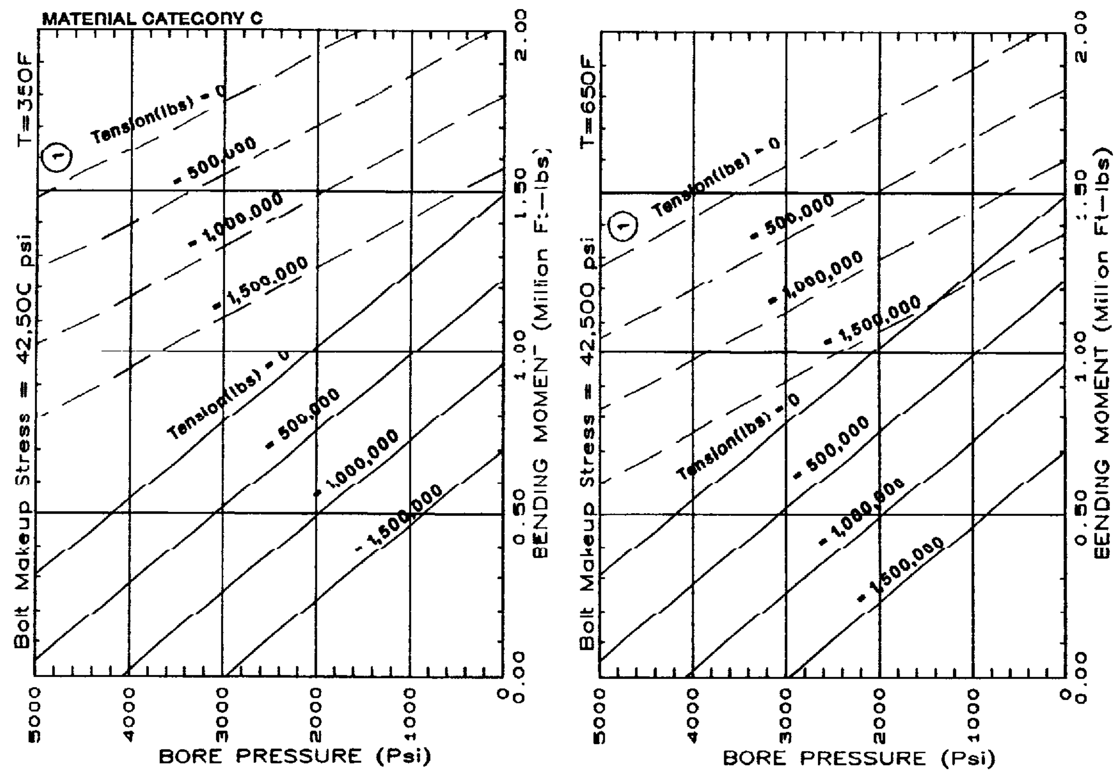
13-5/8"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



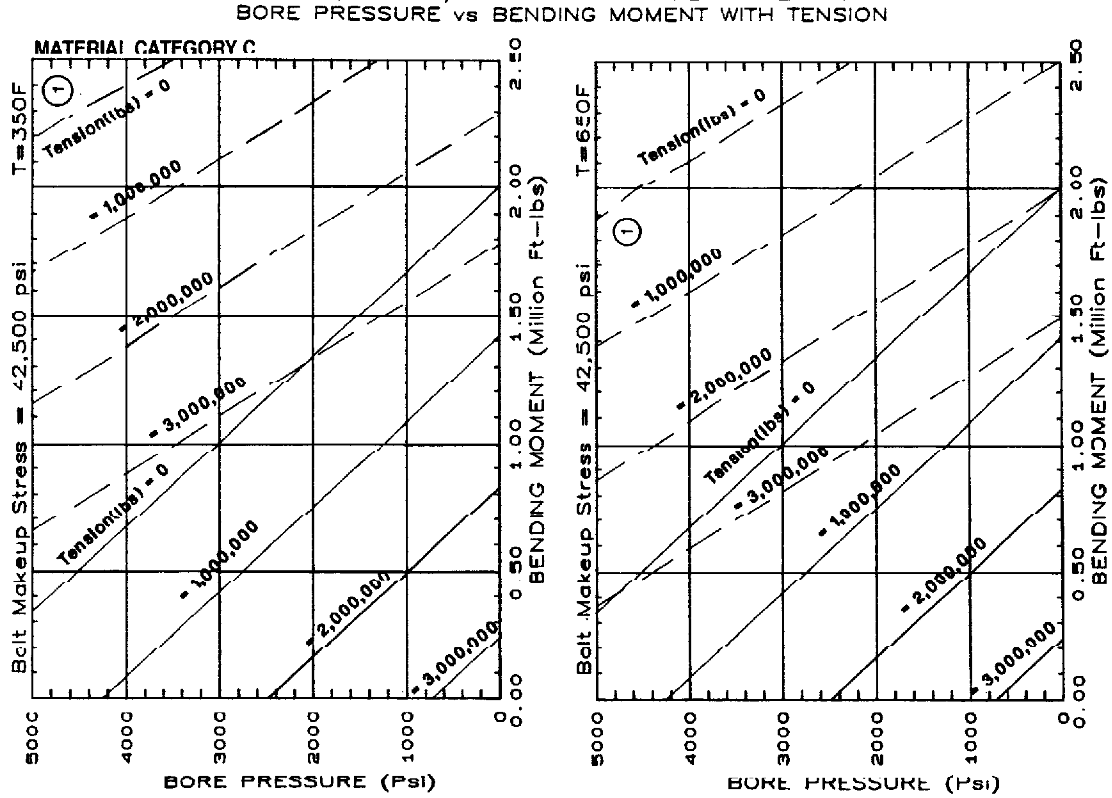
16-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



18-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

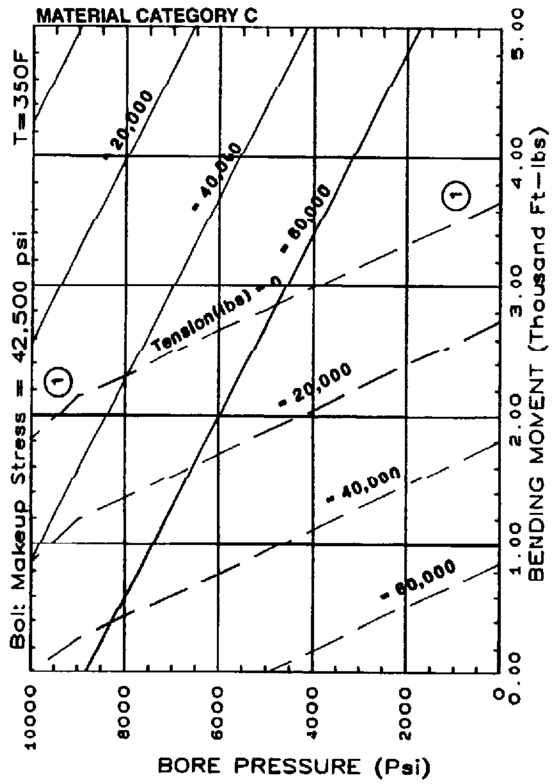


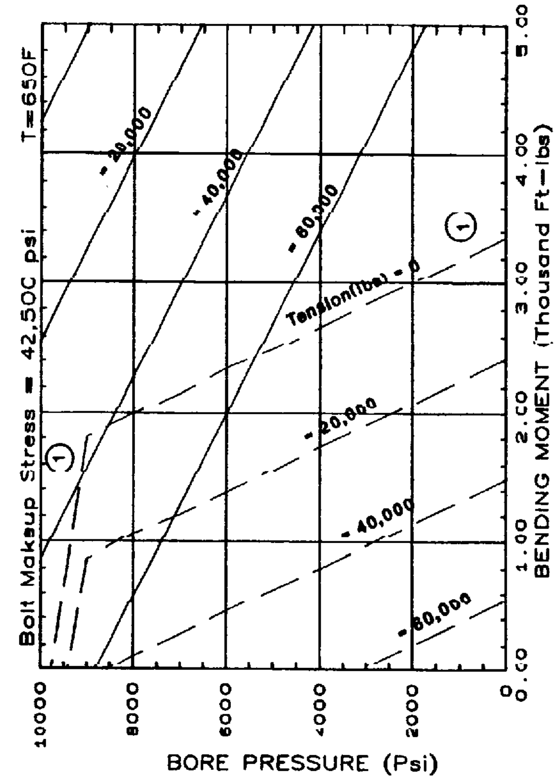
21-1/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



1–13/16"–10,000 PSI API 6BX–FLANGE

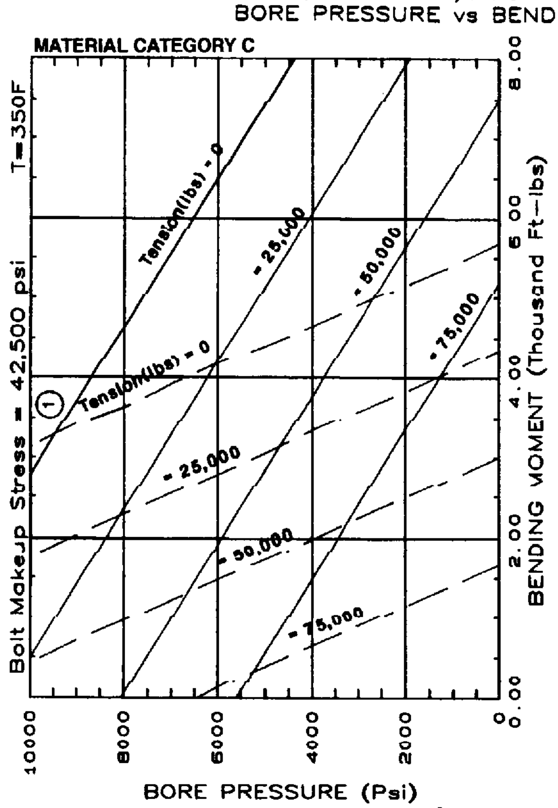
BORE PRESSURE vs BENDING MOMENT WITH TENSION

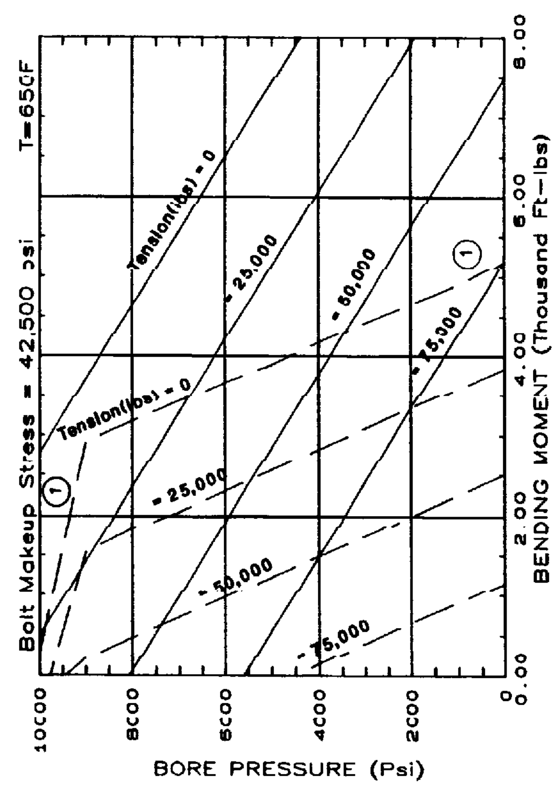




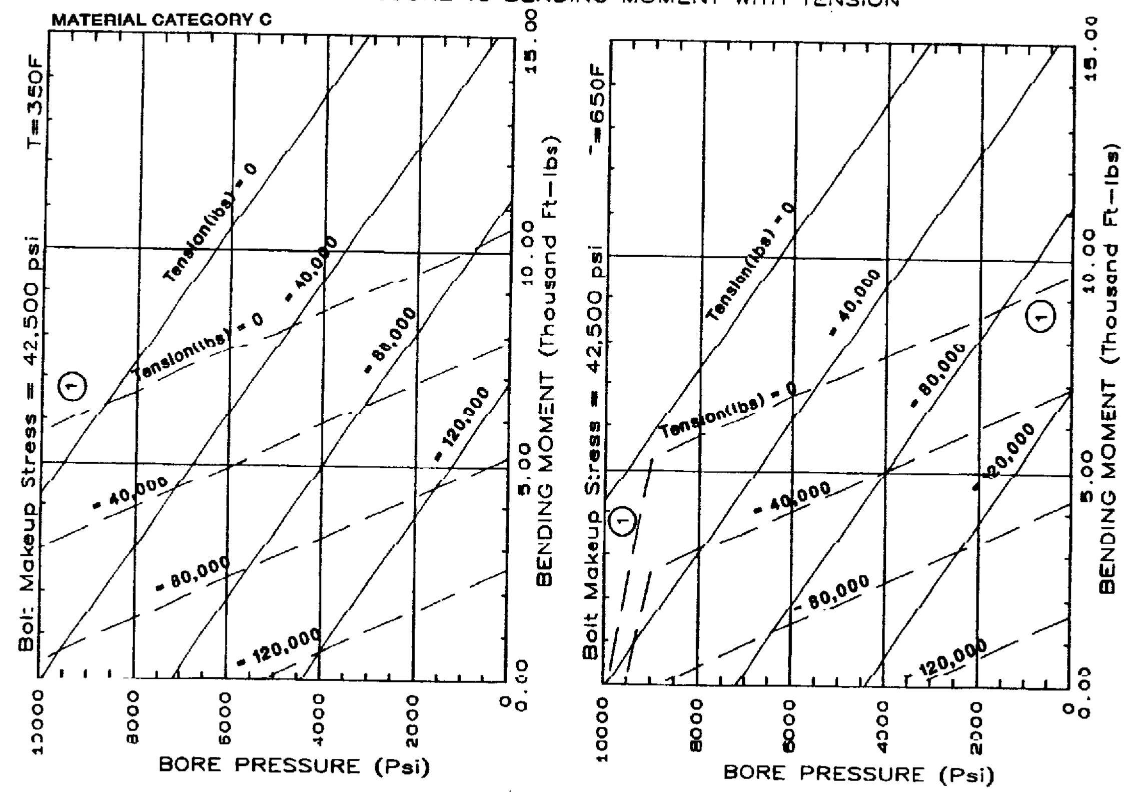
2–1/16"–10,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

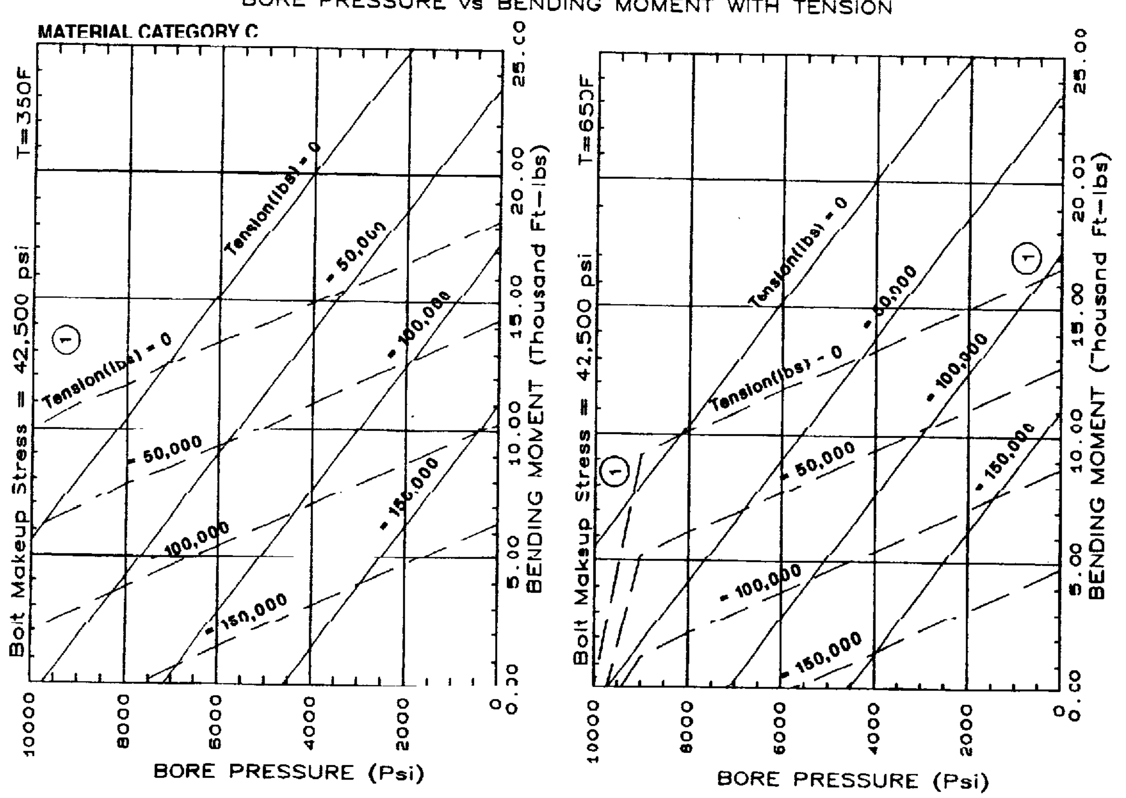




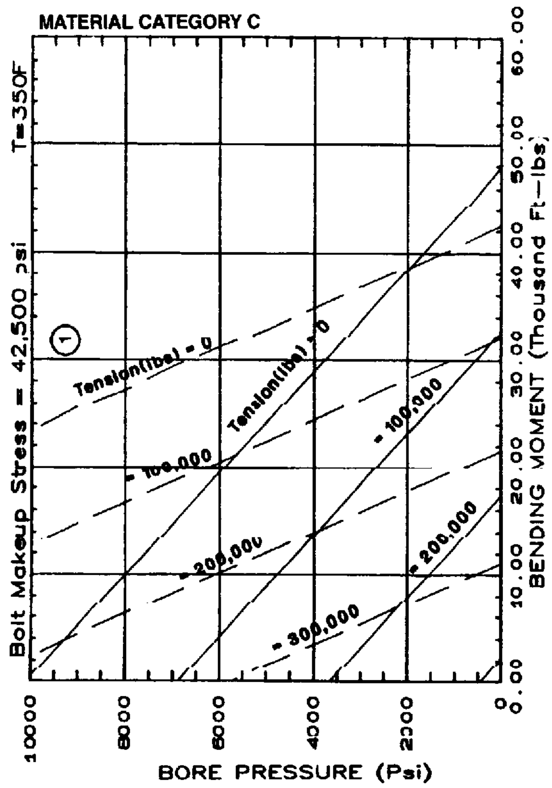
2-9/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

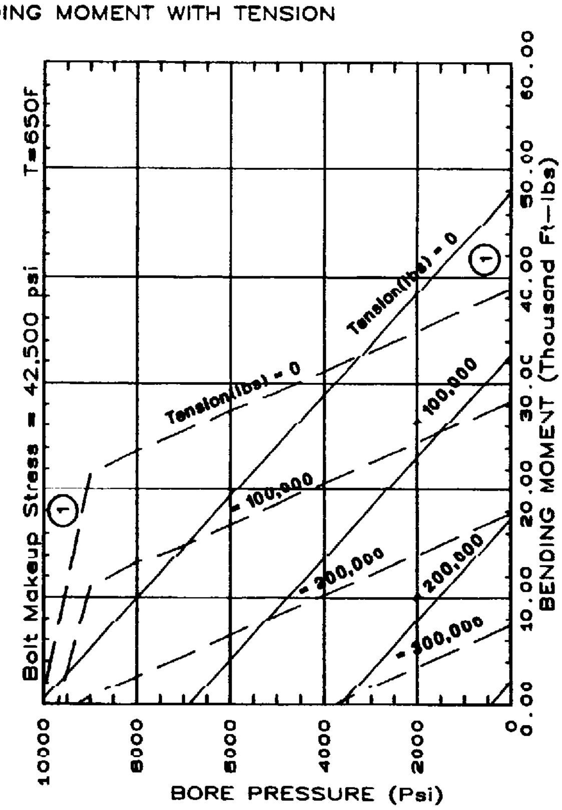


3-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

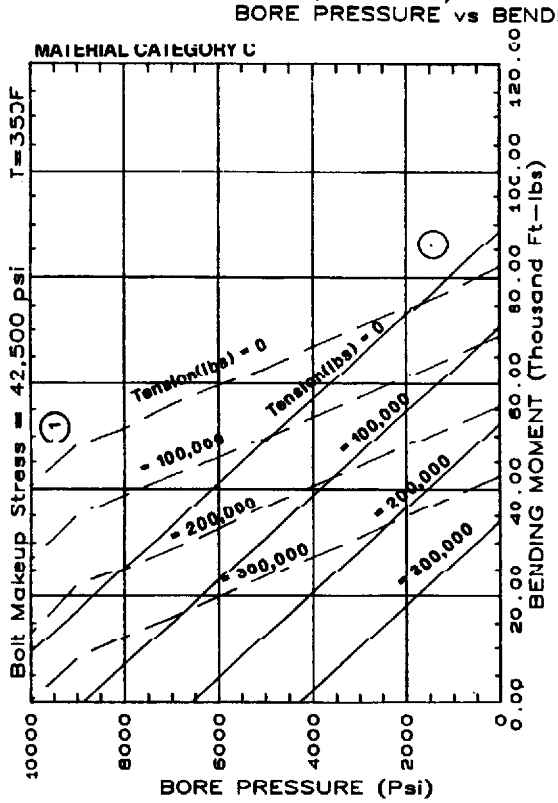


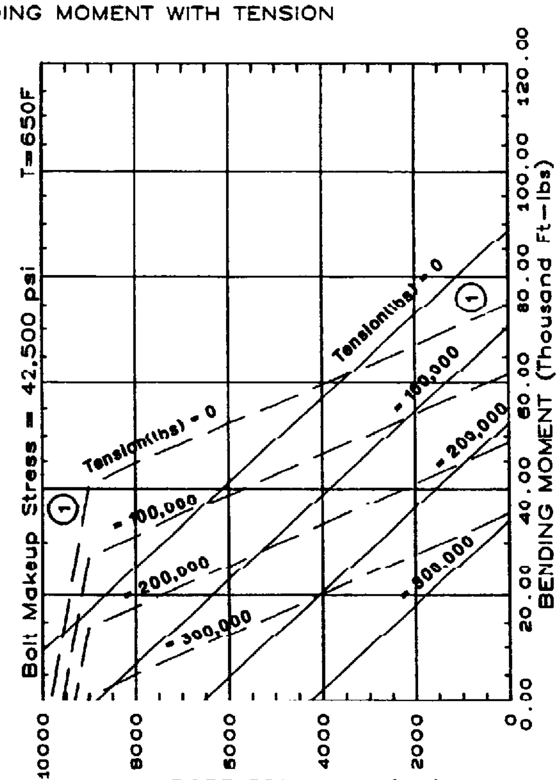
4-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





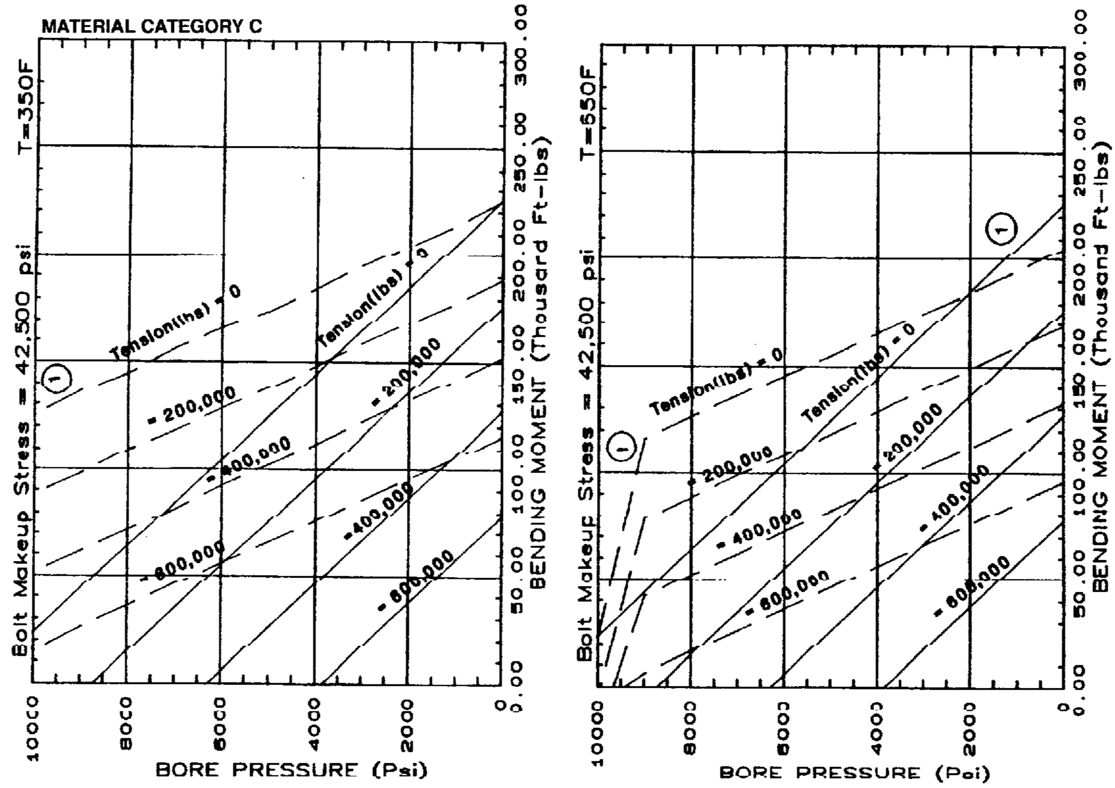
5-1/8"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





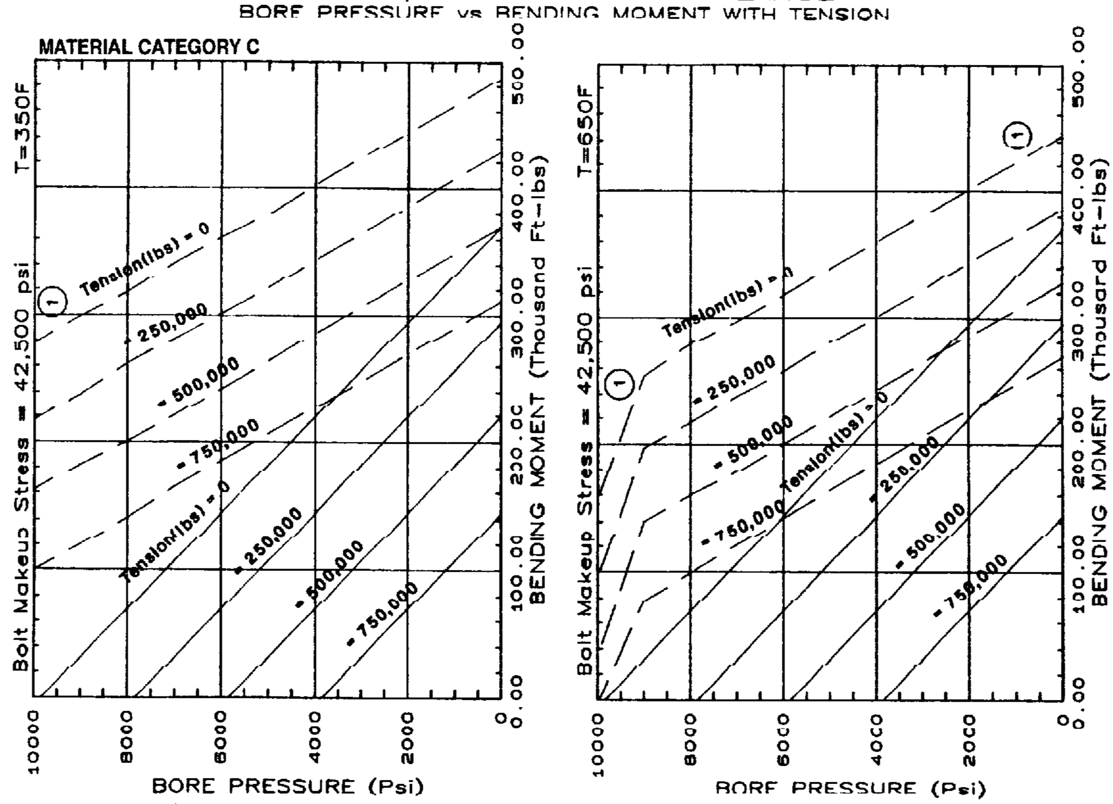
7-1/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

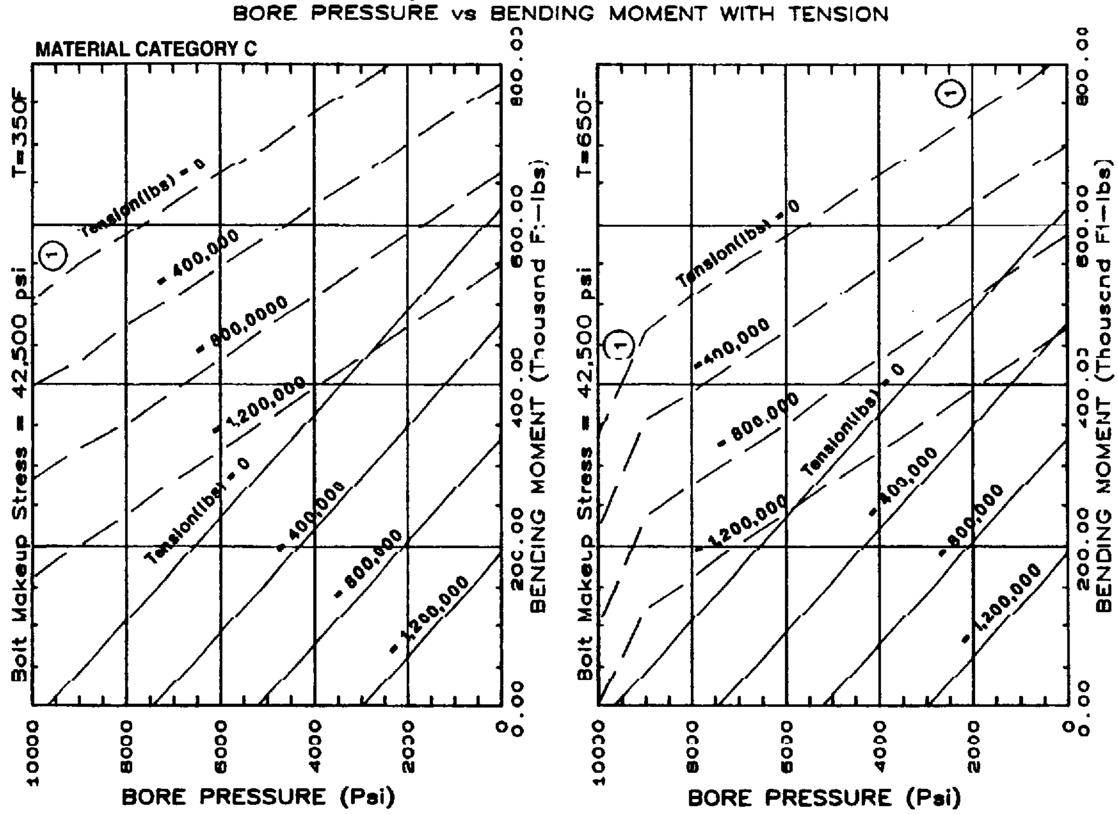


9"-10,000 PSI API 6BX-FLANGE

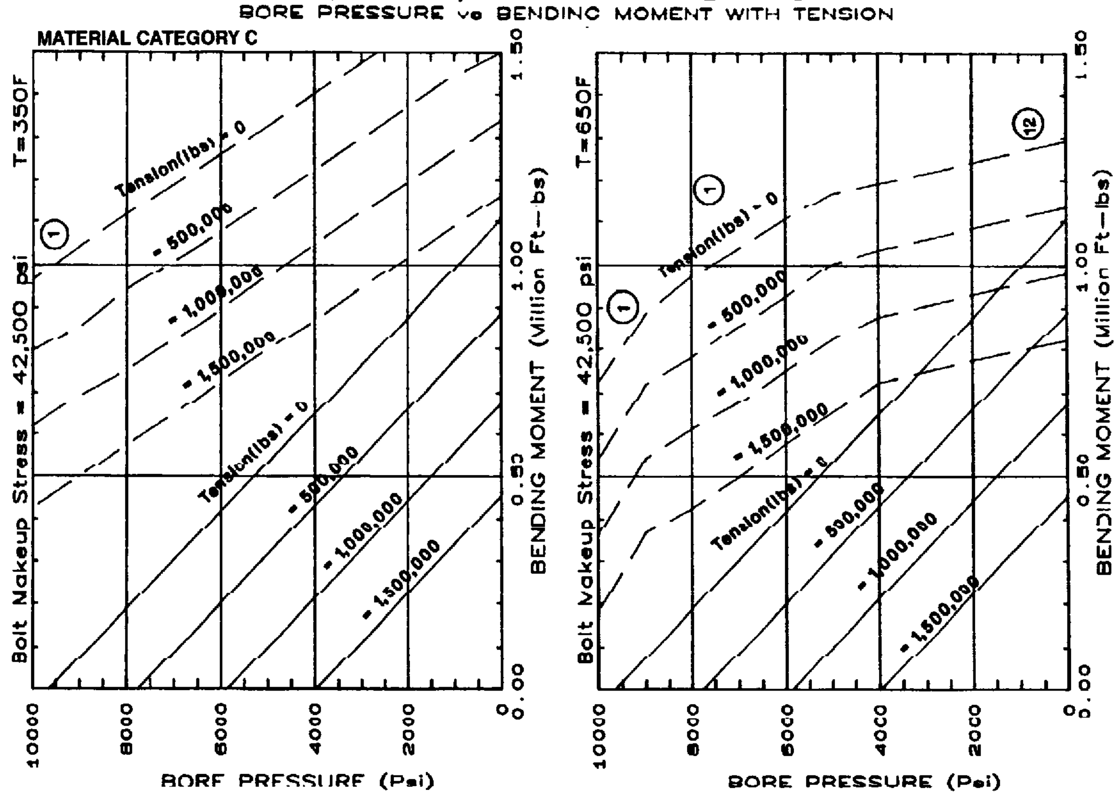
BORE PRESSURE vs BENDING MOMENT WITH TENSION



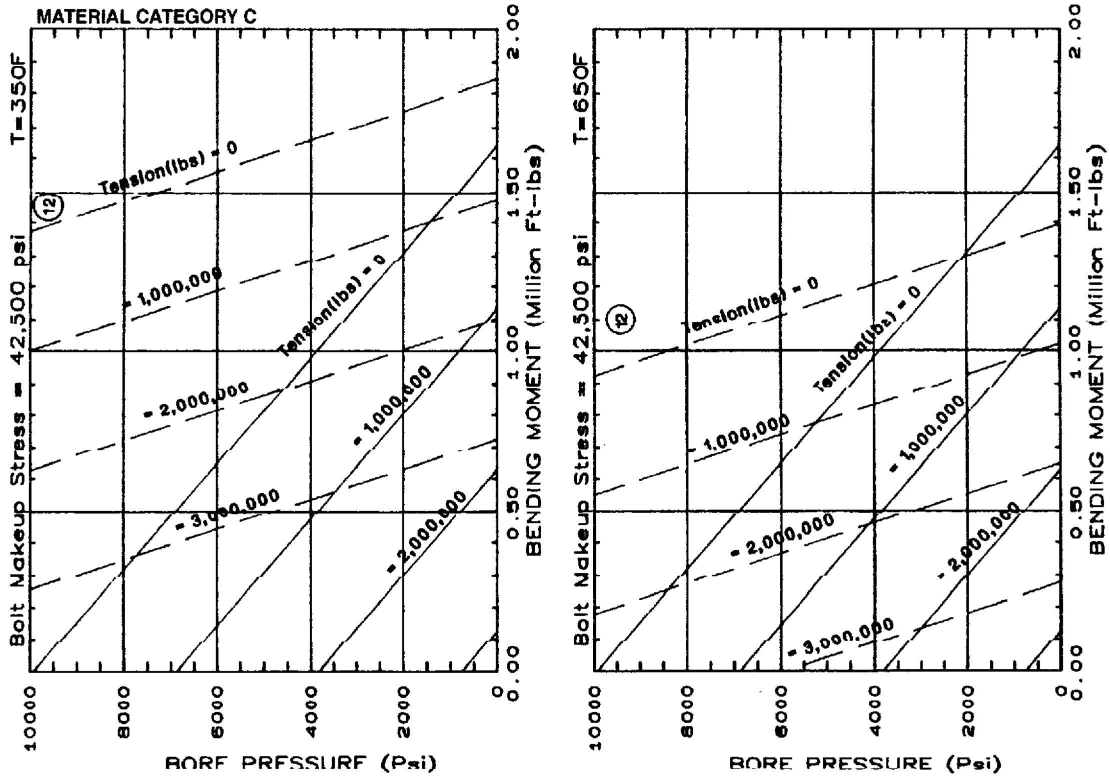
11"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



