Technical Report on Capabilities of API Flanges Under Combinations of Load

API 6AF
SECOND EDITION, SEPTEMBER 1, 1995
(FORMERLY BULLETIN 6AF)

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

Technical Report on Capabilities of API Flanges Under Combinations of Load

Exploration and Production Department

API 6AF
SECOND EDITION, SEPTEMBER 1, 1995
(FORMERLY BULLETIN 6AF)

American
Petroleum
Institute

SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API publications are reviewed and revised, reaffirmed, or withdrawn at least every 5 years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect 5 years after its publication date as an operative API publication or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Authoring Department [telephone (214) 953-1101]. A catalog of API publications and materials is published annually and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

This document was produced solely for the purpose of disseminating technical information, and is not an API *standard*. Questions concerning the interpretation of the content of this document or comments and questions concerning the procedures under which this document was developed should be directed in writing to the director of the Exploration and Production Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

API technical reports may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

API technical reports are published to facilitate the broad availability of the information contained therein. These documents are not intended to obviate the need for applying sound engineering judgment regarding when and where this information should be utilized. The formulation and publication of API technical reports is not intended in any way to inhibit anyone from using any other data, information, or practices.

CONTENTS

FOREWORD

This technical report is under the jurisdiction of the API Subcommittee on Valves and Wellhead Equipment. The report was first issued as API Bulletin 6AF, First Edition, April 1, 1989, and was reaffirmed and reissued in 1995 as a technical report designated API 6AF.

This document was produced solely for the purpose of disseminating technical information and is not an API standard. API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted in writing to the director of the Exploration and Production Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

This documents shall become effective on the date printed on the cover but may be used voluntarily form the date of distribution.

Technical Report on Capabilities of API Flanges Under Combinations of Load

1 Introduction and Scope

This technical report presents the results of analysis work done in PRAC 86-21 to establish the load capacity of all flanges given in the April 1986 Editions of API 6A and 6AB. A total of 69 different geometries were analyzed. The various loads considered were:

- Bolt makeup (preload).
- Internal pressure.
- Tension.
- Bending moment.

All 69 flanges were analyzed with an axisymmetric finite element model for each of the four load cases. A post-processor program was written to calculate the maximum moment capacity for various levels of pressure and tension, based on linear superposition of results. Three different criteria were used to establish the maximum moment:

1. ASME Section VIII, Division 2 allowable stress categories for the flange with the basic membrane stress allowable established by API.
2. Allowable bolt stresses as established by API.
3. Loss of preload on the ring joint. The results of this post-processing are presented in plots of pressure vs. allowable moment for various tension levels in Section 4.

There are several limitations to this work which should be understood. First, the effects of transverse shear or torsion were not considered in the analysis. Second, the results are for static loading only. No dynamic, fatigue, or fretting phenomena were considered in these results. Third, no thermal stresses or elevated temperature effects were considered for this Bulletin. 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 general guidelines for design.

2 References

This technical report references the following documents:

"Capabilities of API Flanges Under Combination of Loading PRAC 86-21," by K.C. Walker and Joe R. Fowler, Stress Engineering Services, Inc., report prepared for API, October 1987.

Spec 6A *Specification for Wellhead and Christmas Tree Equipment*, Fifteenth Edition, April 1, 1986.

As a convenience for reference, Table 1 of this technical report presents requirements for body, bonnet, and flange physical properties and material types from API Specification 6A, Fifteenth Edition.

3 Instructions for Using Rating Charts

3.1 DESCRIPTION OF RATING CHARTS

3.1.1 The plotted results for the combined load capacity of each flange analyzed in this project are given in Section 4. The results are arranged in the same order as found in API 6A. 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 in. 2,000 psi 6B flange is before the 2 1/16 in. 3,000 psi 6B flange; and the 11 in. 5,000 psi 6B flange is before the 26 3/4 in. 2,000 psi 6BX flange.) 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.

3.1.2 The combined load rating for all flanges was plotted even if the stress criteria were exceeded for makeup and/or hydrostatic test pressure load cases. There were only four flanges that did not meet these criteria (Table 2). These flanges all failed to meet the criterion for an extreme fiber (membrane plus bending) stress at a section in the hub immediately behind the back of the flange for a bolt makeup of 52.5 ksi. Until these overstressed flanges are modified, it is recommended that the user consider derating the flanges to an appropriate level.

3.2 USE OF RATING CHARTS

3.2.1 An explanation of the proper use of the plotted results in Section 4 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 for the 3 1/16 in. 10,000 psi 6BX flange for reference in the discussion below.

3.2.2 The plotted results given in Section 4 show limiting load combinations of makeup, pressure, tension, and moment. The results are based on the stress criterion or leak criterion that controls at each load combination. As a result, some curves have a "knee" in them when the controlling criterion changes from a stress limitation to a leak limitation. This can be seen in Figure 1.

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

3.2.3.1 Establish magnitude of each load condition:

a. Bolt makeup stress (52.5 ksi or 40 ksi).
b. Pressure (psi).
c. Tension (lb).
d. Moment (ft-lb).

Note: 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.

3.2.3.2 Determine Flange Load Capacity

a. Pick the appropriate rating chart based on makeup desired.
b. Enter the rating chart from left side with pressure.
c. Move to right to find required moment.
d. Intersection is point that defines maximum tension rating.
e. Interpolate between lines to get maximum tension rating.

3.2.3.3 Evaluation

a. If the maximum tension rating is greater than the required tension, the flange is satisfactory for the intended use based on the axisymmetric analyses.
b. If the maximum 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.

3.2.4 Example No. 1

Using the $3^{1}/_{16}$ in. 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.
c. Tension = 0 lb.
d. Moment = 5,000 kip-ft.

Reading from Figure 2, the maximum tension rating for this pressure/moment combination is:

Maximum tension rating = 61,000 lb

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

3.2.5 Example No. 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.

Reading from Figure 2, the maximum tension rating for this pressure/moment combination is:

Maximum tension rating = 15,000 lb

Since the required tension is 80,000 lb, the flange is not adequate for this application. Possible lower combinations are:

a. Reduced Tension:

Pressure = 8,000 psi.
Tension = 15,000 lb.
Moment = 15,000 ft-lb.

b. Reduced Moment:

Pressure = 8,000 psi.
Tension = 80,000 lb.
Moment = 7,500 ft-lb.

c. Reduced Pressure:

Pressure = 1,800 psi.
Tension = 80,000 lb.
Moment = 15,000 ft-lb.

3.3 DISCUSSION OF RESULTS WITH BOLT MAKEUP STRESS = 40,000 PSI

Ten of the 10,000 and 15,000 API 6BX do not have the capacity of rated pressure with a bolt makeup stress of 40,000 psi. This applies when bolts with a yield strength of 80 ski are used.

Table XC1 of API Spec 6A, Fifteenth Edition, indicates that these bolts are only applicable to 5,000 psi flanges less than $13^{5}/_{8}$ in. diameter, 10,000 psi flanges less than $4^{1}/_{16}$ in. diameter, and to 15,000 psi flanges less than $2^{1}/_{16}$ in. diameter. The results of Section 4 show that this caution is warranted yet slightly conservative, since several of the flanges in question do have adequate pressure capacity with 80 ksi bolting.

4 Rating Charts

Refer to Pages 6–76.

Table 1—API Physical Properties and Material Types (See Note)

API Material Property Requirements Bodies, Bonnets, and Flanges (PSL 1–4)

(1)	(2)	(3)	(4)	(5)
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	22	No requirement
45K	45,000	70,000	19	32
60K	60,000	85,000	18	35
75K	75,000	95,000	18	35

API Material Applications for Bodies, Bonnets, and Flanges (PSL 1–4)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pressure Ratings (psi)						
	1,000	2,000	3,000	5,000	10,000	15,000	20,000
Part	API Material Designation						
Body,[a] bonnet	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							Use
Flanged	NA	60K	60K	60K	60K	75K	75K ← these.
Threaded	NA	60K	60K	60K	NA	NA	NA
Independent screwed wellhead equipment	36K, 45K, 60K, 75K	36K, 45K, 60K, 75K	NA	NA	NA	NA	NA
Loose flanges							
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

Note: From API Specification 6A, Fifteenth Edition, April 1, 1986, Tables V D1 and V D2.
[a]Provided end connections are of the API material designation indicated, welding is done in accordance with Section VI and design is performed in accordance with Section III.

Table 2—Flanges Not Meeting ASME Stress Allowables for Makeup Load Case (See Note)

(1)	(2)	(3)	(4)
		Stress Intensity (psi)	
Size	Location	FEA	Allowable
13⅝ in. 2,000 psi 6B	ID of hub	65,909	60,000
	OD of hub	61,846	60,000
16¾ in. 2,000 psi 6B	ID of hub	67,057	60,000
	OD of hub	65,032	60,000
21¼ in. 2,000 psi 6B	ID of hub	62,824	60,000
	OD of hub	60,994	60,000
13⅝ in. 3,000 psi 6B	ID of hub	65,373	60,000
	OD of hub	60,066	60,000

Note: Bolt makeup stress = 52.5 ksi.

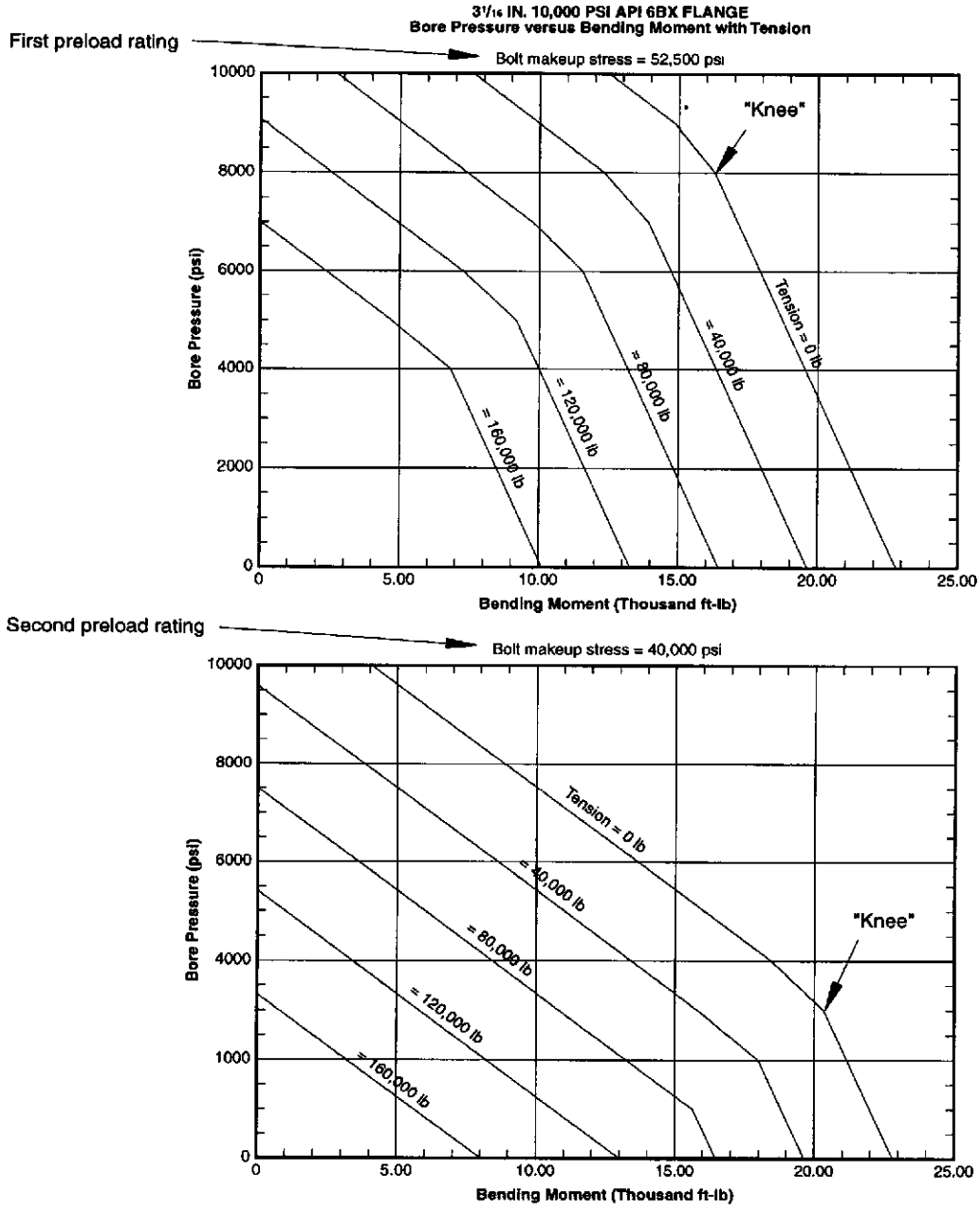


Figure 1—Typical Combined Load Capacity Results

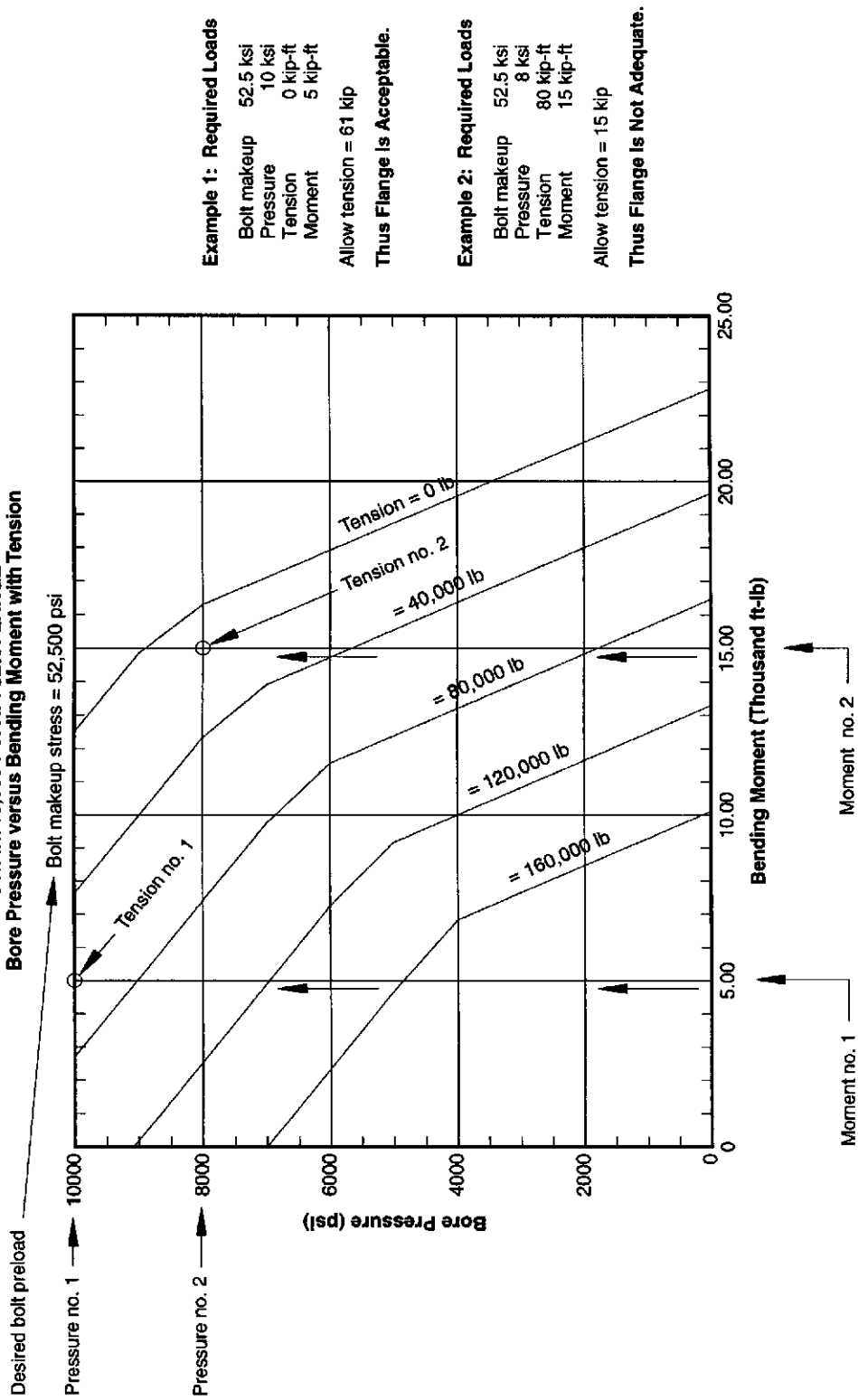
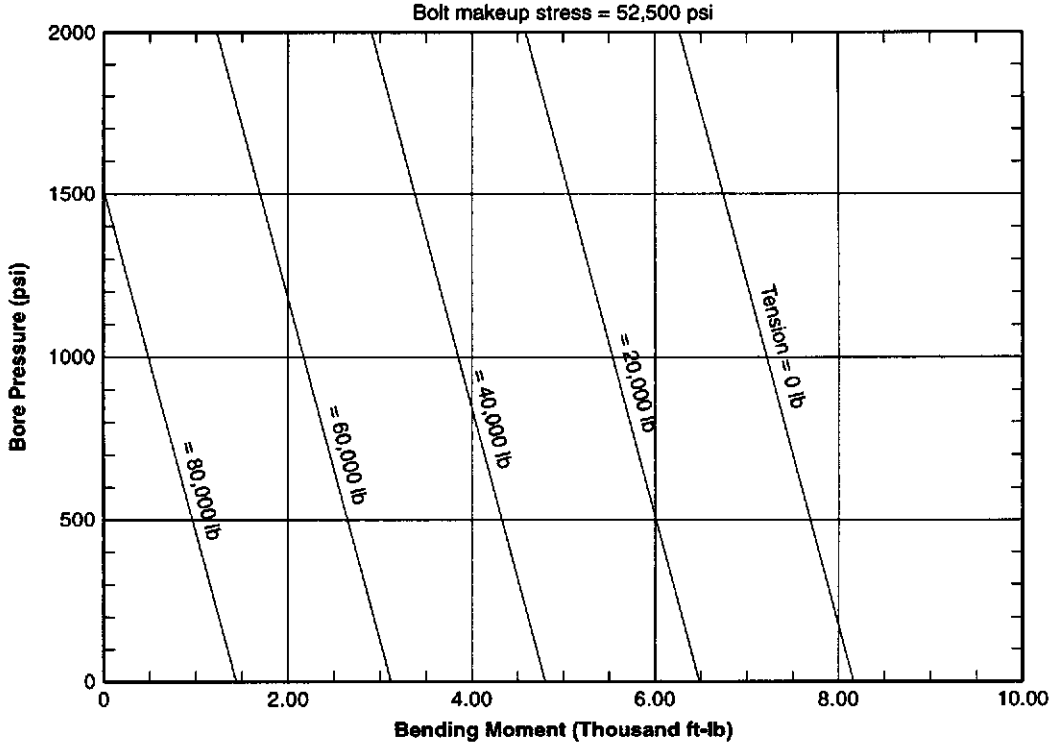


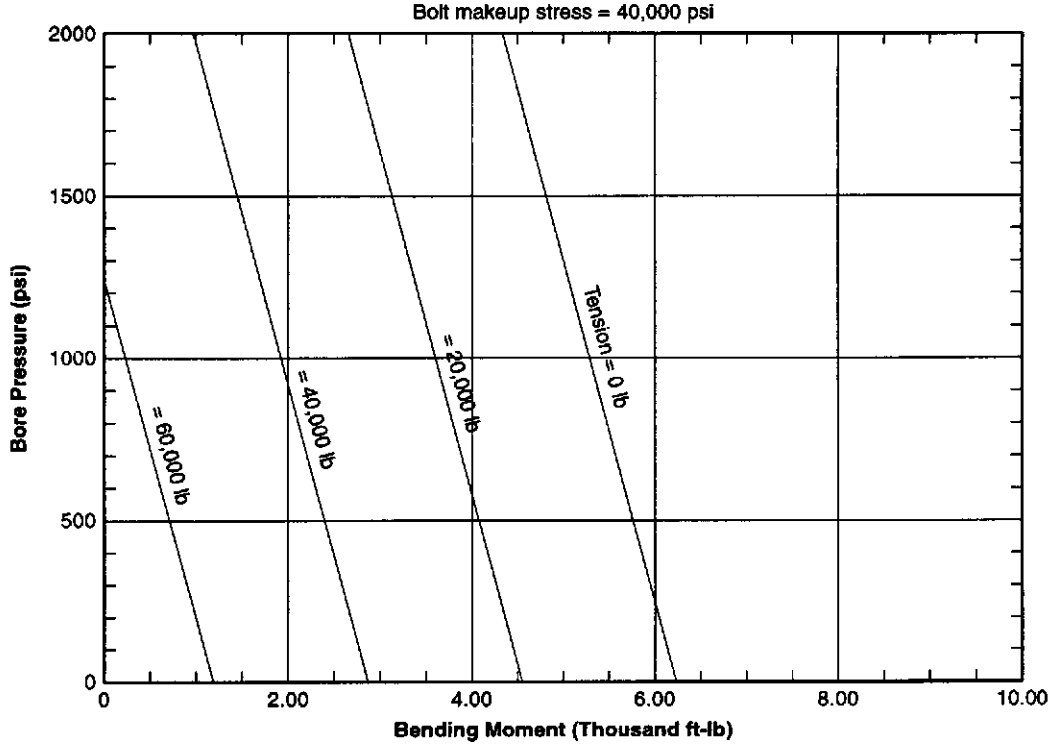
Figure 2—Load Capacity Results To Use with Example Problems

2 1/16 IN. 2,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

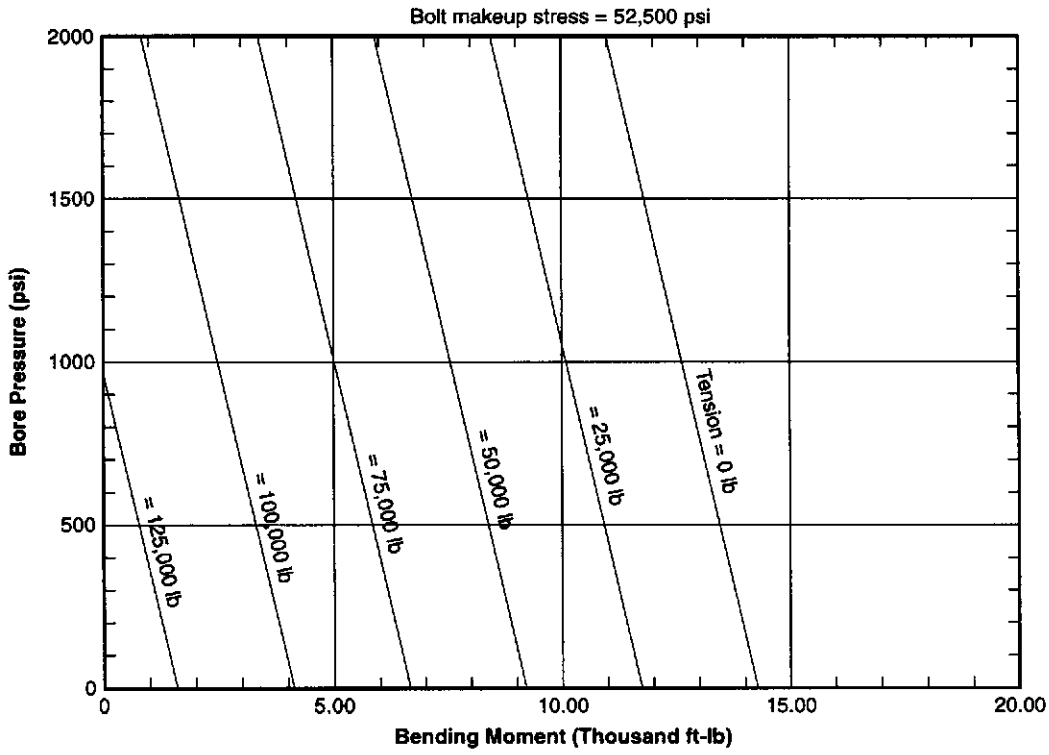
Bolt makeup stress = 52,500 psi

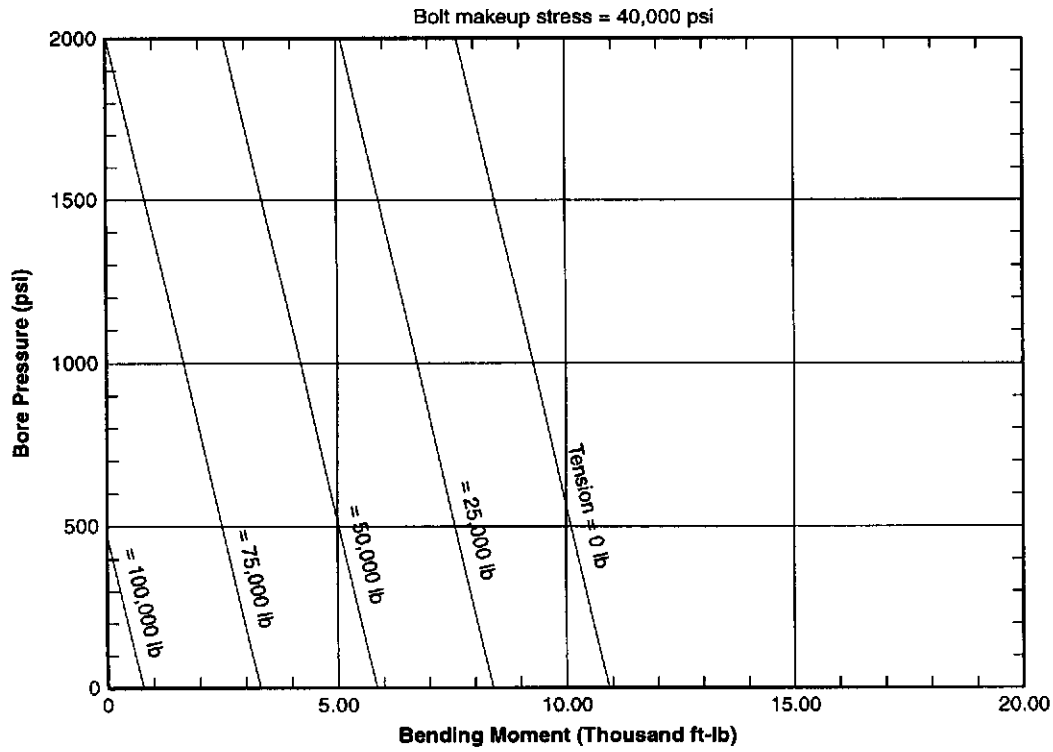


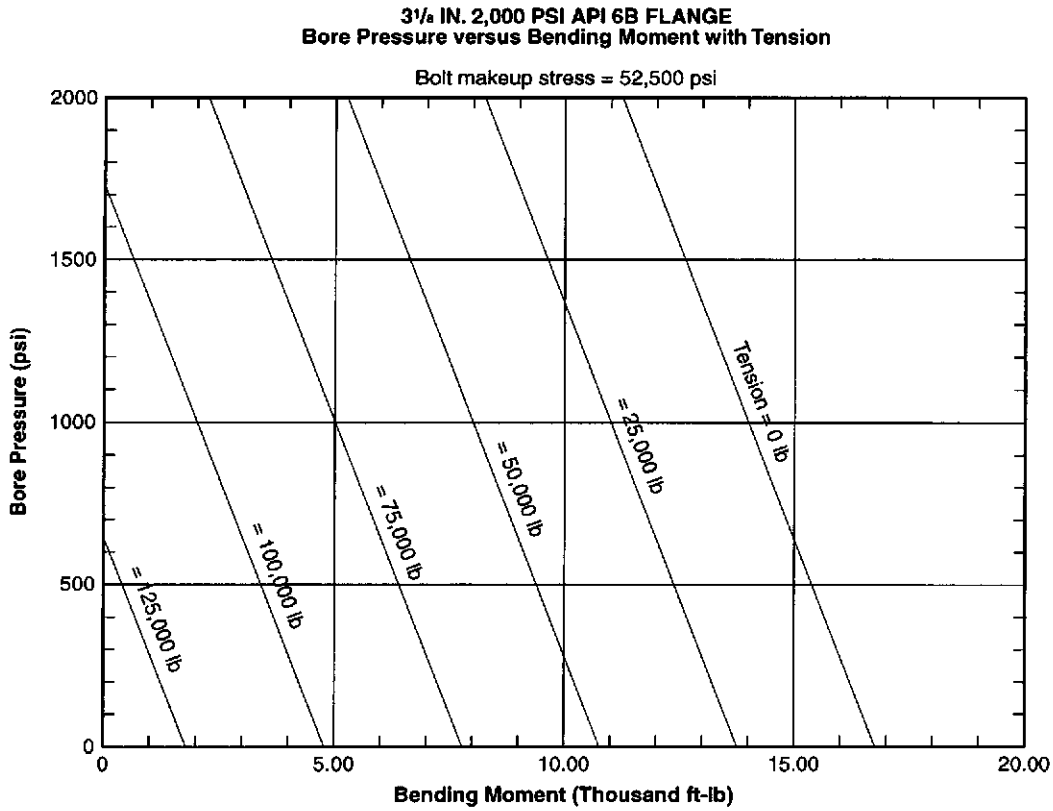
Bolt makeup stress = 40,000 psi

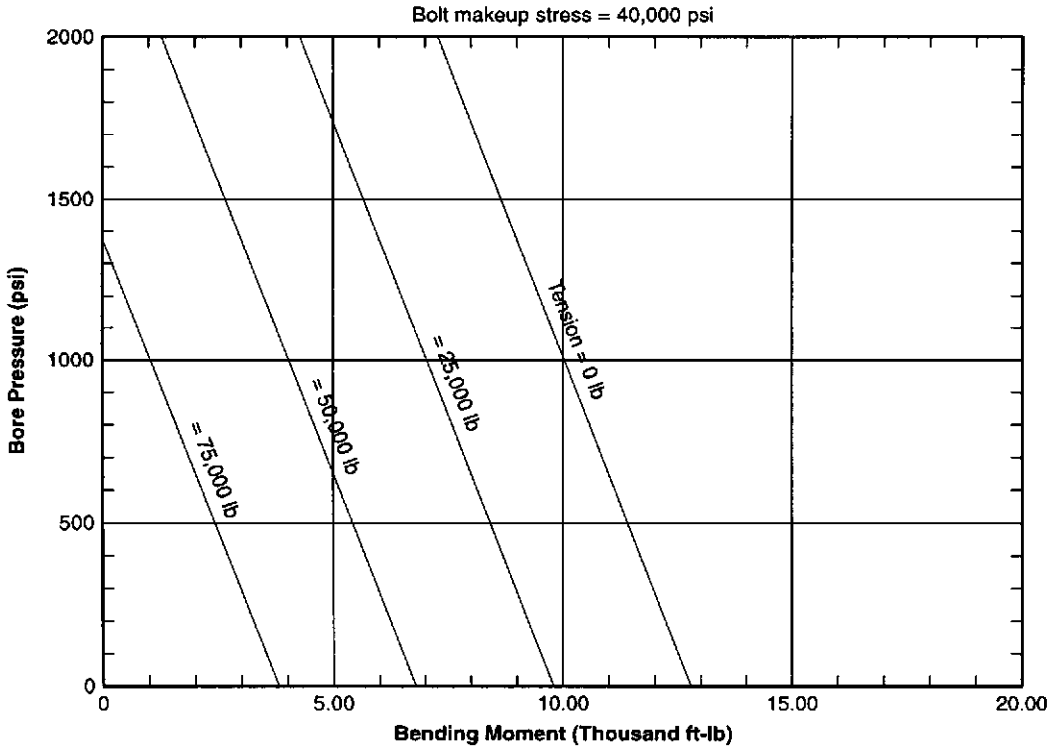


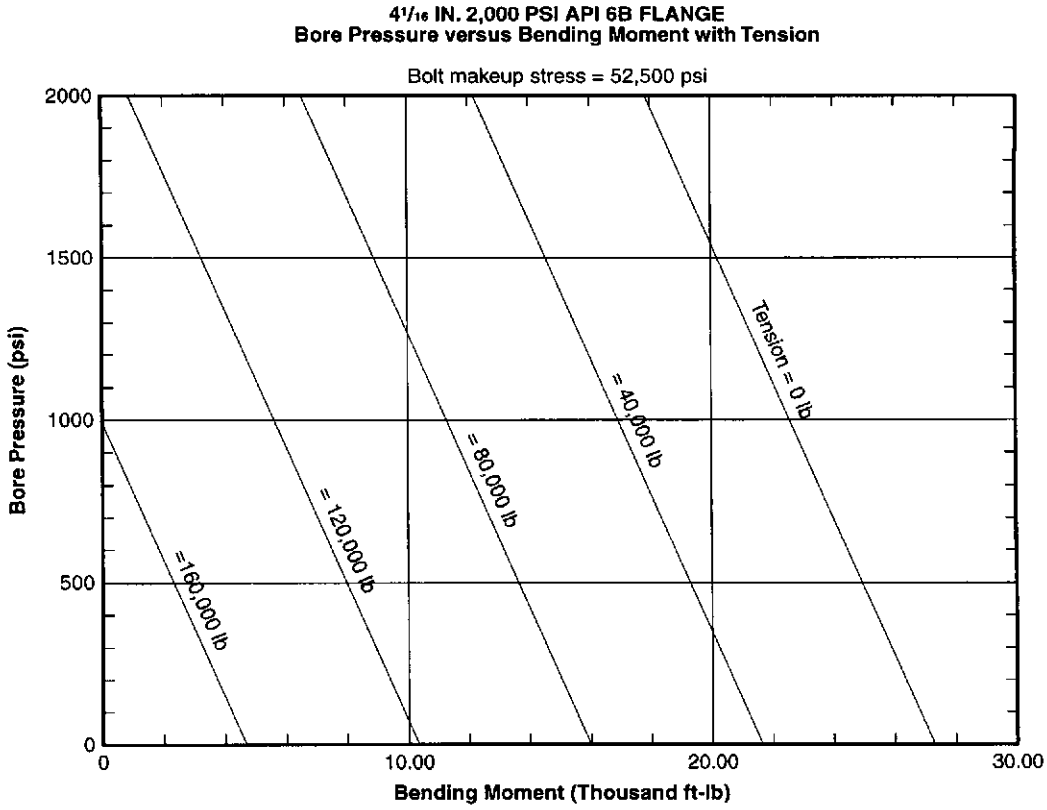
2 9/16 IN. 2,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