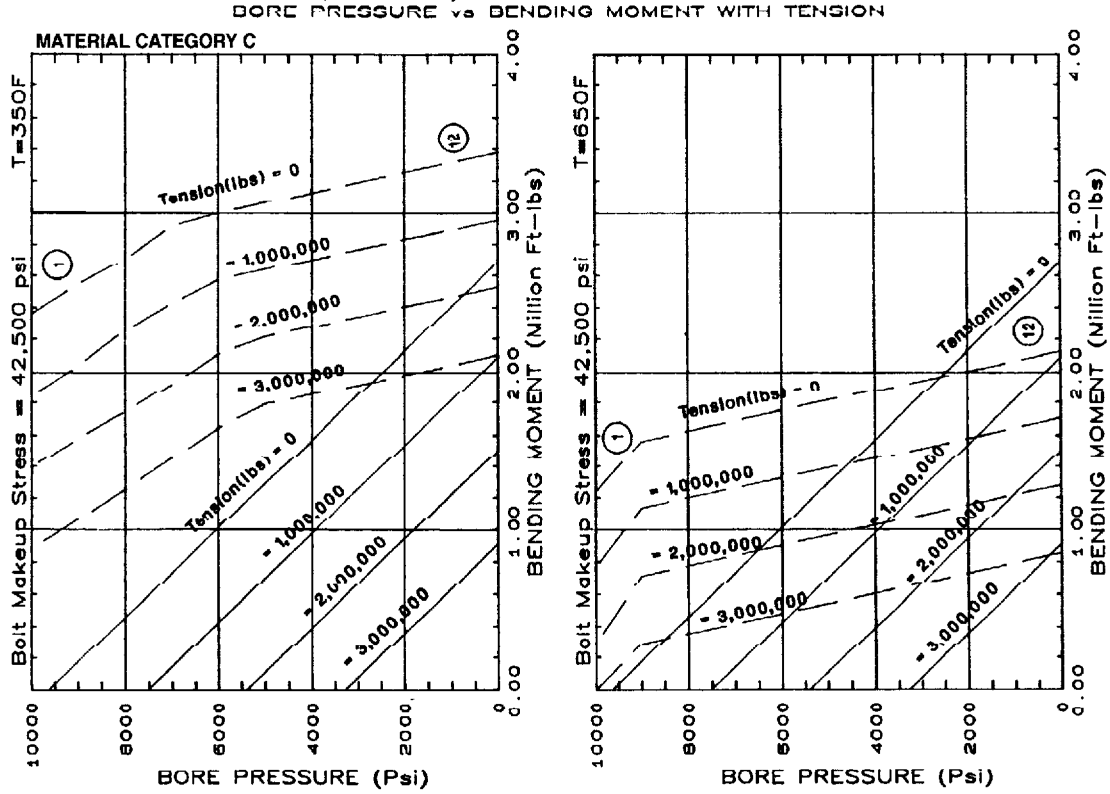
13–5/8"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



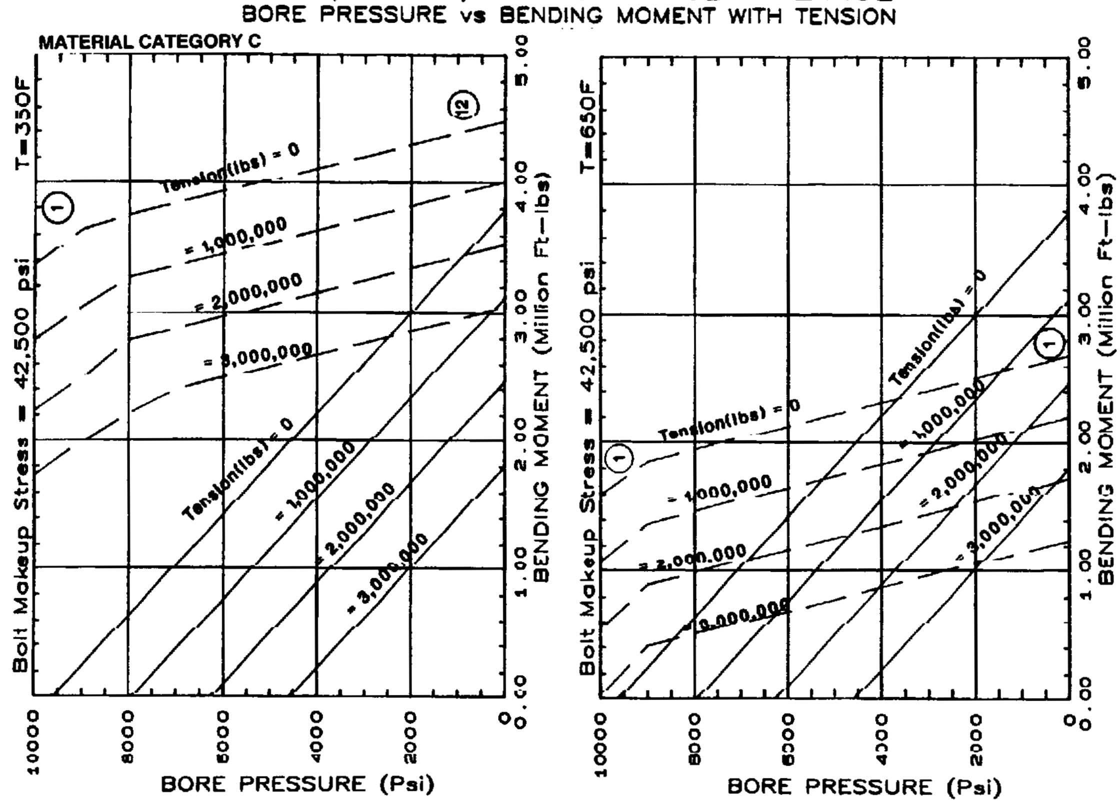
16–3/4"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



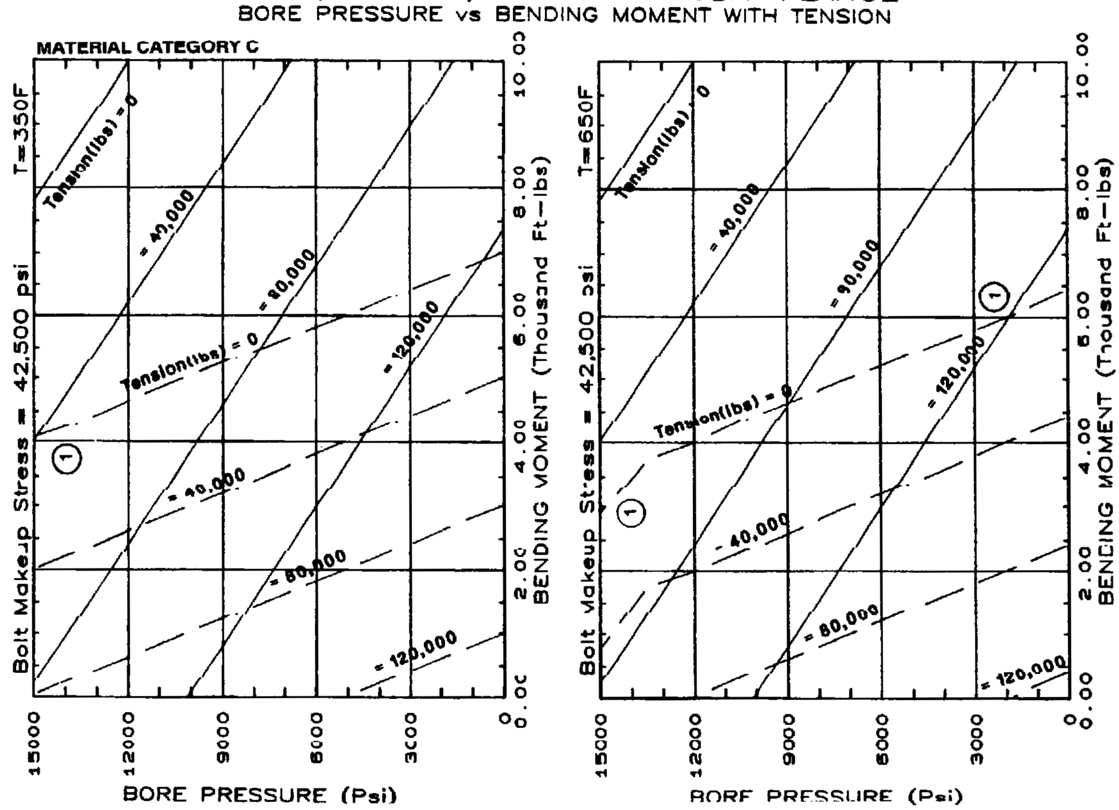
18–3/4"–10,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



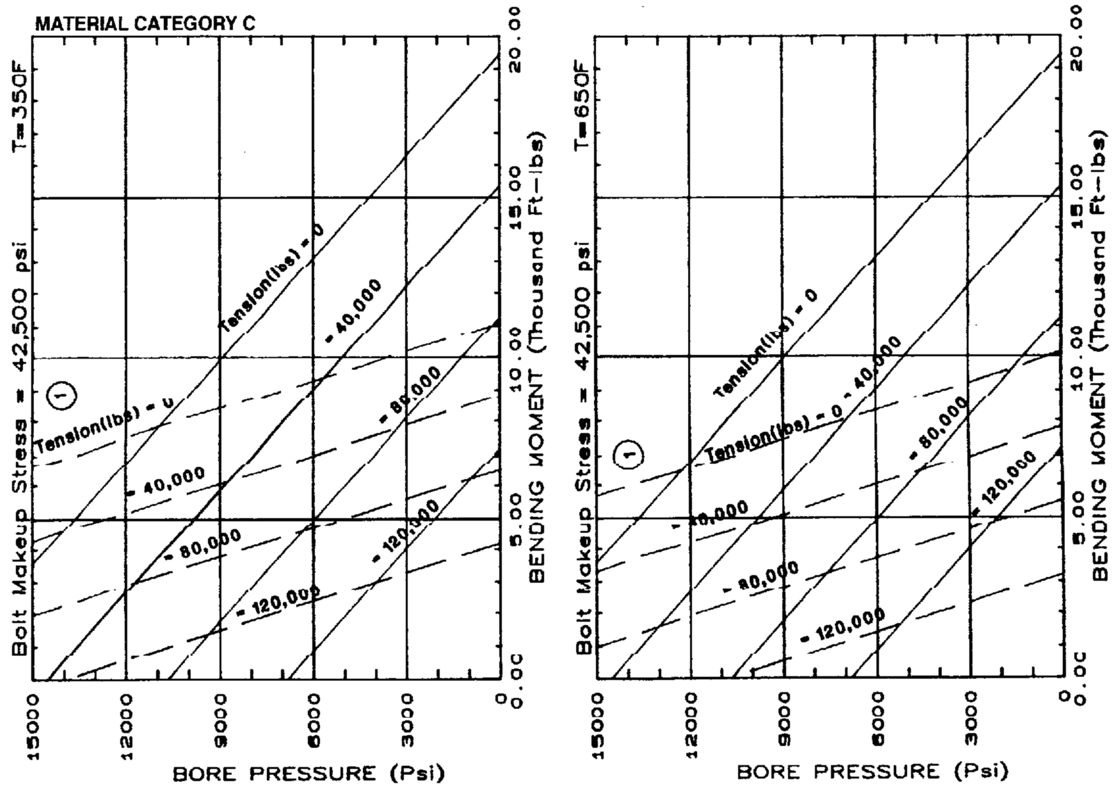
21-1/4"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



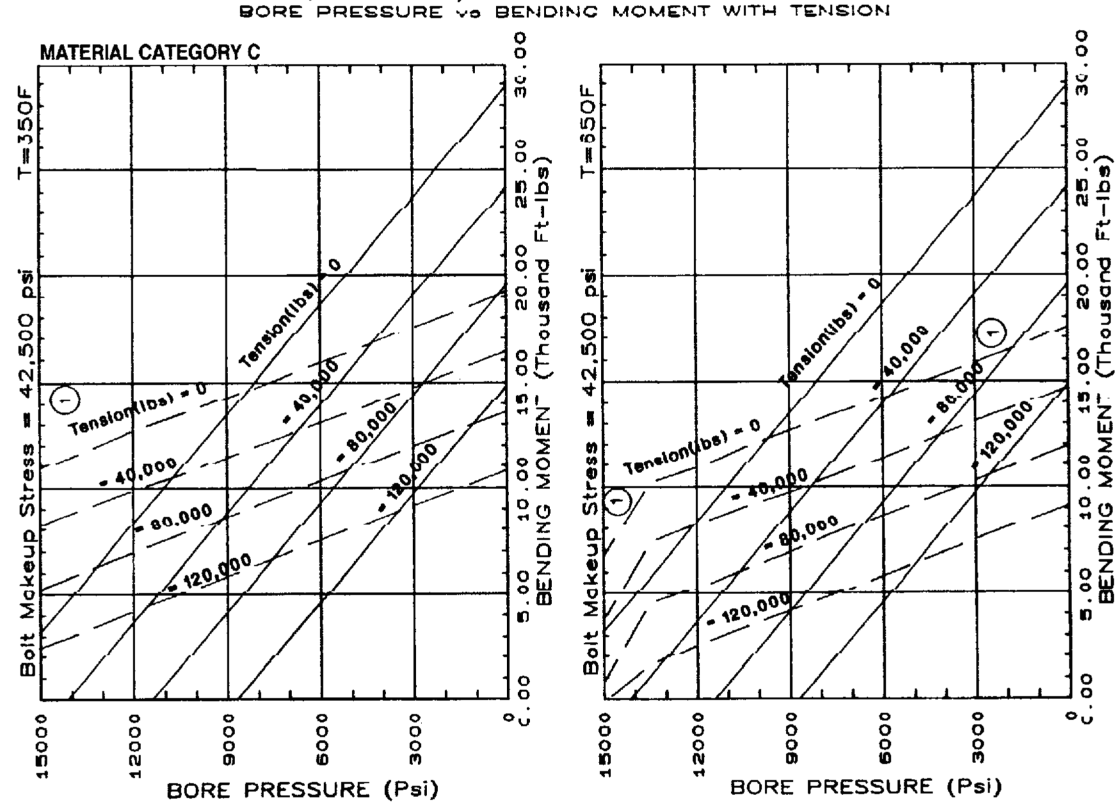
1-13/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



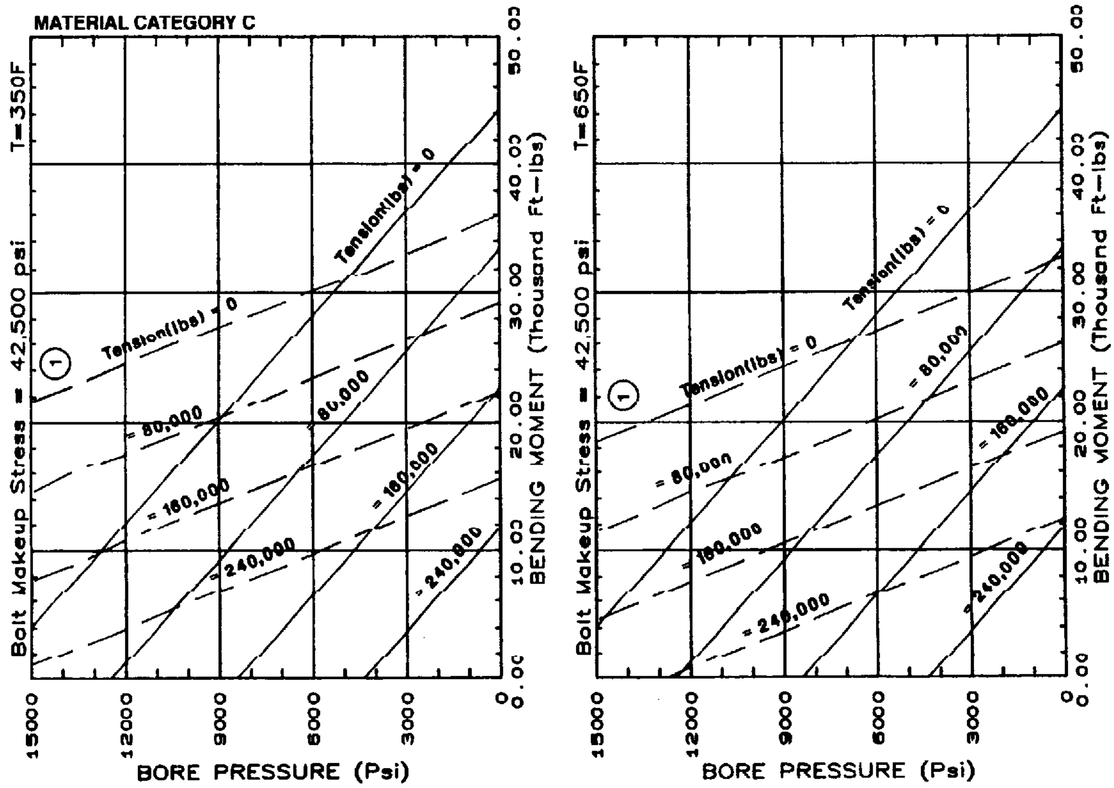
2-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



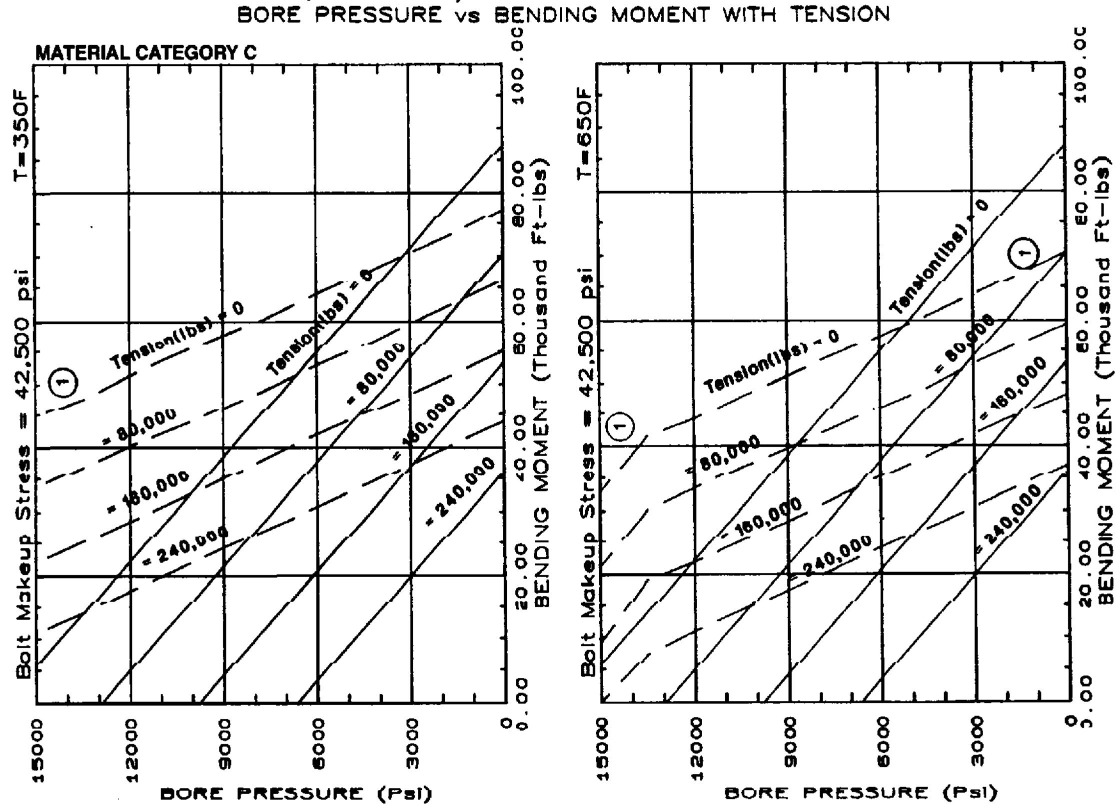
2-9/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



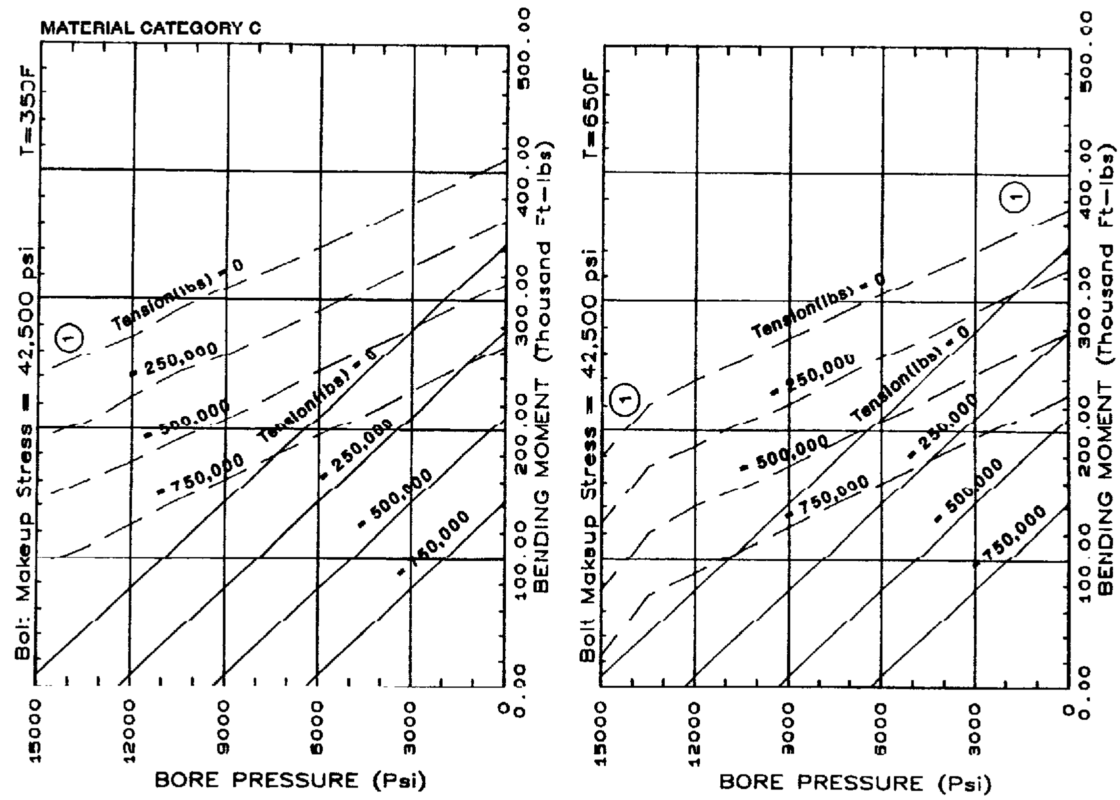
3-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



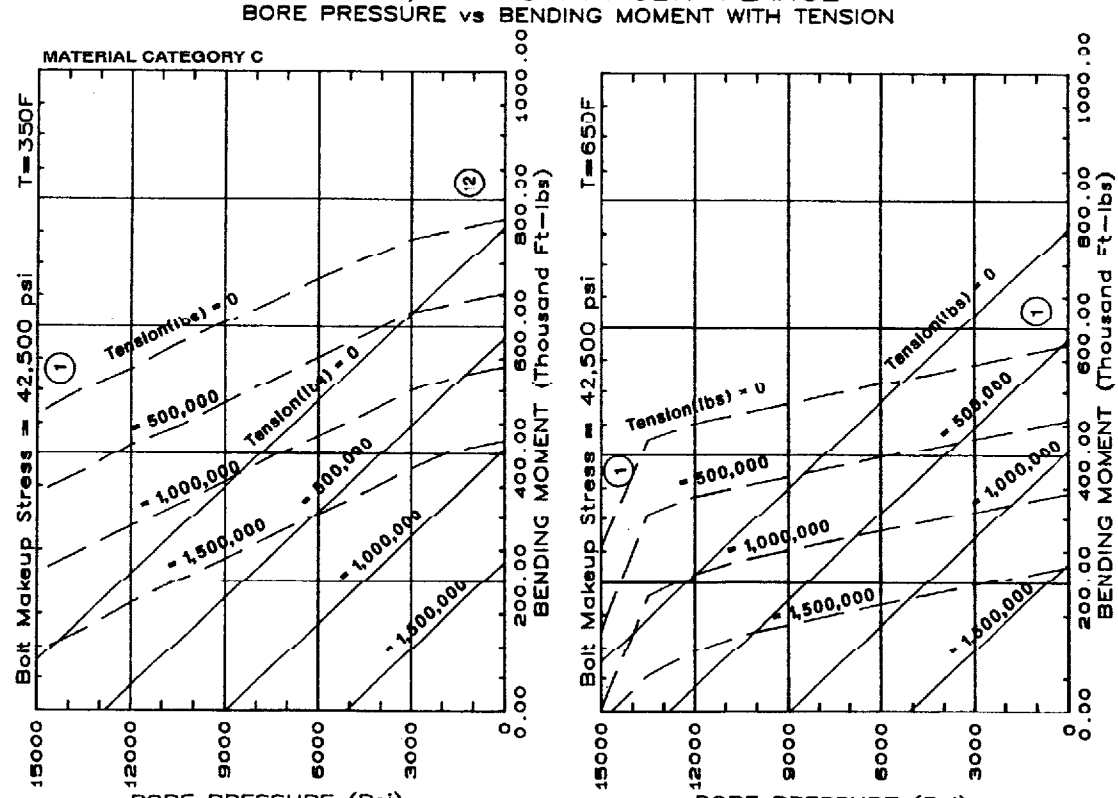
4-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



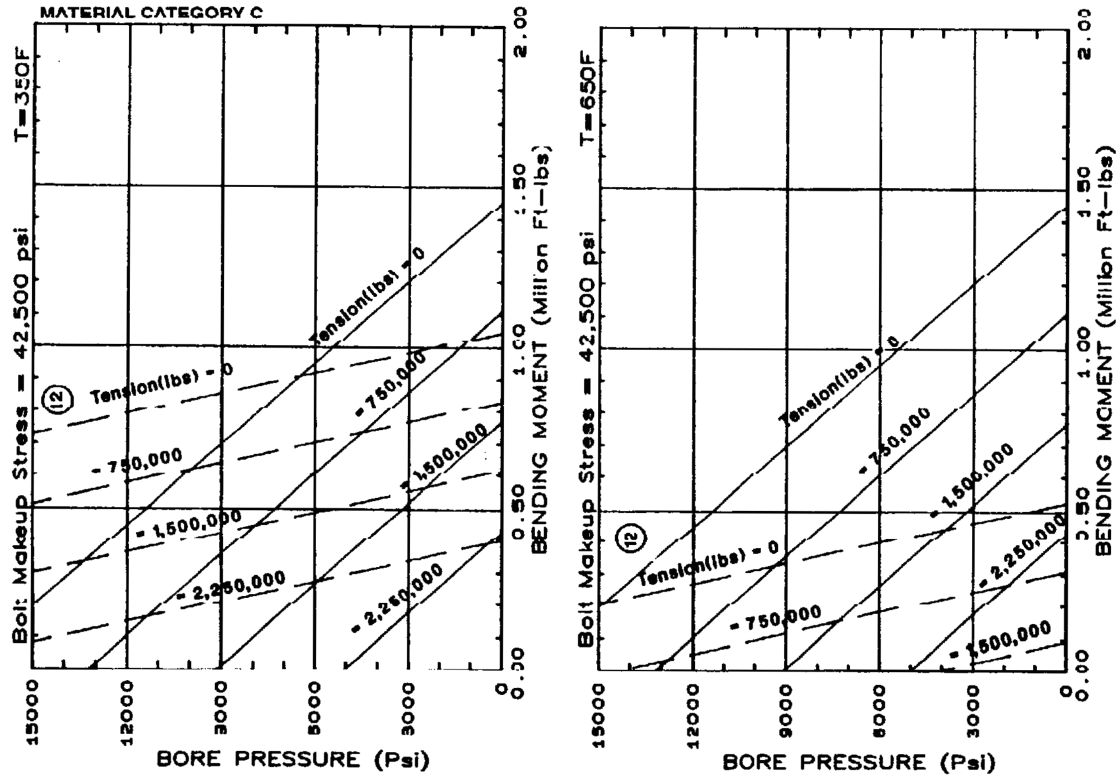
7-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



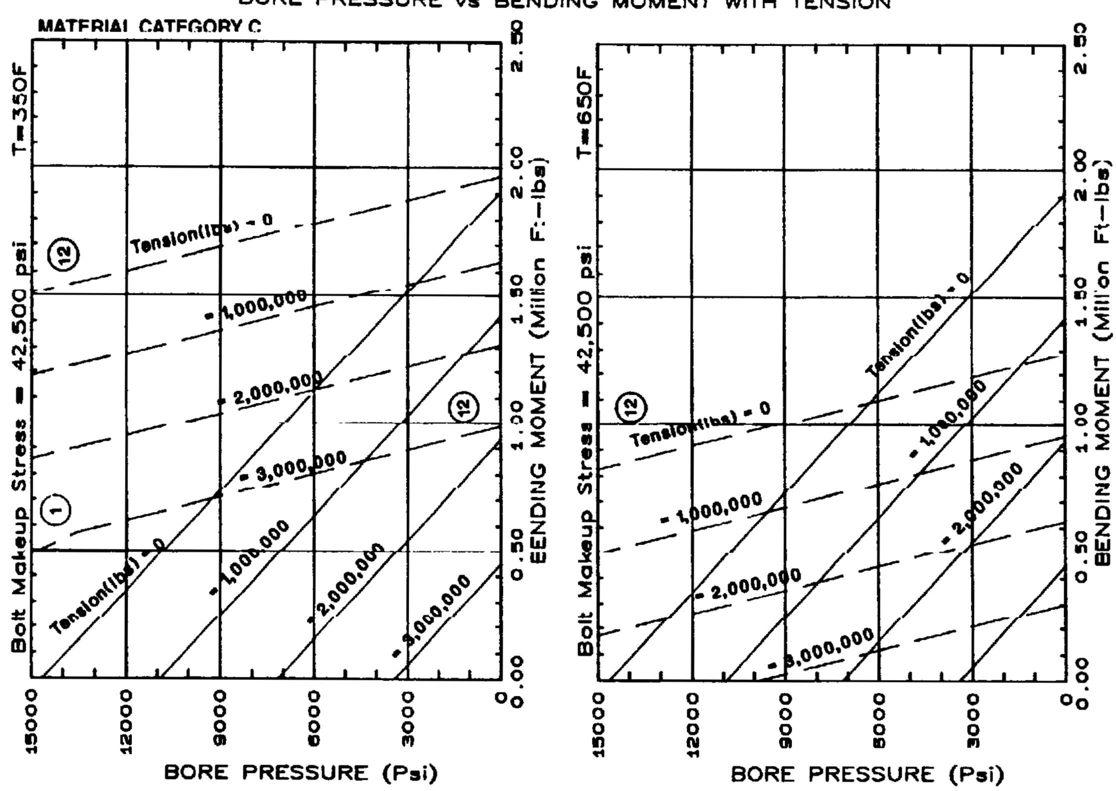
9"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



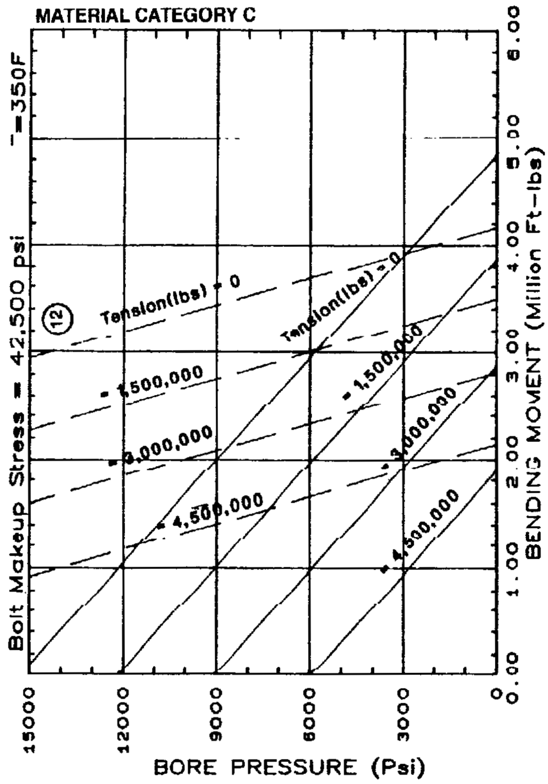
11"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

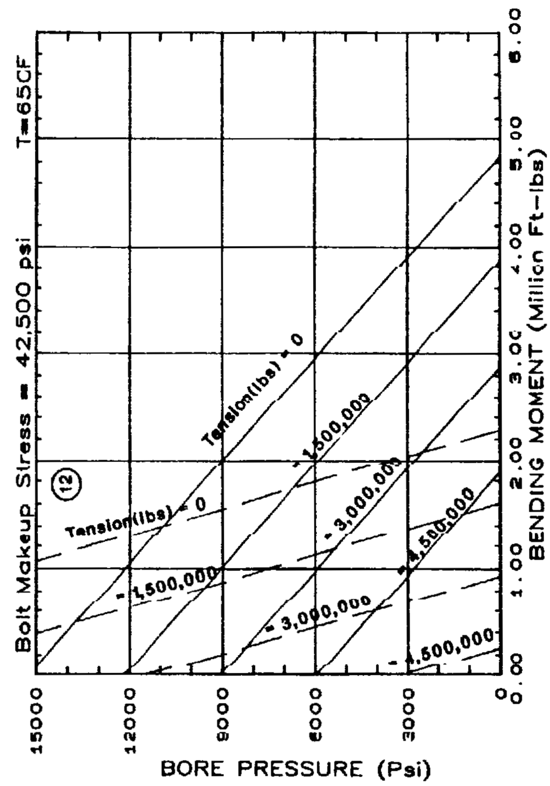


13–5/8"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

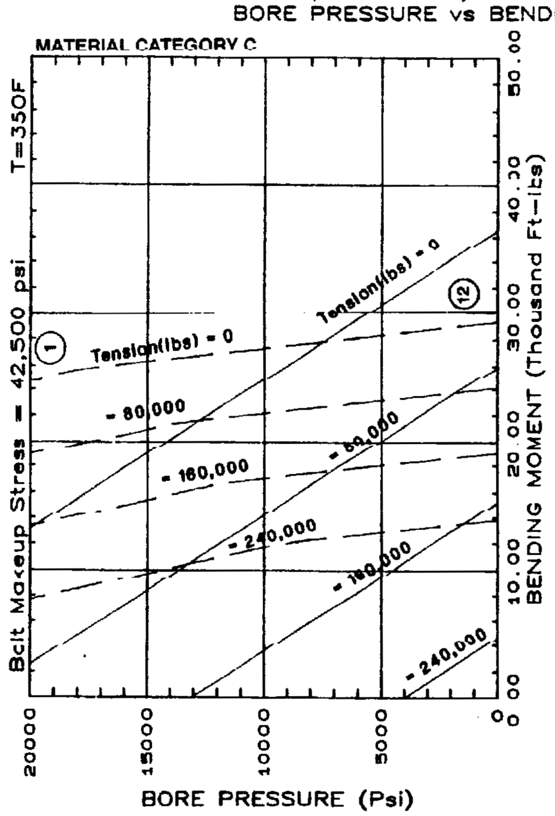


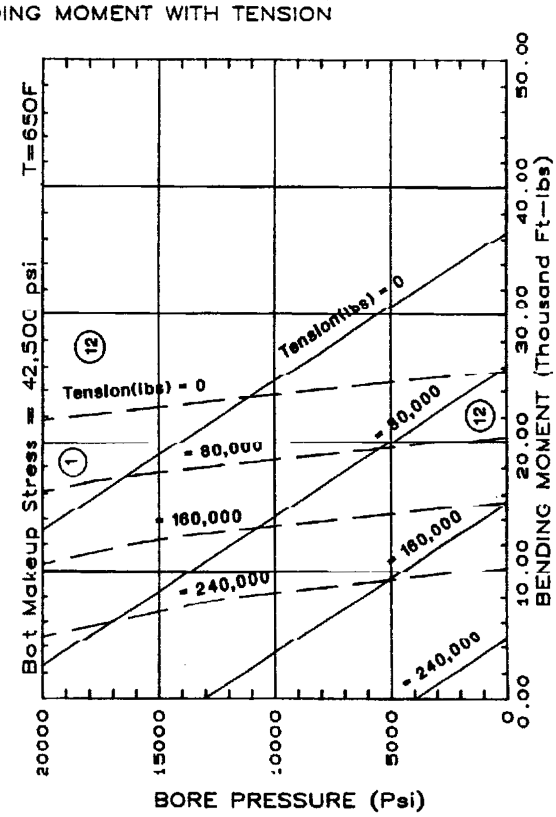
18-3/4"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





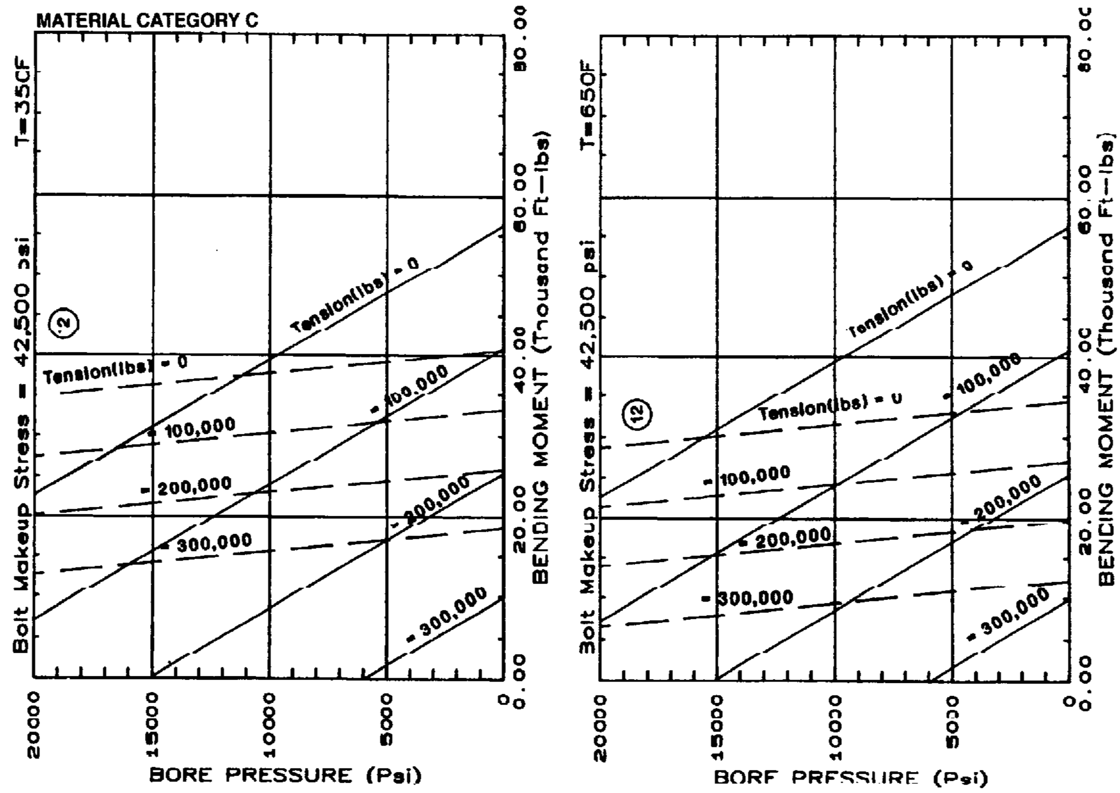
1-13/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION