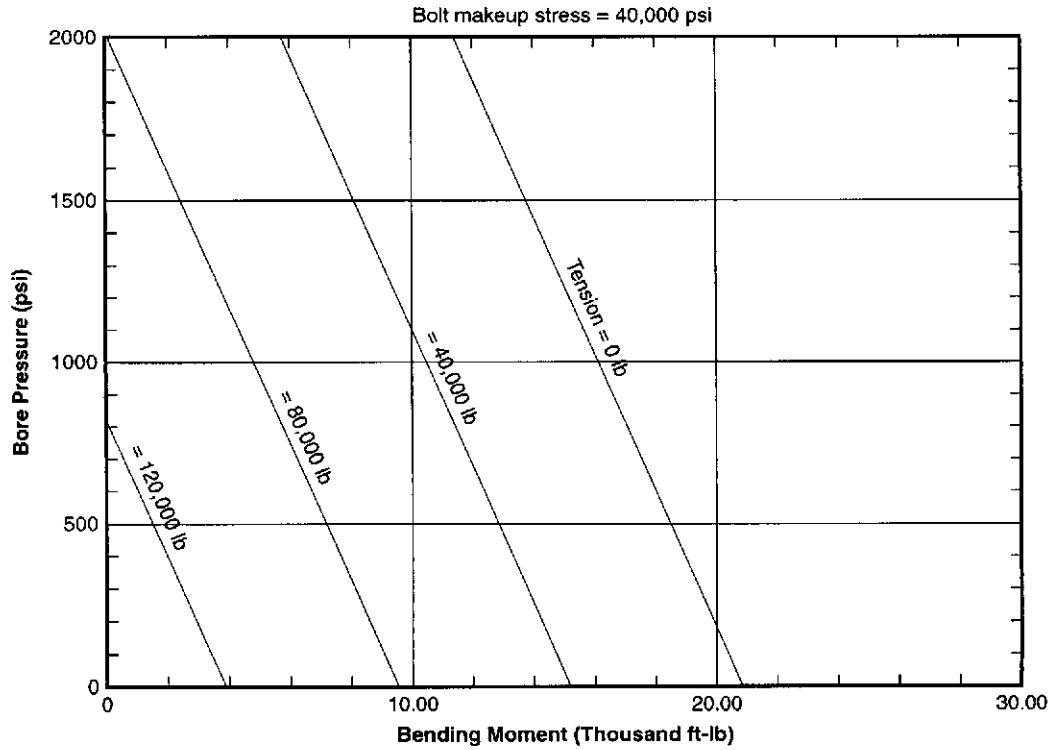




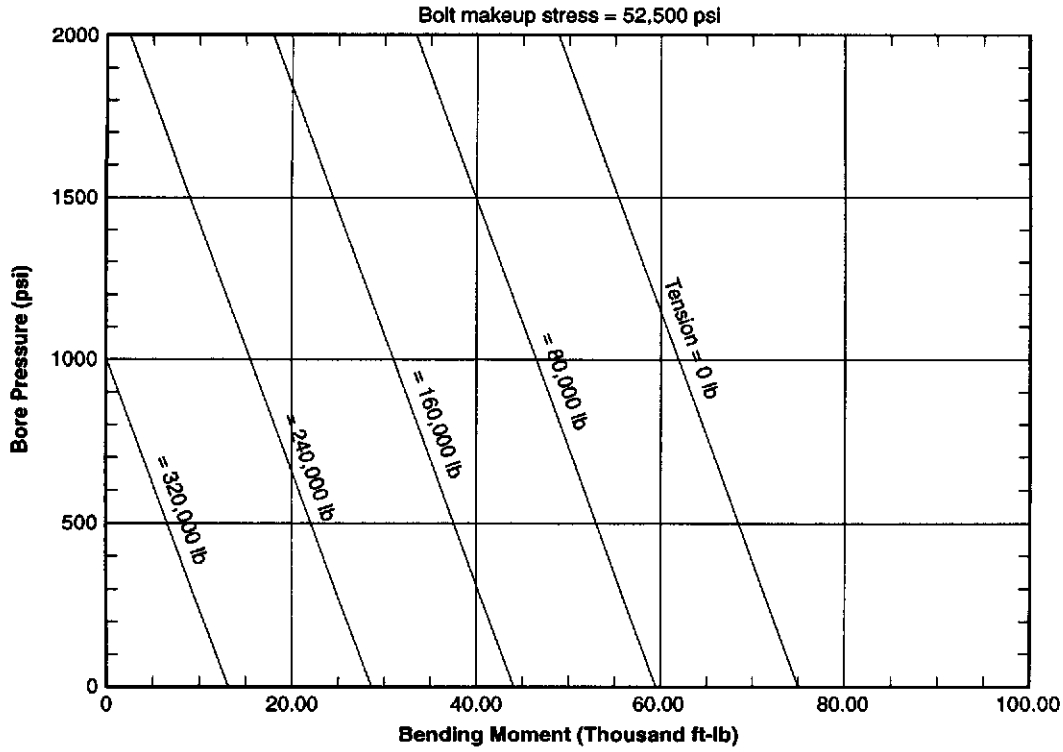


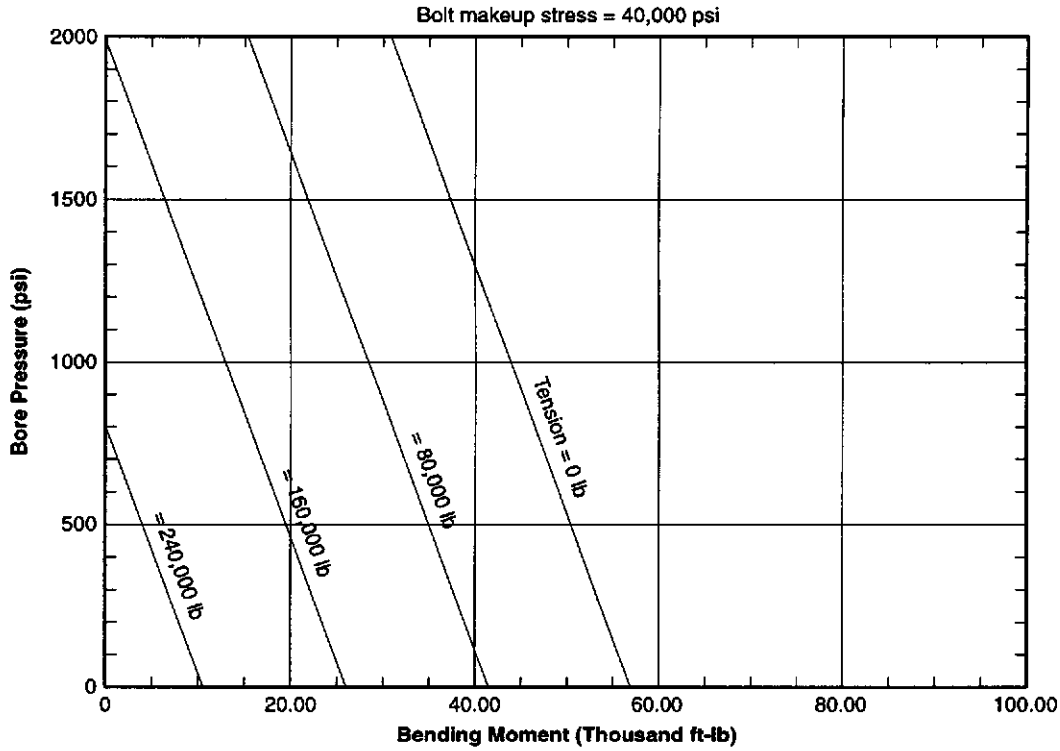




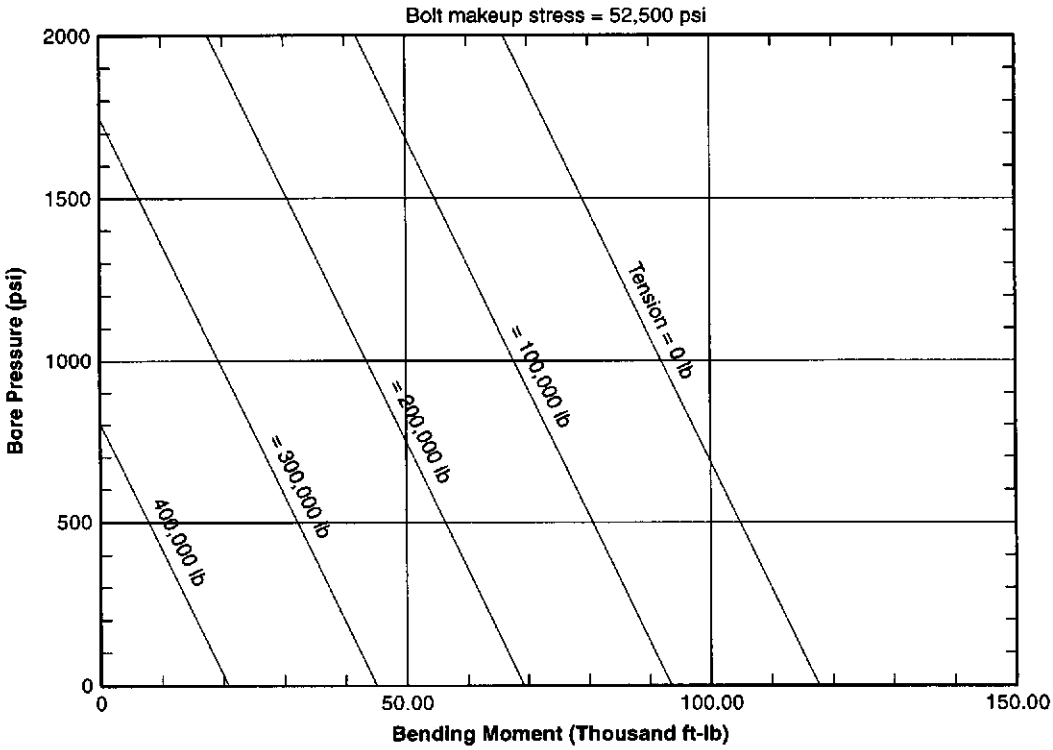


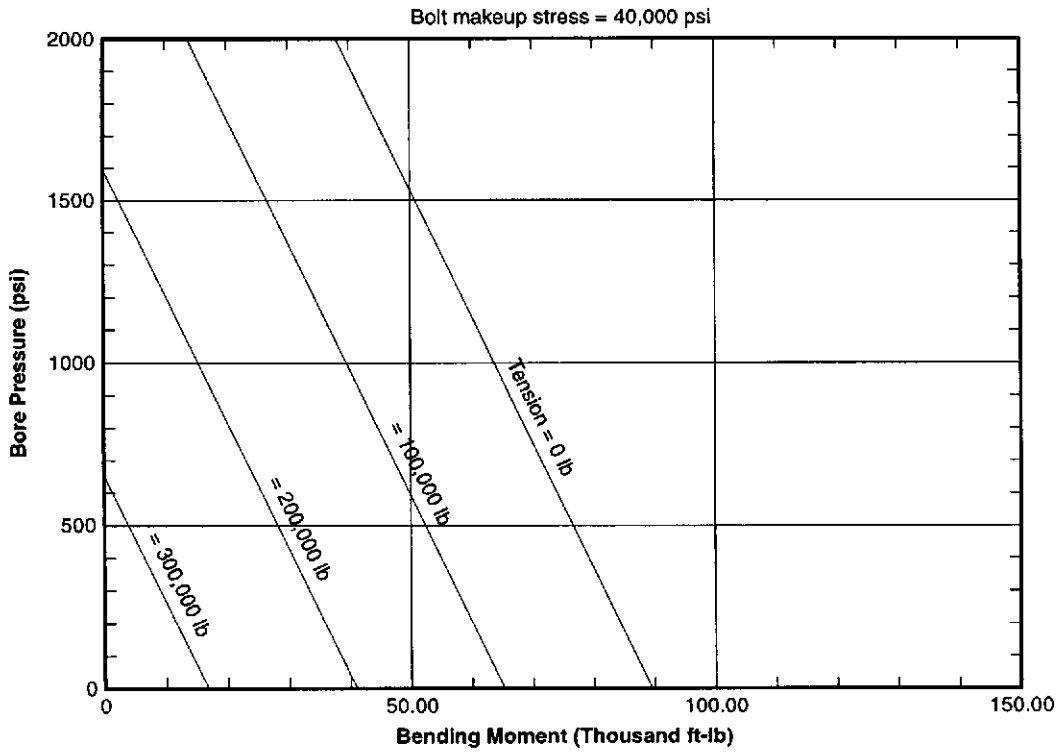
7 1/16 IN. 2,000 PSI API 6B FLANGE
Bore Presssure versus Bending Moment with Tension



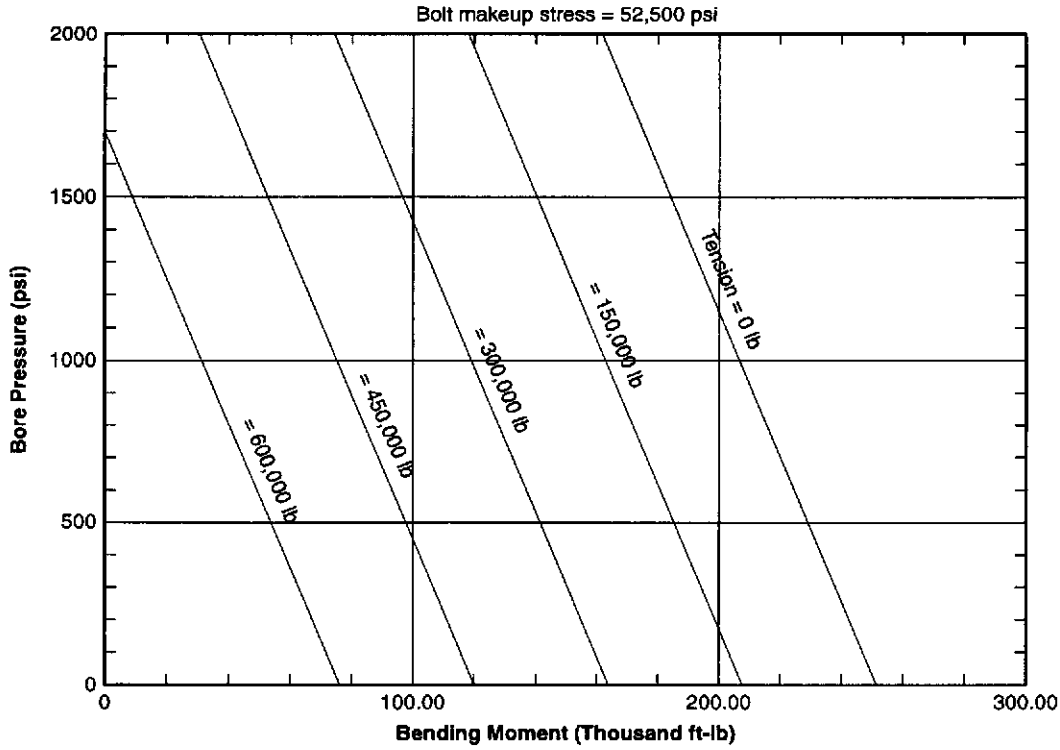


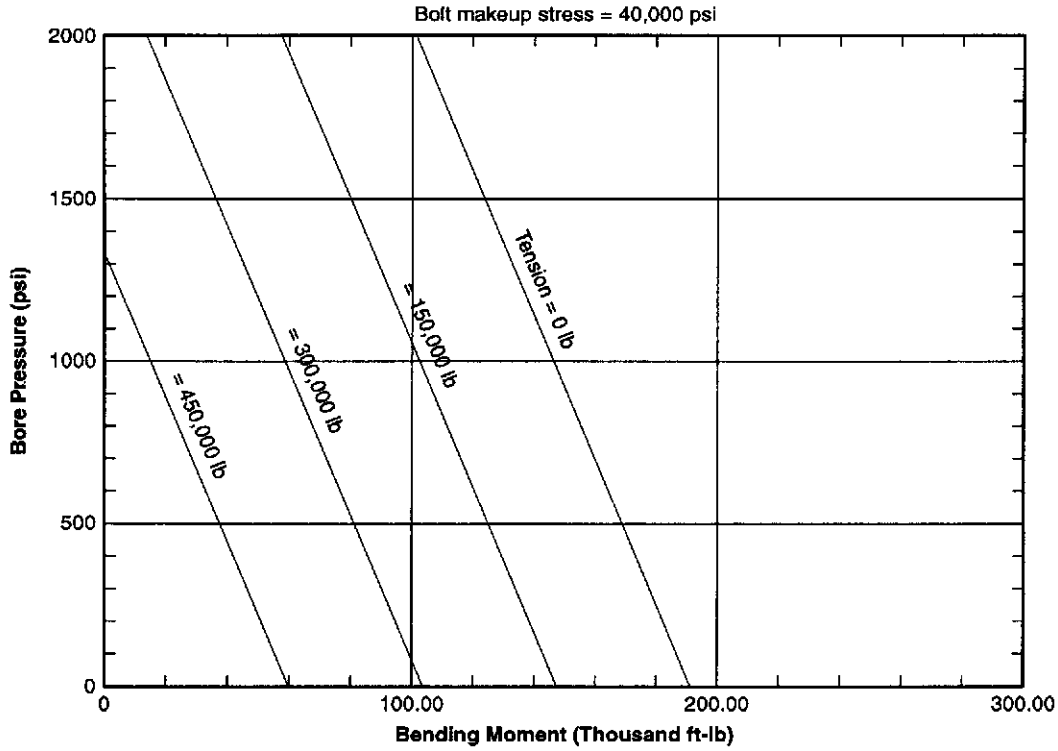
9 IN. 2,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

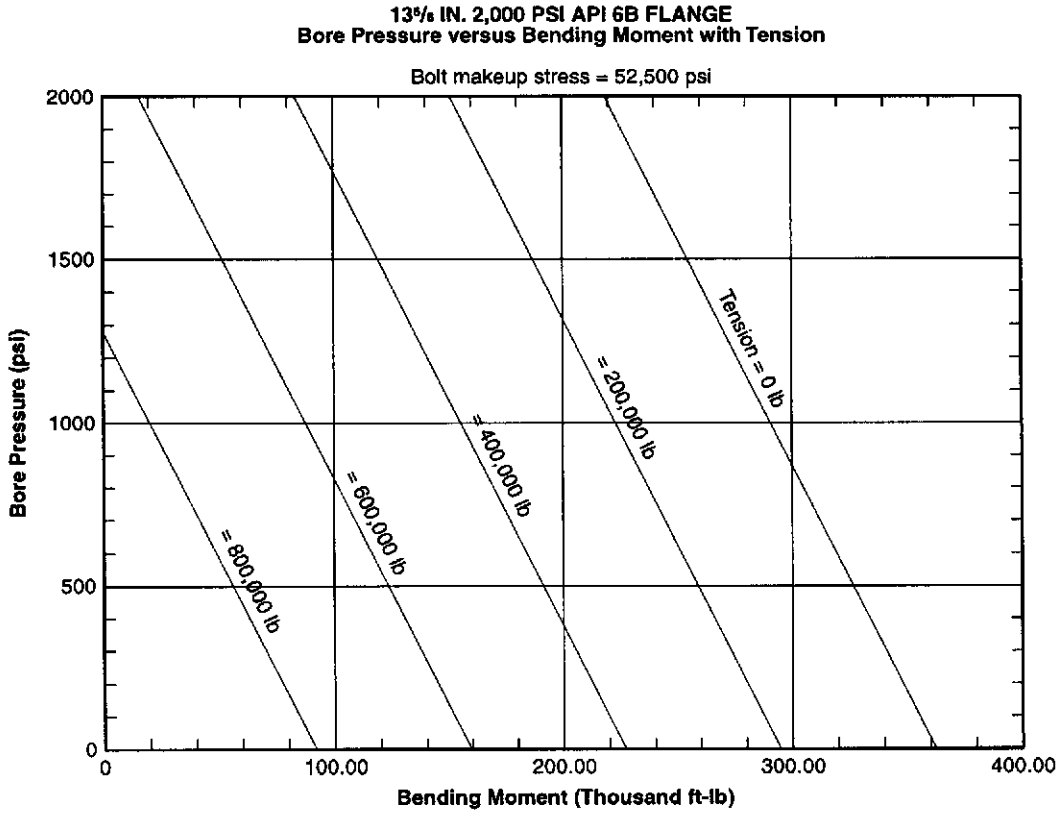


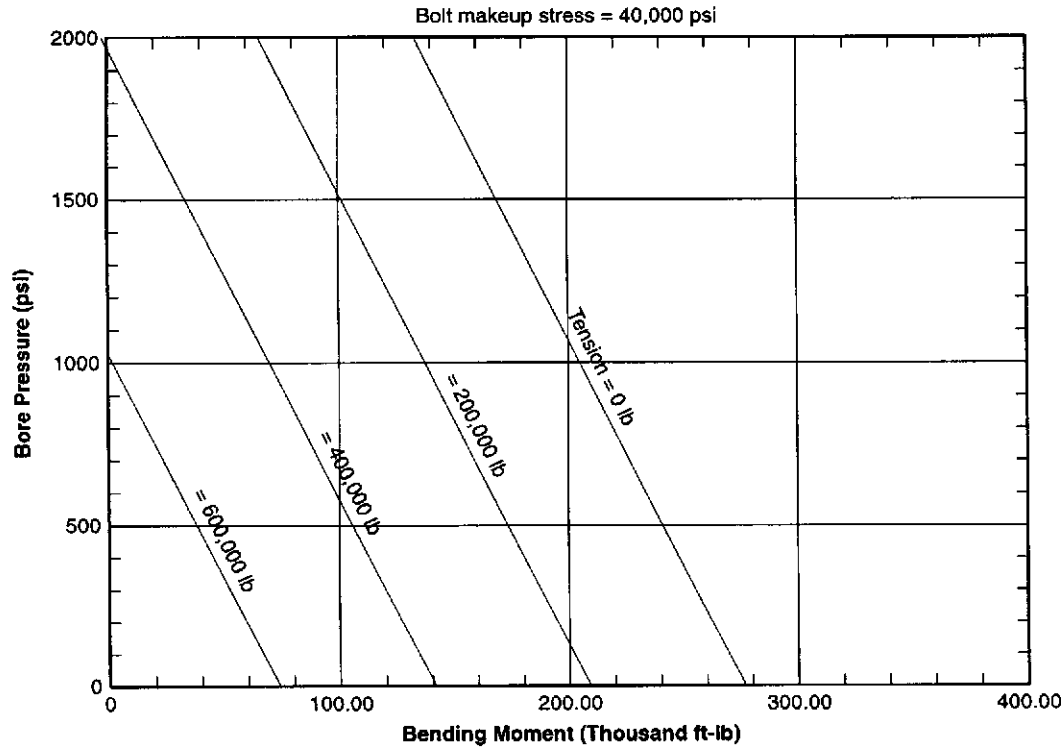


11 IN. 2,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

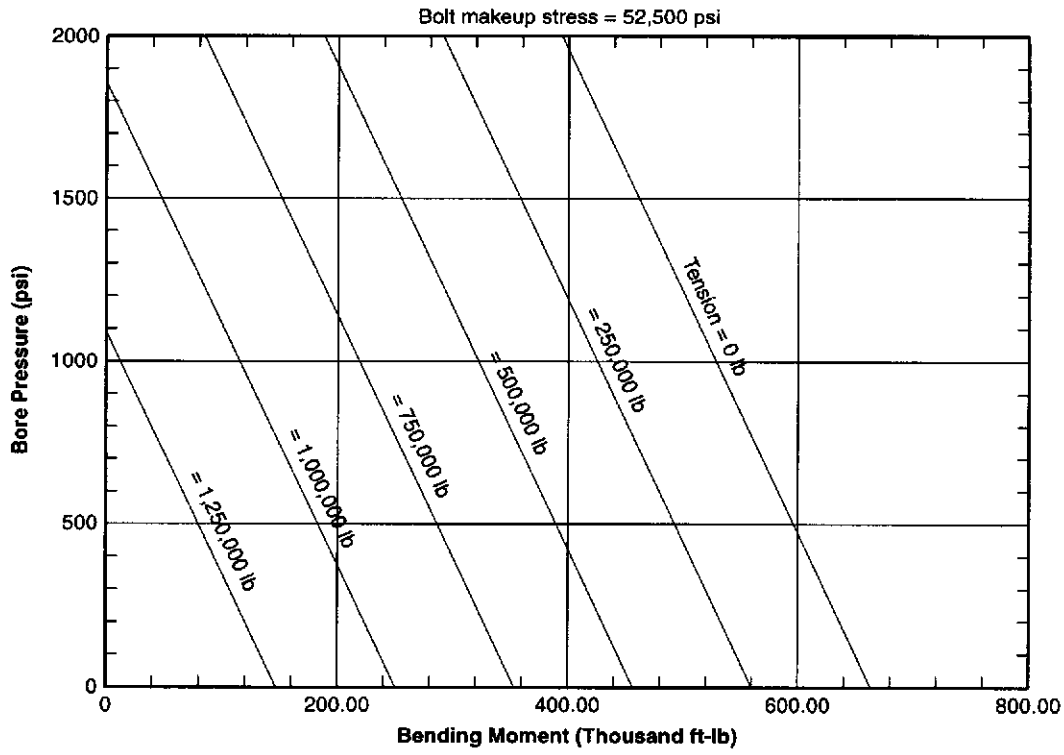


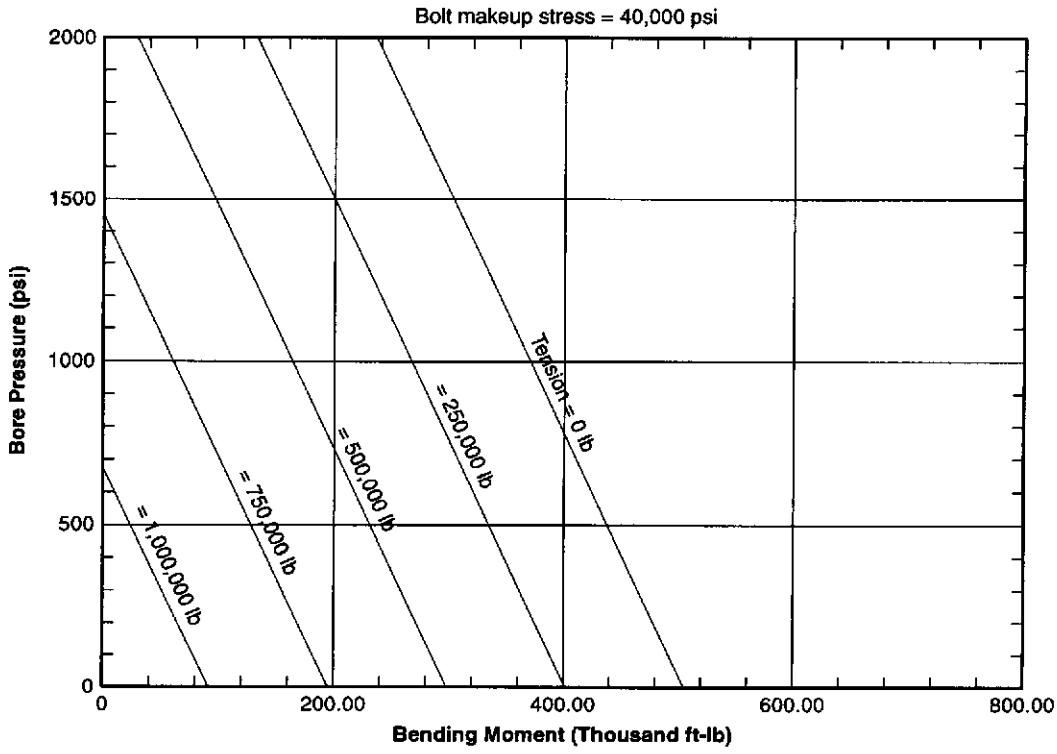


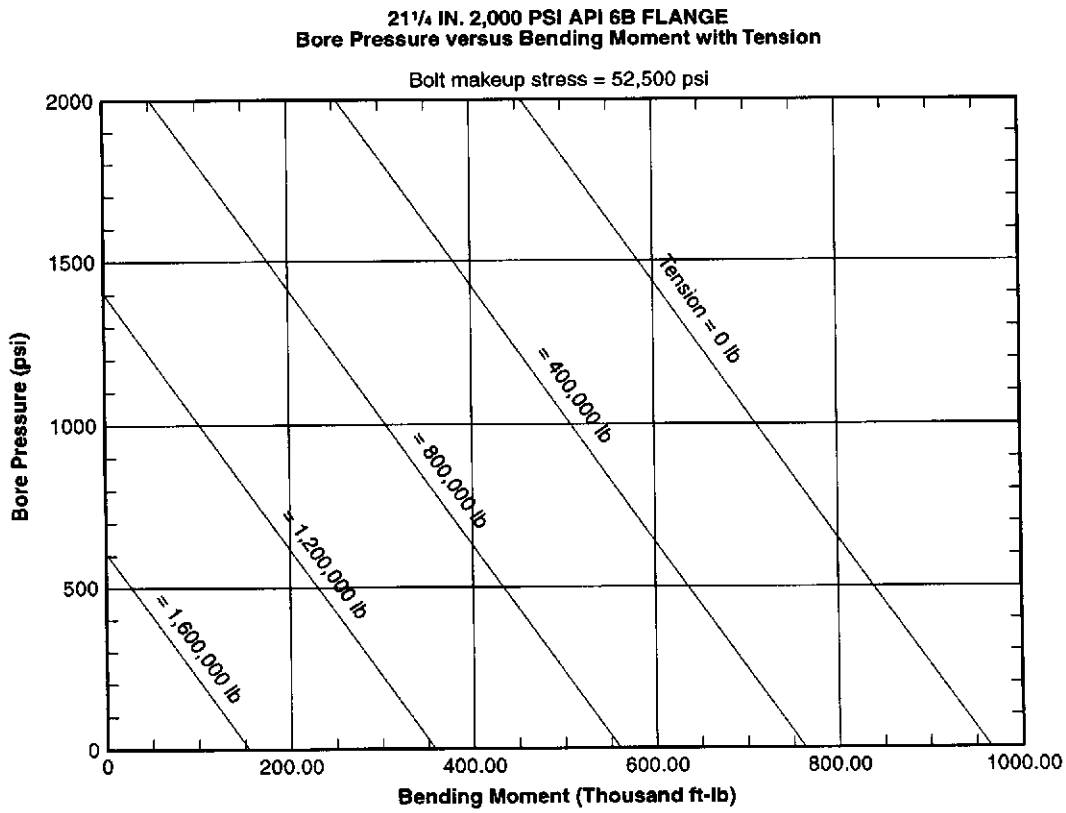


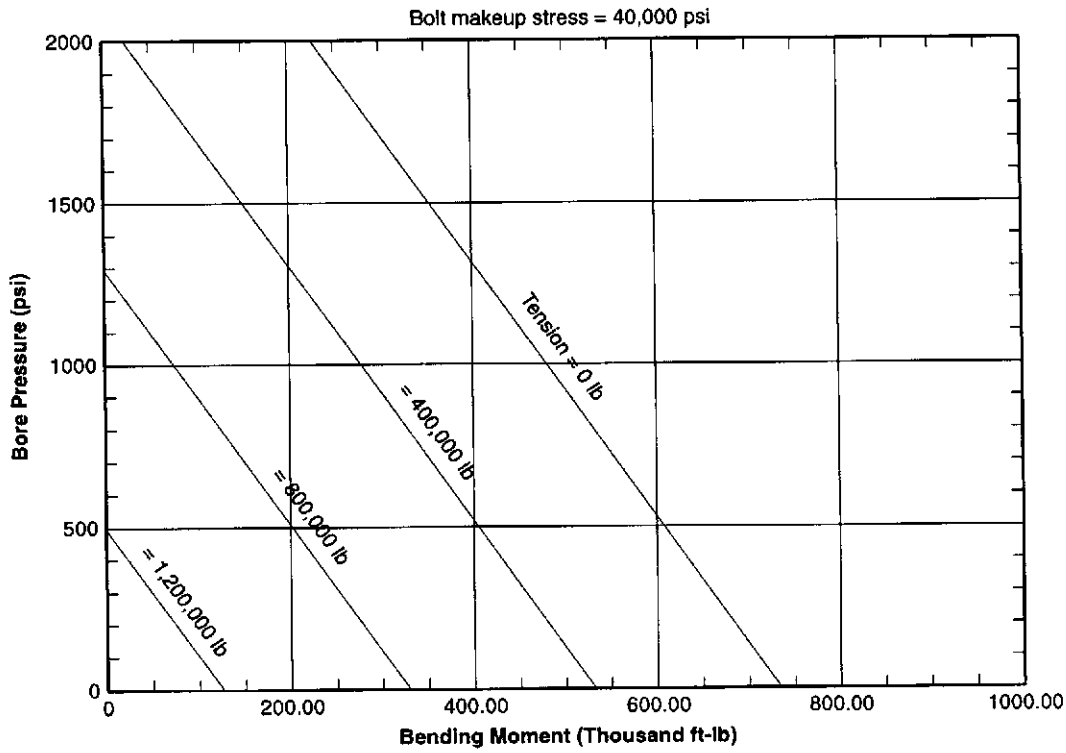


16¾ IN. 2,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