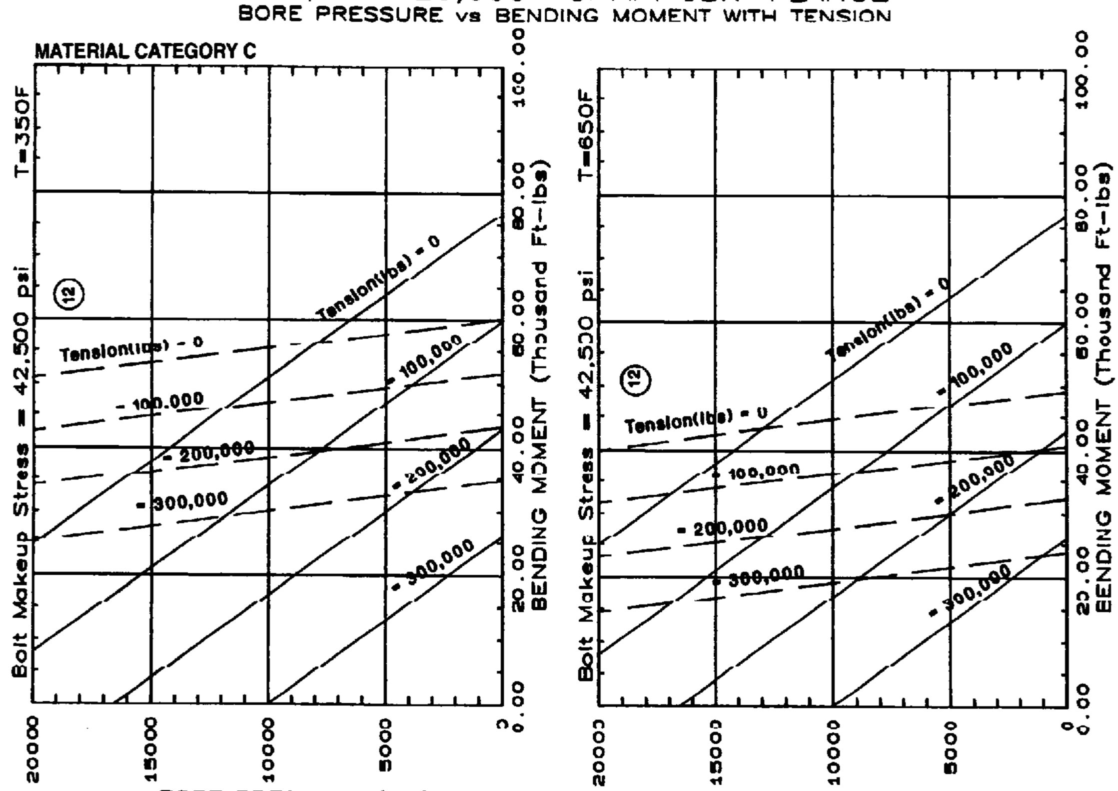
2-1/16"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

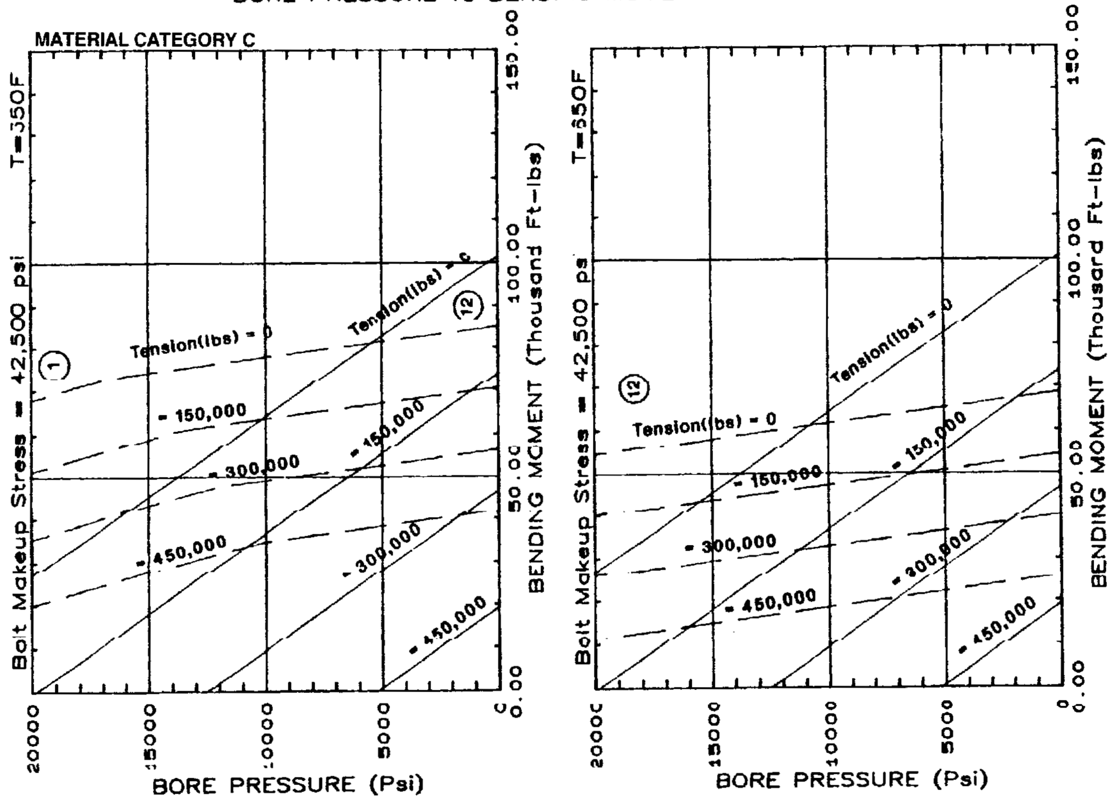


2-9/16"-20,000 PSI API 6BX-FLANGE

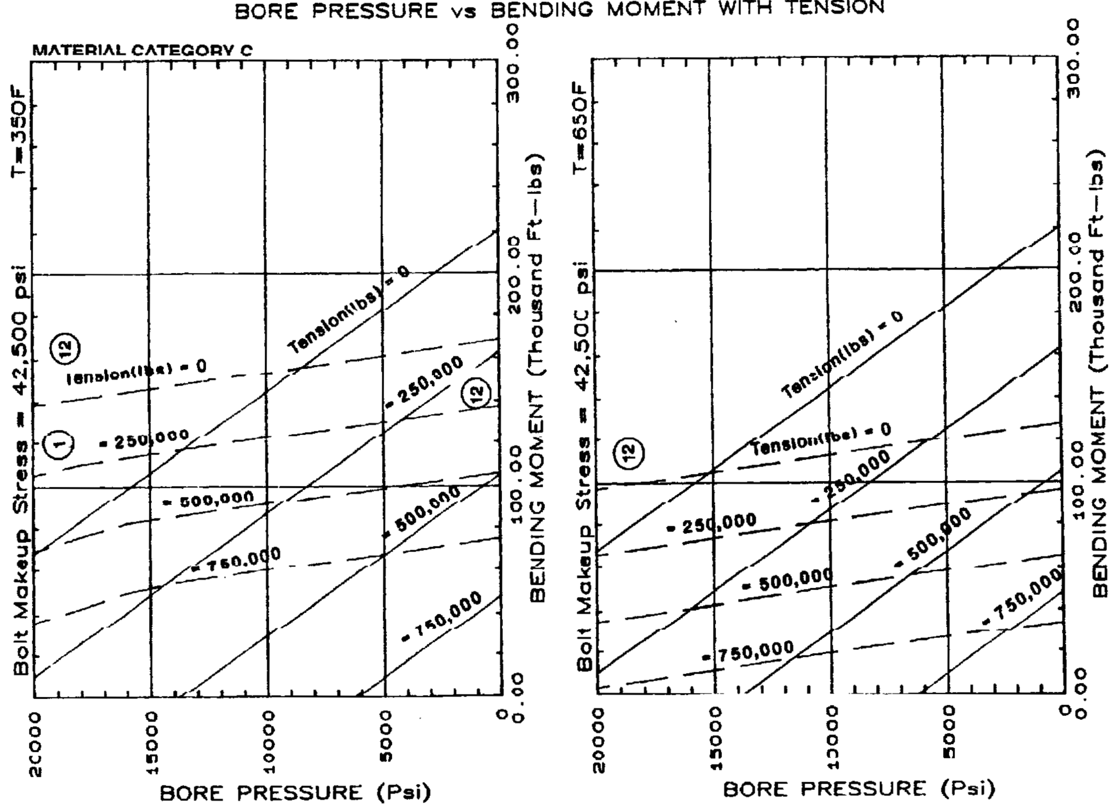
BORE PRESSURE vs BENDING MOMENT WITH TENSION



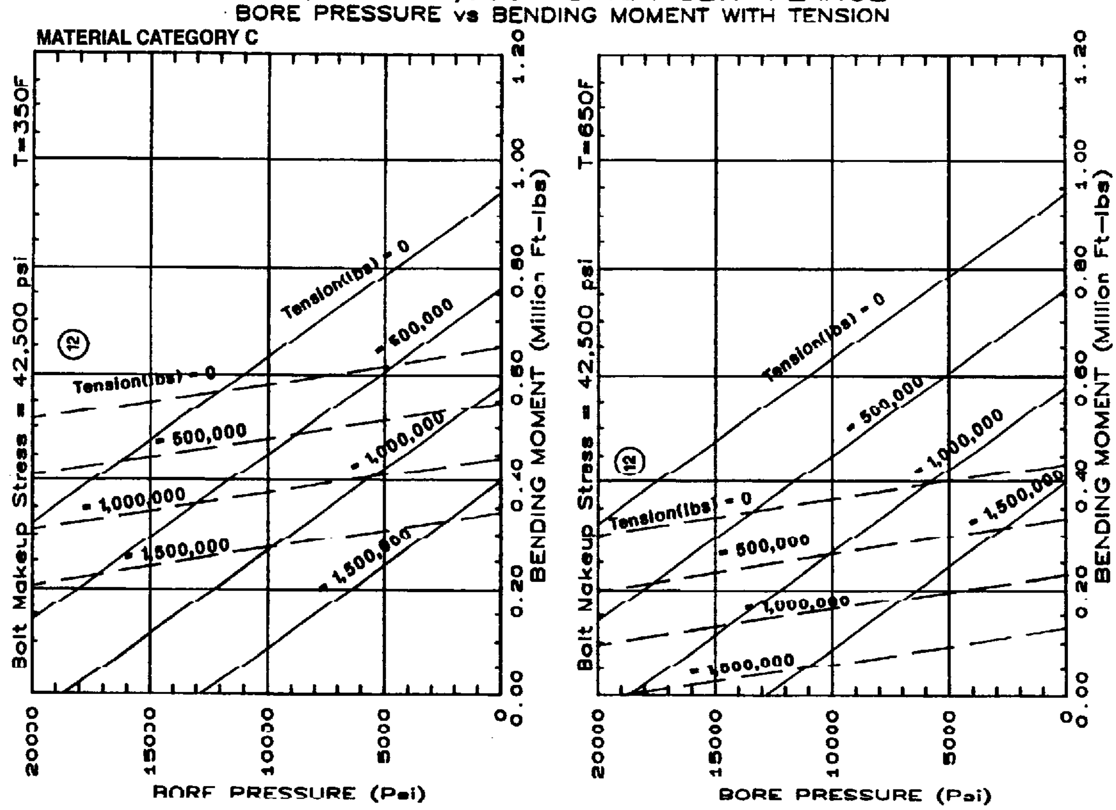
3-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



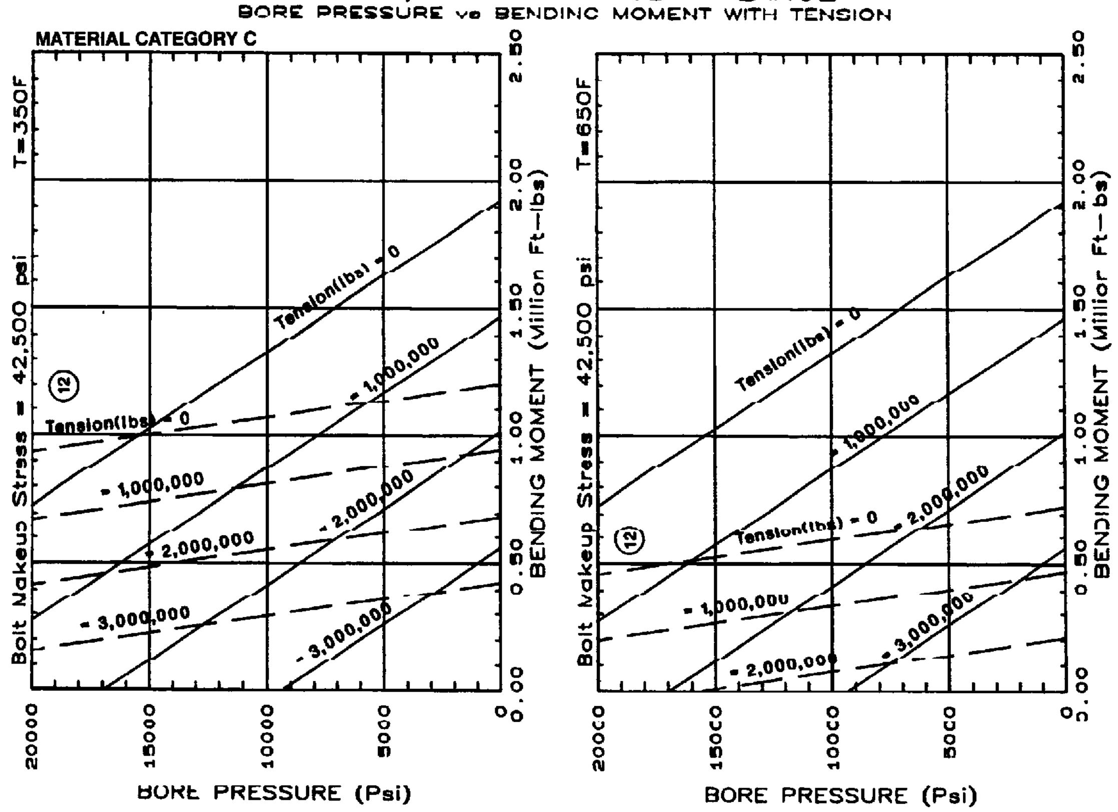
4-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



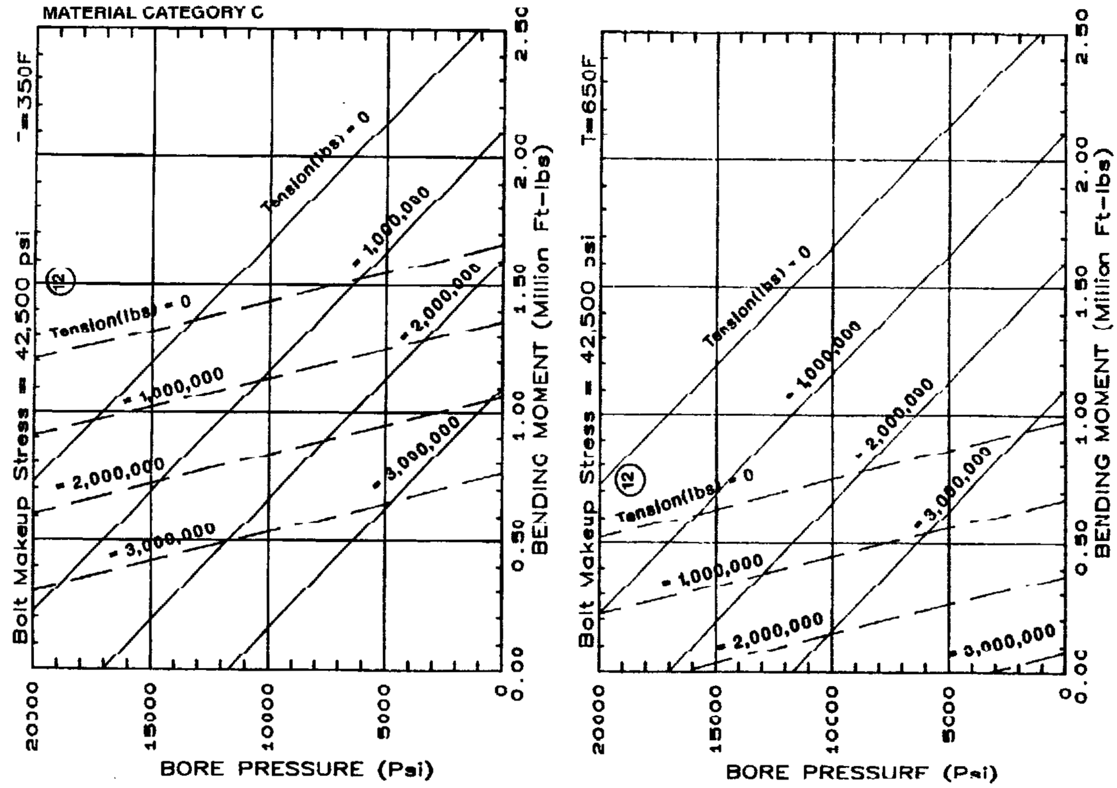
7-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



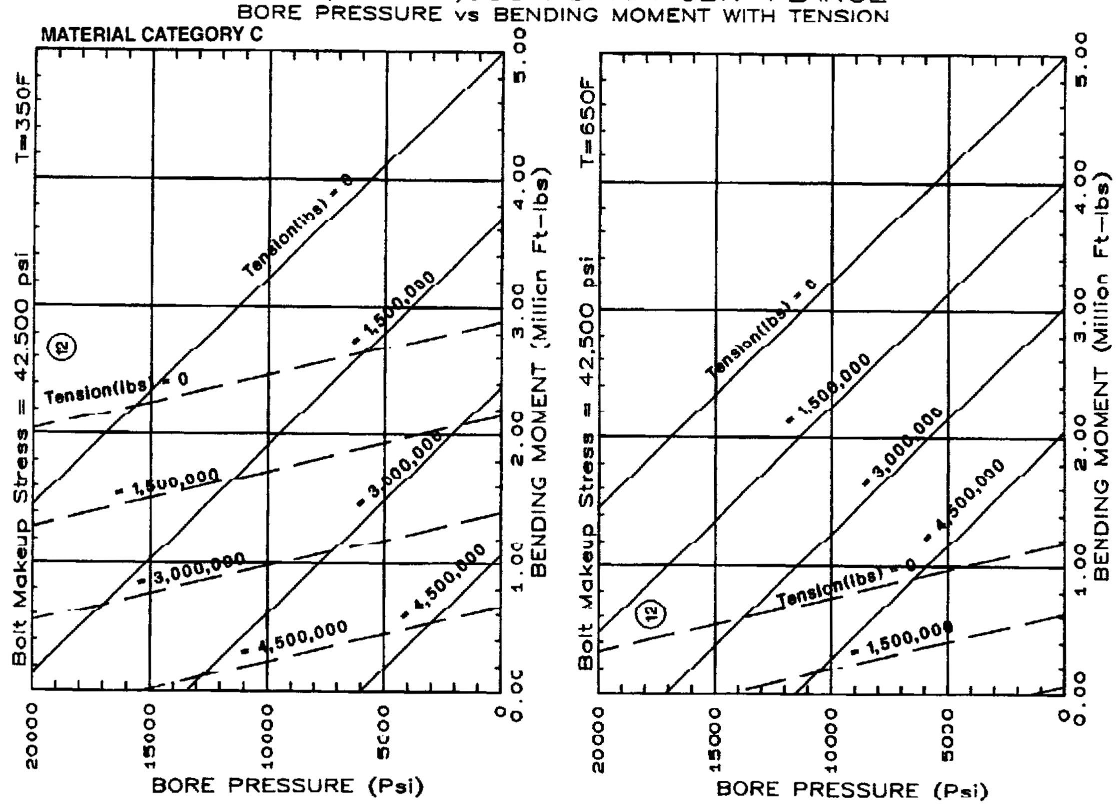
9"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

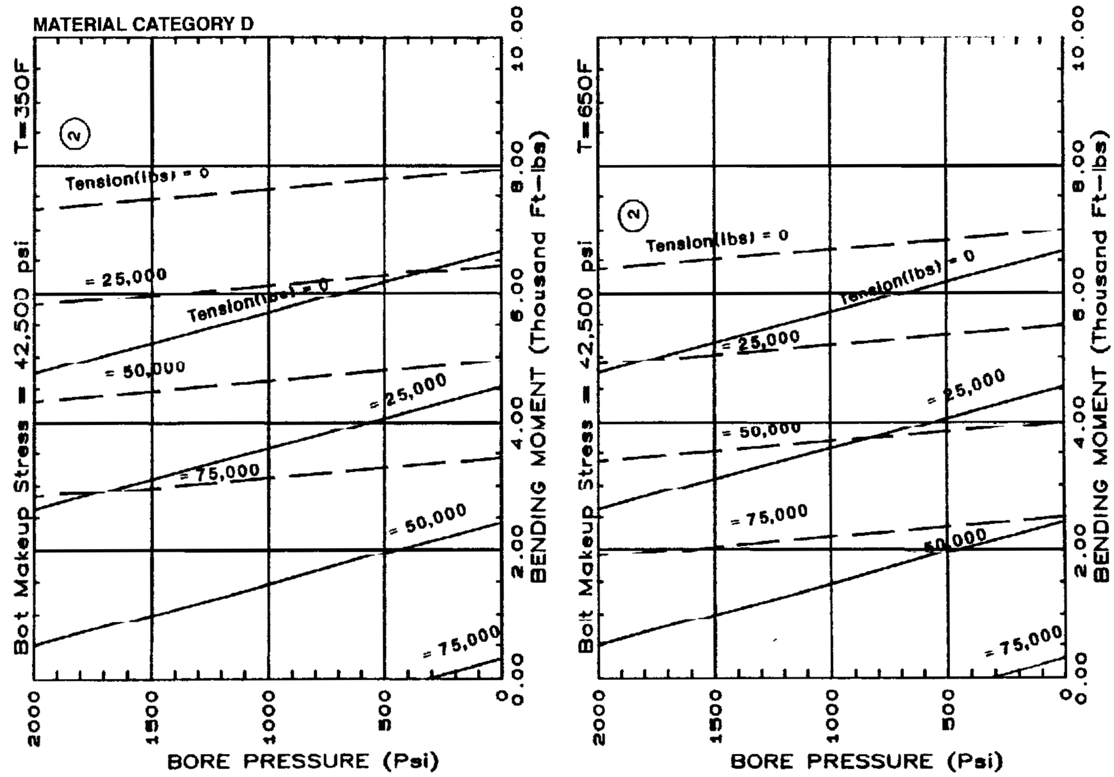


13-5/8"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

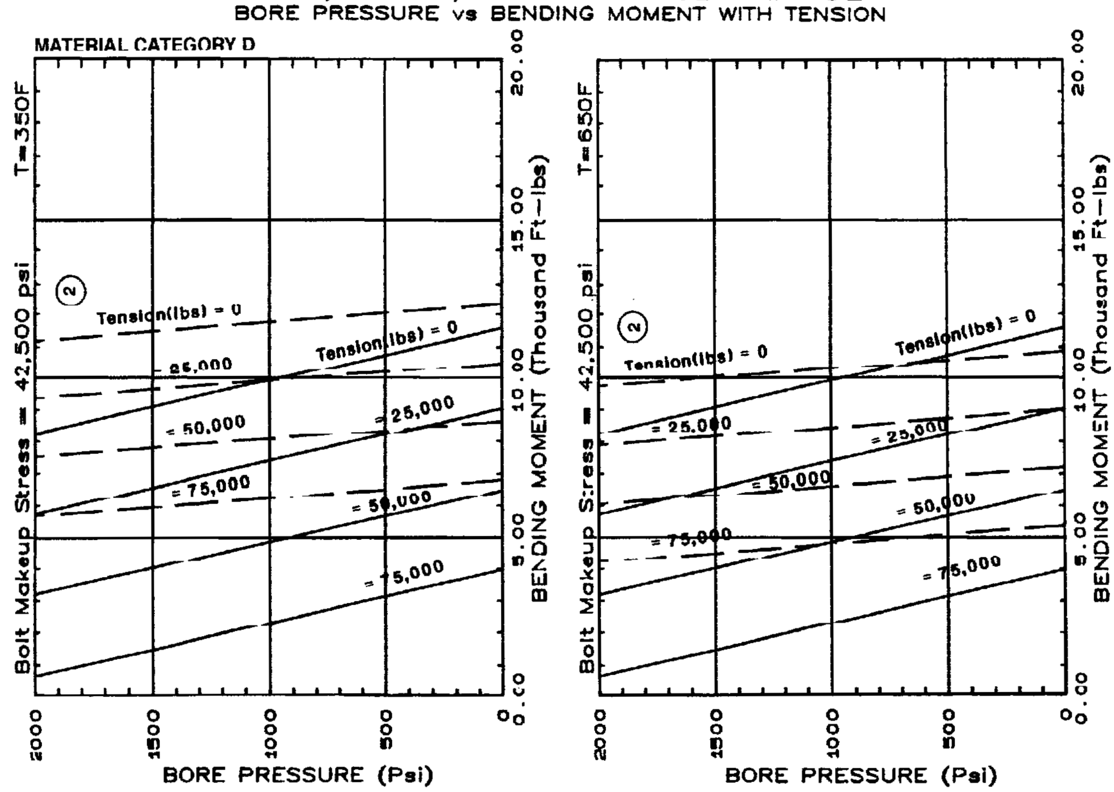


APPENDIX D—MATERIAL CATEGORY D

2-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



2-9/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



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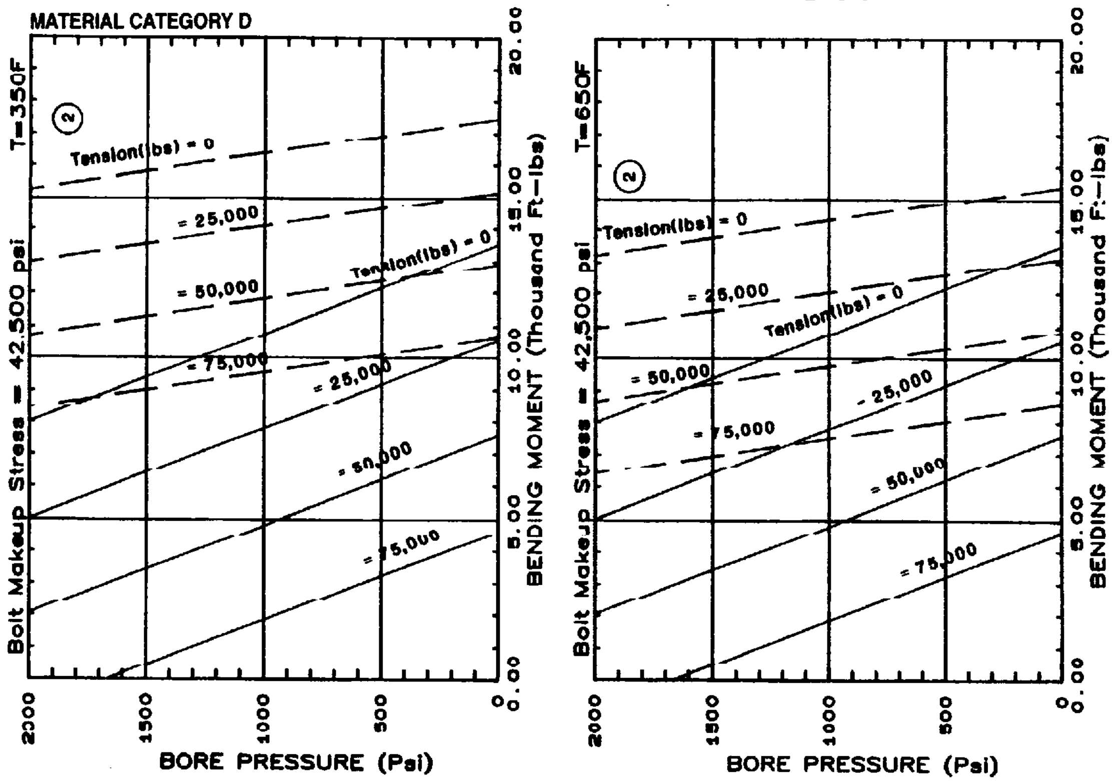
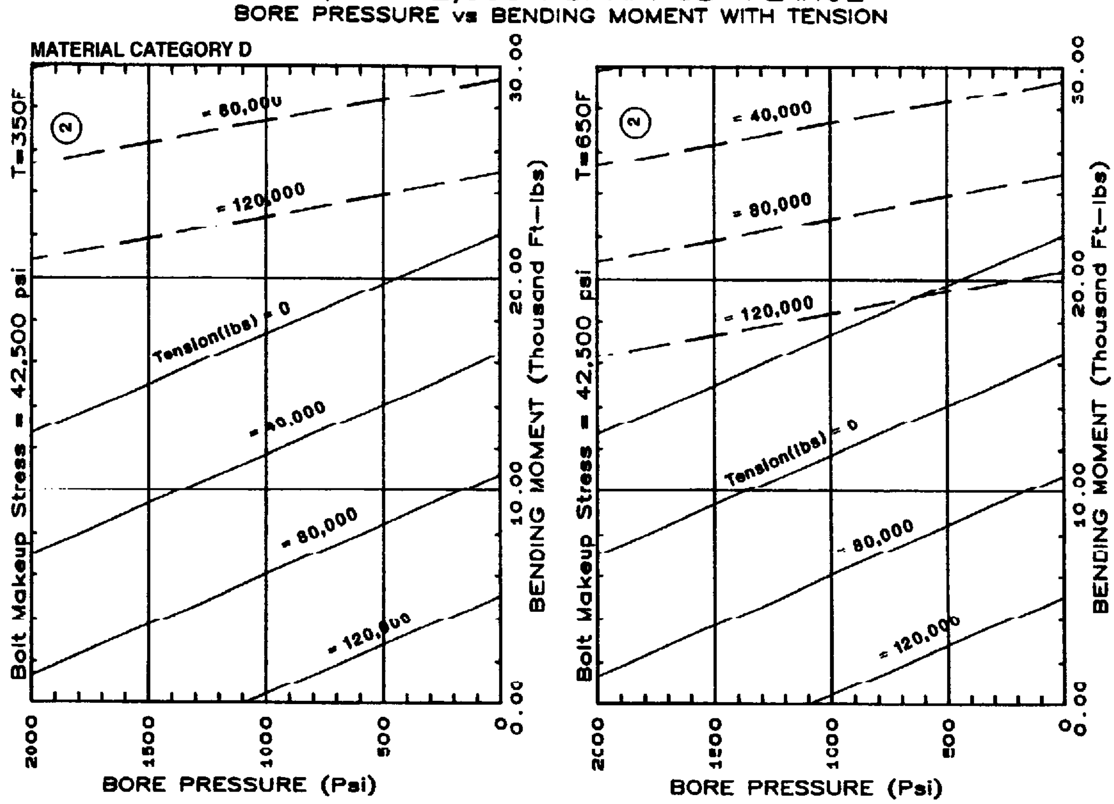
3-1/8"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

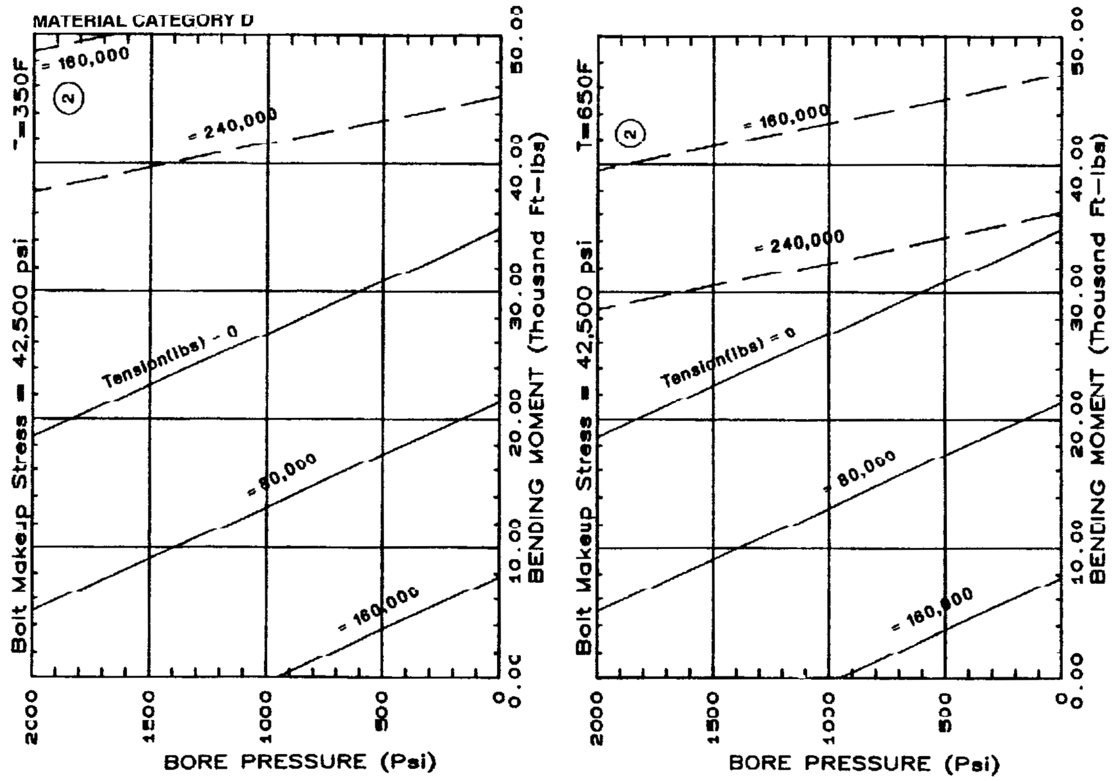


4-1/16"-2,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



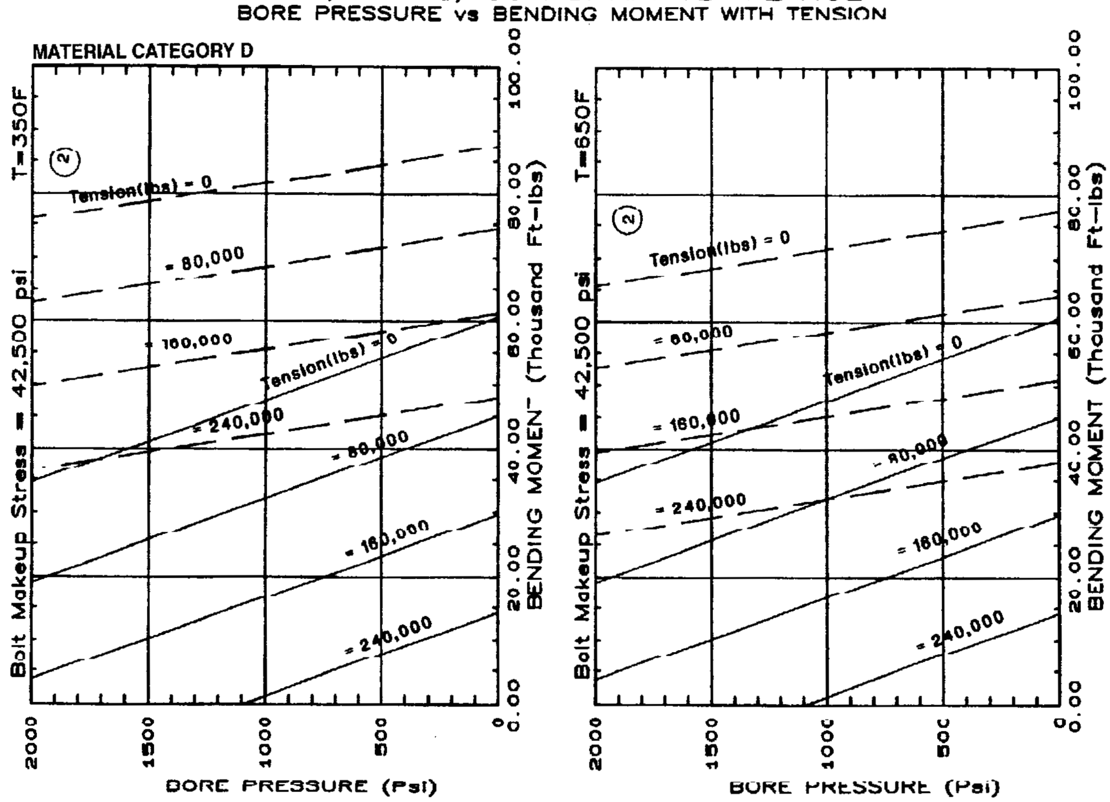
5-1/8"-2,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