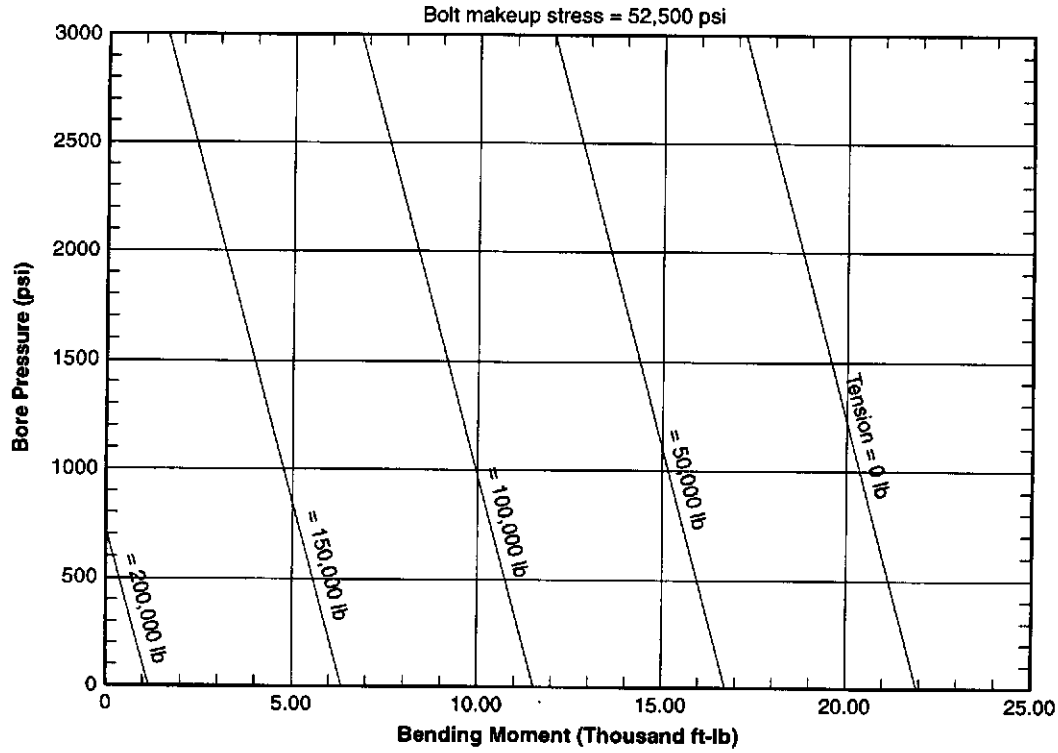


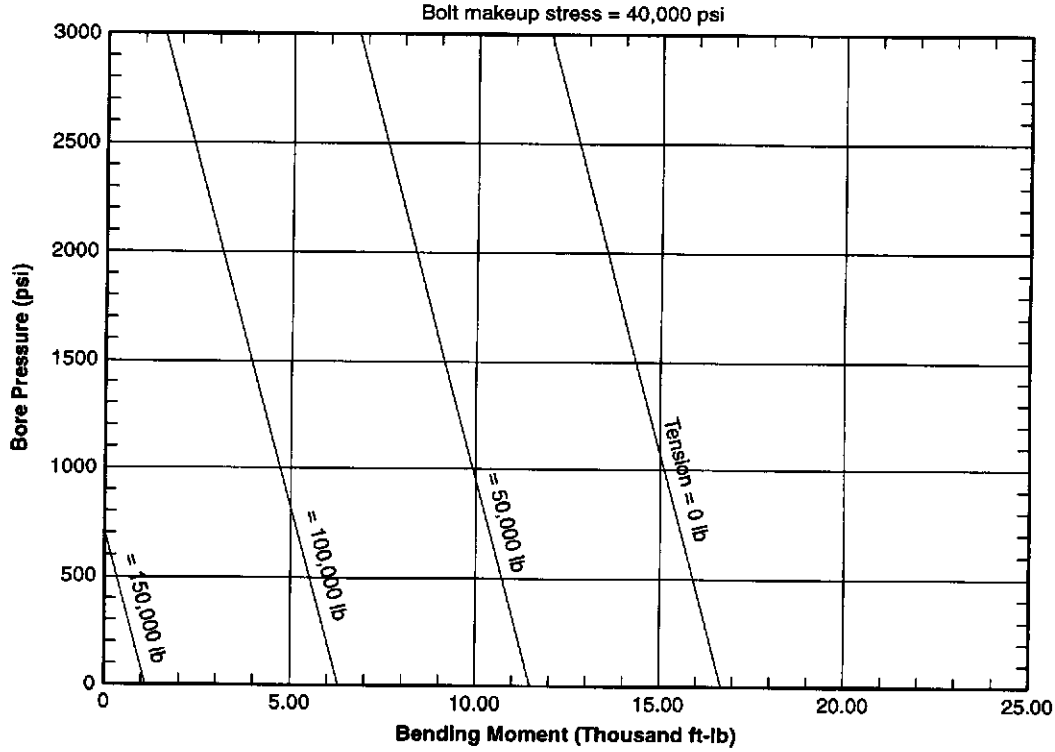




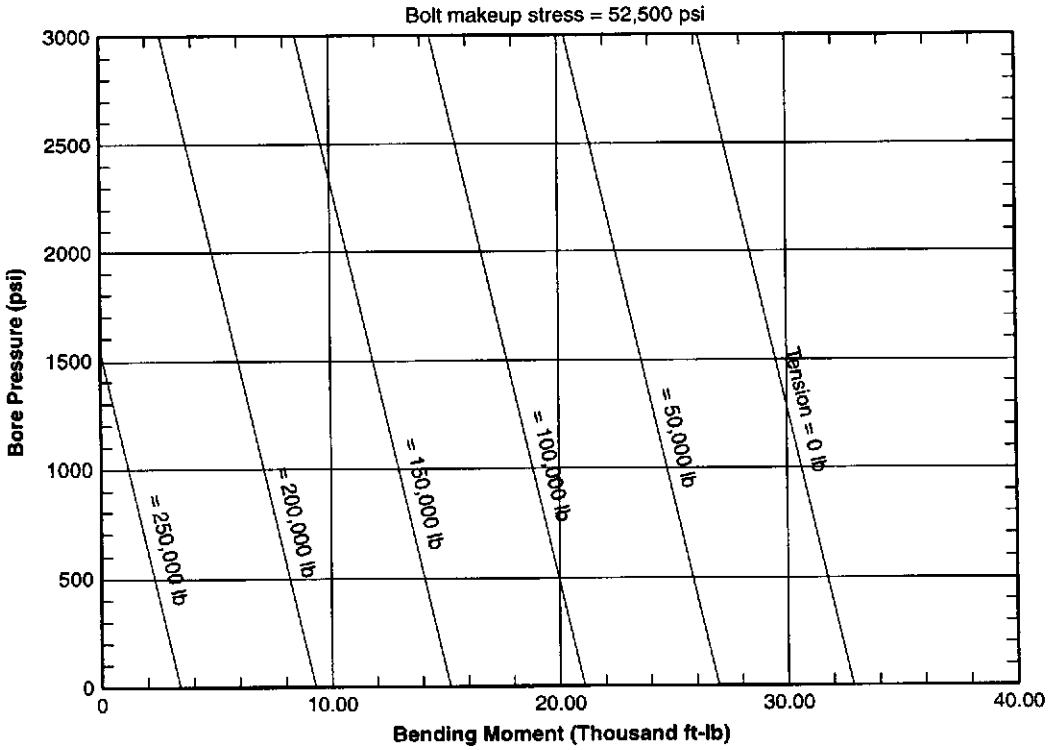


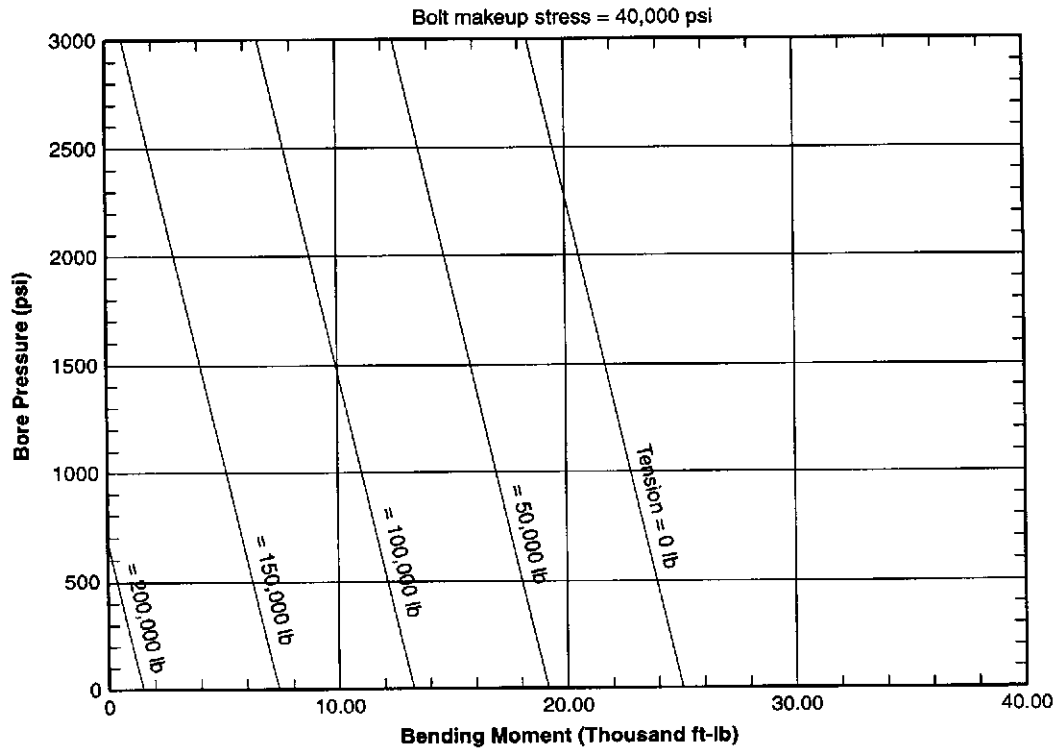
2 1/16 IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension



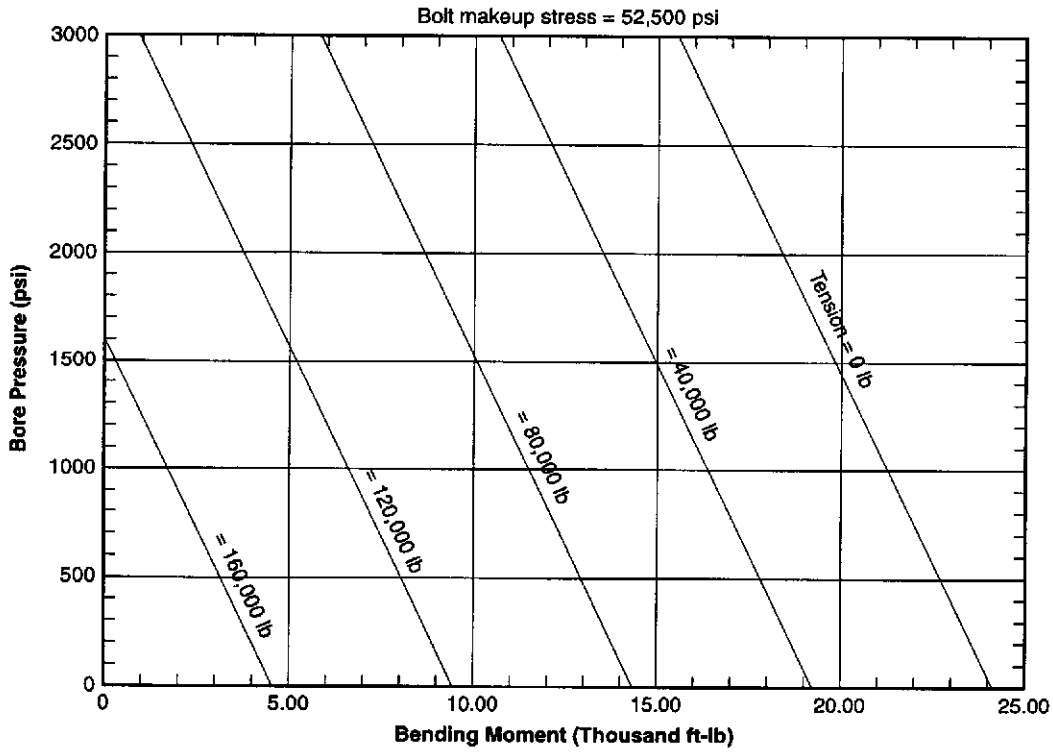


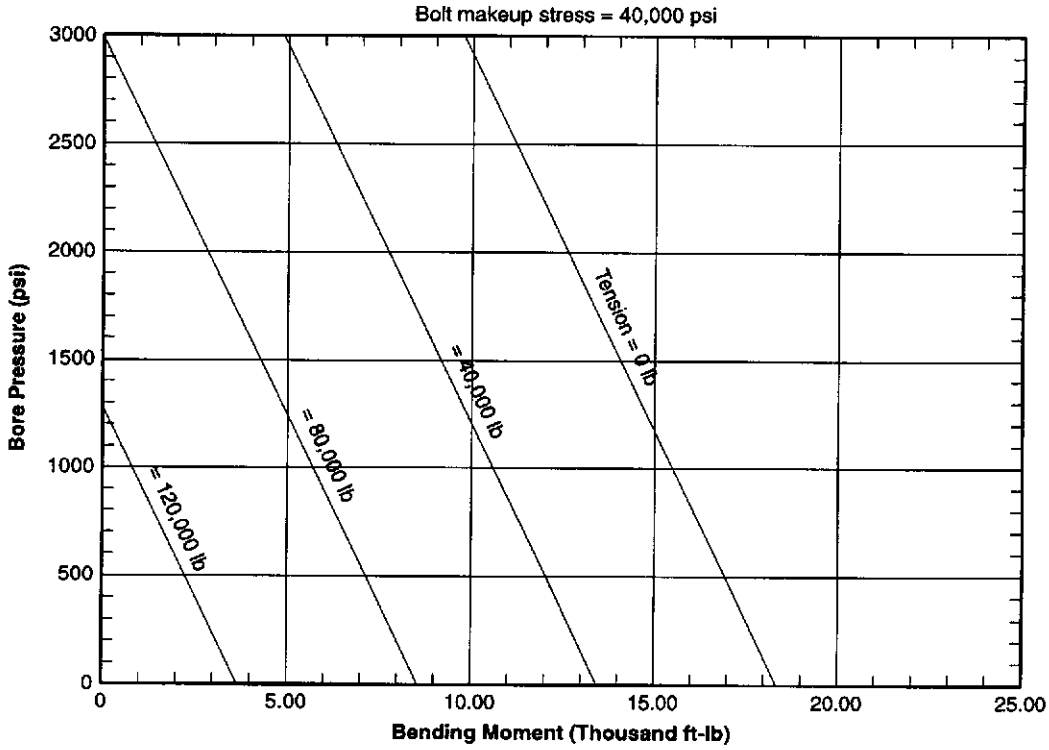
2⁹/₁₆ IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension