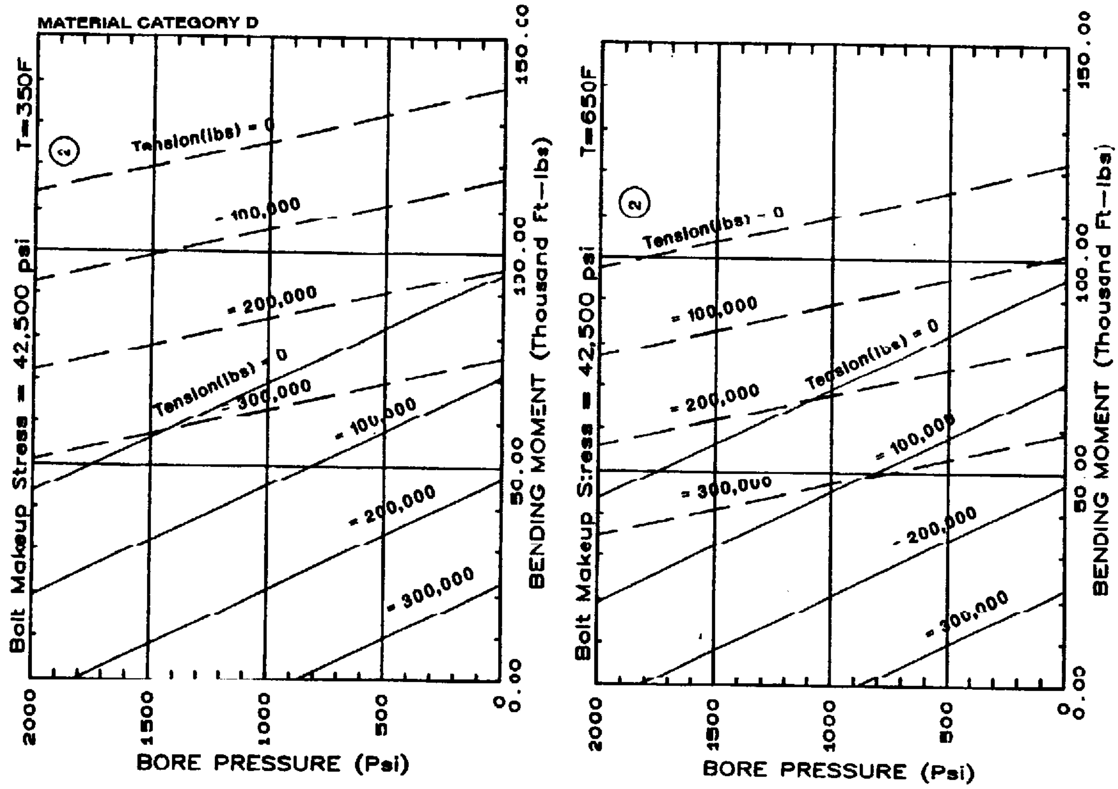


7-1/16"-2,000 PSI API 6B-FLANGE

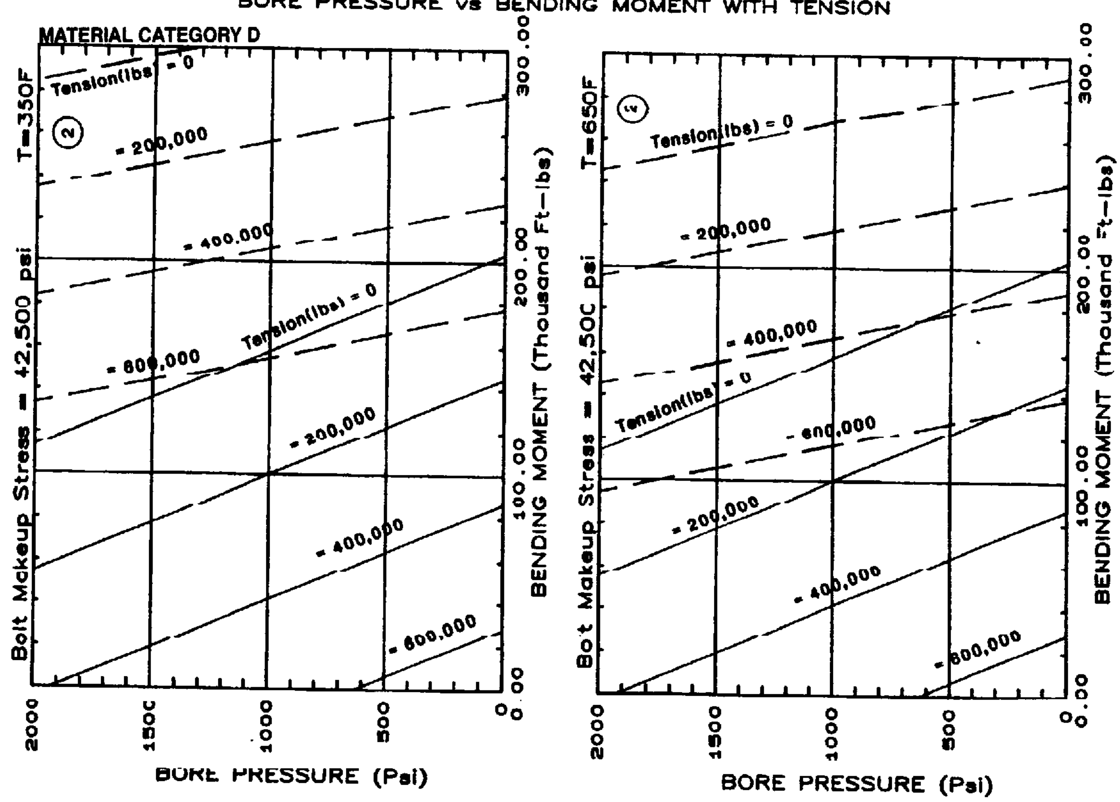
BORE PRESSURE vs BENDING MOMENT WITH TENSION



9"—2,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

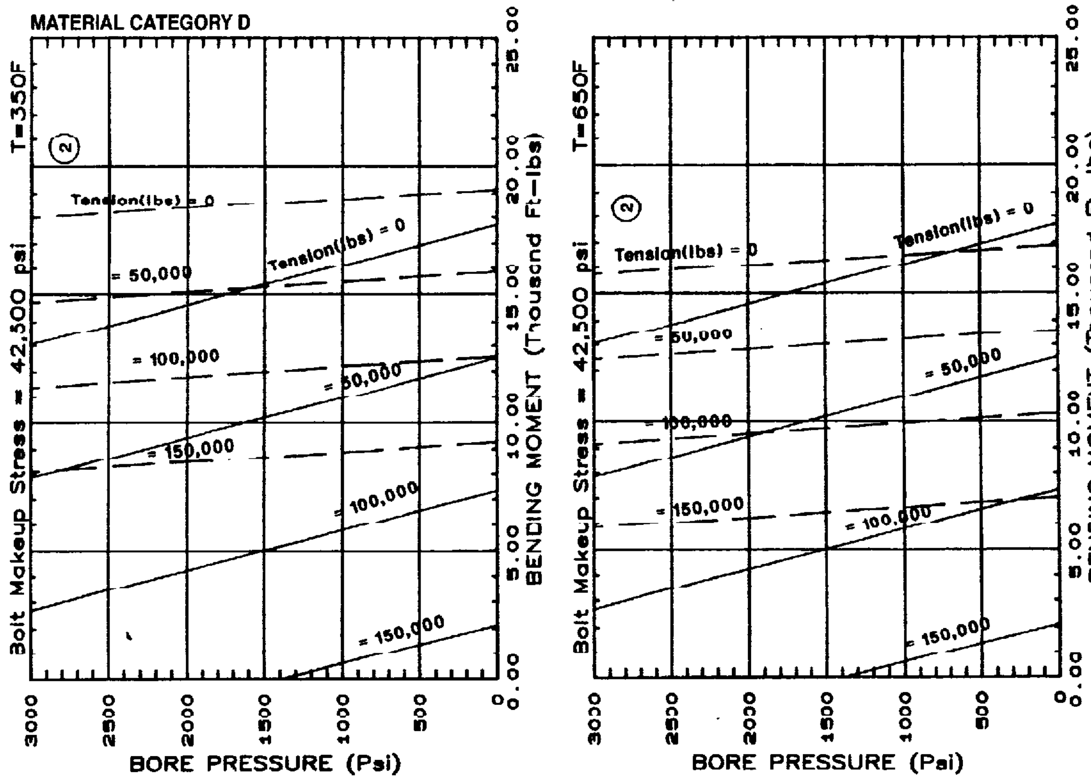


11"—2,000 PSI API 6B—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



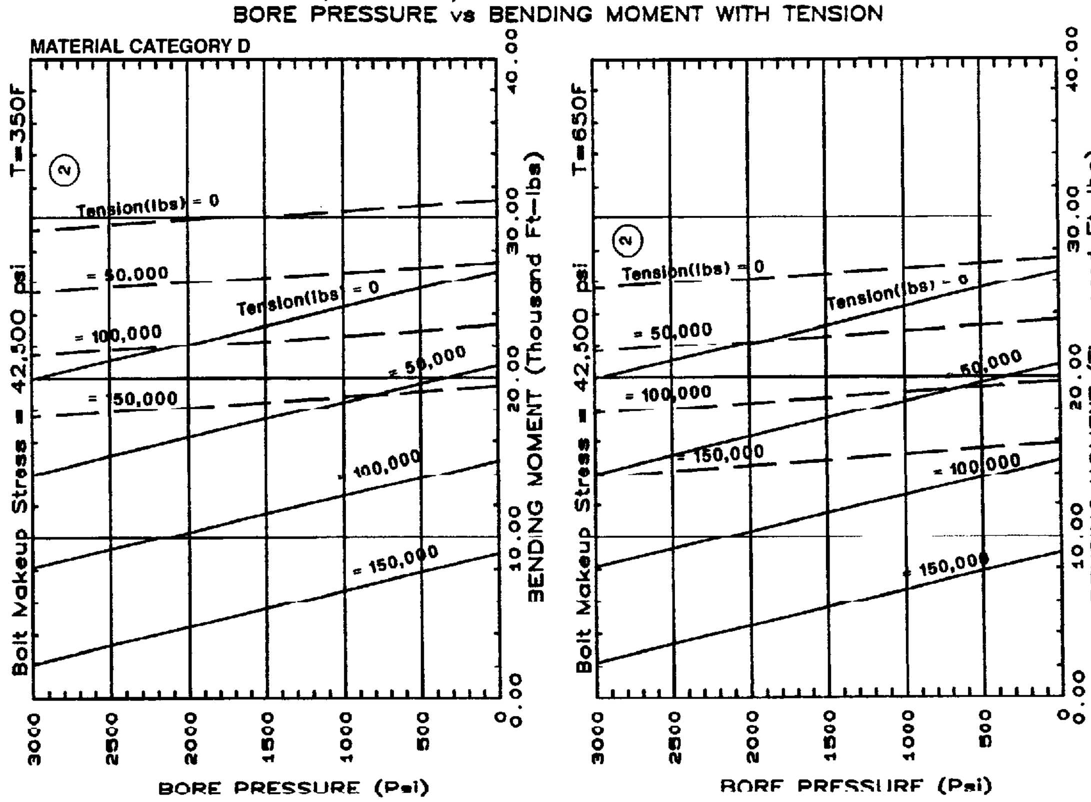
2-1/16"-3,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



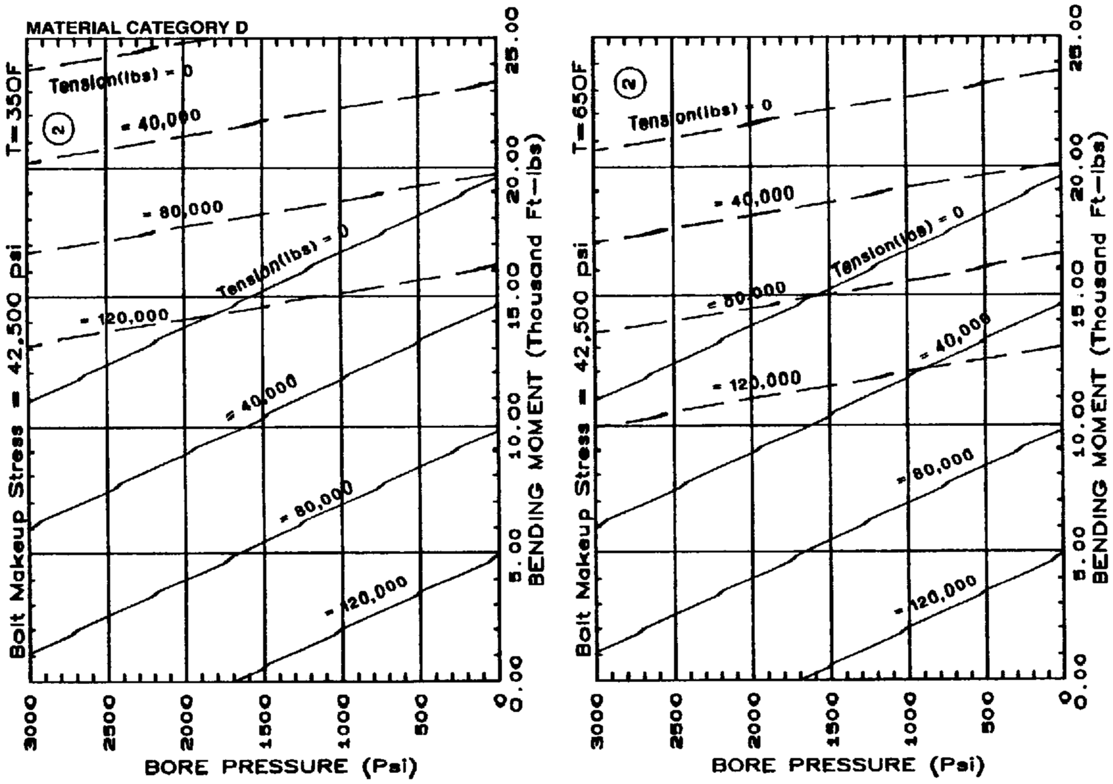
2-9/16"-3,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



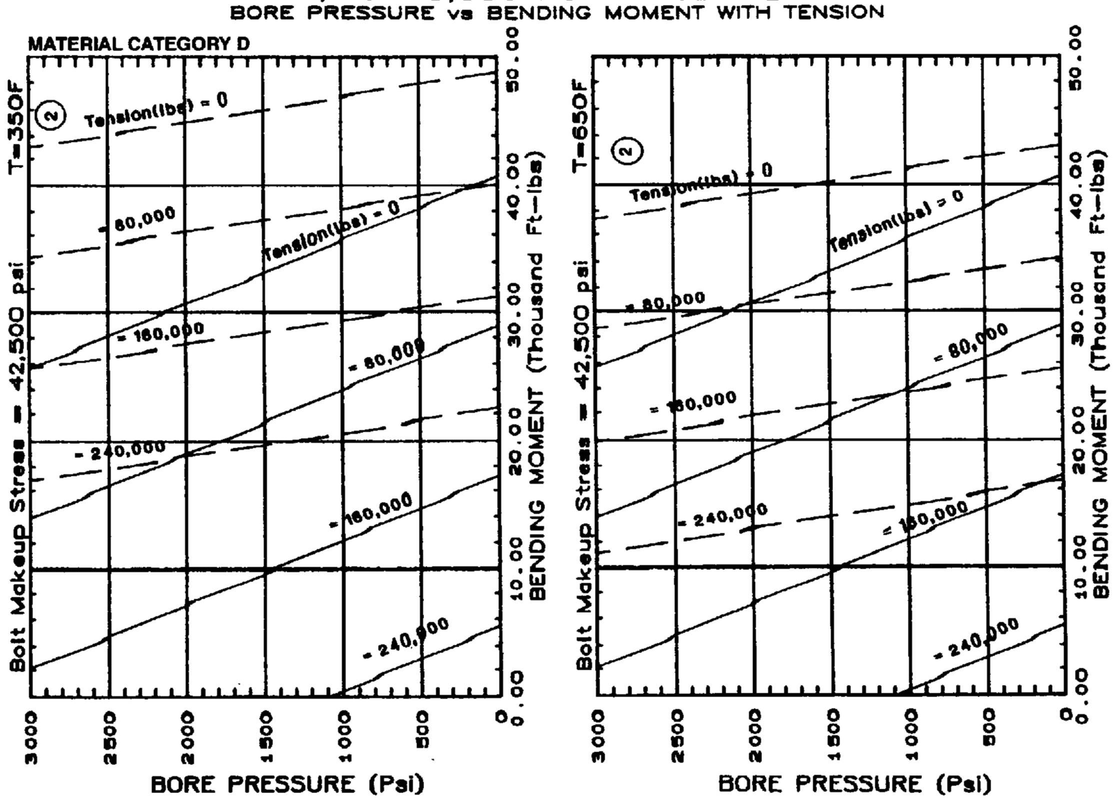
3-1/8"-3,000 PSI API 6B-FLANGE

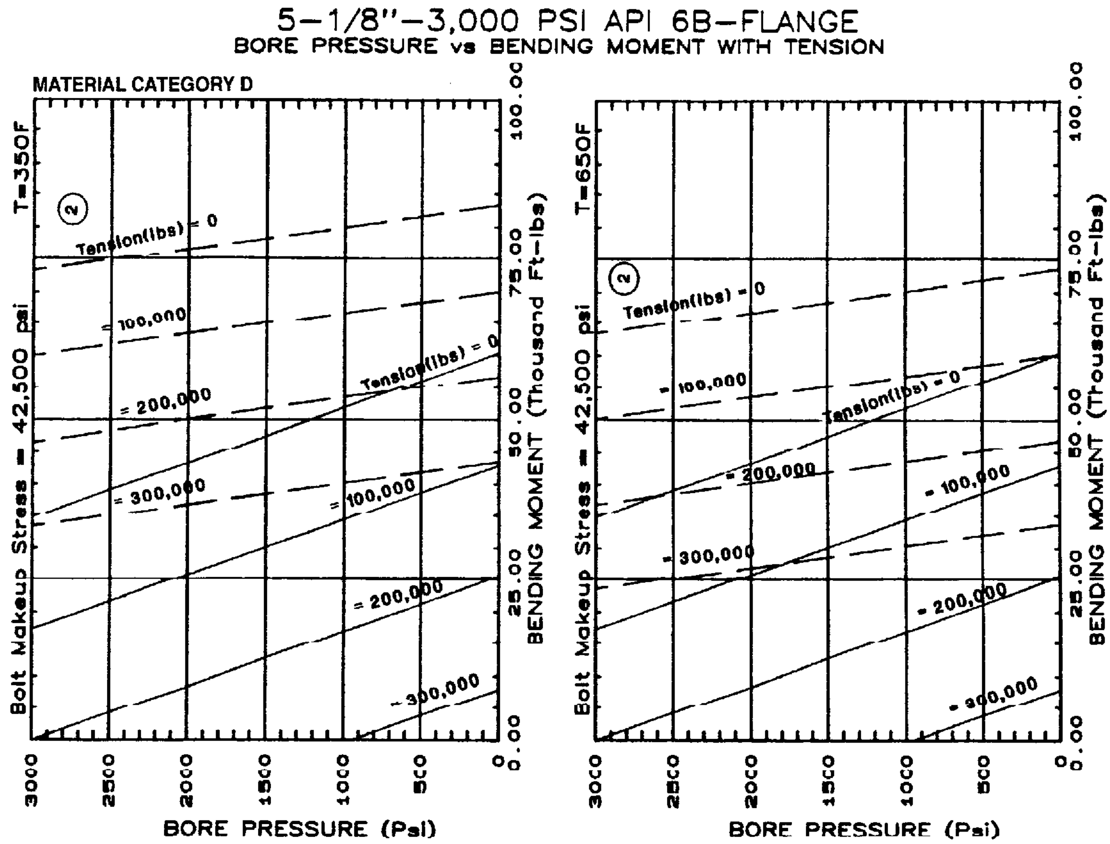
BORE PRESSURE vs BENDING MOMENT WITH TENSION



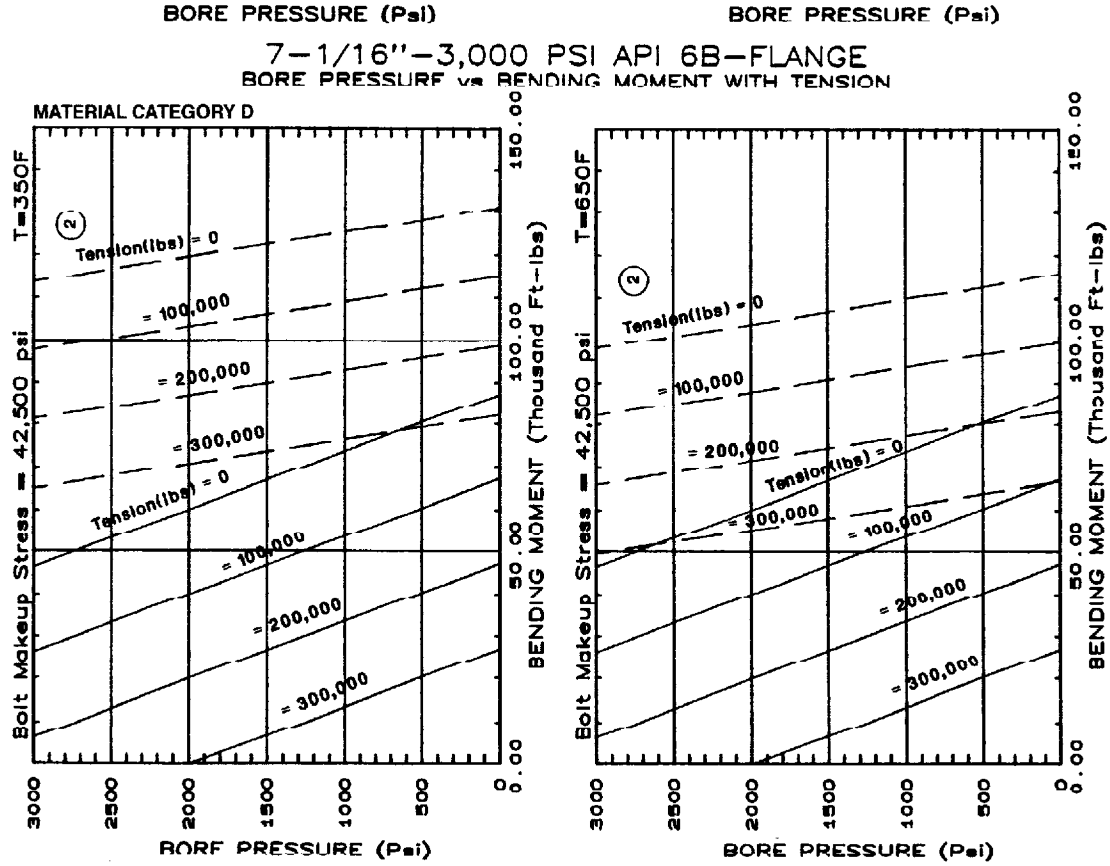
4-1/16"-3,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



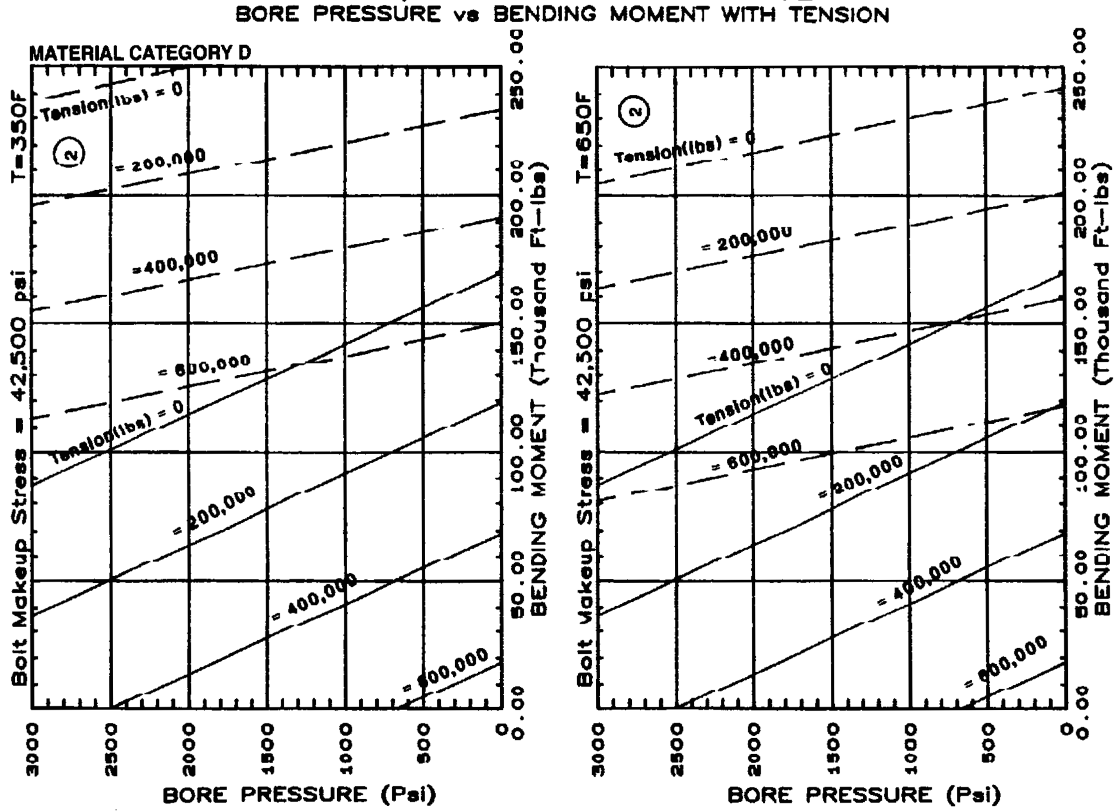


5-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY D
T=350F
T=650F
Bolt Makeup Stress = 42,500 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 100,000
= 200,000
= 300,000

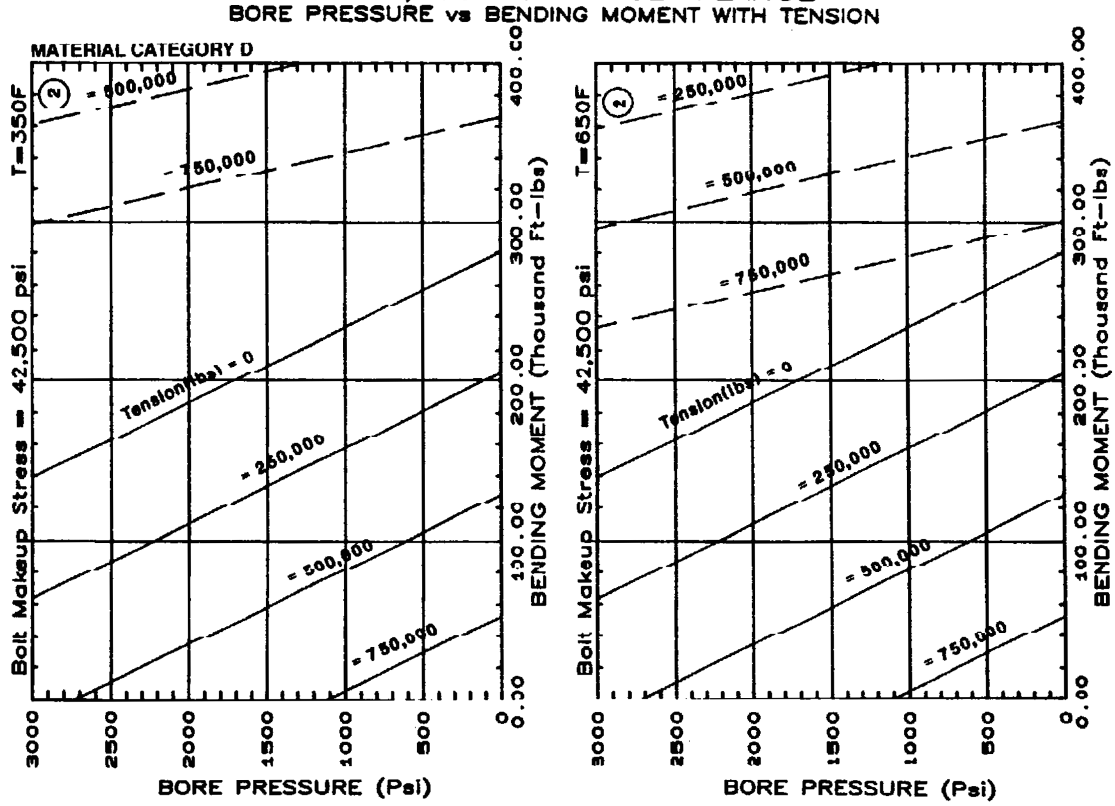


7-1/16"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION
MATERIAL CATEGORY D
T=350F
T=650F
Bolt Makeup Stress = 42,500 psi
BENDING MOMENT (Thousand Ft-lbs)
BORE PRESSURE (Psi)
Tension(lbs) = 0
= 100,000
= 200,000
= 300,000

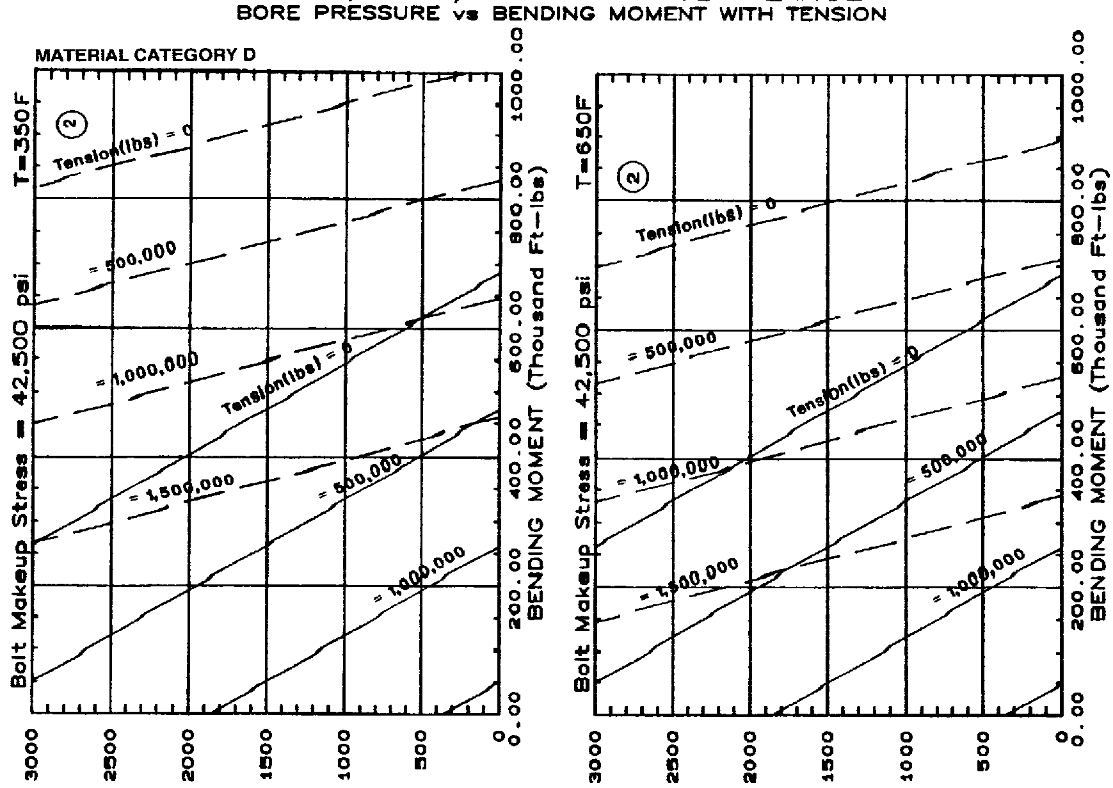
9"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



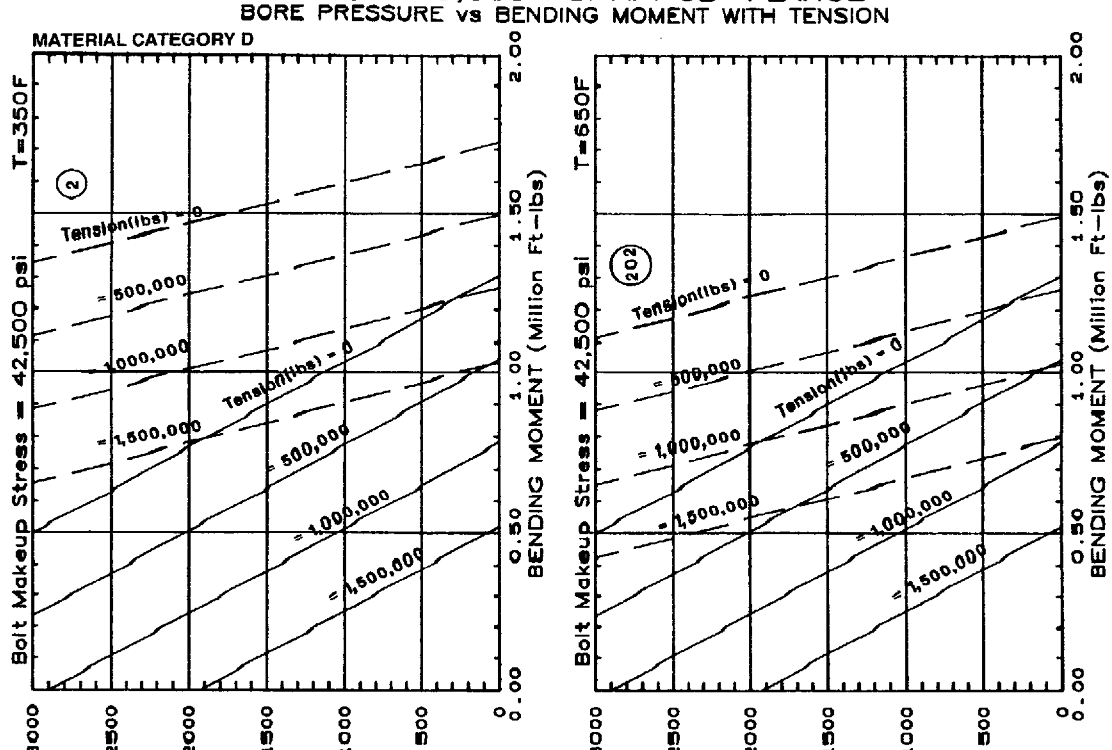
11"–3,000 PSI API 6B–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



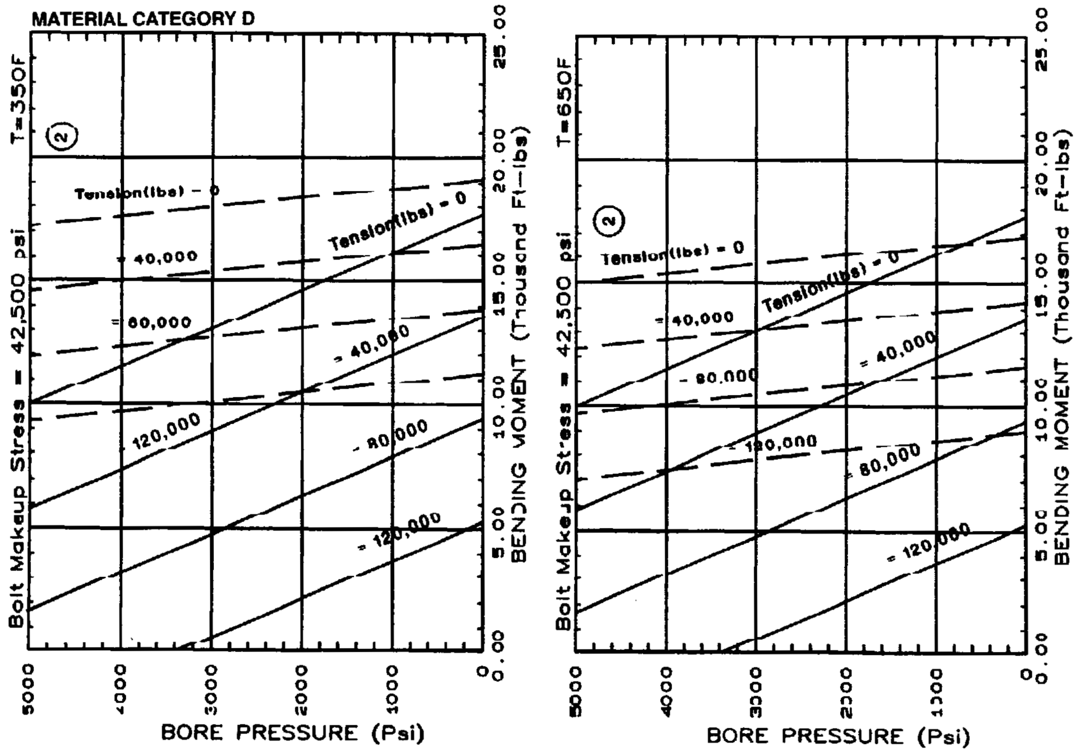
16-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