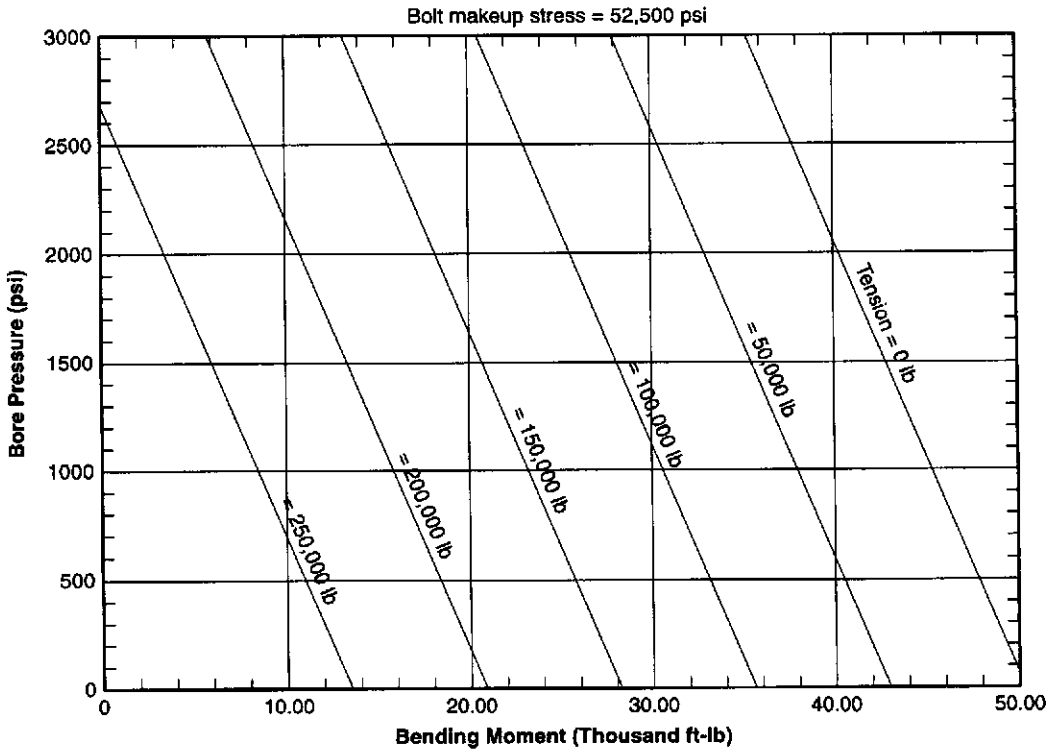


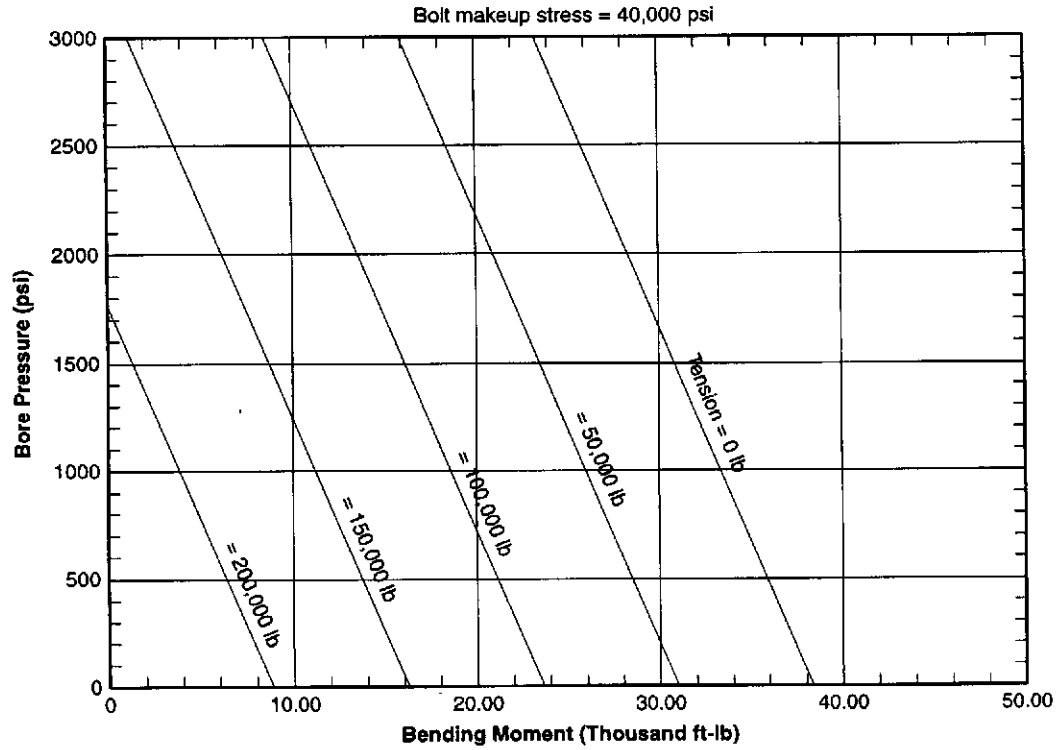
3⅛ IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension



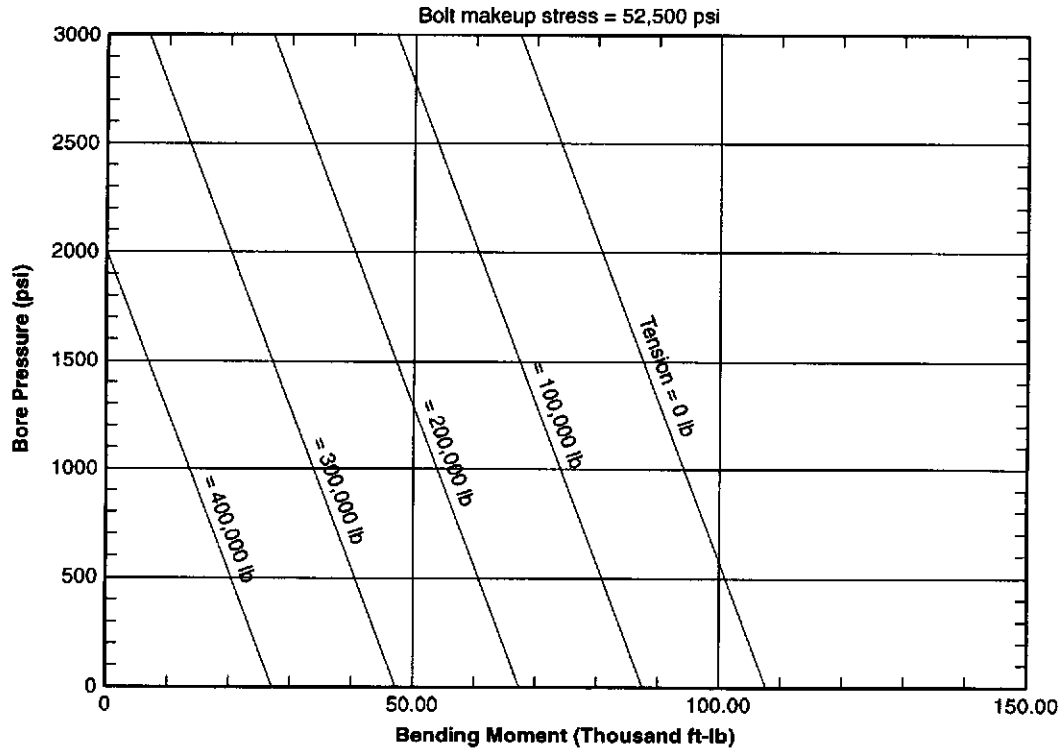


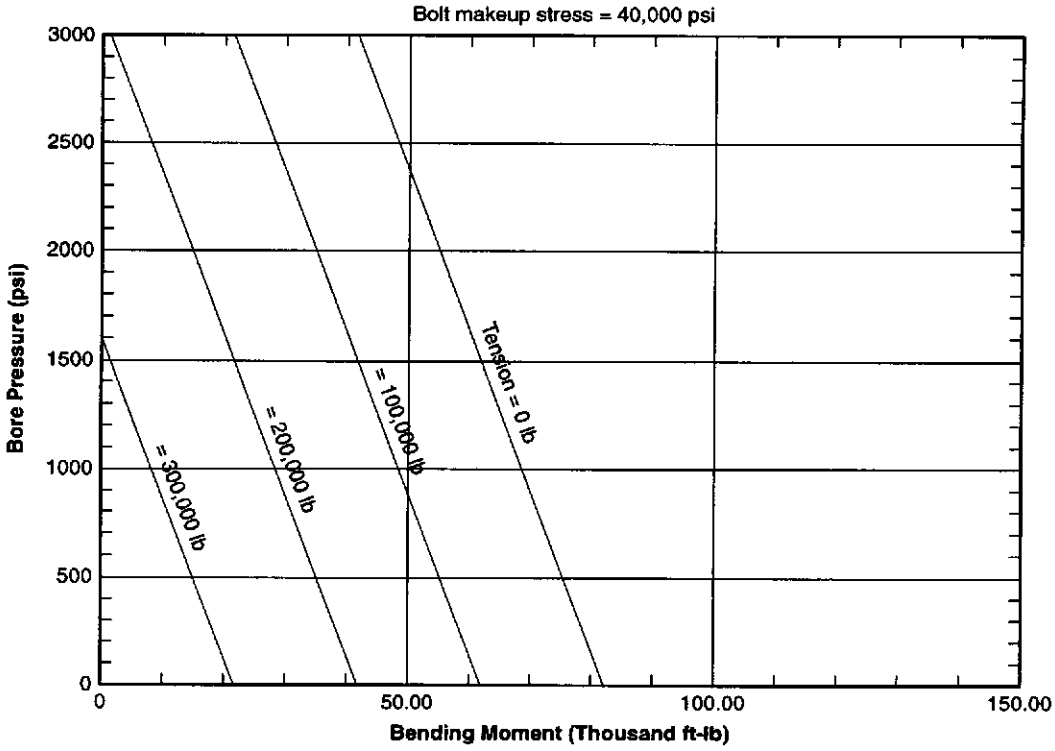
4 1/16 IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

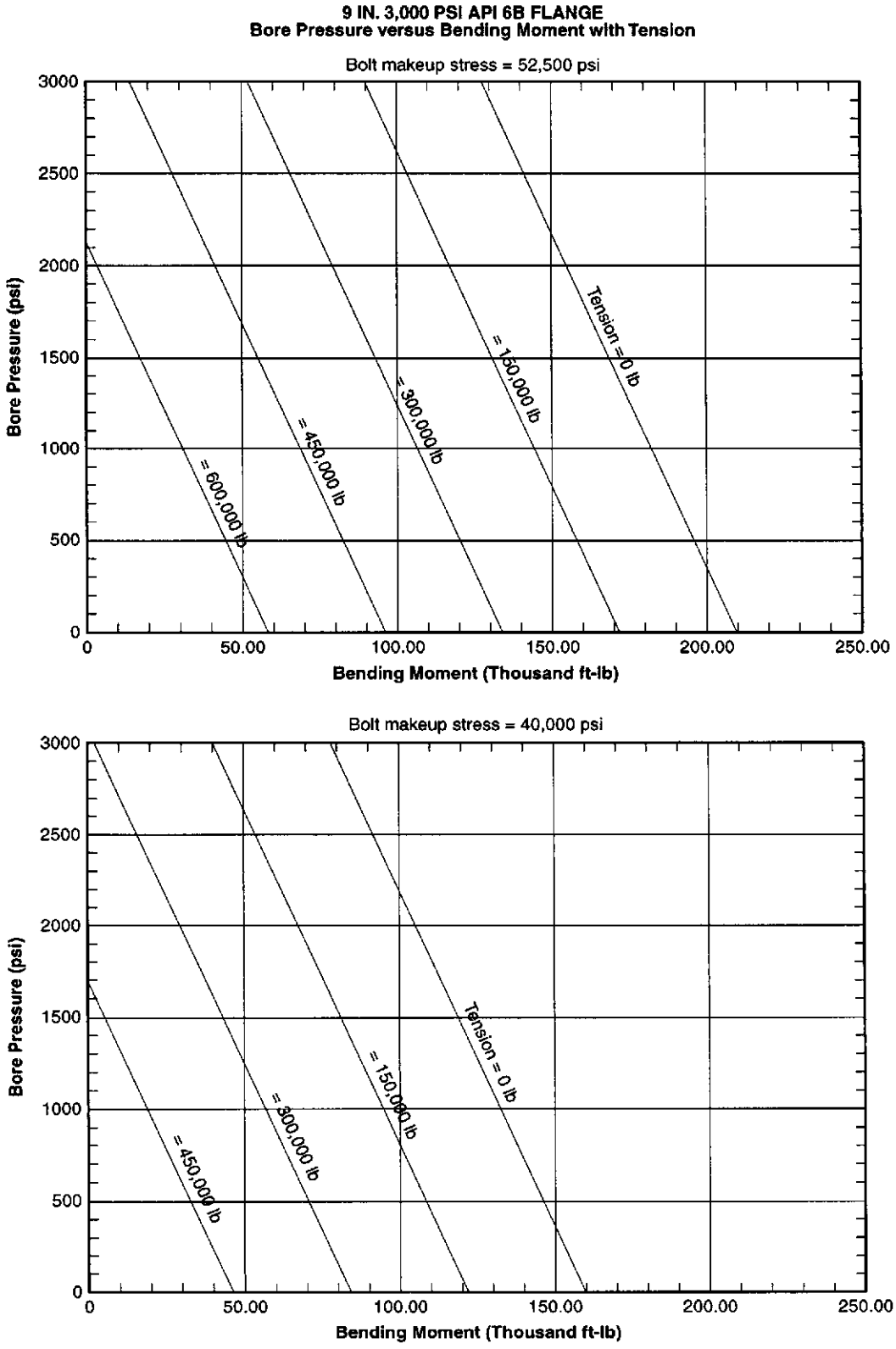




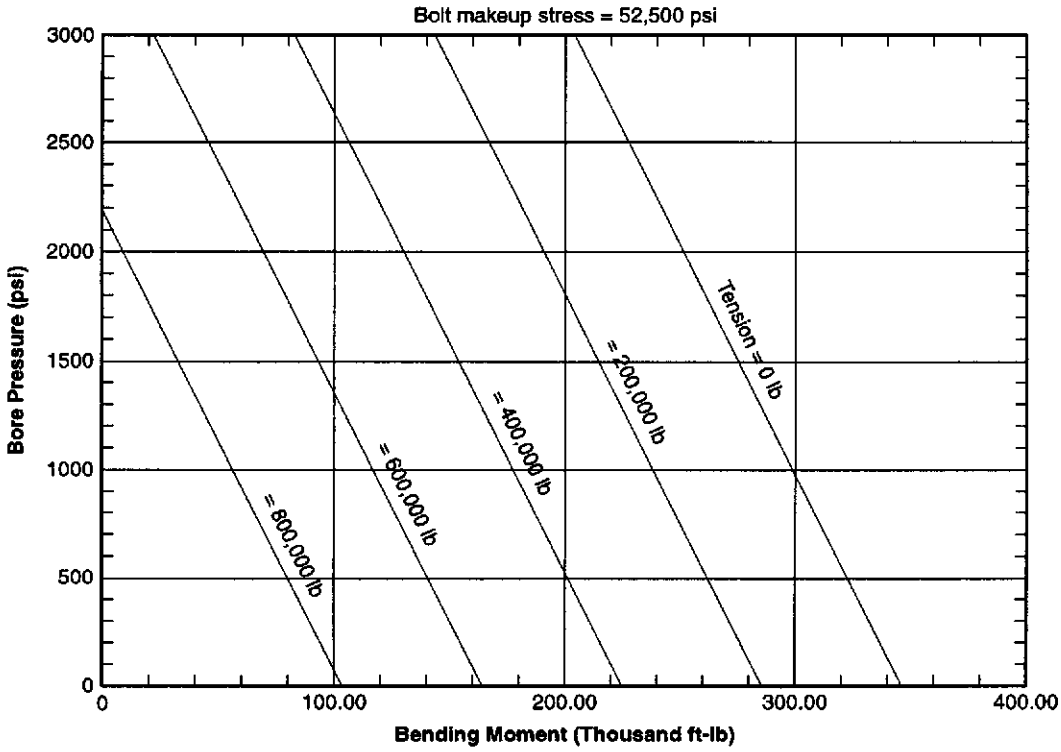
7 1/16 IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

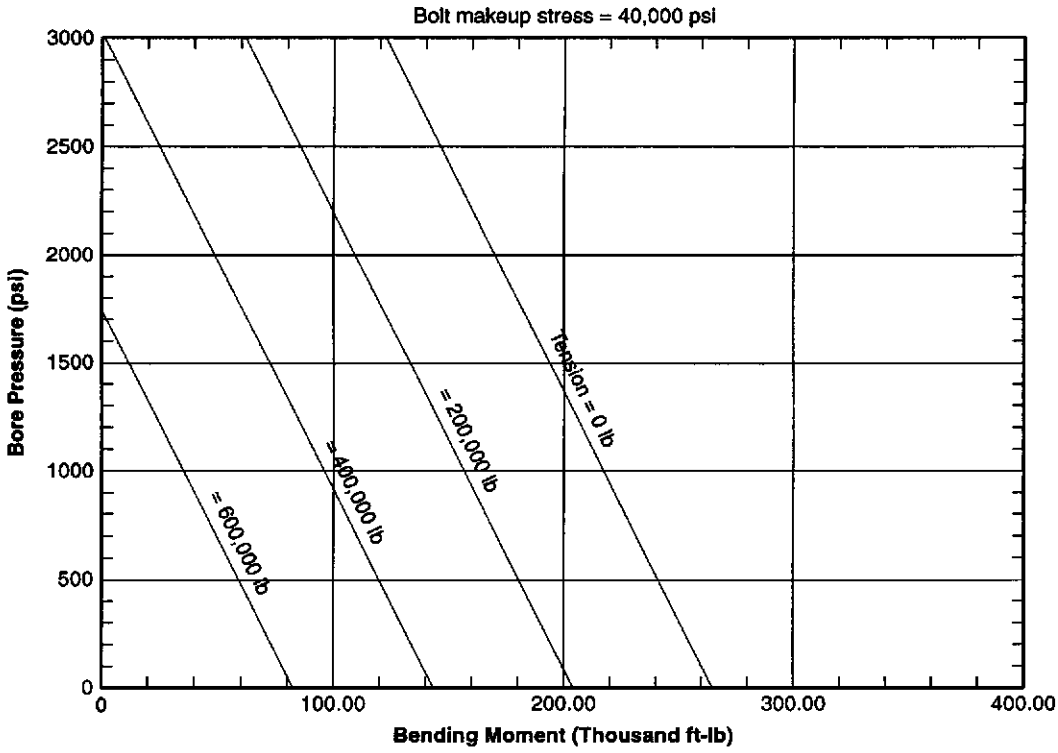


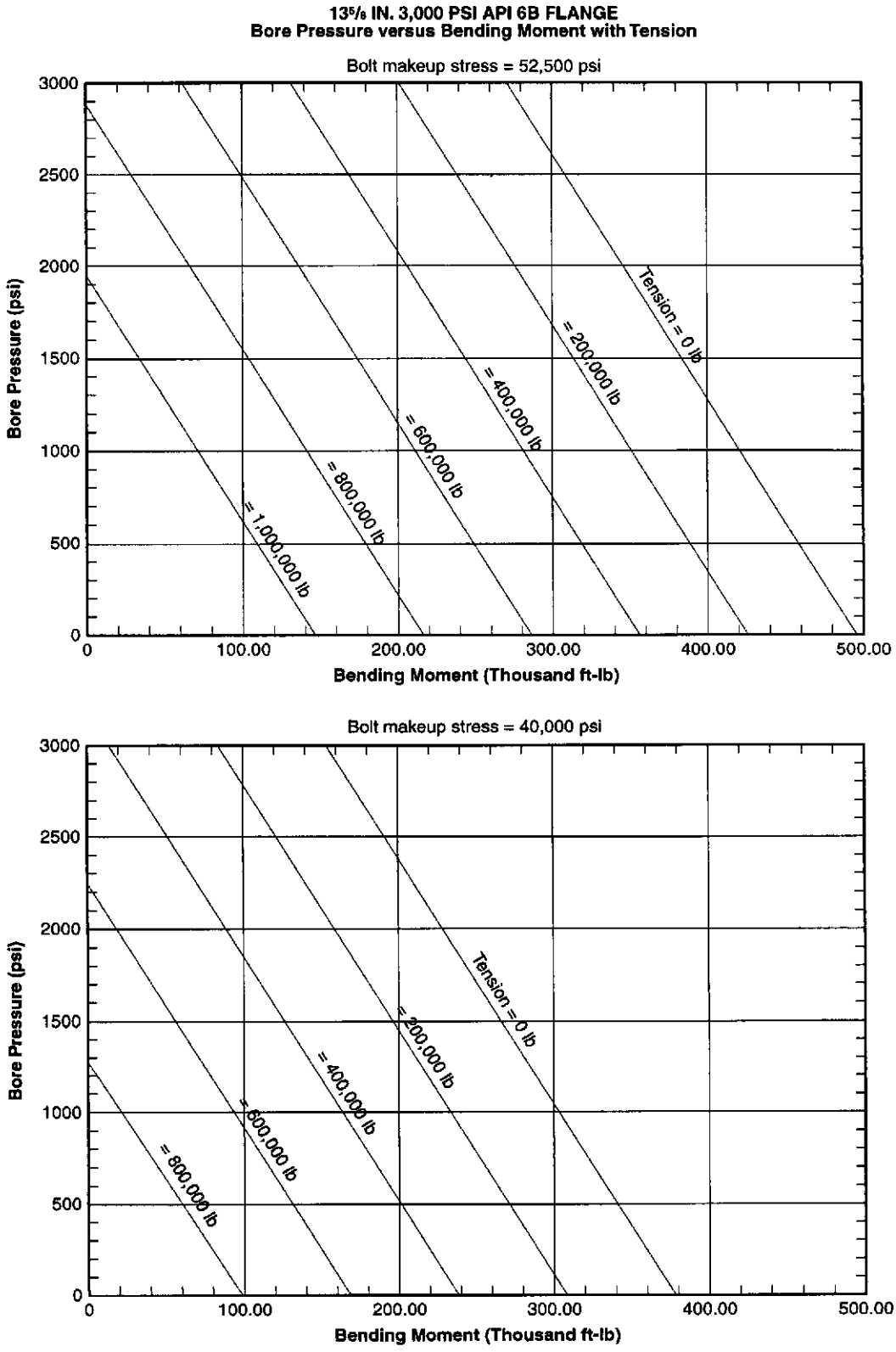




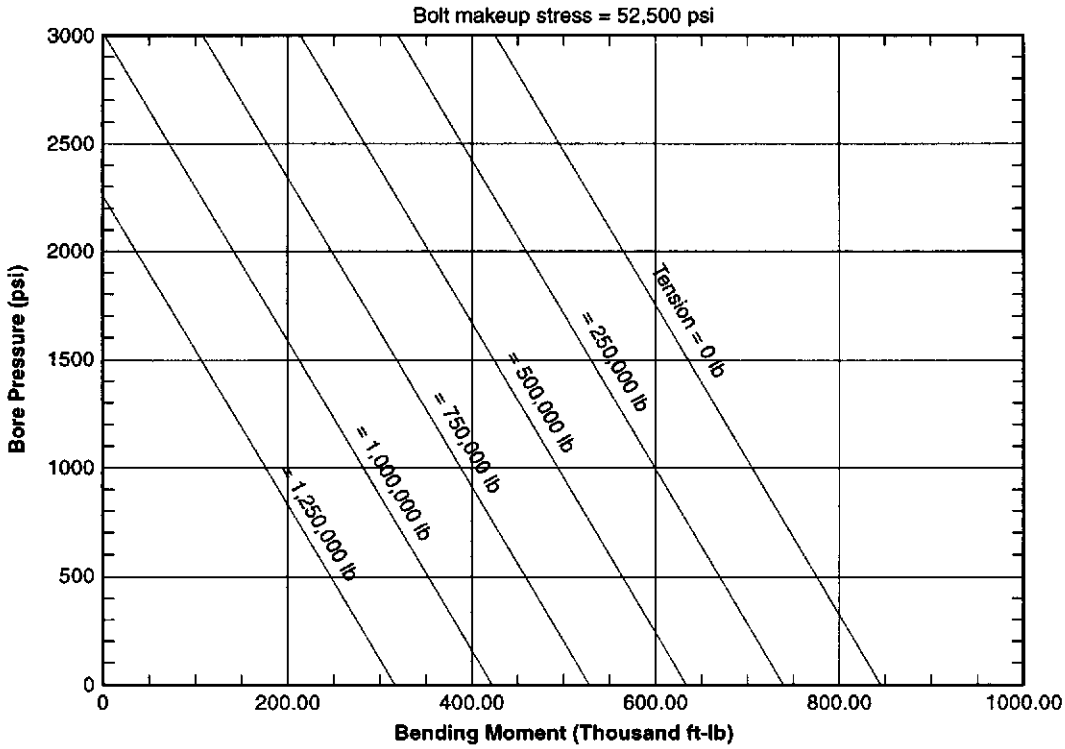
11 IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

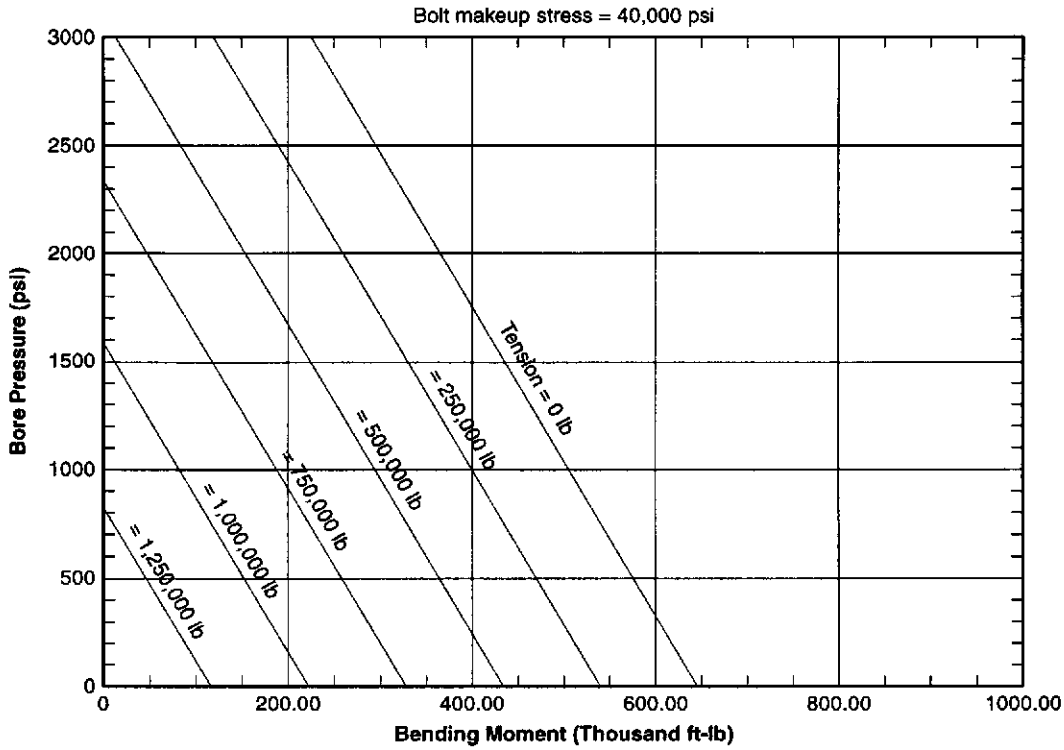


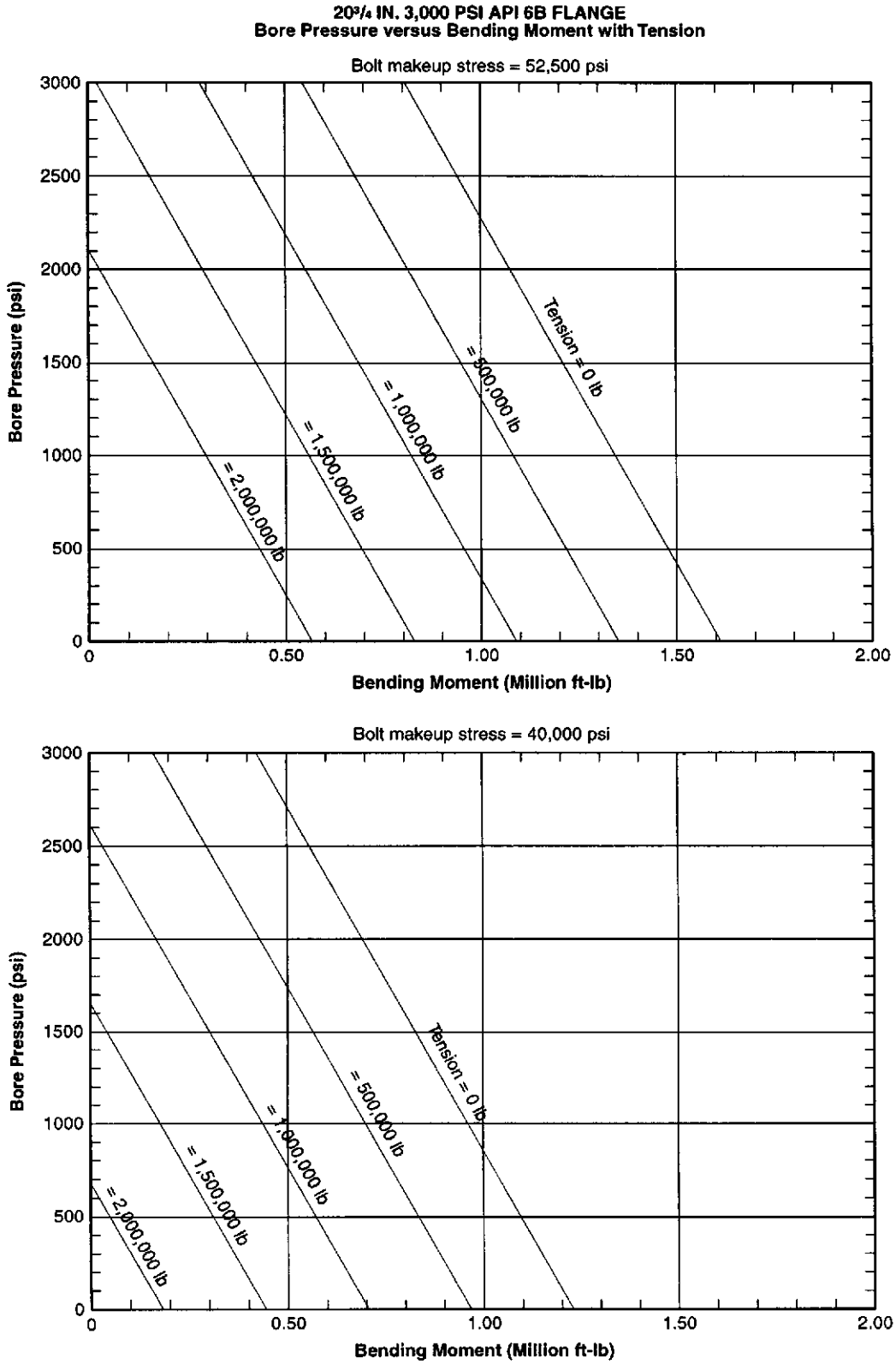




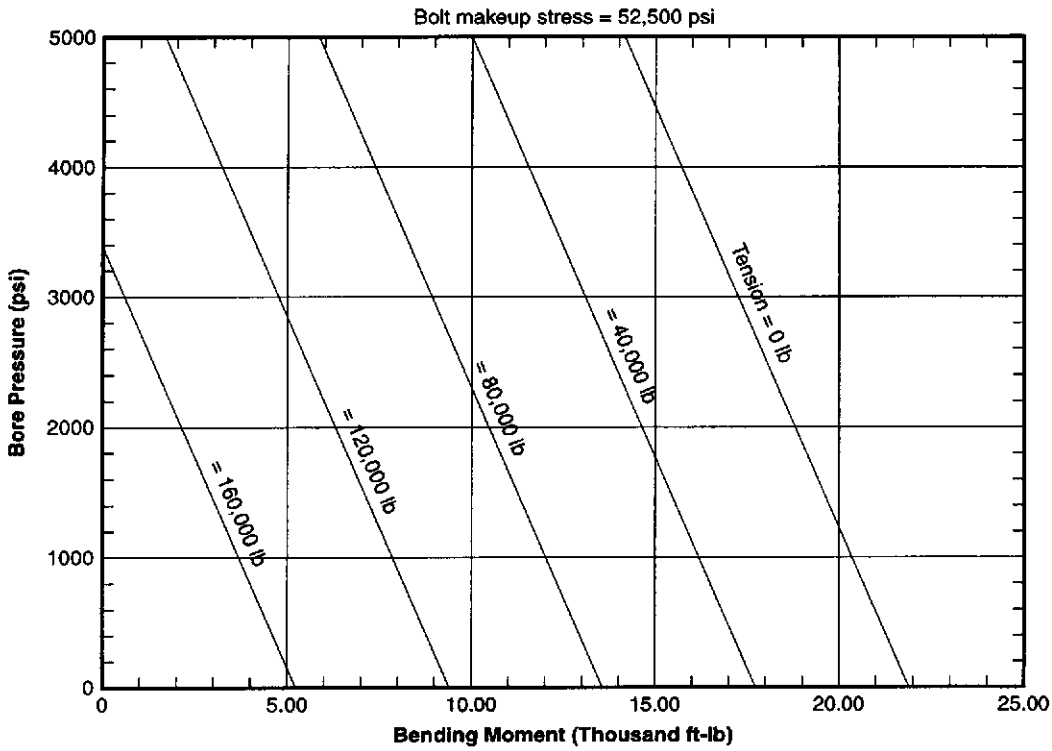
16¾ IN. 3,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