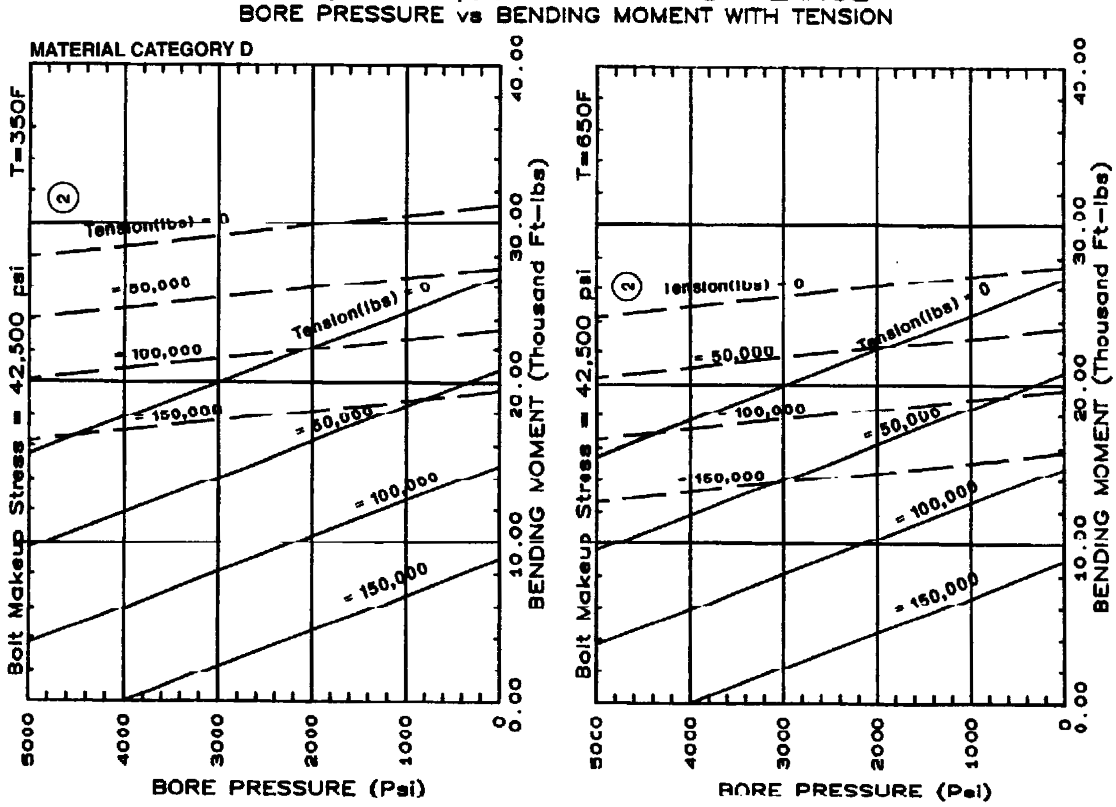
20-3/4"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



2-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

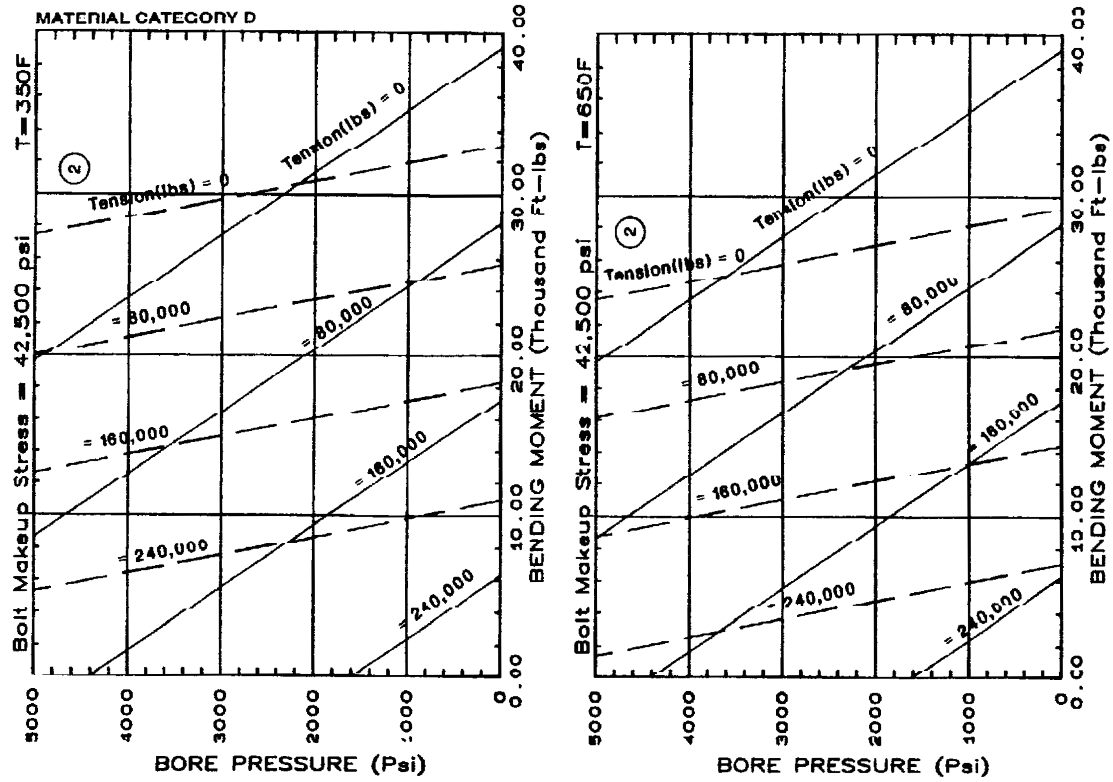


2-9/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



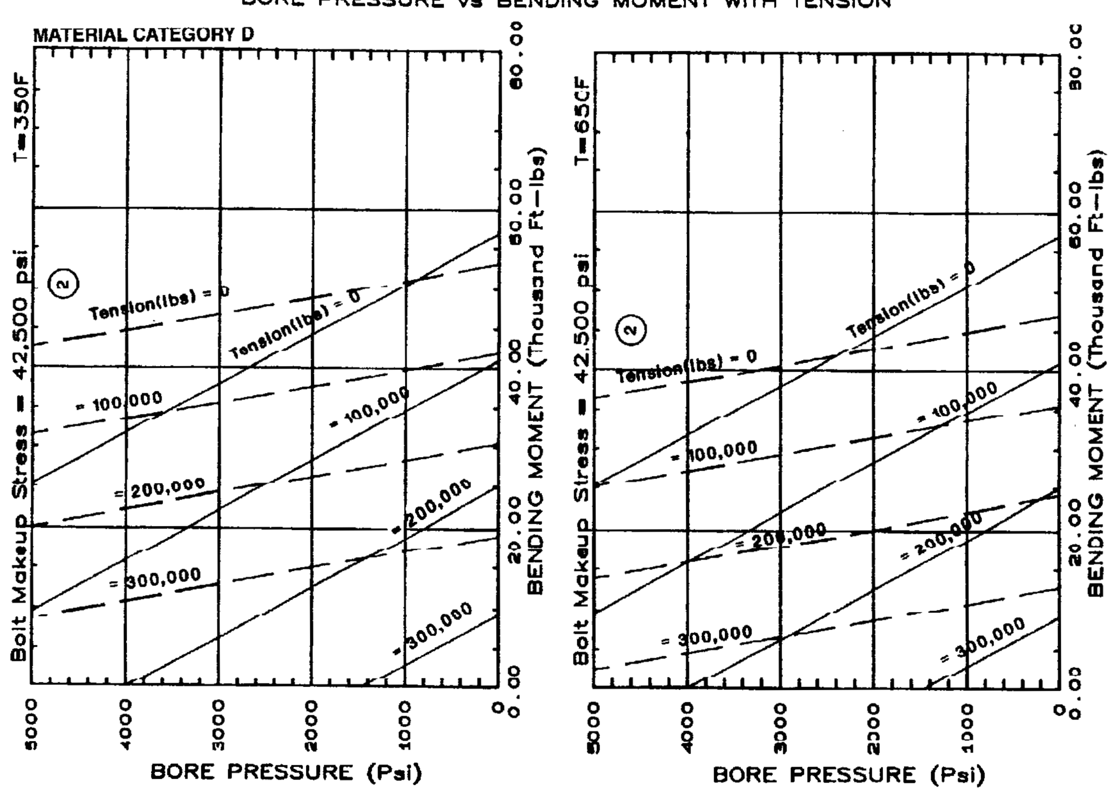
3-1/8"-5,000 PSI API 6B-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

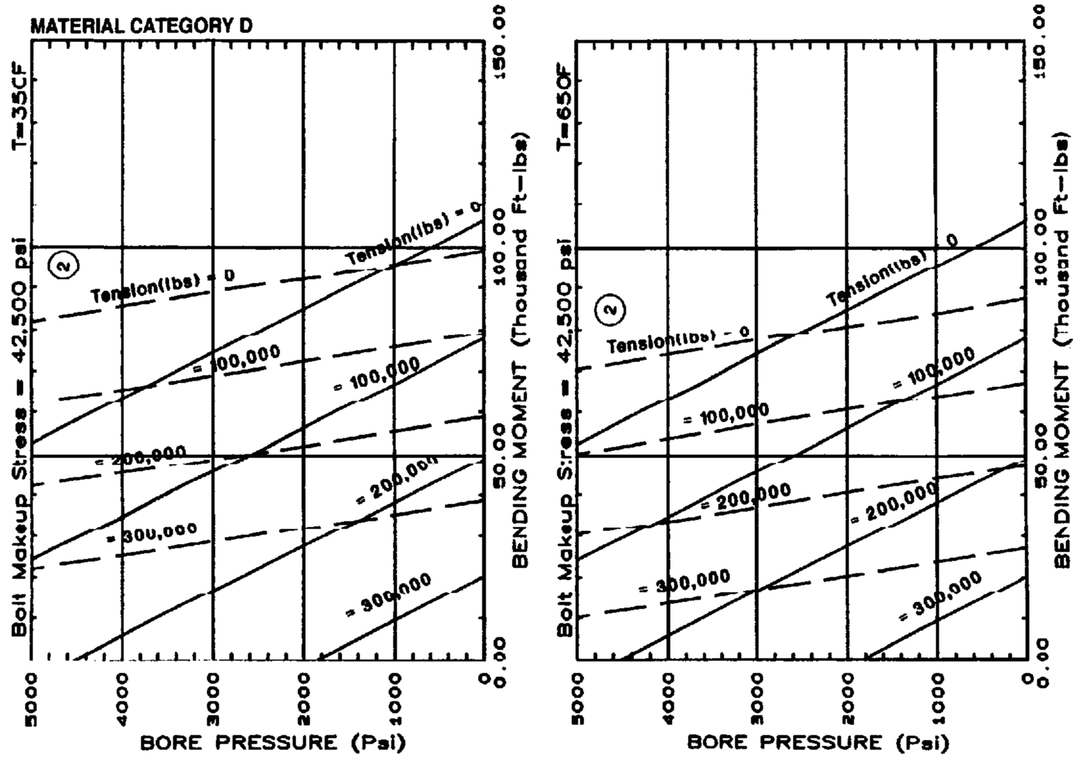


4-1/16"-5,000 PSI API 6B-FLANGE

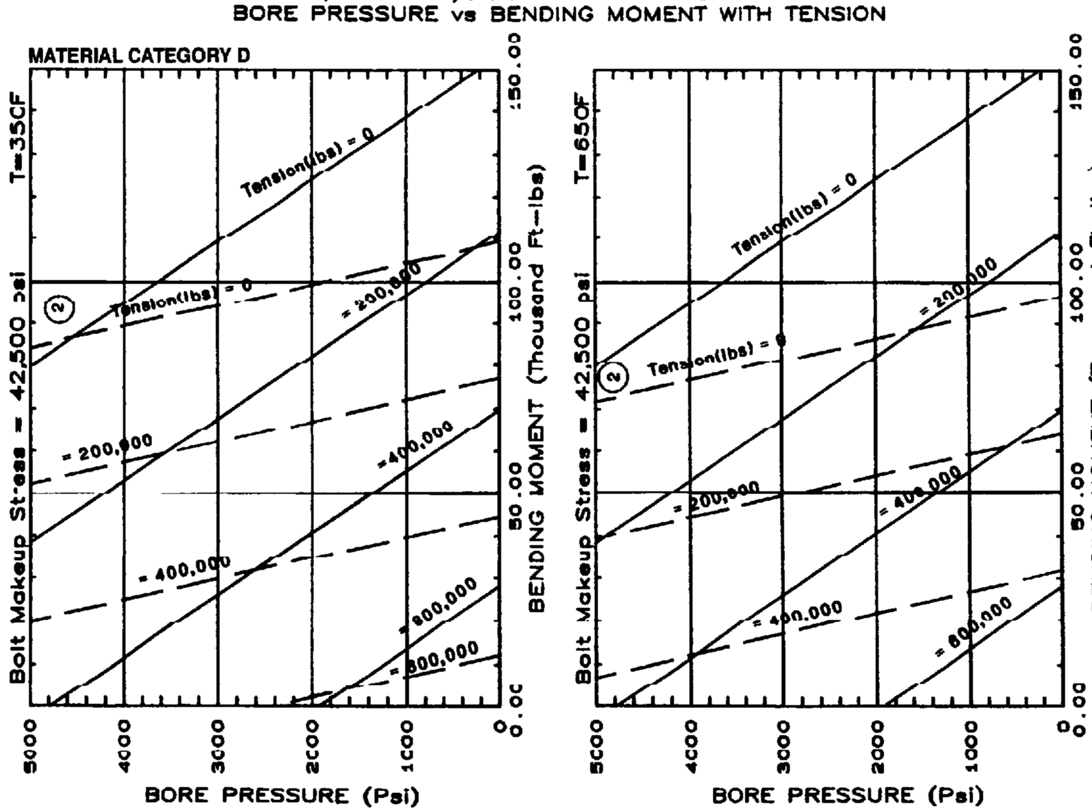
BORE PRESSURE vs BENDING MOMENT WITH TENSION



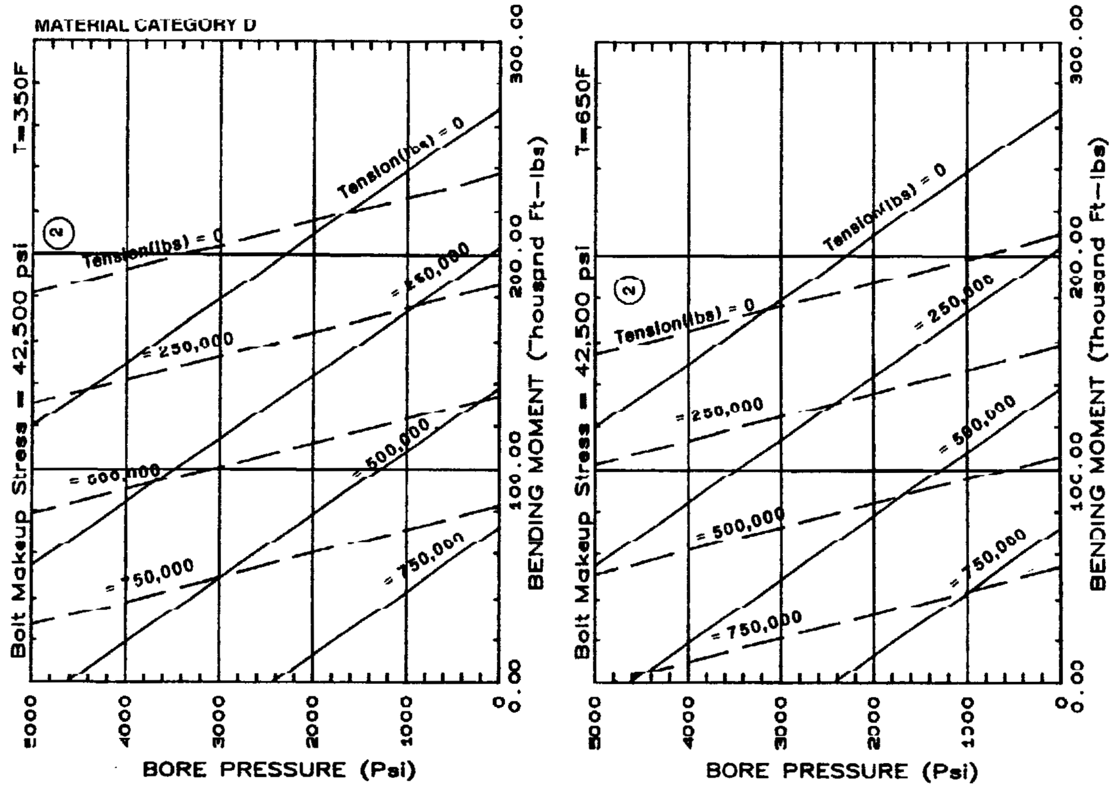
5-1/8"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



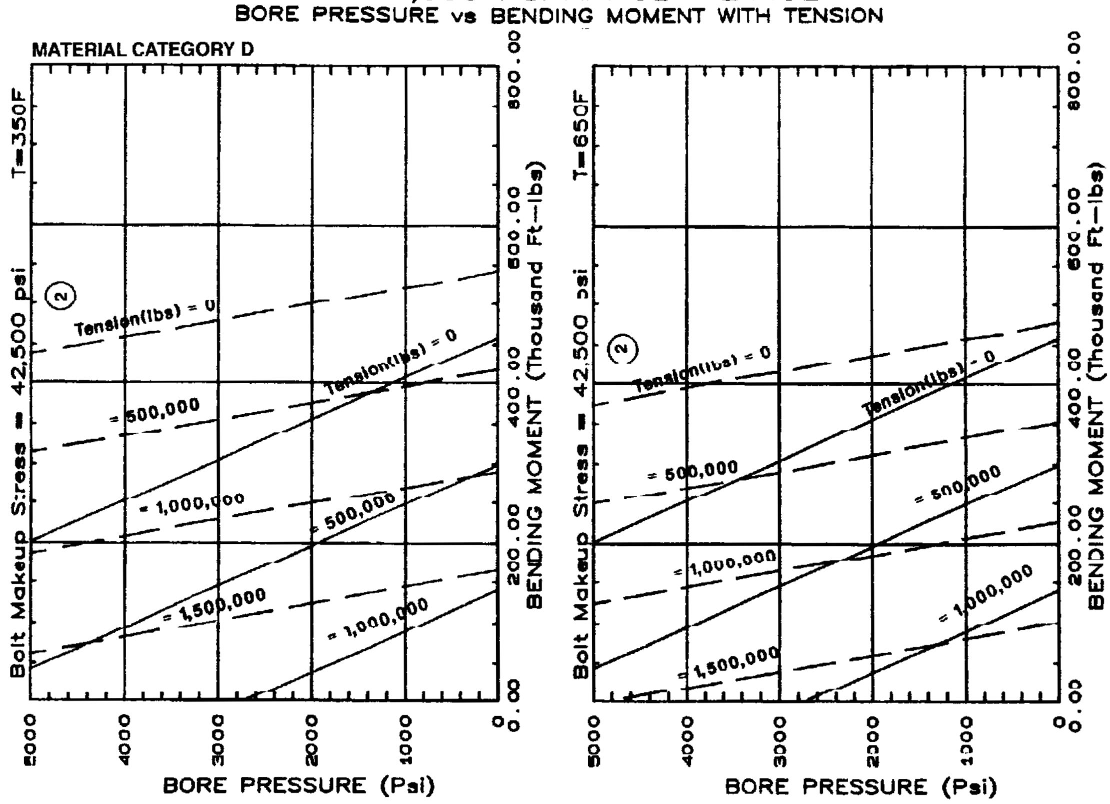
7-1/16"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



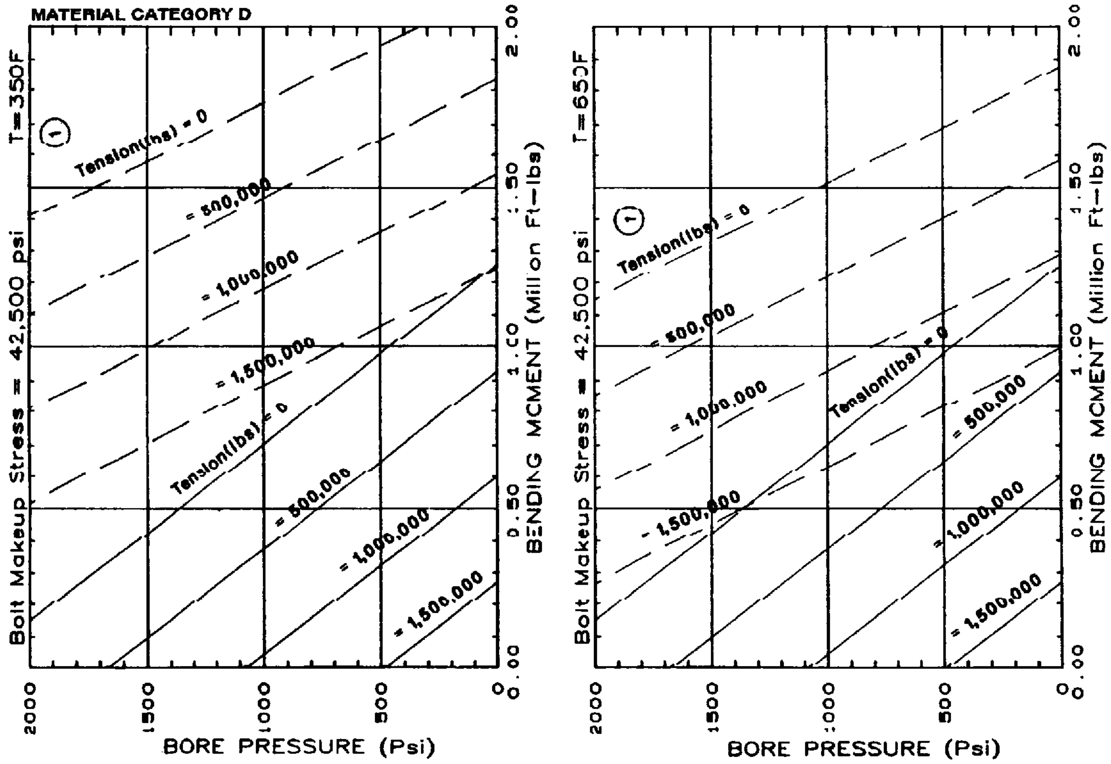
9"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



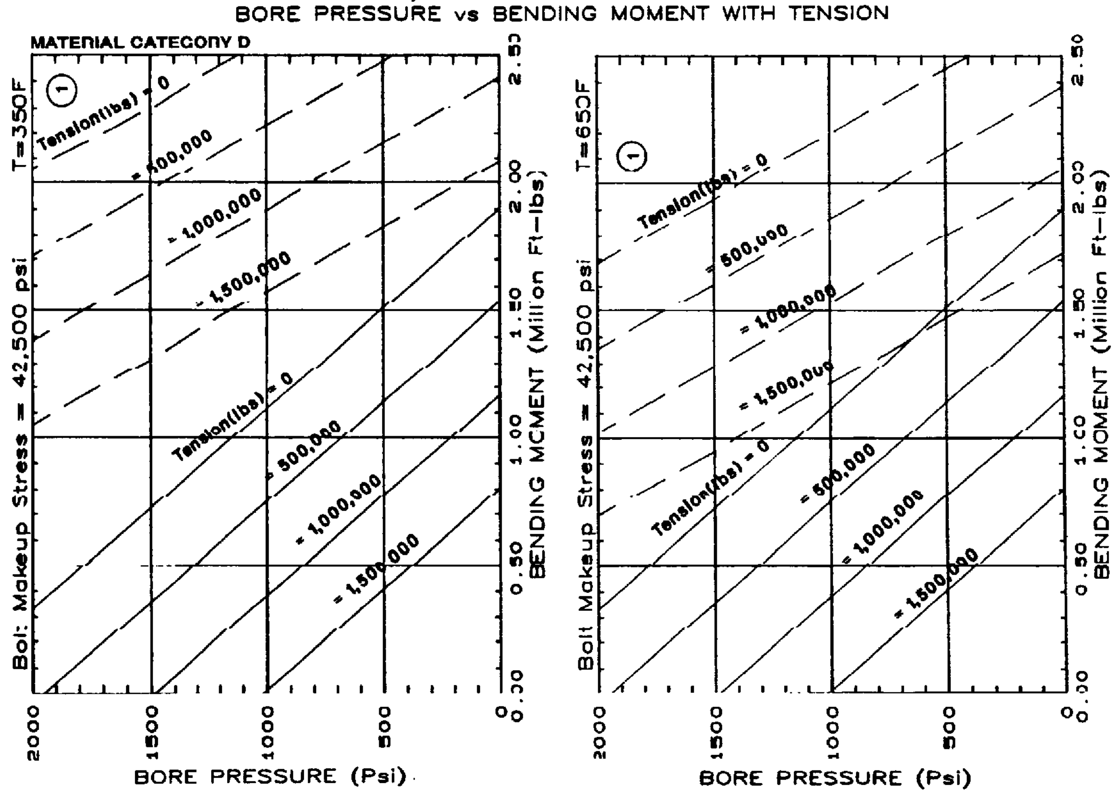
11"-5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



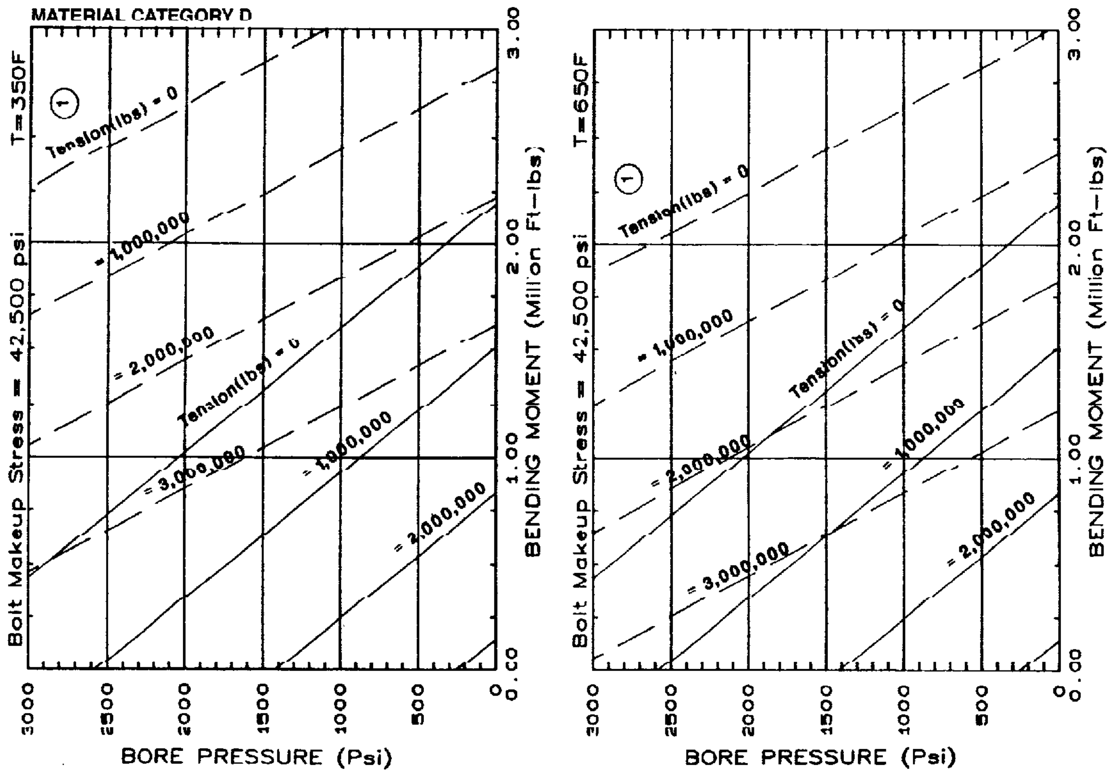
26-3/4"-2,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



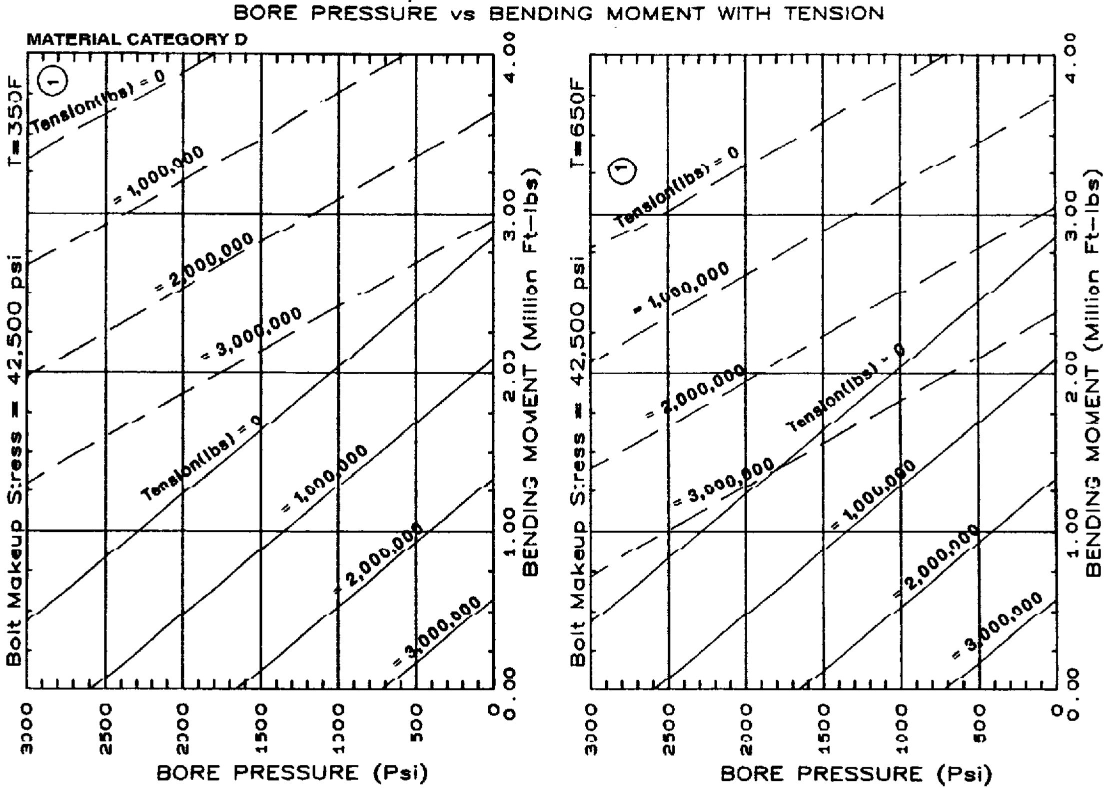
30"-2,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



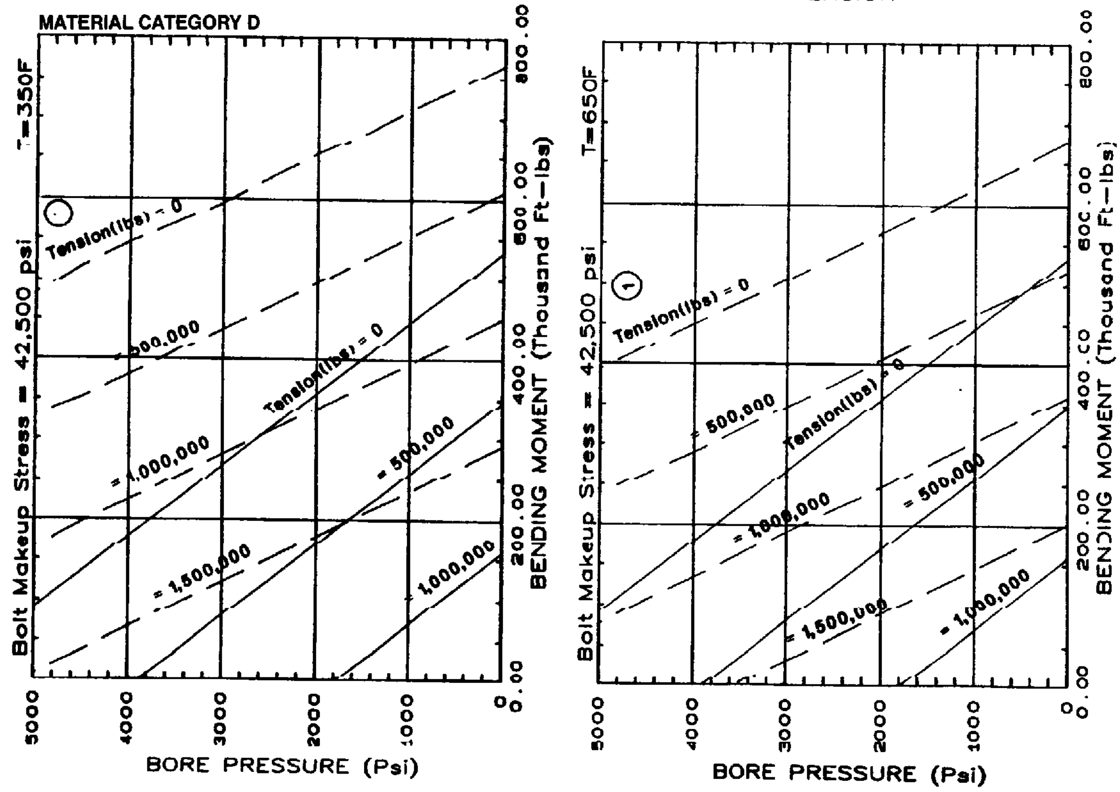
26–3/4"–3,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



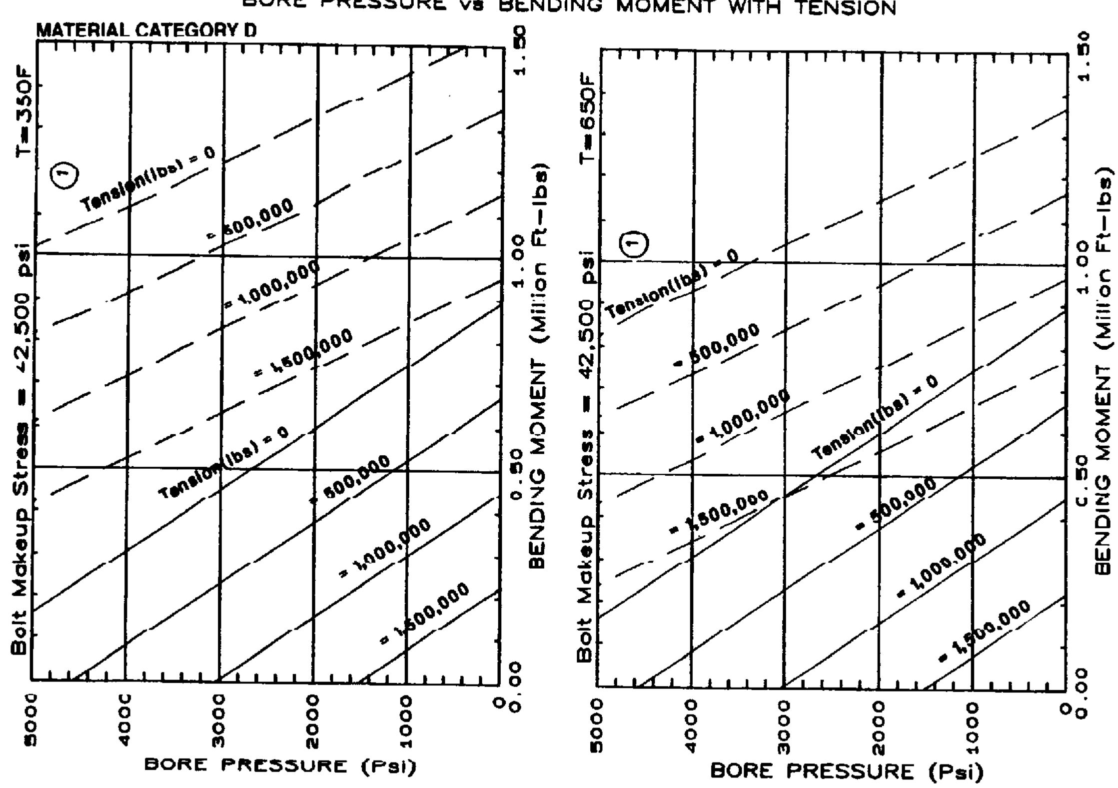
30"–3,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



13-5/8"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

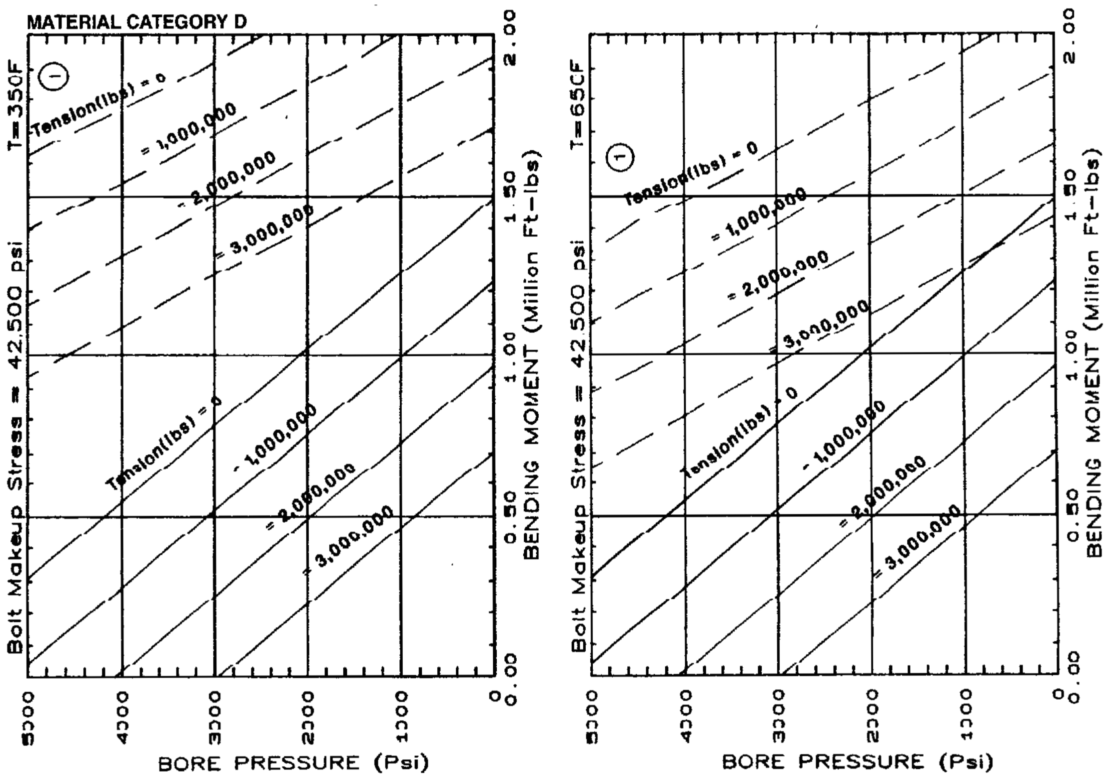


16-3/4"-5,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



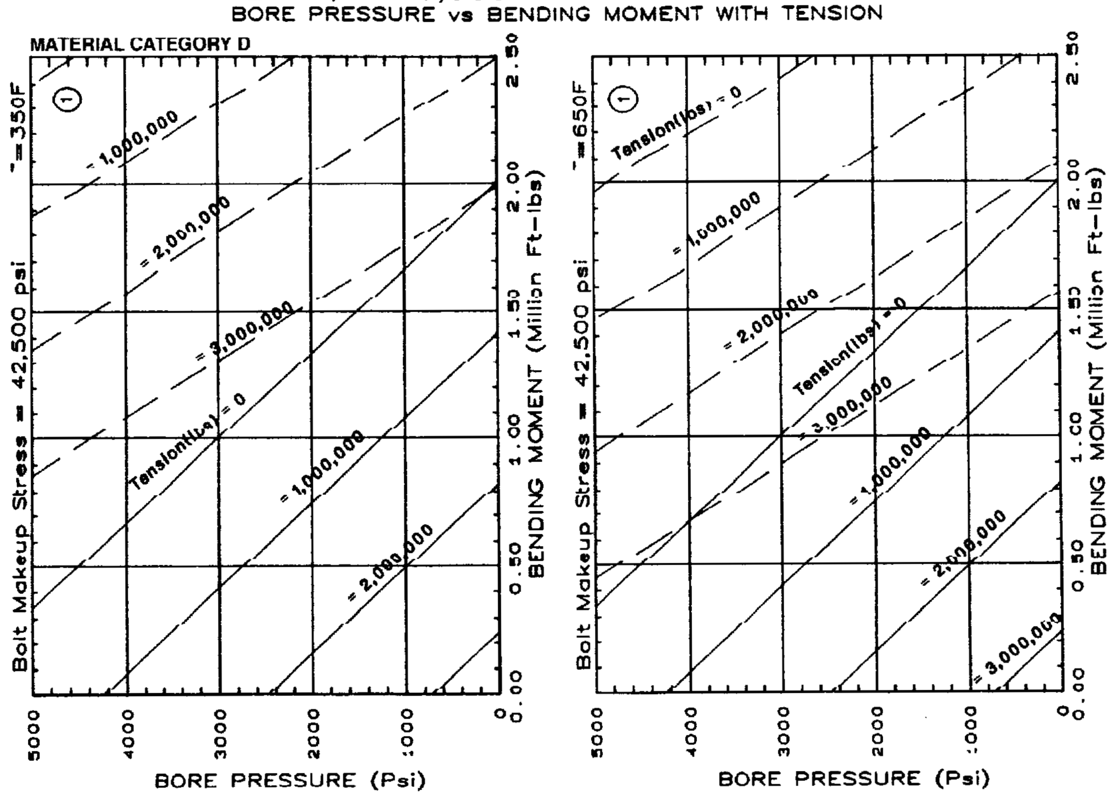
18–3/4"–5,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



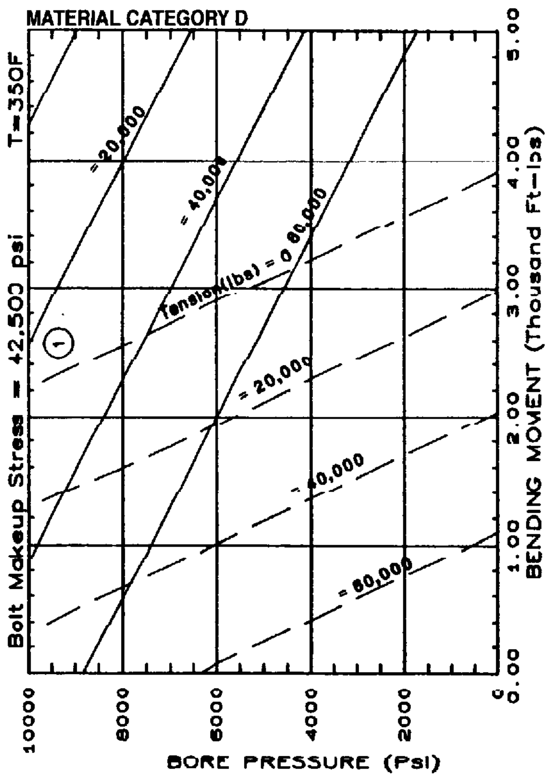
21–1/4"–5,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



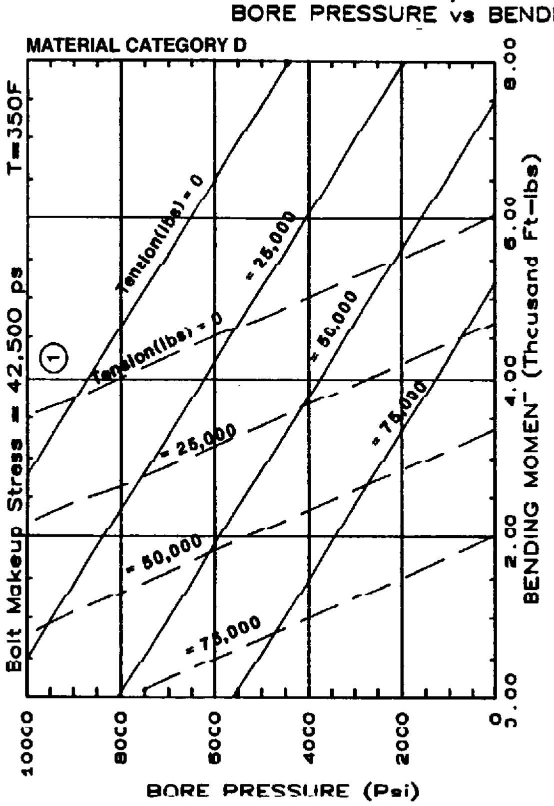
1—13/16"—10,000 PSI API 6BX—FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

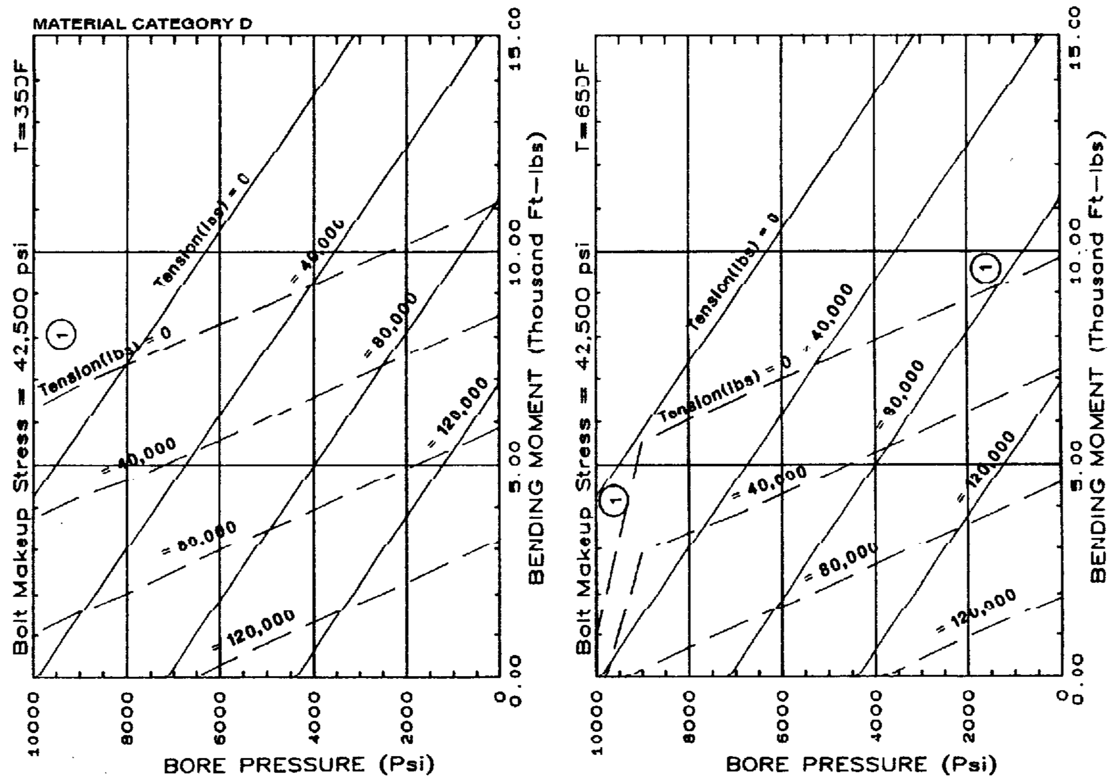


2—1/16"—10,000 PSI API 6BX—FLANGE

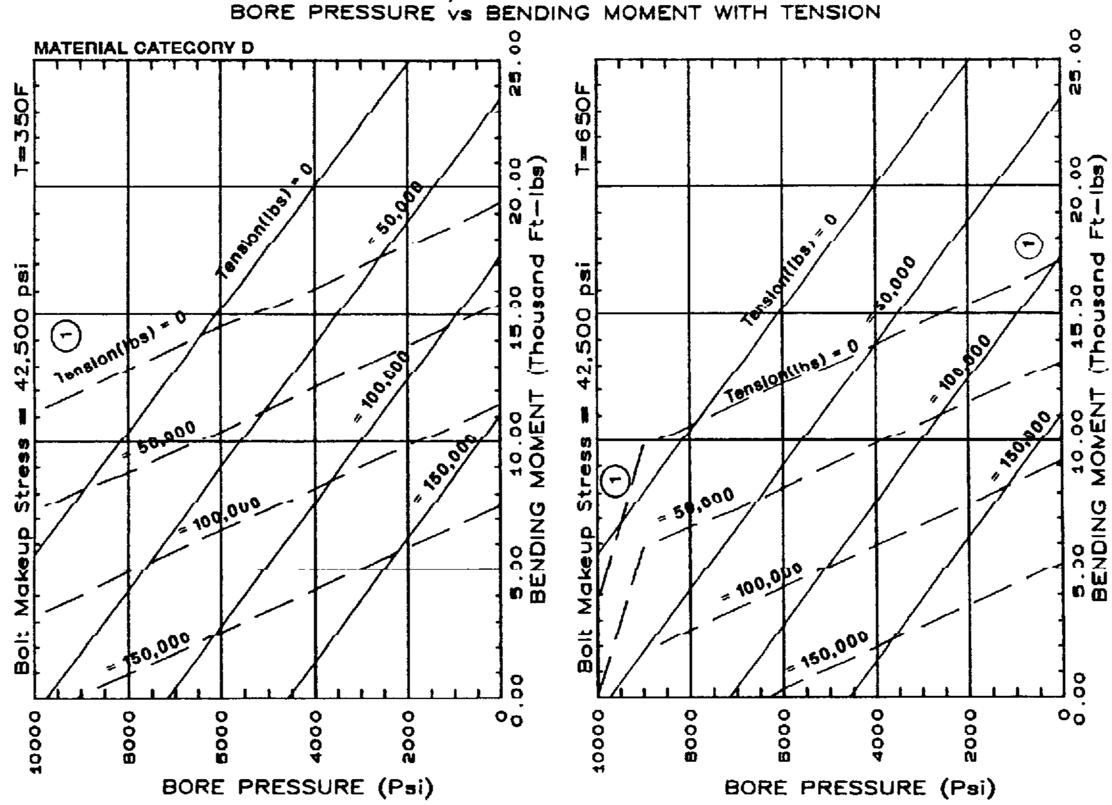
BORE PRESSURE vs BENDING MOMENT WITH TENSION



2-9/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

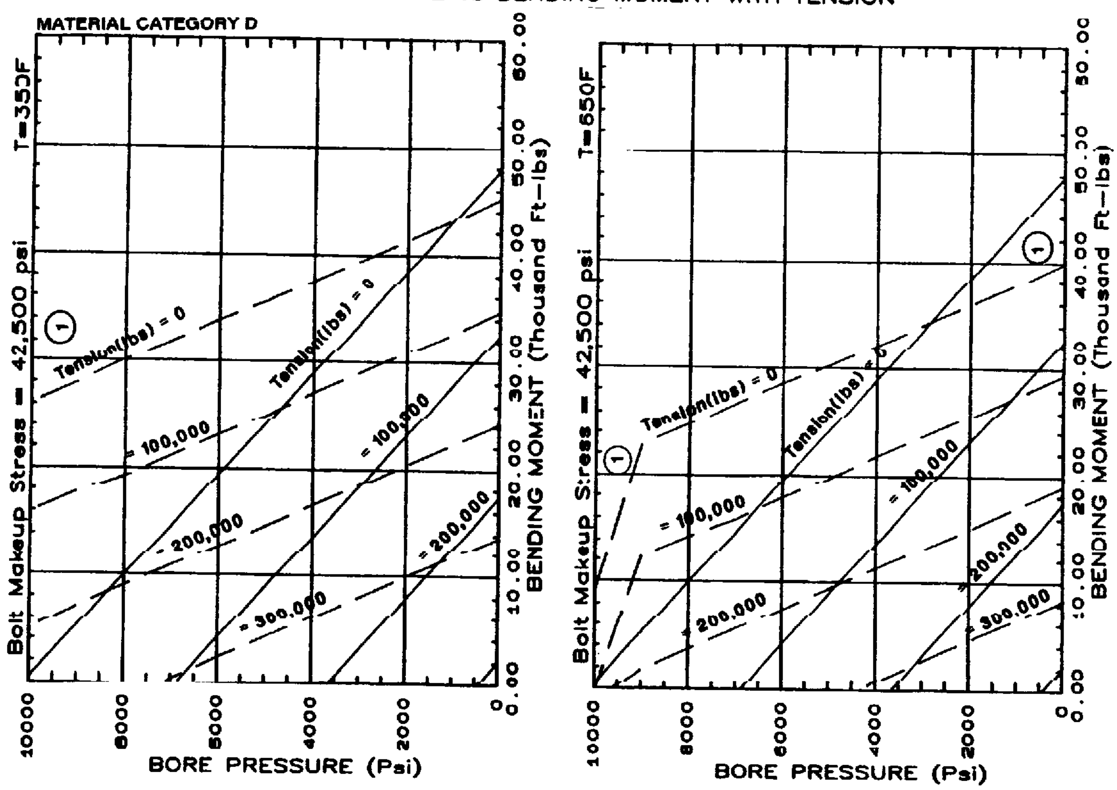


3-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



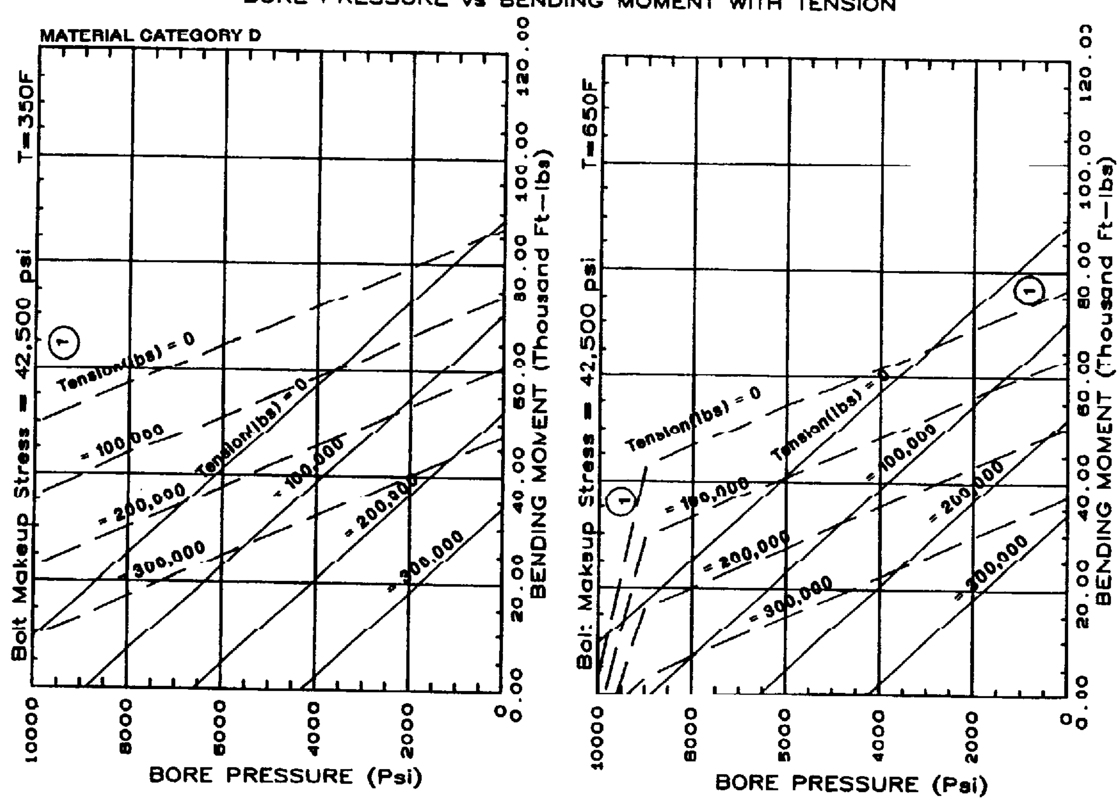
4-1/16"-10,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

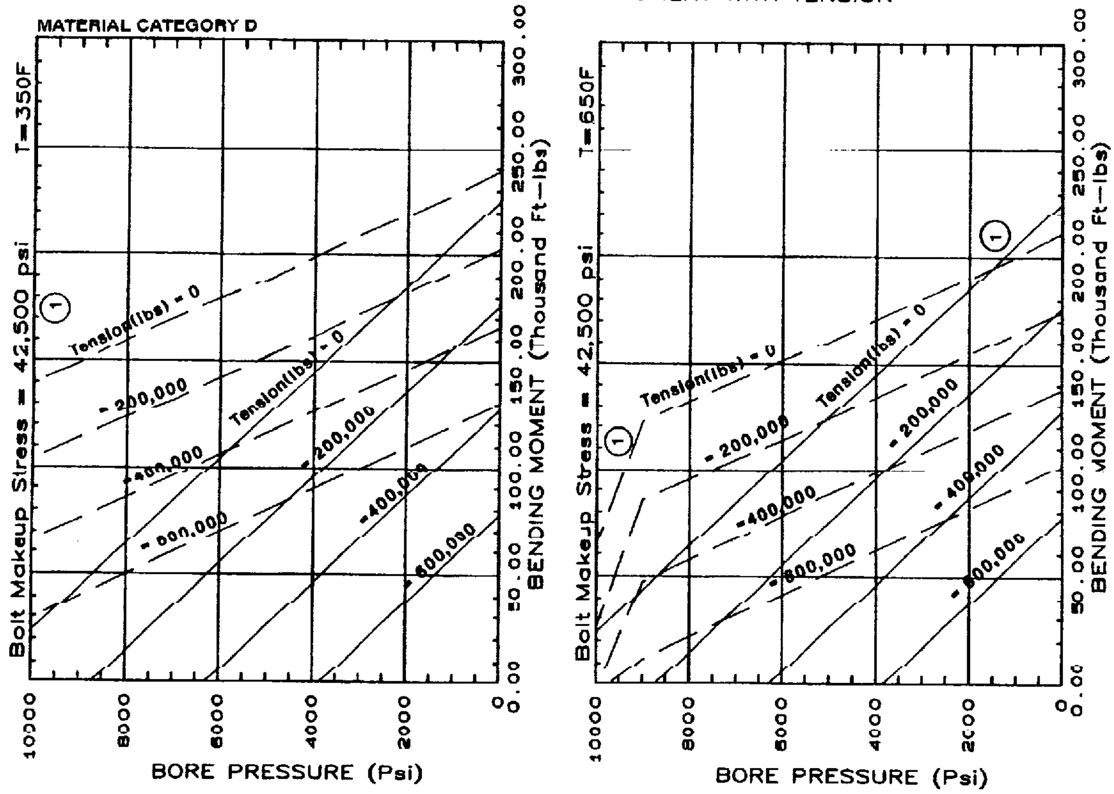


5-1/8"-10,000 PSI API 6BX-FLANGE

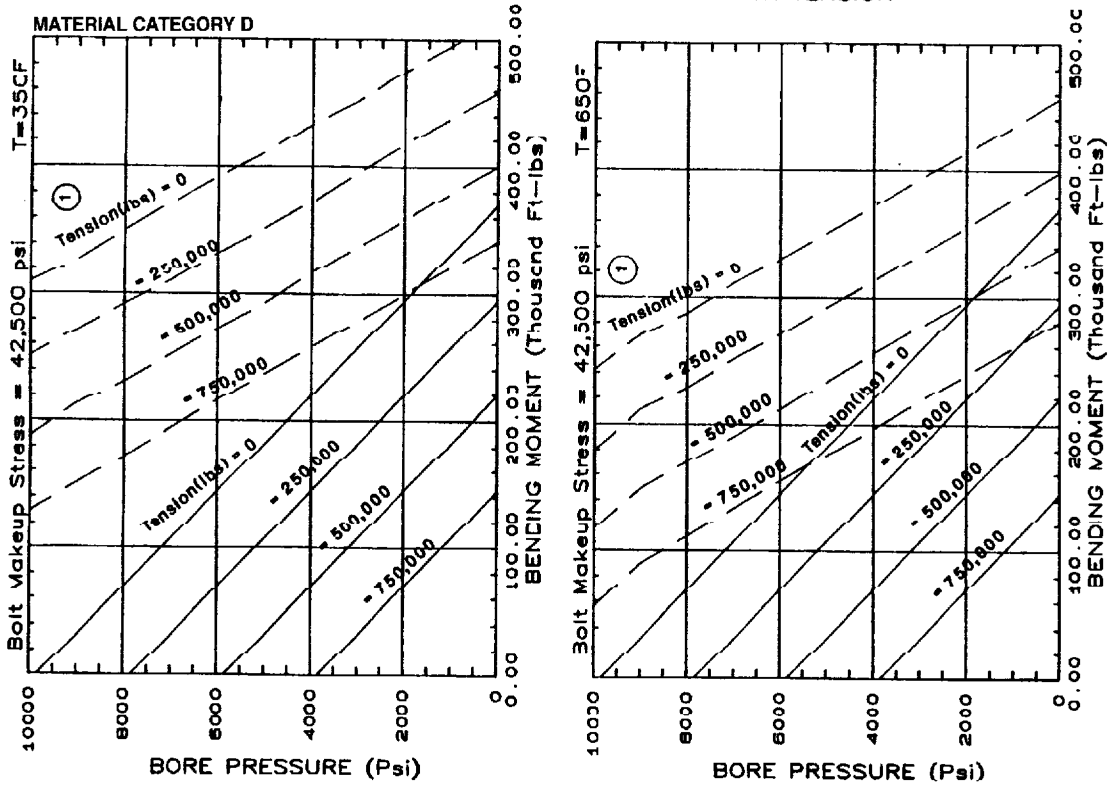
BORE PRESSURE vs BENDING MOMENT WITH TENSION



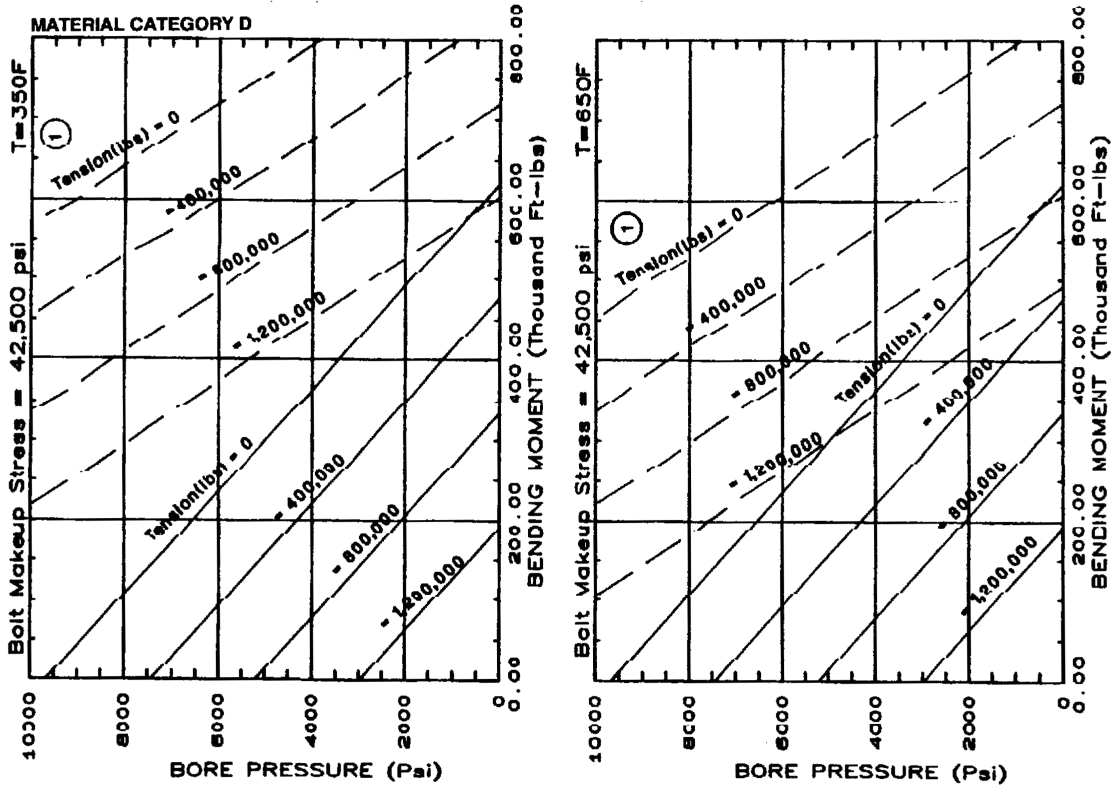
7-1/16"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



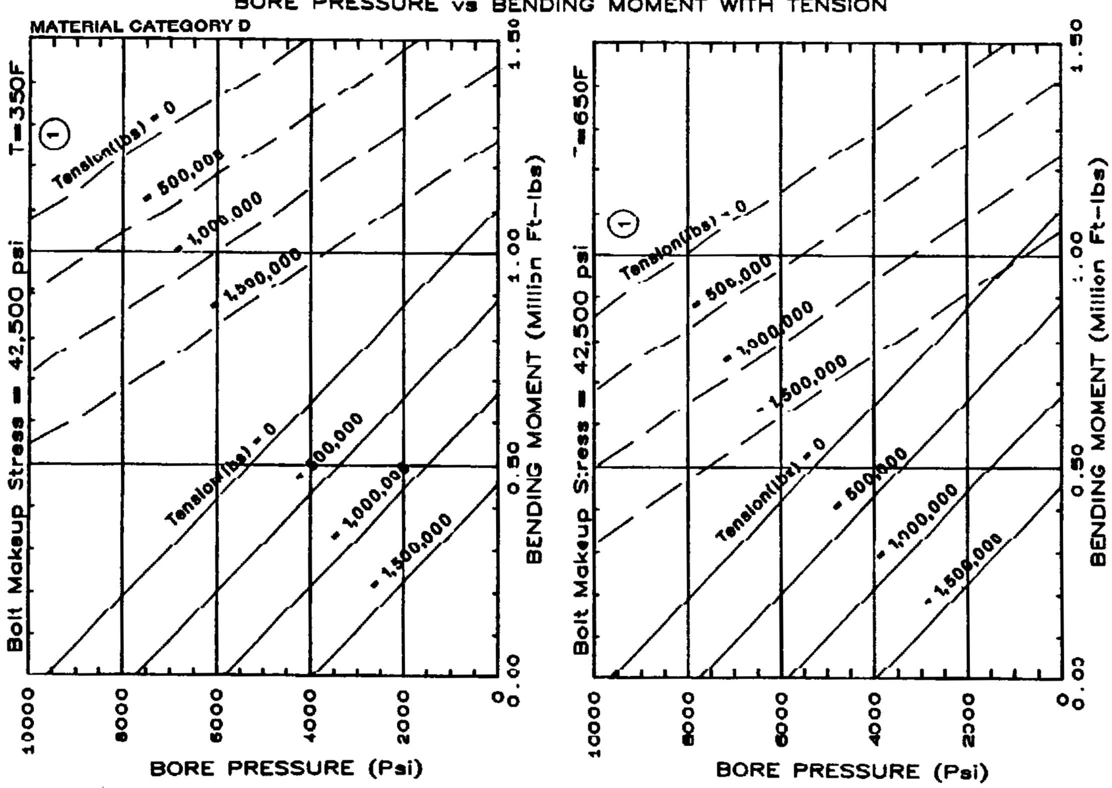
9"-10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"—10,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

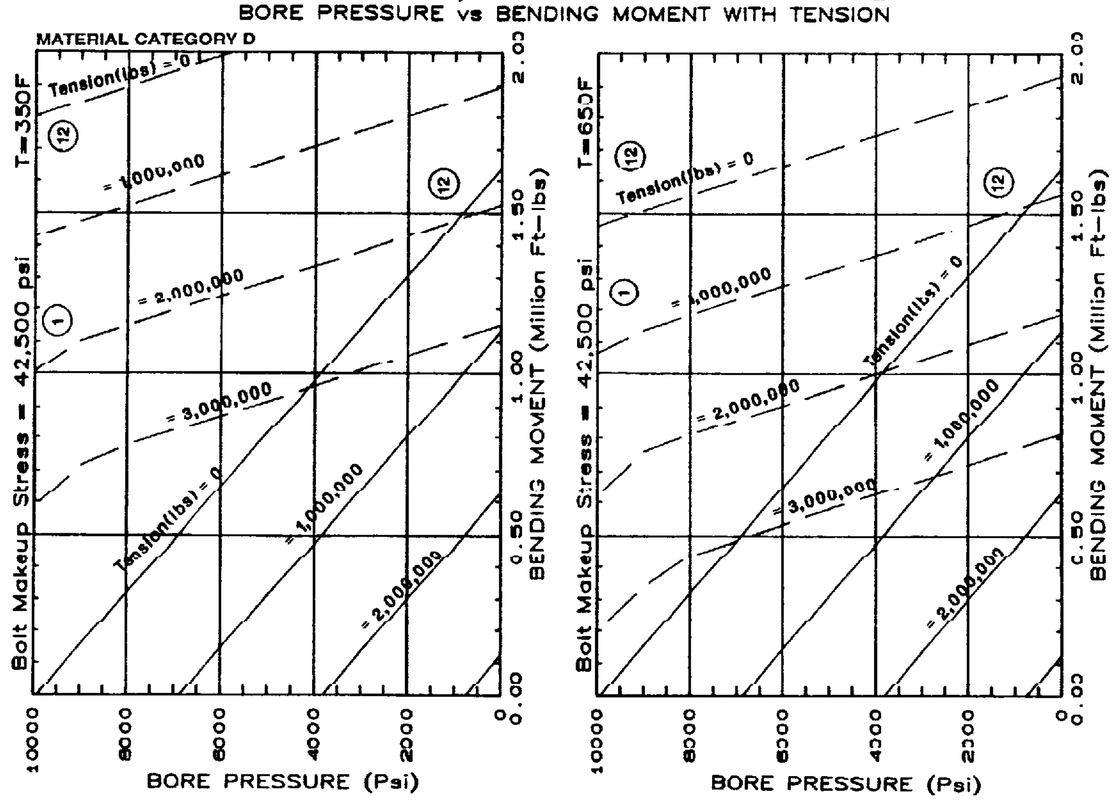


13-5/8"—10,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



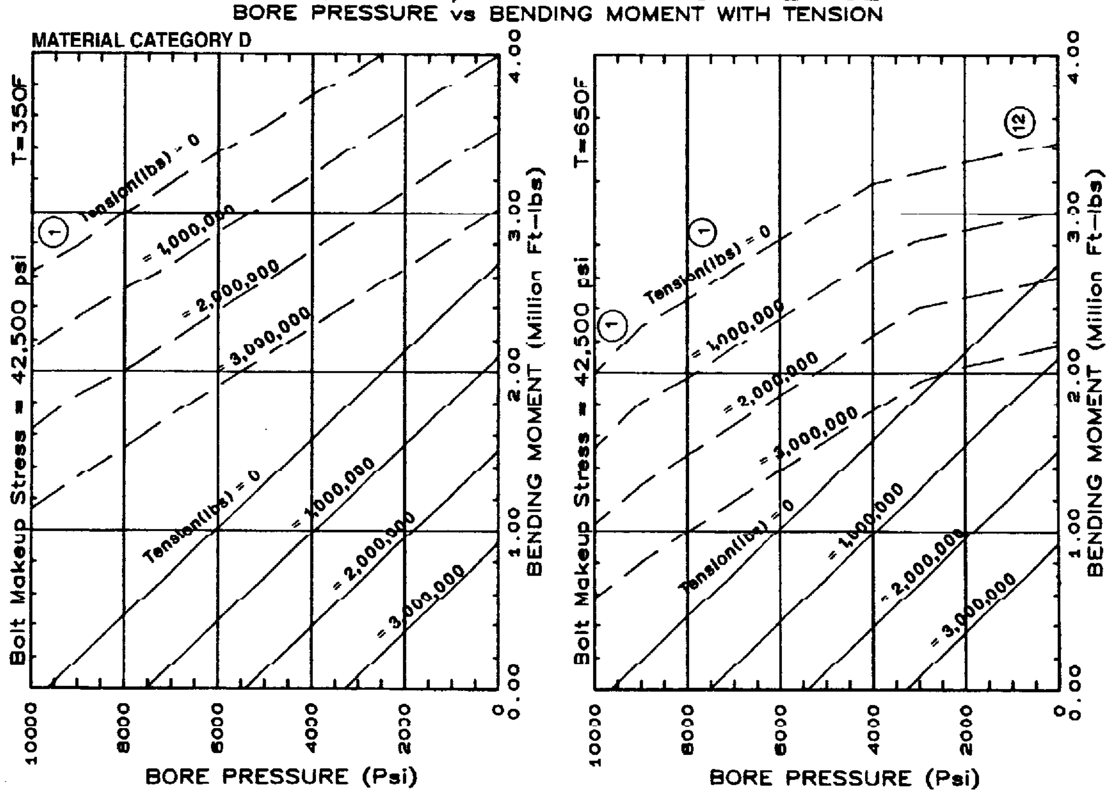
16–3/4"–10,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

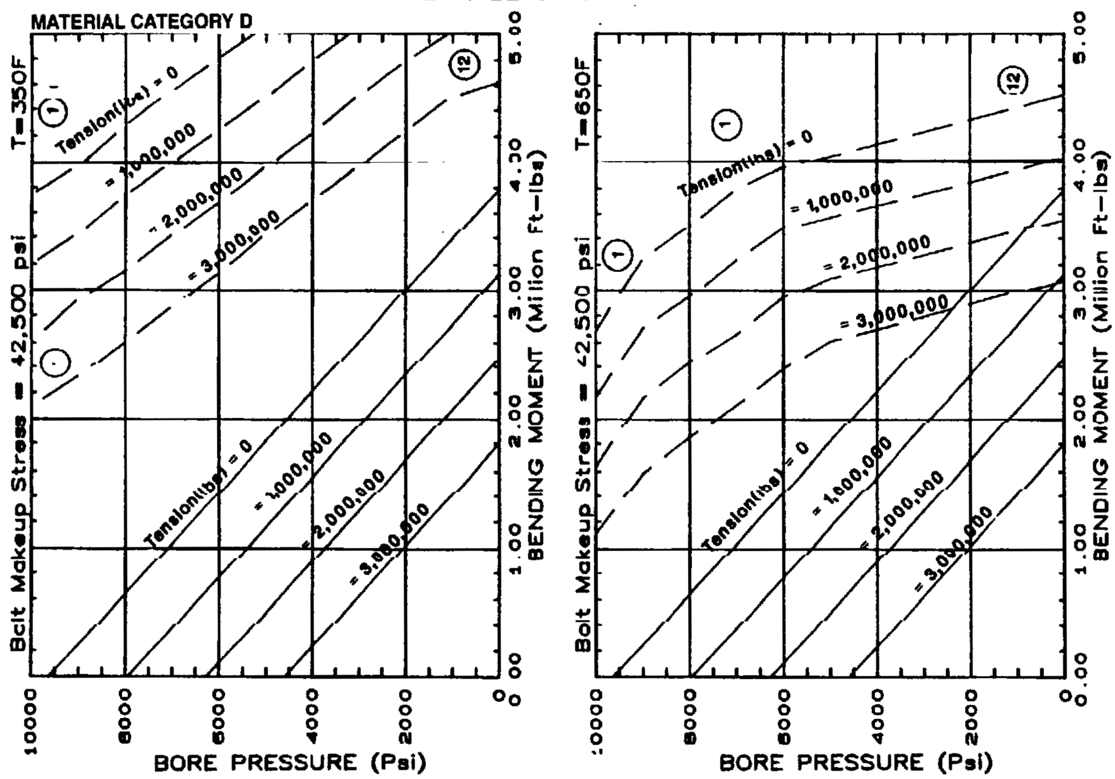


18–3/4"–10,000 PSI API 6BX–FLANGE

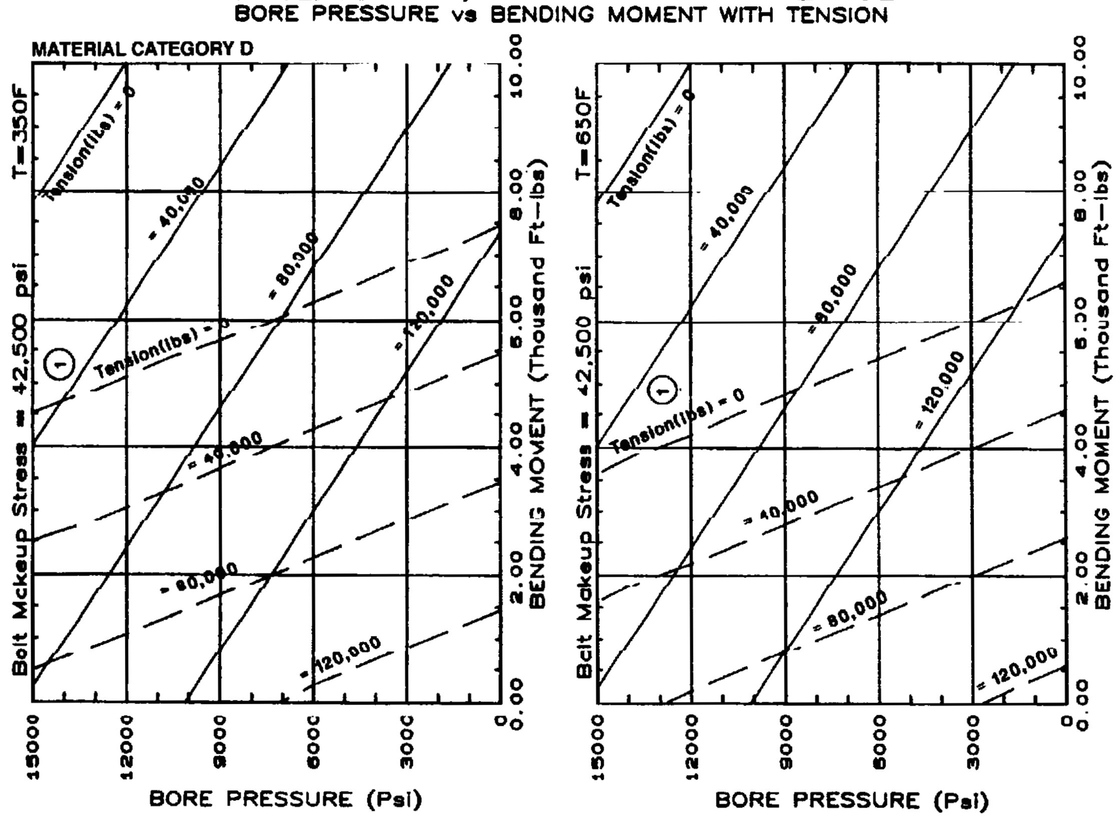
BORE PRESSURE vs BENDING MOMENT WITH TENSION



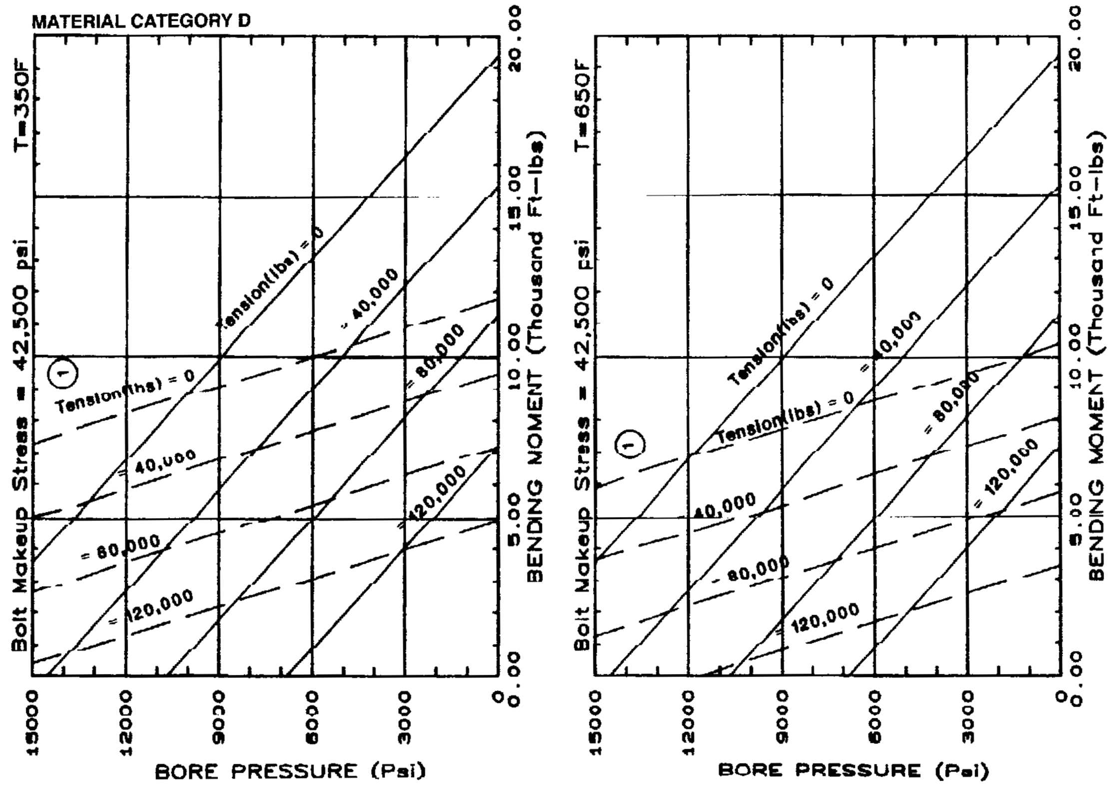
21-1/4" - 10,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



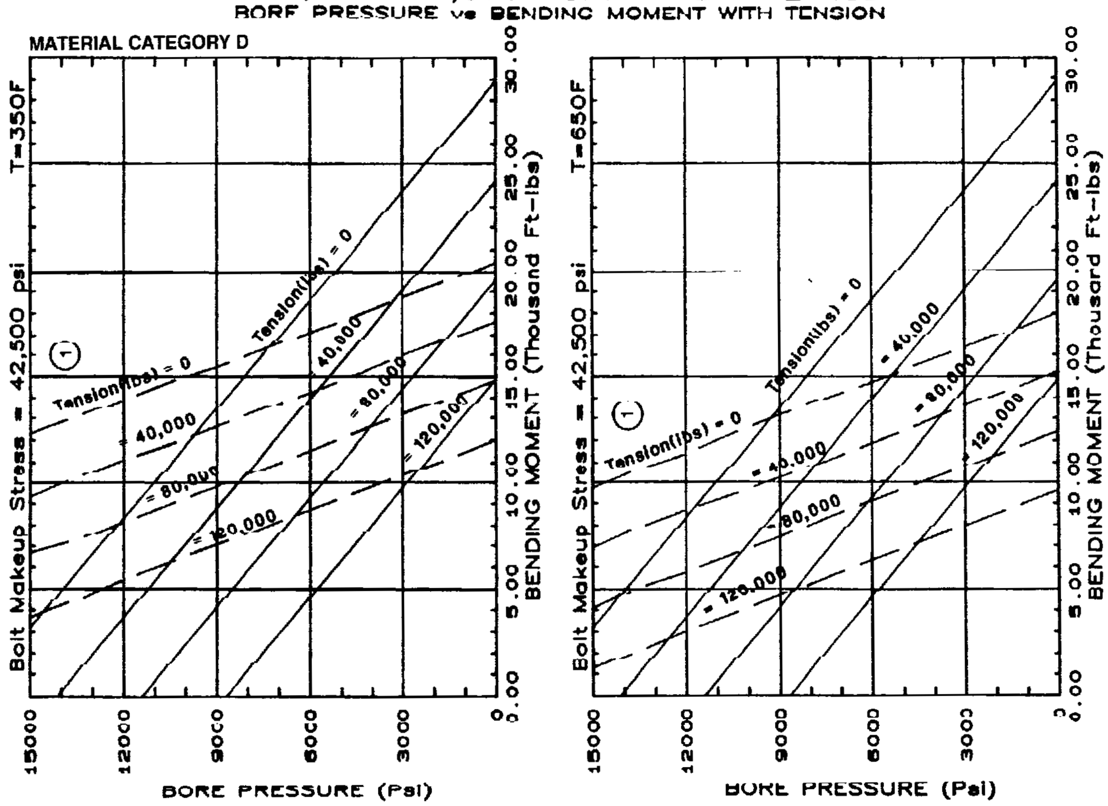
1-13/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



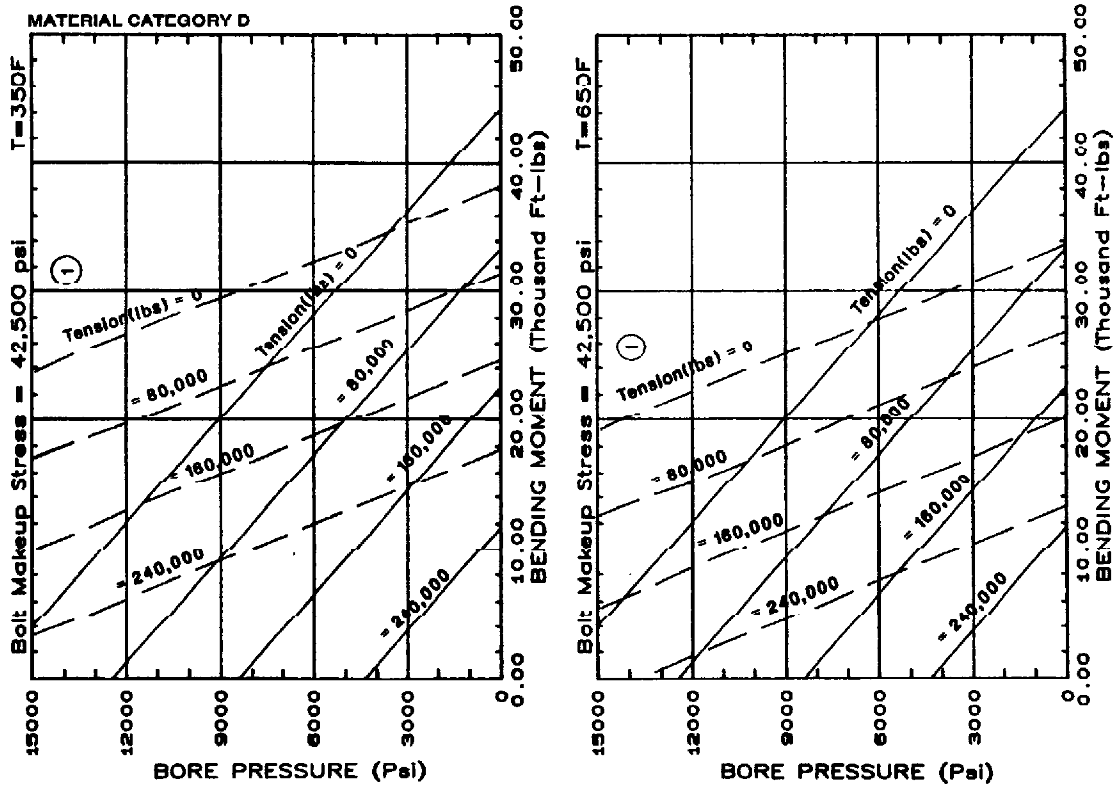
2-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



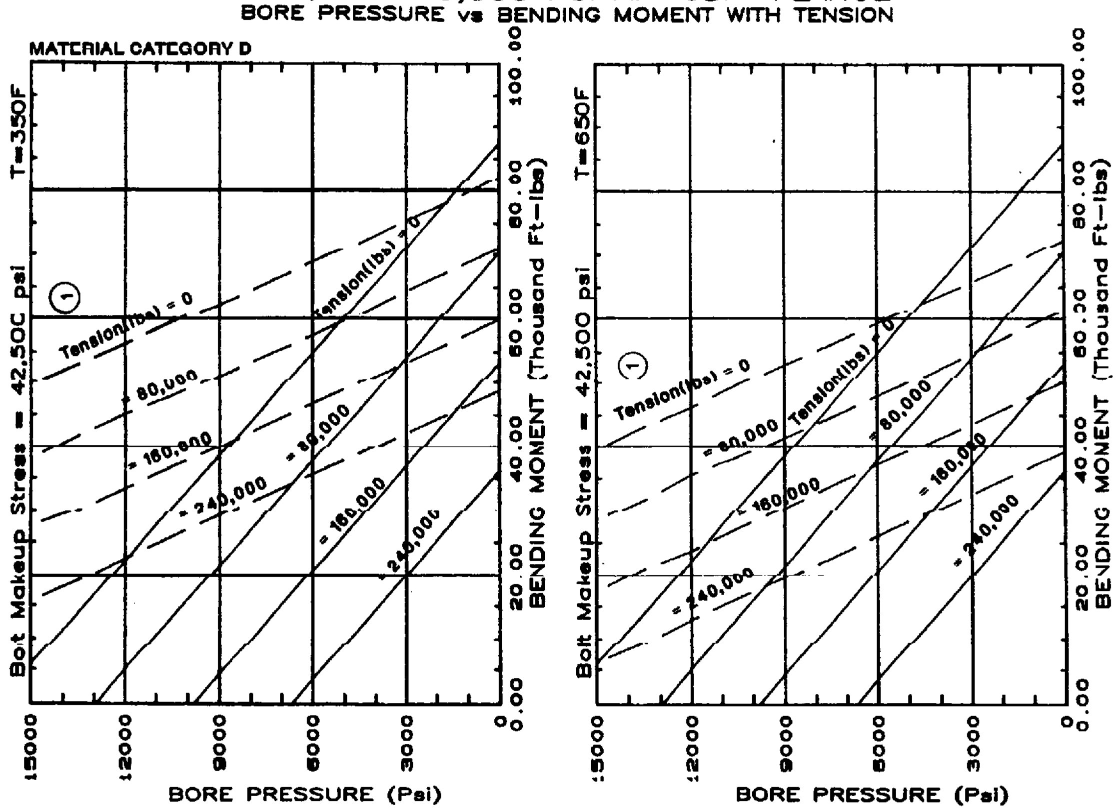
2-9/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



3-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION

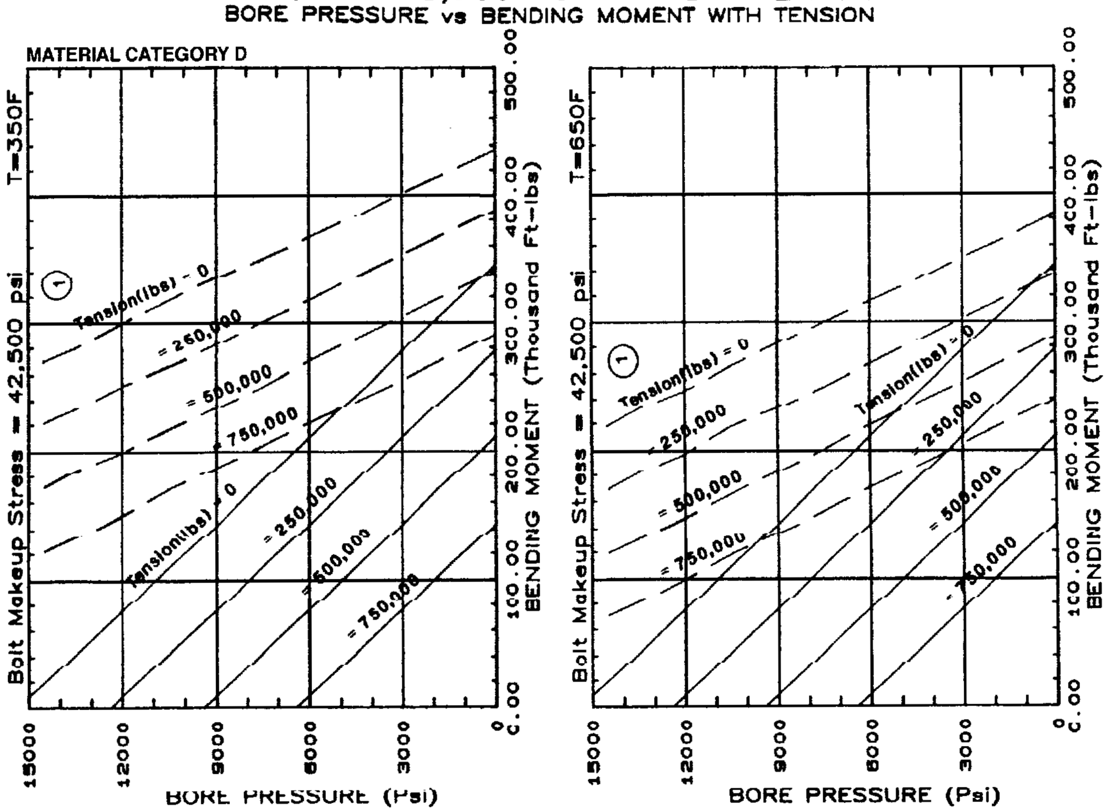


4-1/16"-15,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



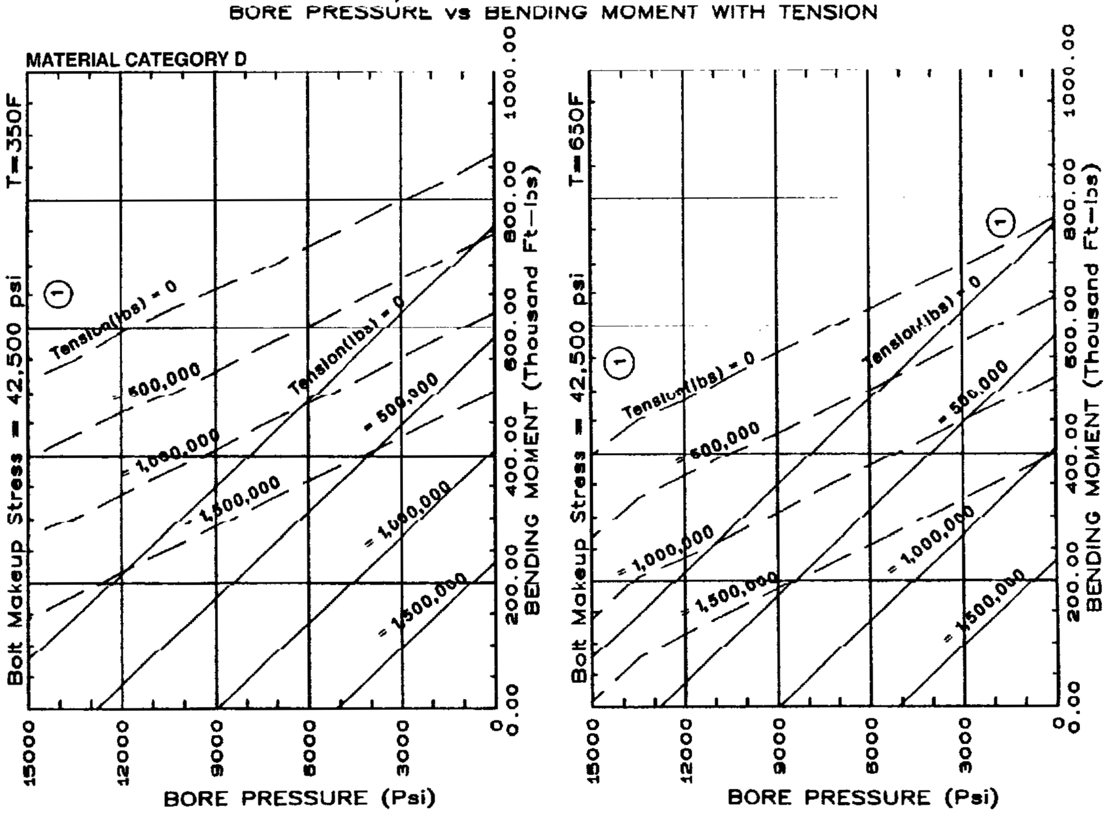
7–1/16"–15,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

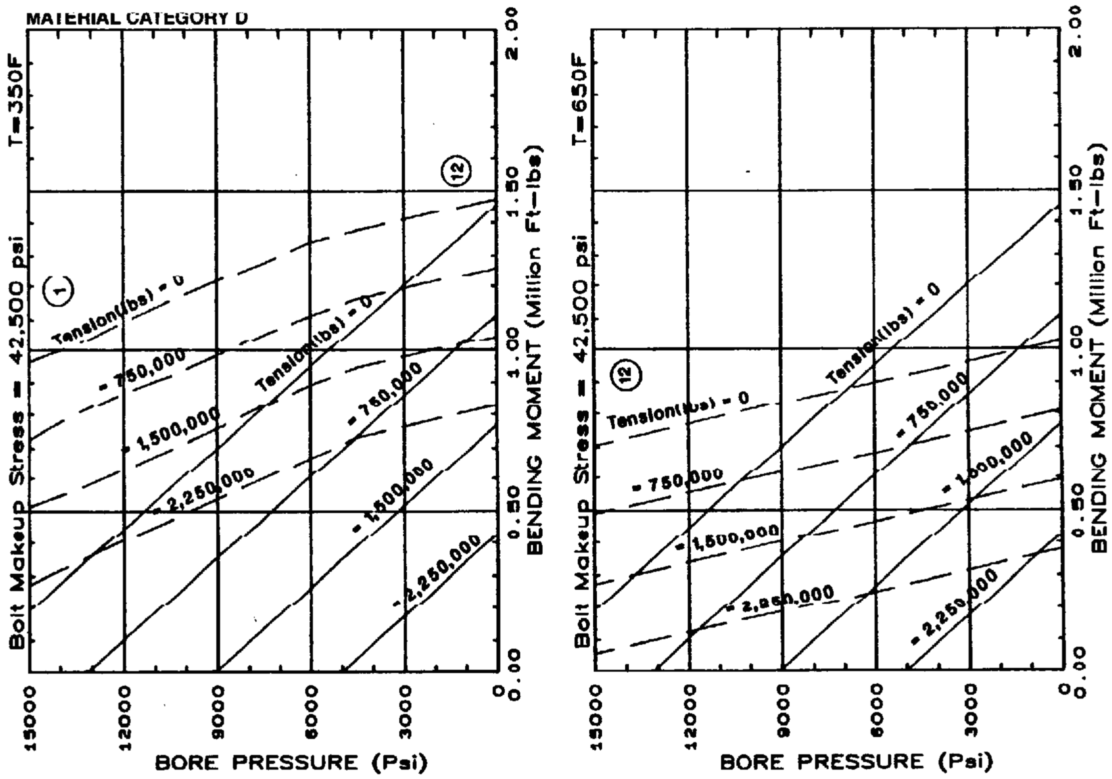


9"–15,000 PSI API 6BX–FLANGE

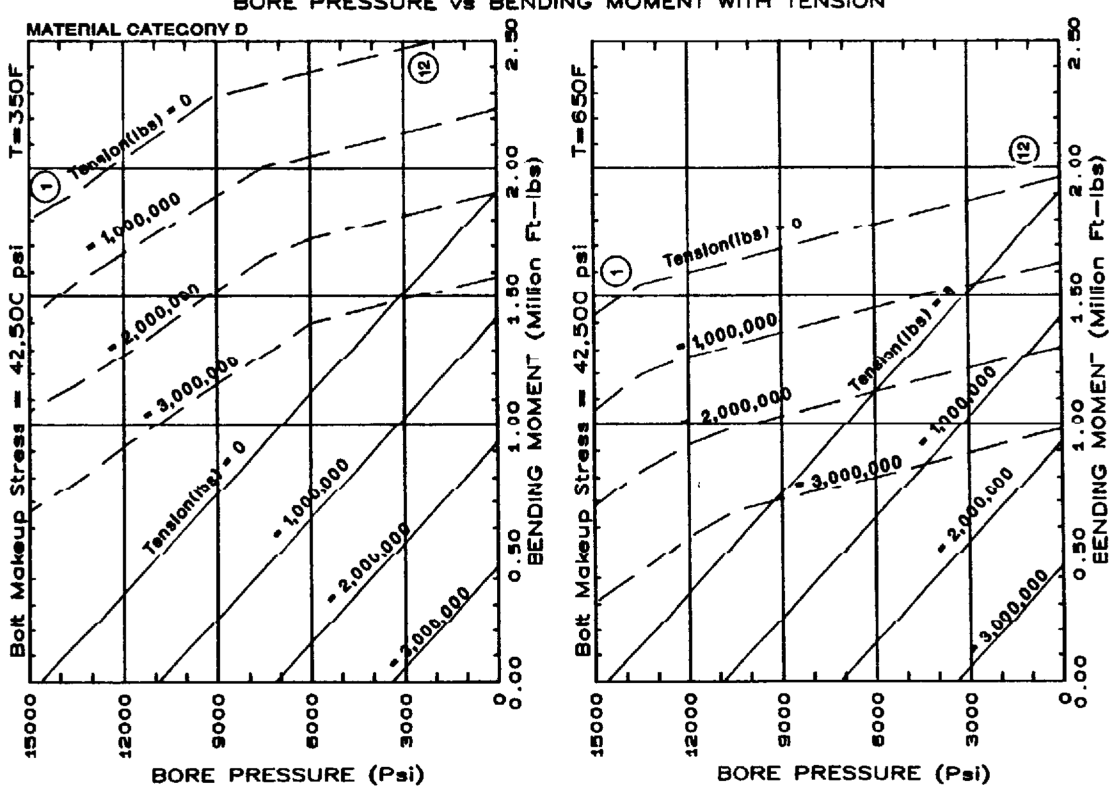
BORE PRESSURE vs BENDING MOMENT WITH TENSION



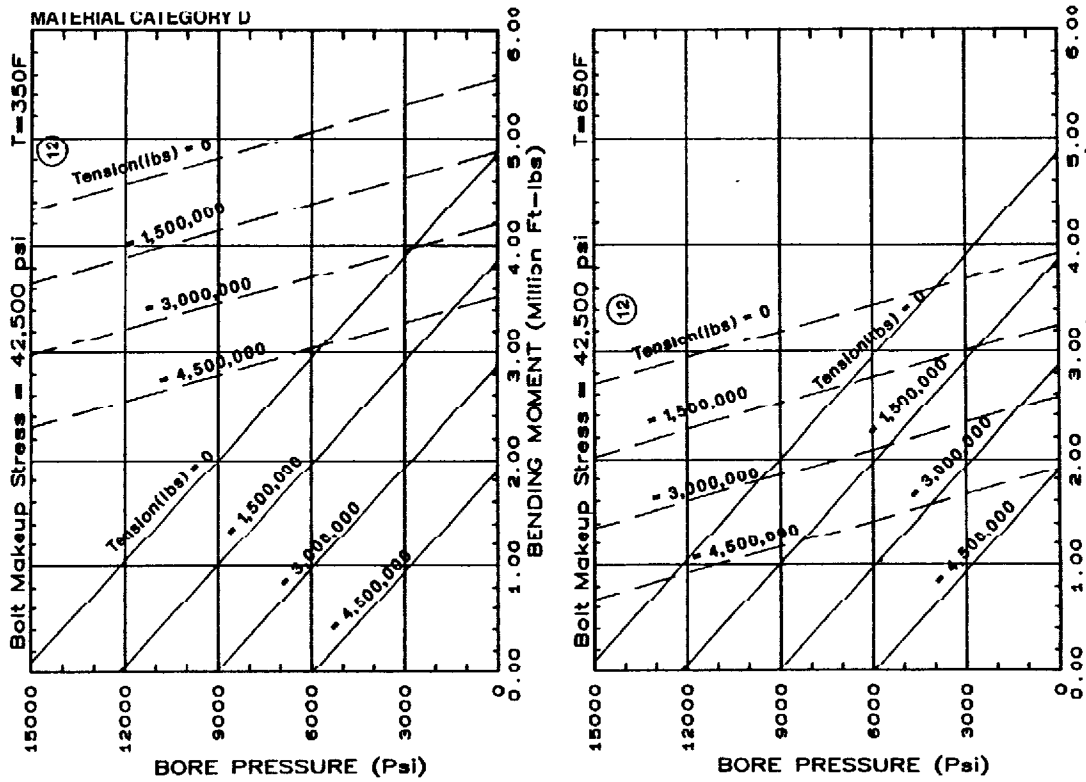
11"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



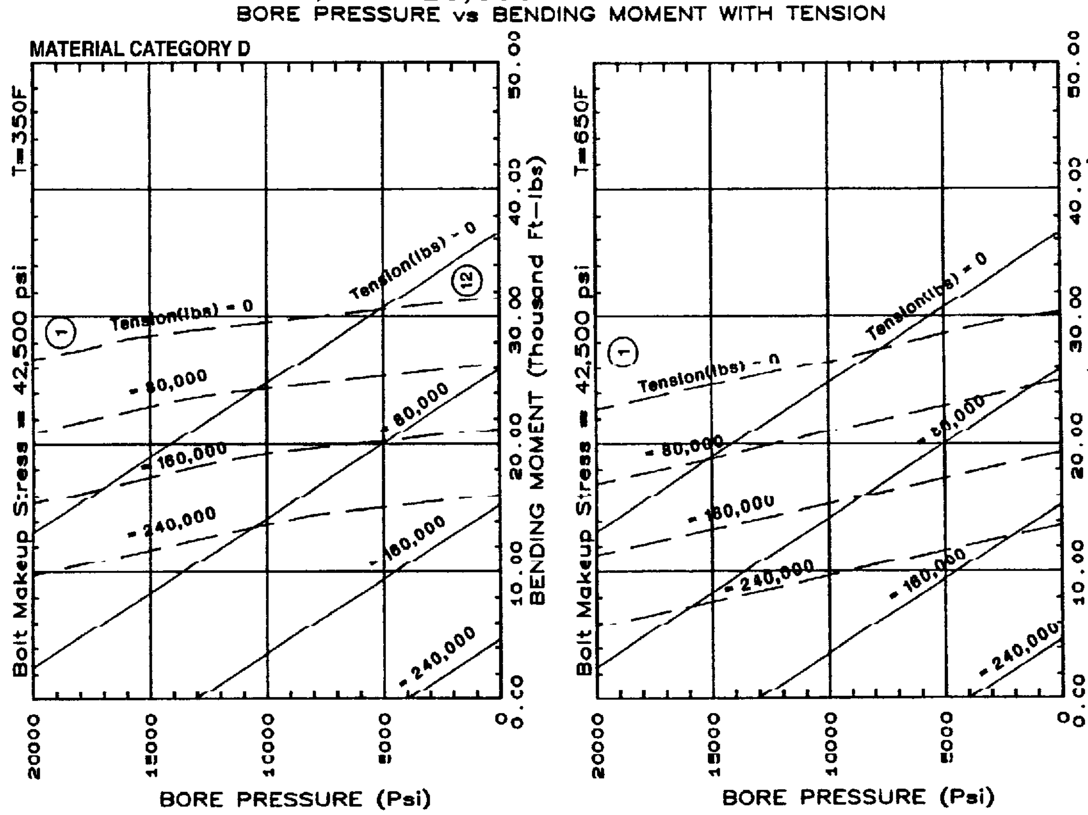
13–5/8"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



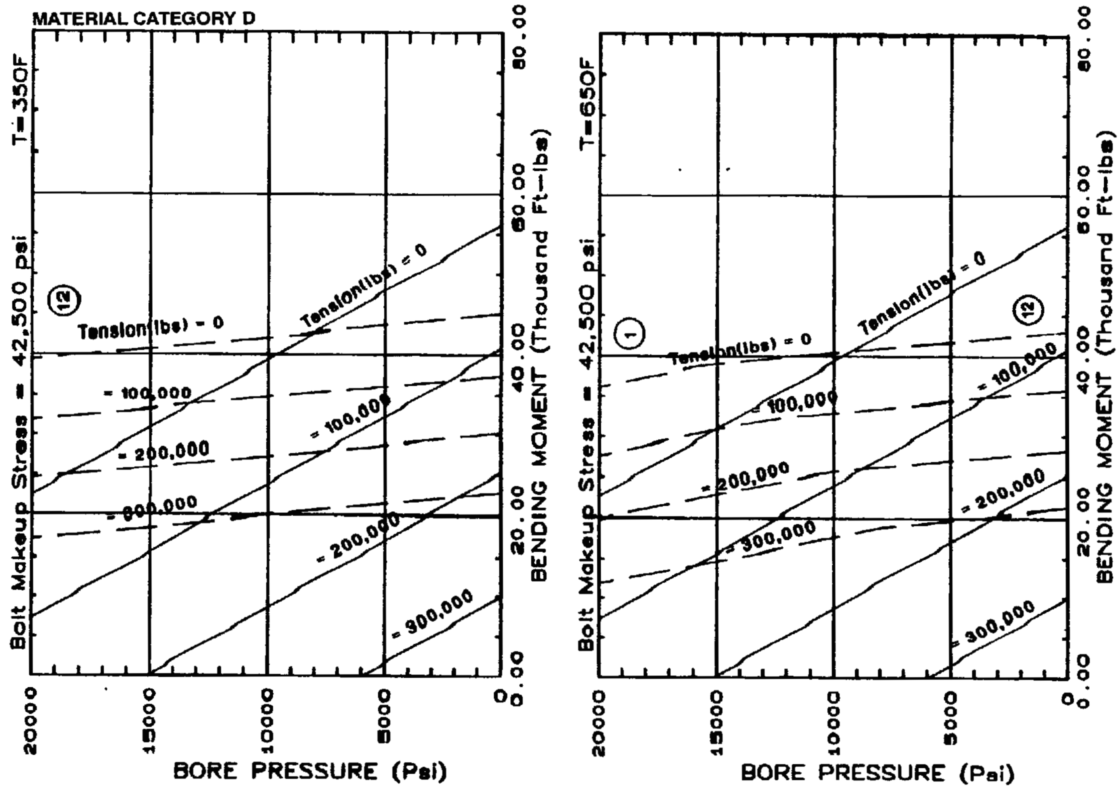
18–3/4"–15,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



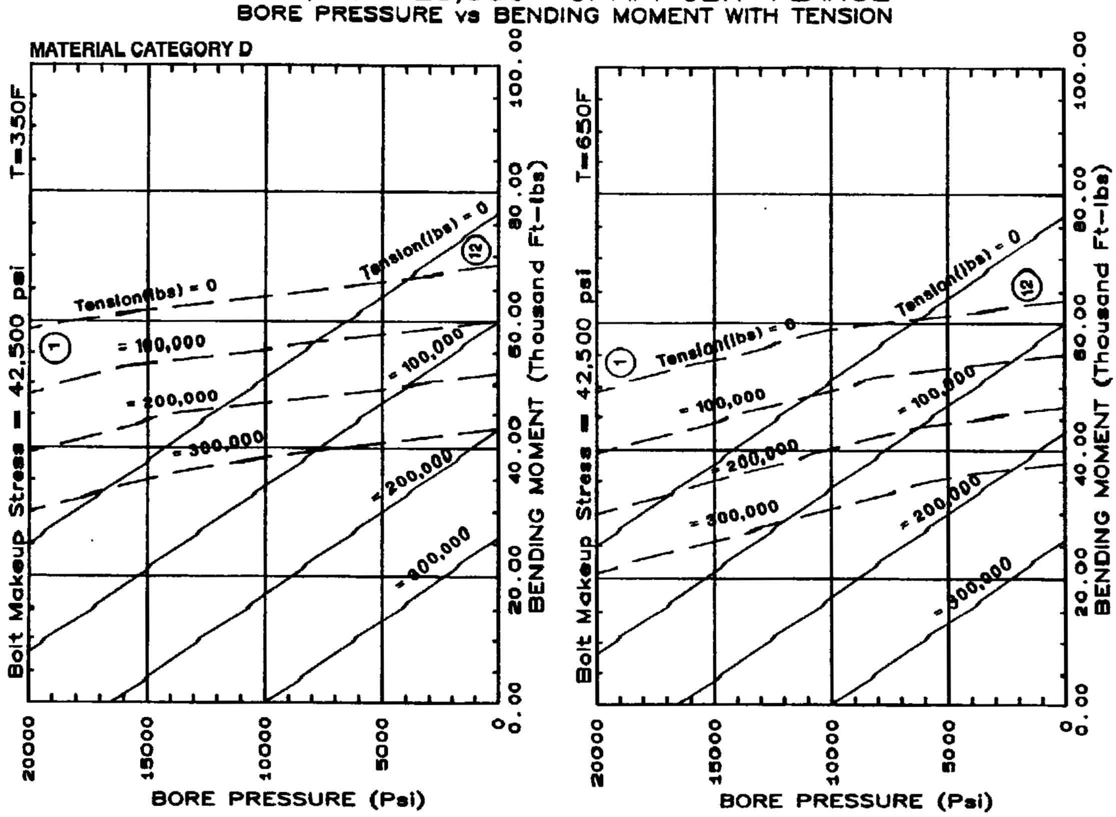
1–13/16"–20,000 PSI API 6BX–FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



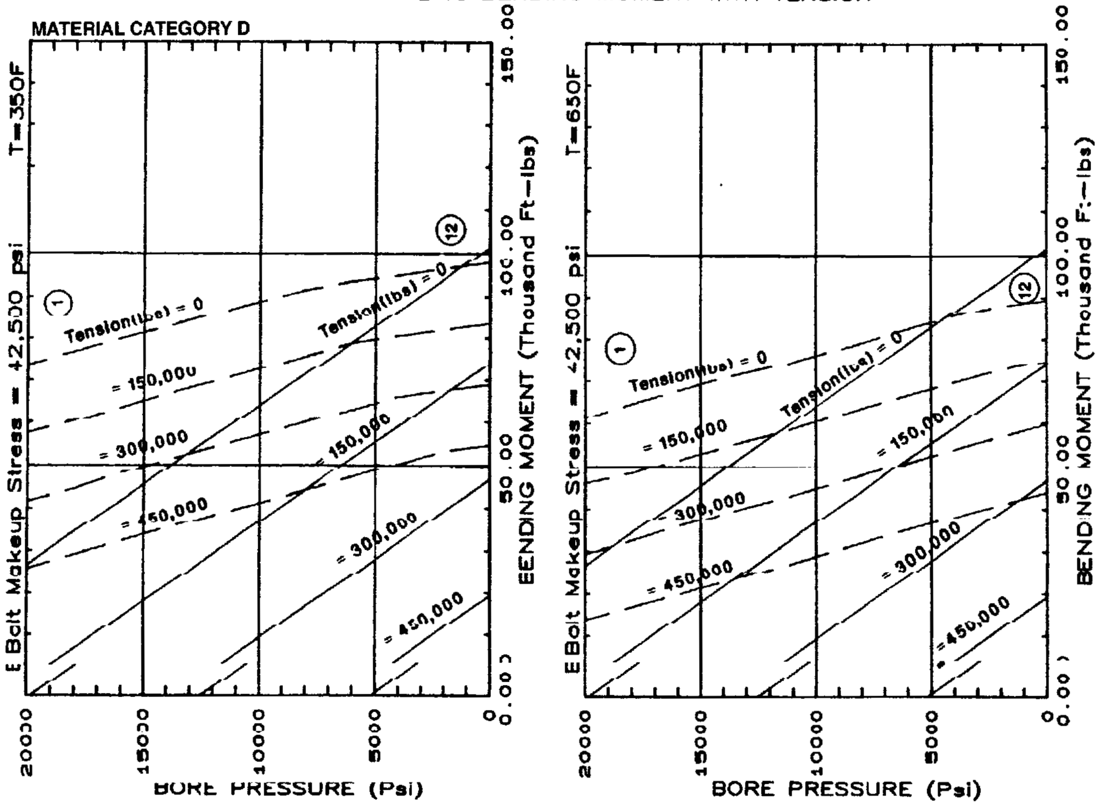
2-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



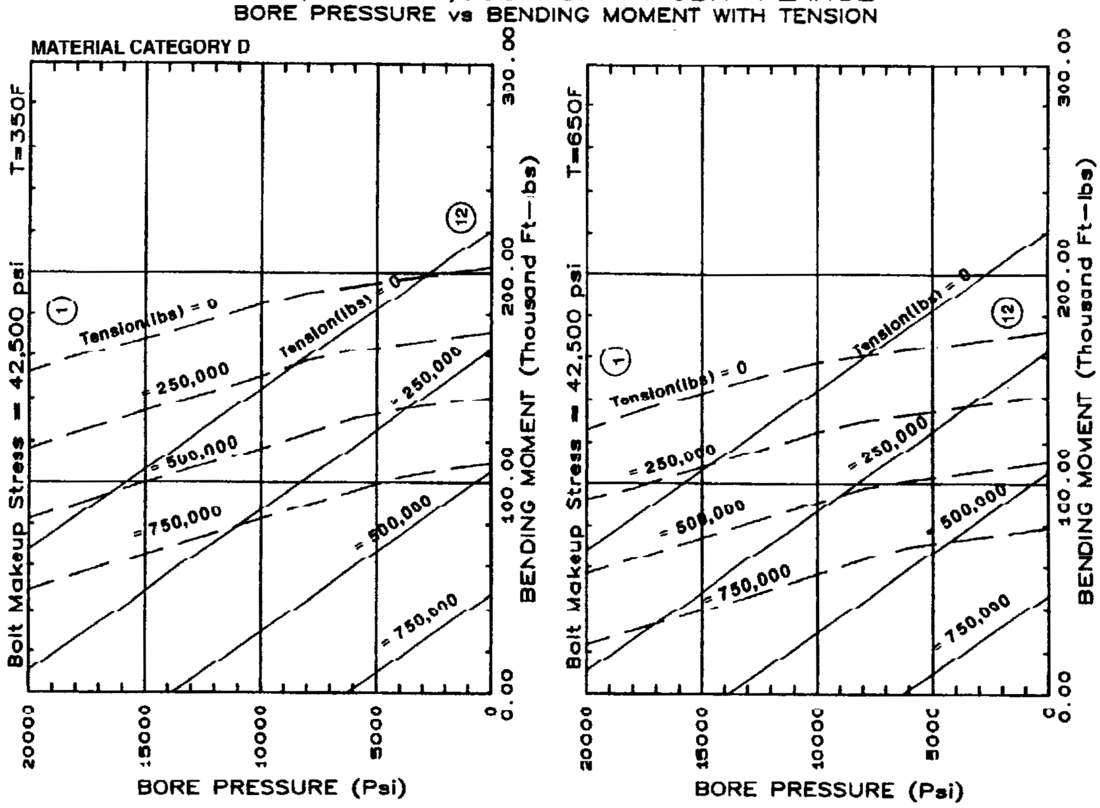
2-9/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



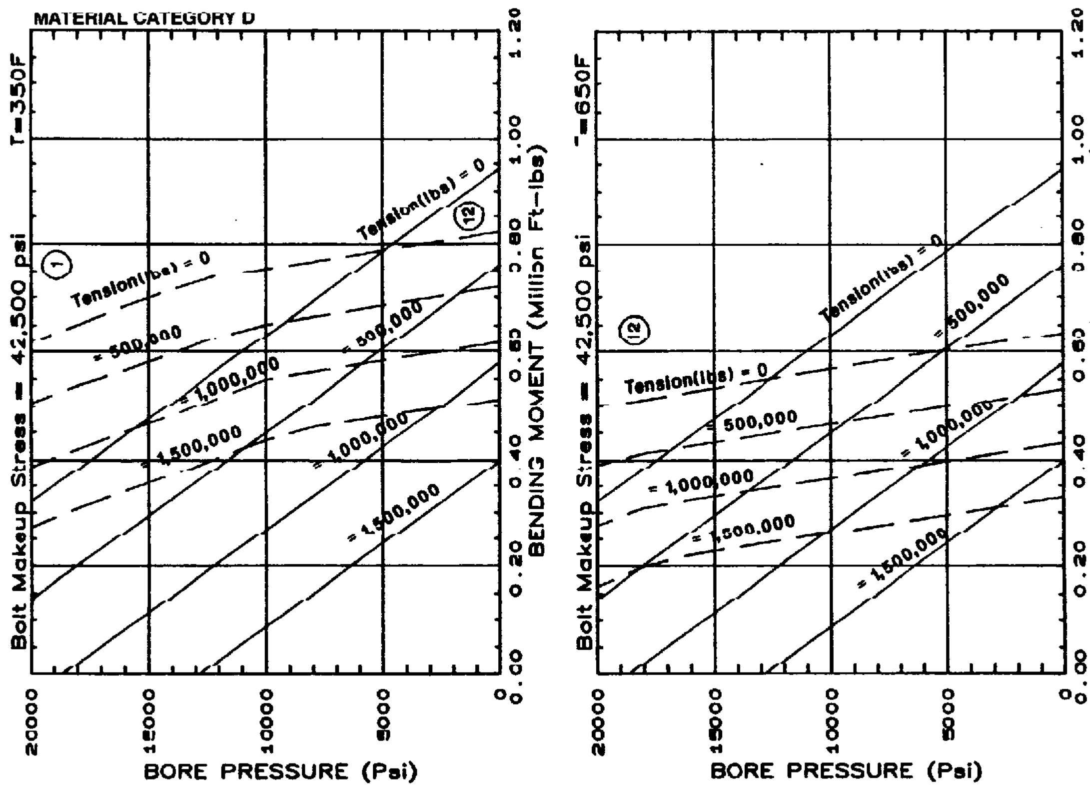
3-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



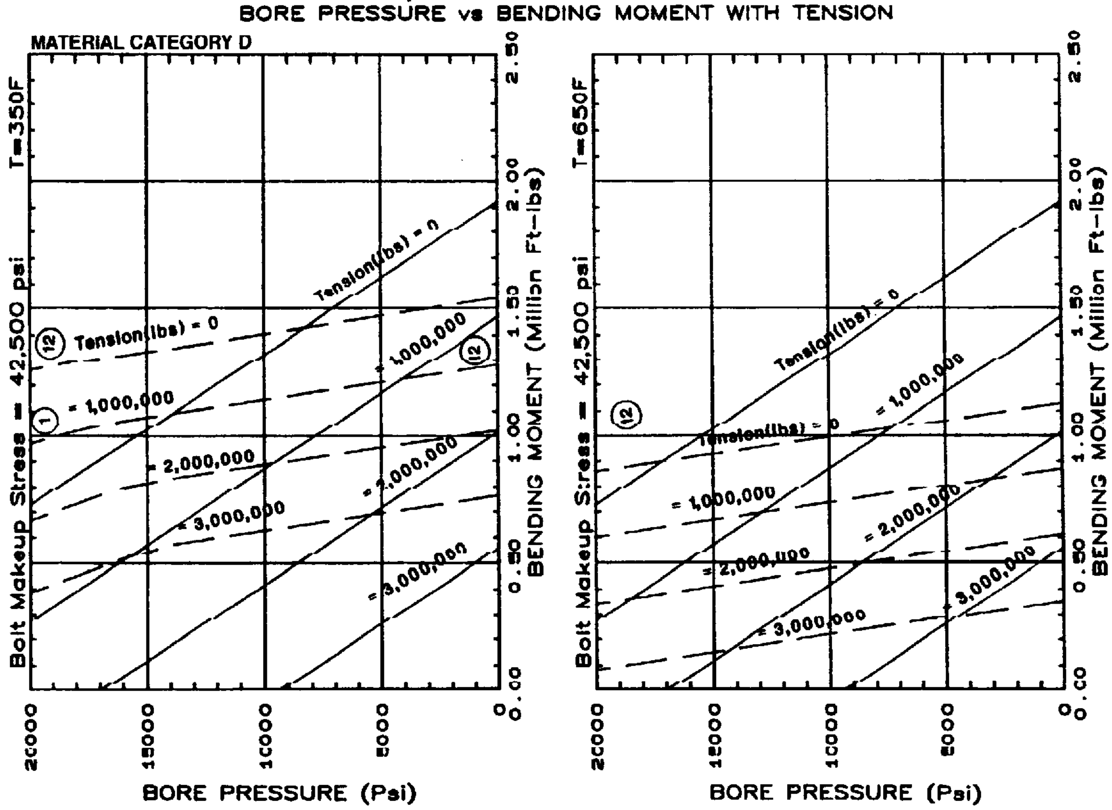
4-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



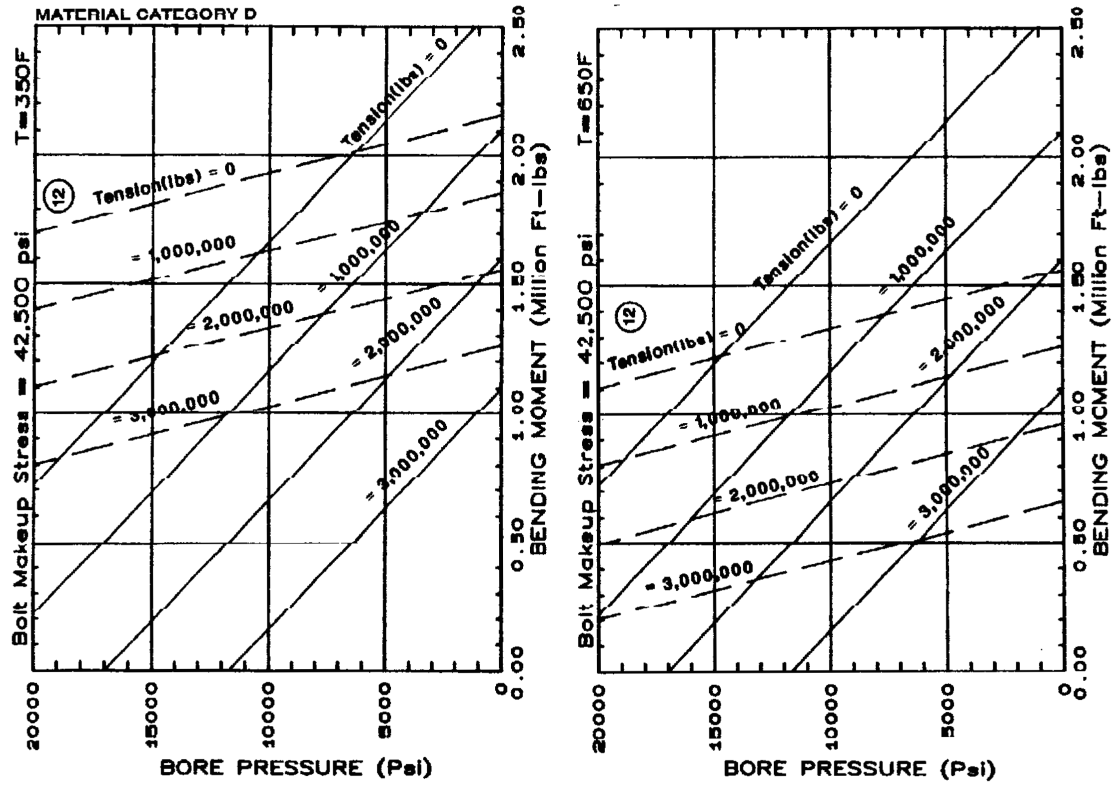
7-1/16"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



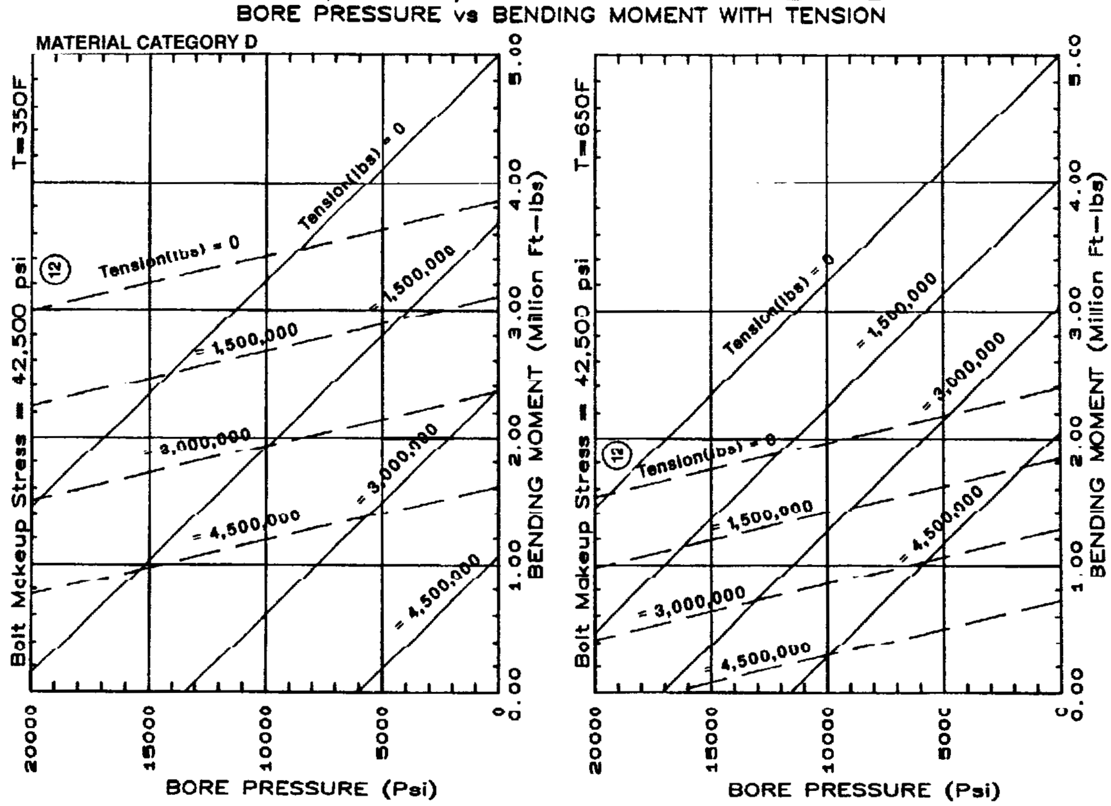
9"-20,000 PSI API 6BX-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



11"—20,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



13—5/8"—20,000 PSI API 6BX—FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



APPENDIX E—30" 2,000/3,000 PSI AND $5^1/_8$—2,000/3,000/5,000 PSI FLANGES

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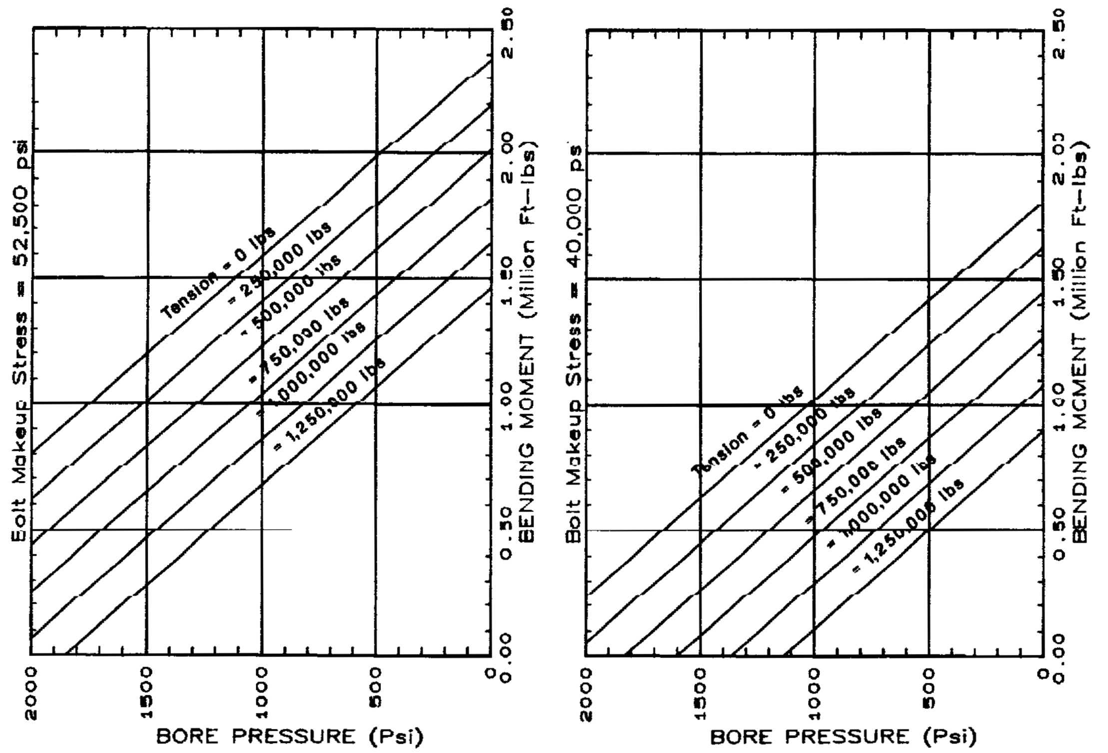
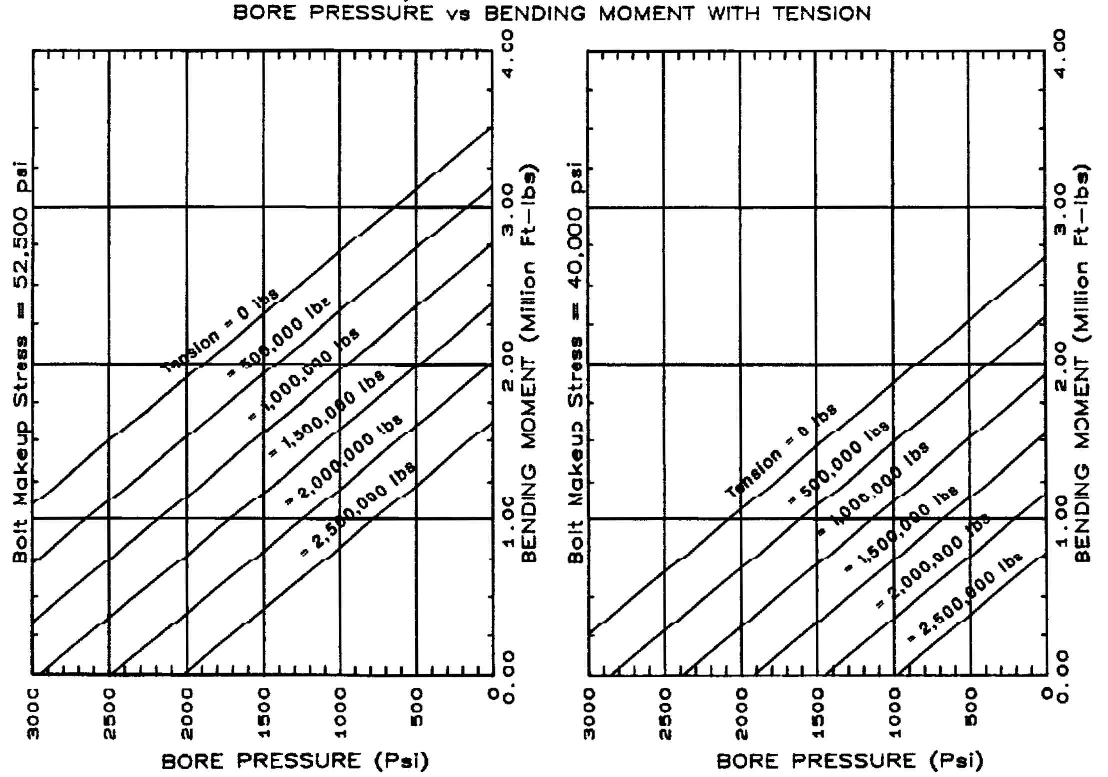
30"–2,000 PSI API 6BX–FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION

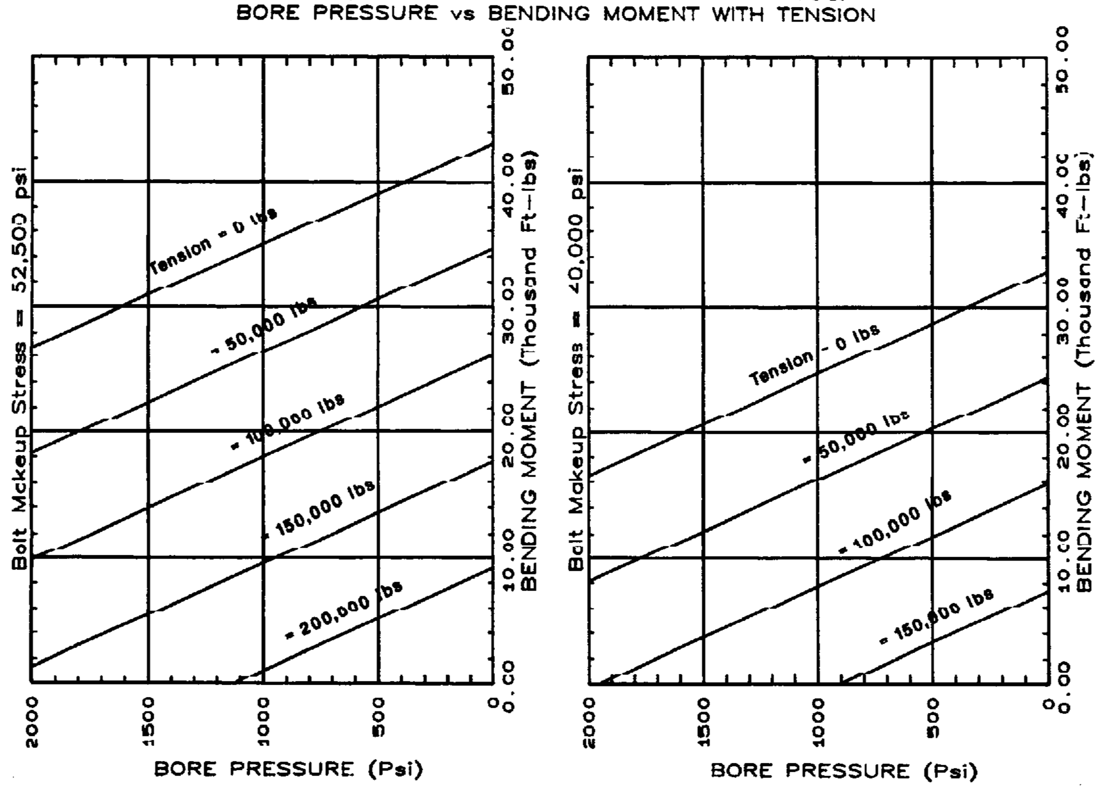


30"–3,000 PSI API 6BX–FLANGE

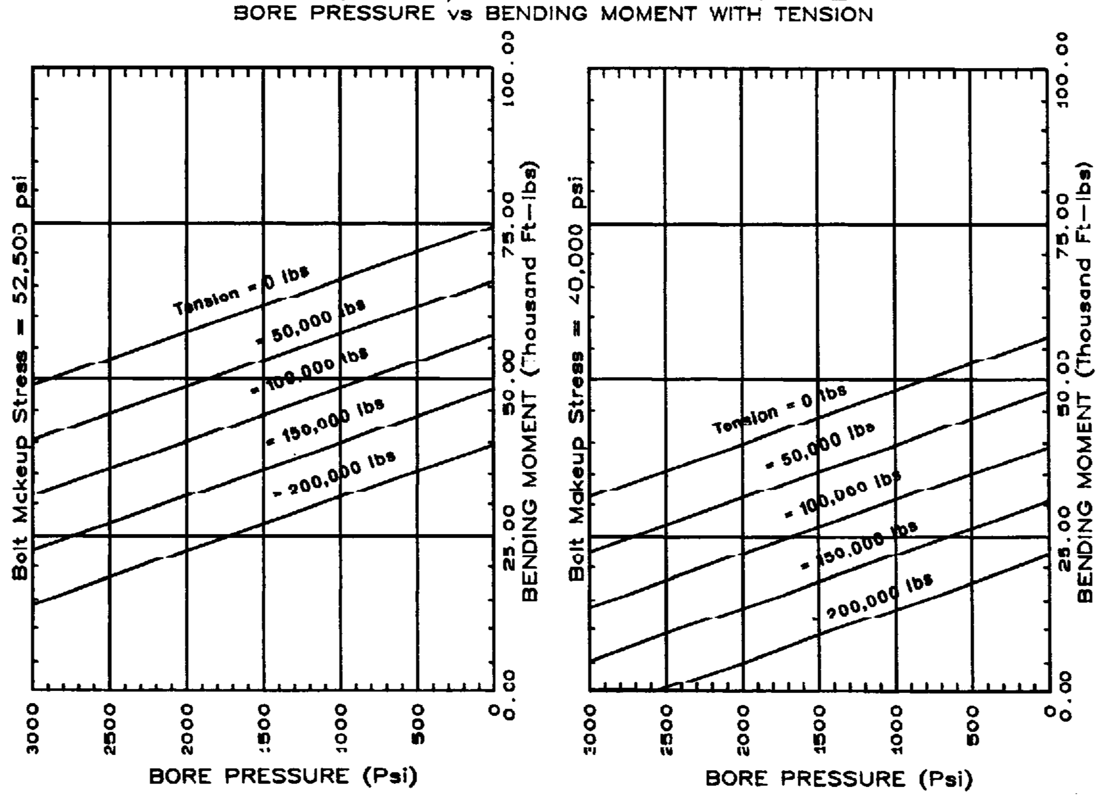
BORE PRESSURE vs BENDING MOMENT WITH TENSION



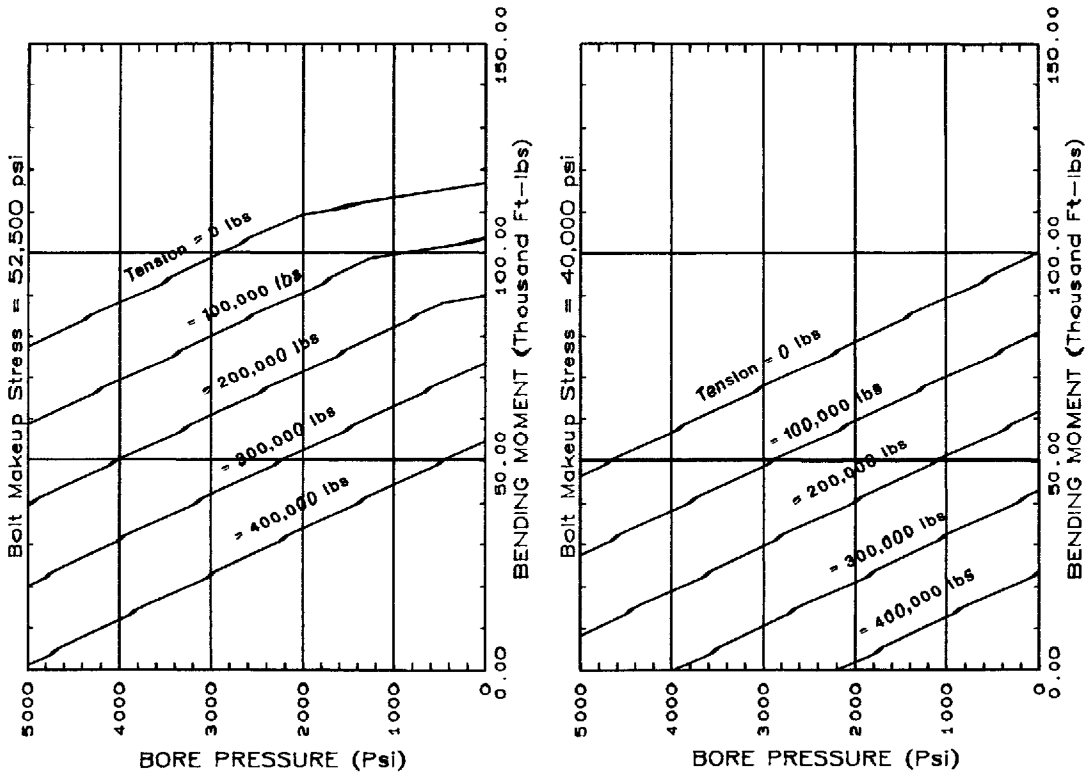
5-1/8"-2000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



5-1/8"-3,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



5-1/8"--5,000 PSI API 6B-FLANGE
BORE PRESSURE vs BENDING MOMENT WITH TENSION



APPENDIX F—13$\frac{5}{8}$ – 20,000 PSI FLANGE

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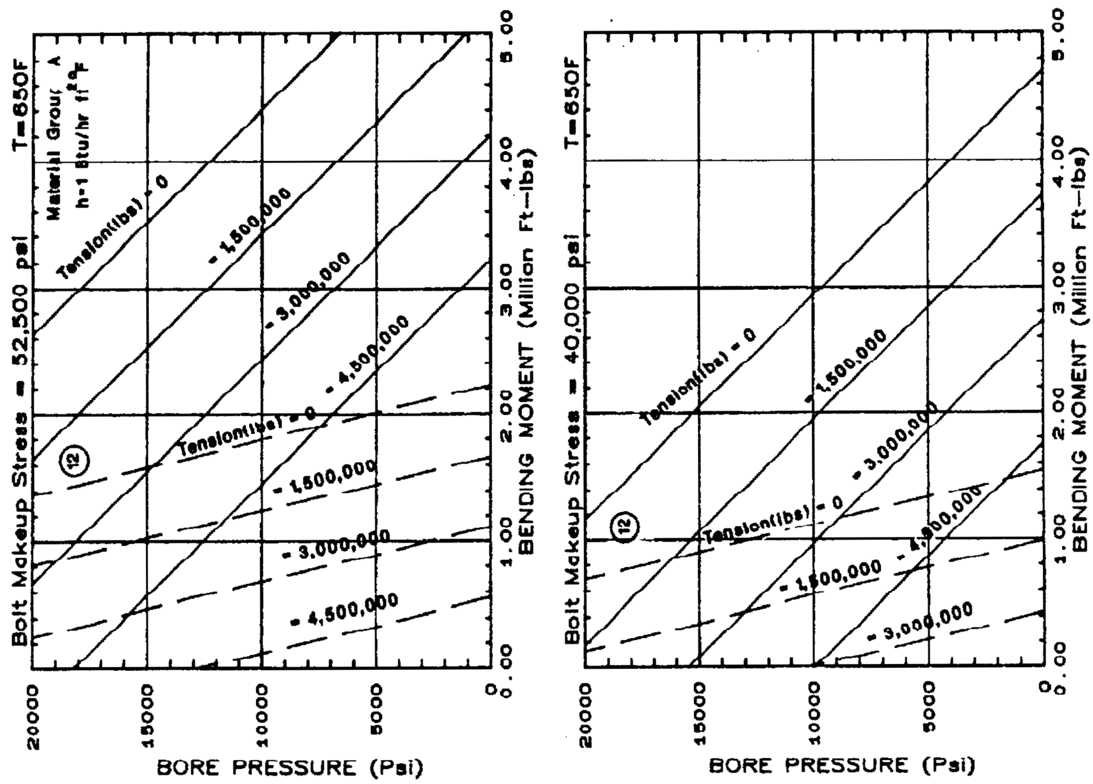
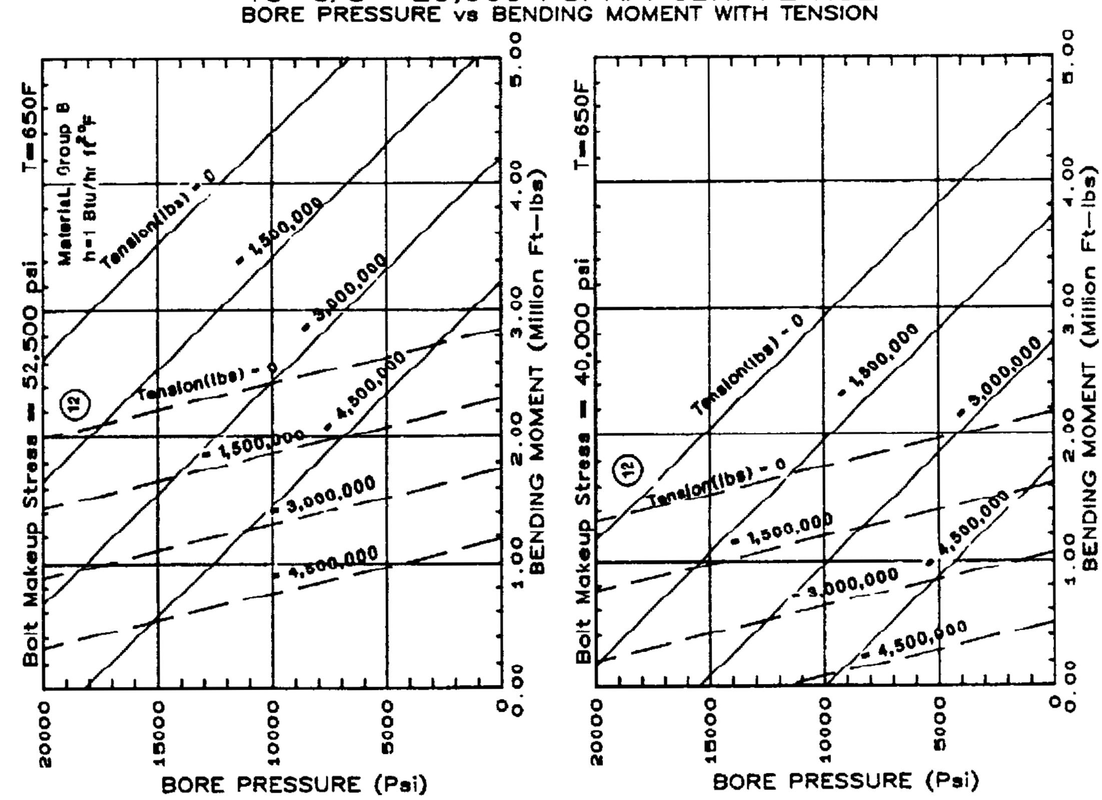
13-5/8"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



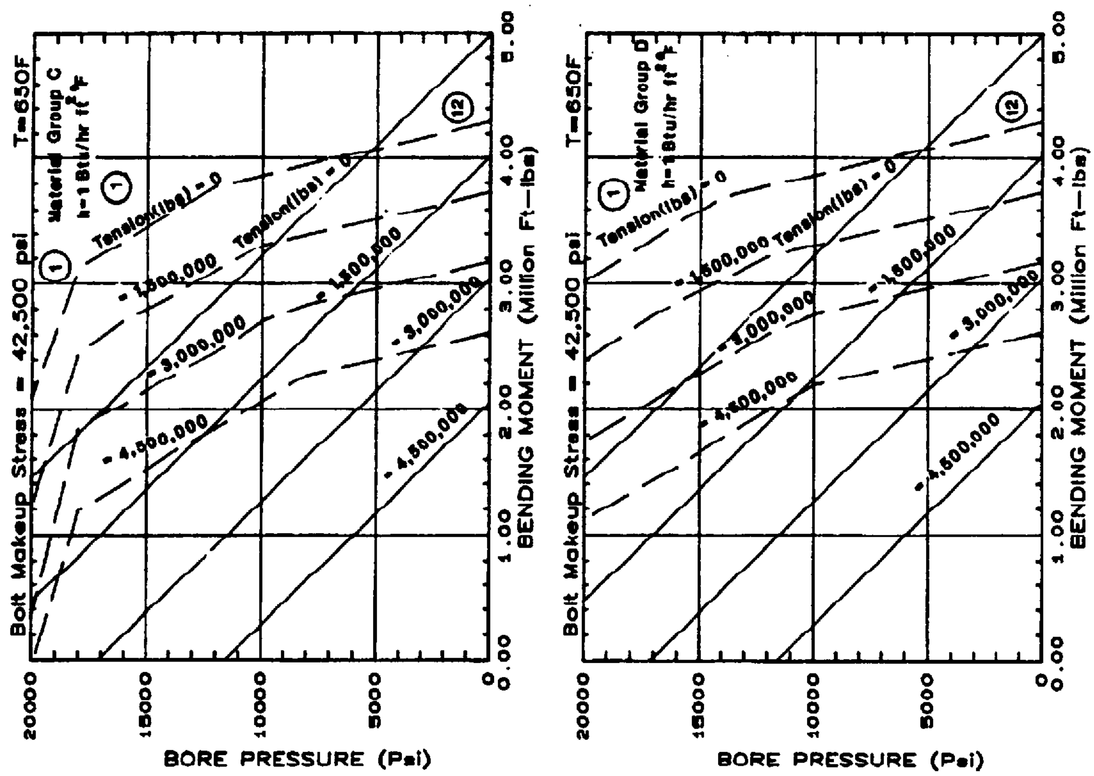
13-5/8"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



13-5/8"-20,000 PSI API 6BX-FLANGE

BORE PRESSURE vs BENDING MOMENT WITH TENSION



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