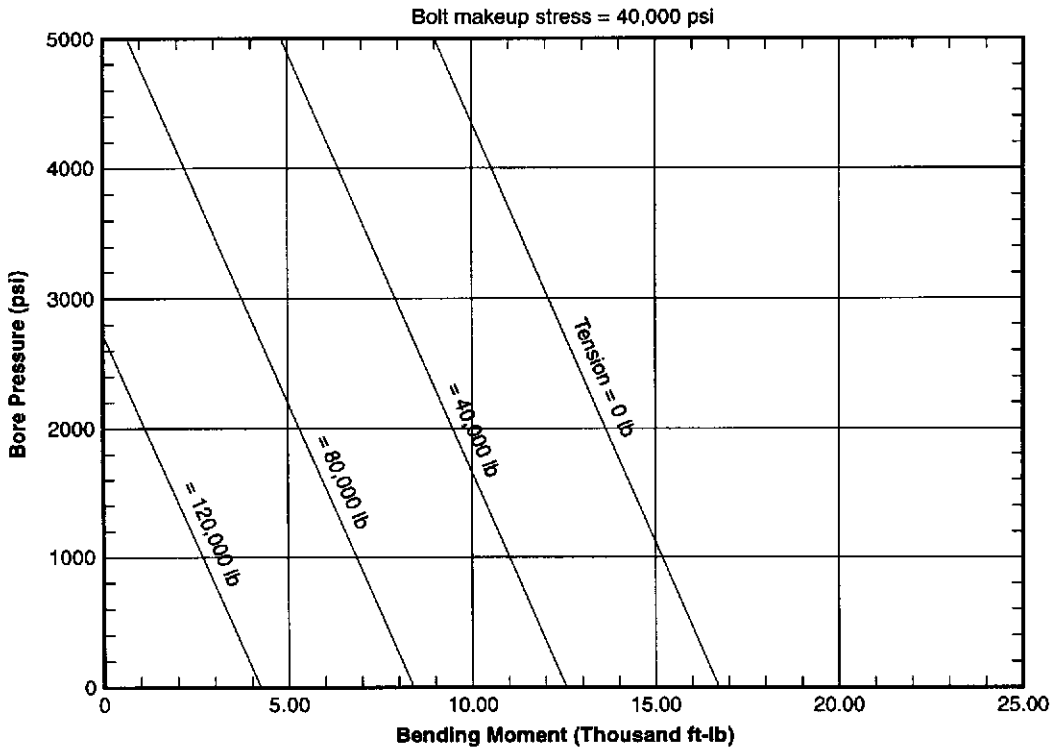


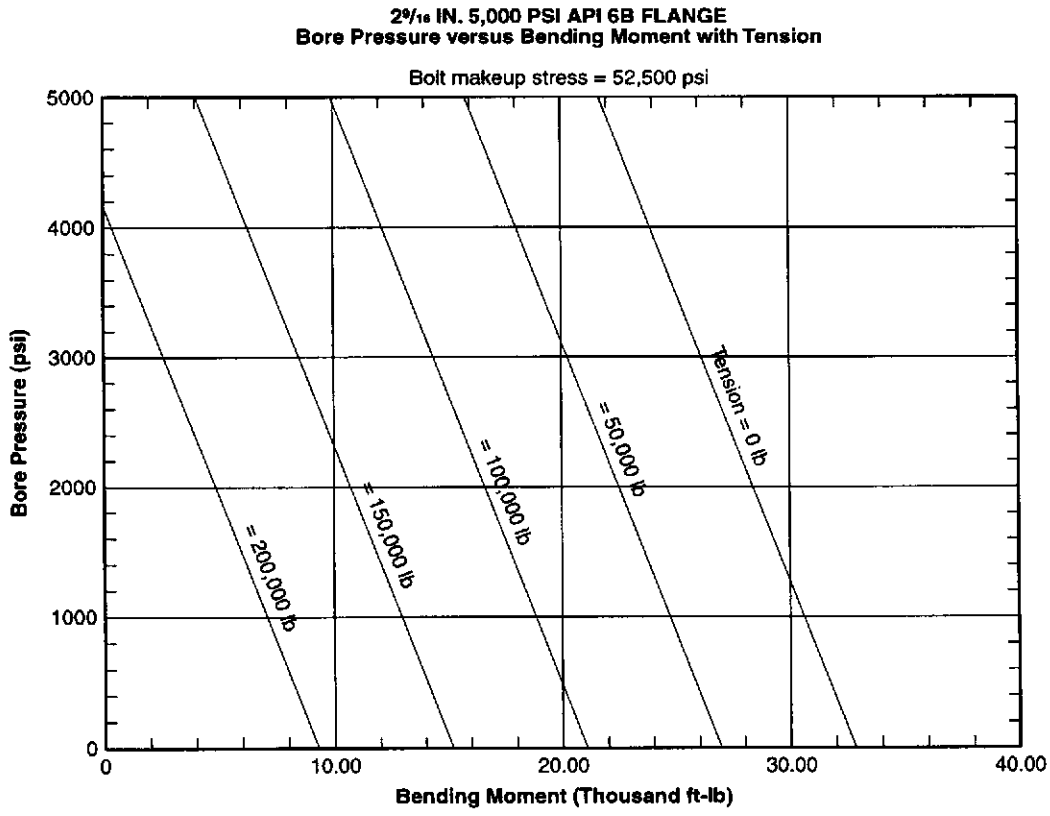


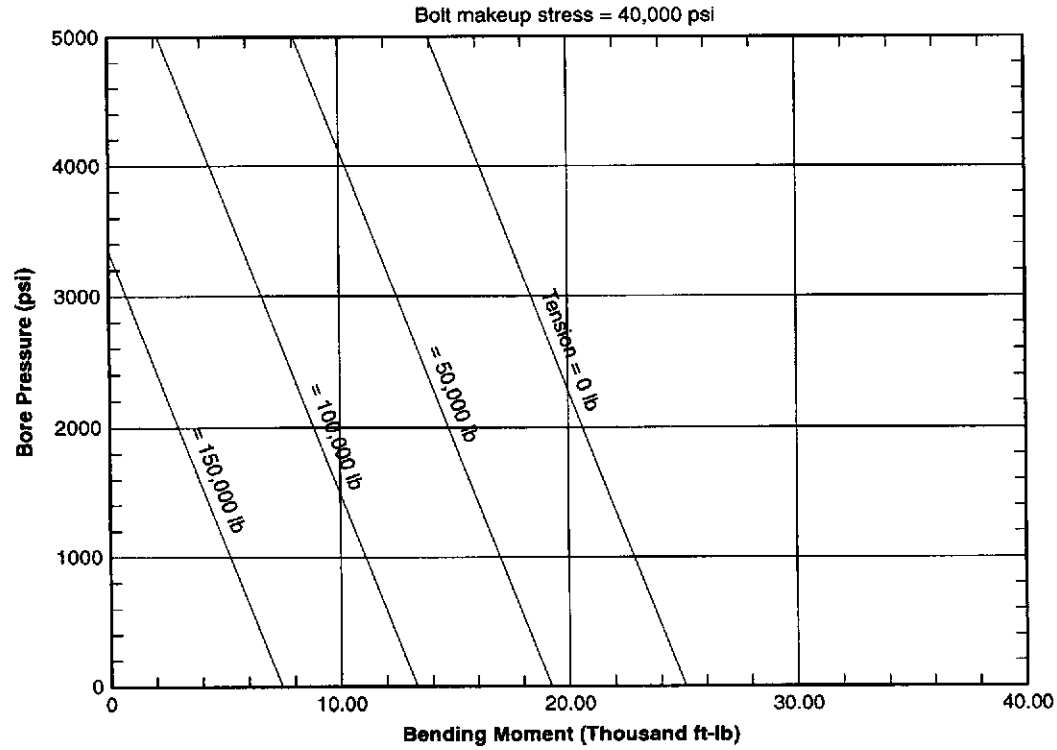


2 1/16 IN. 5,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

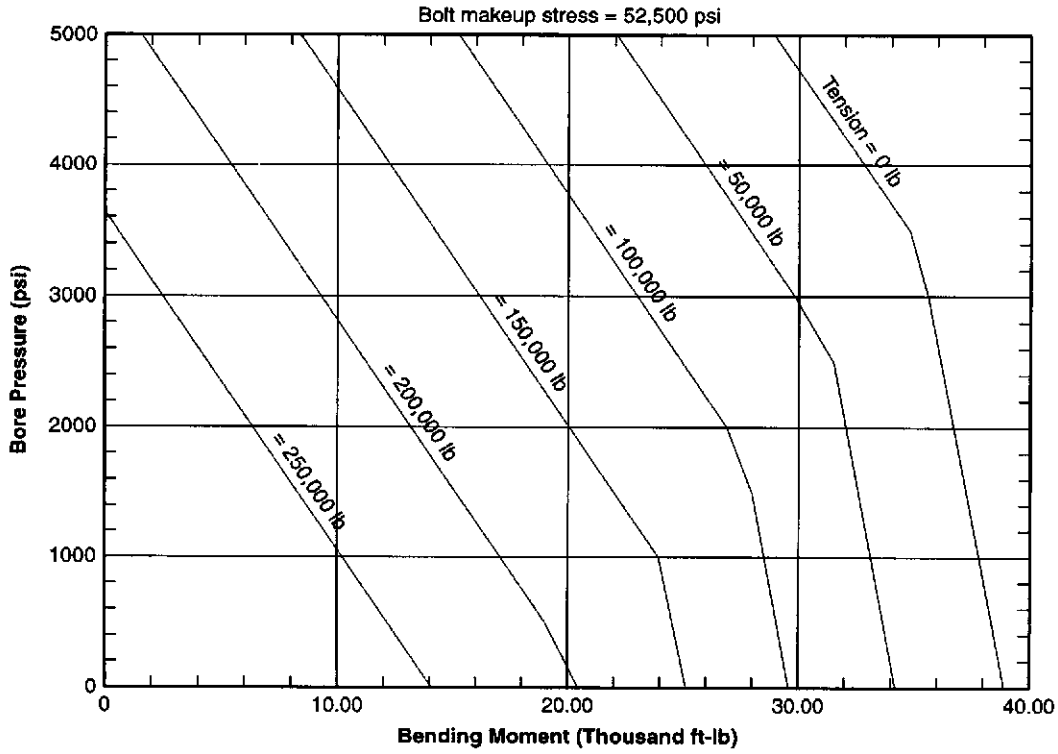


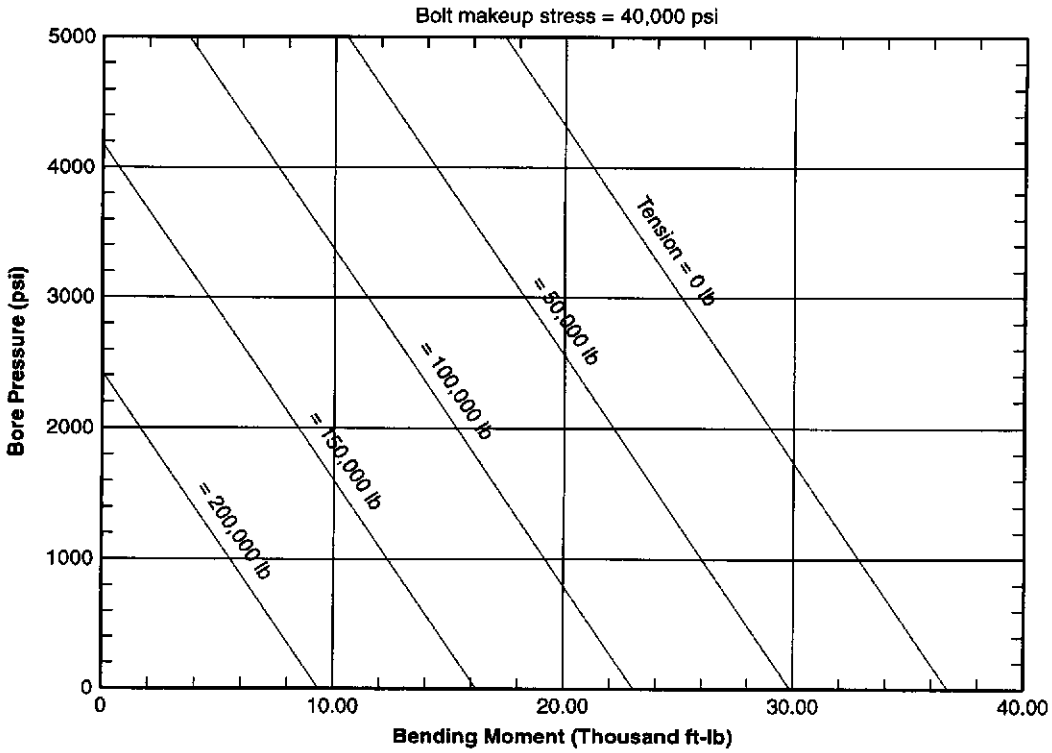


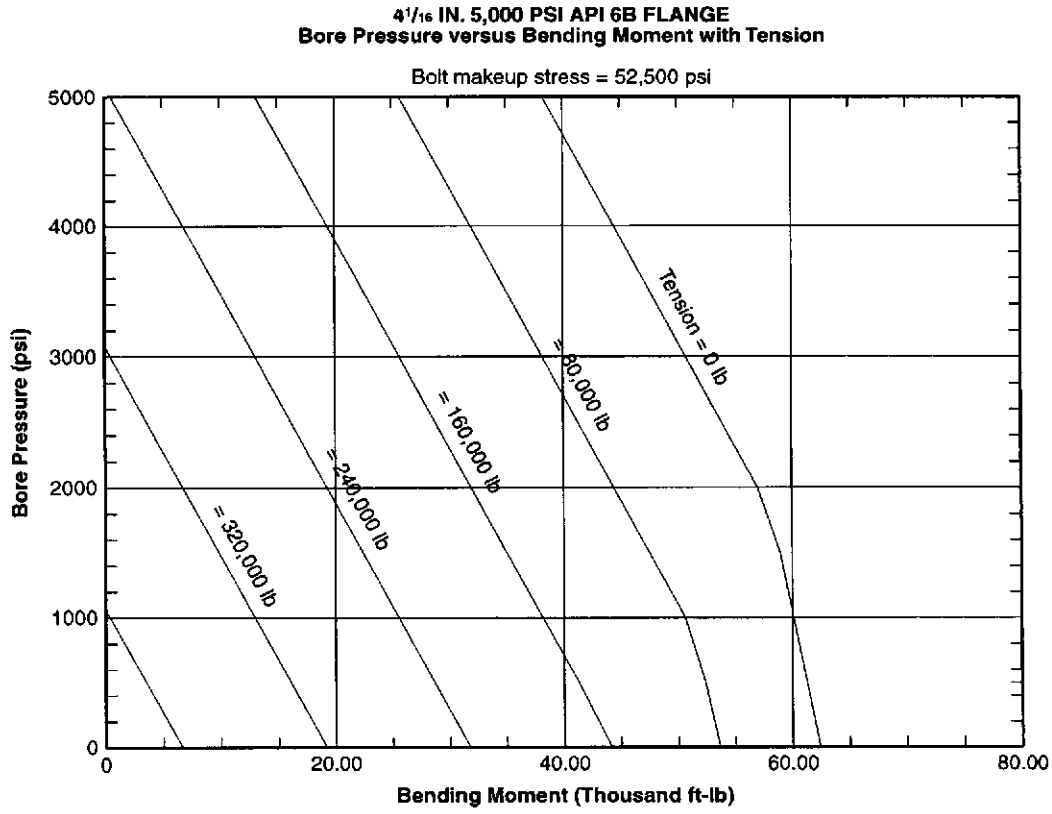


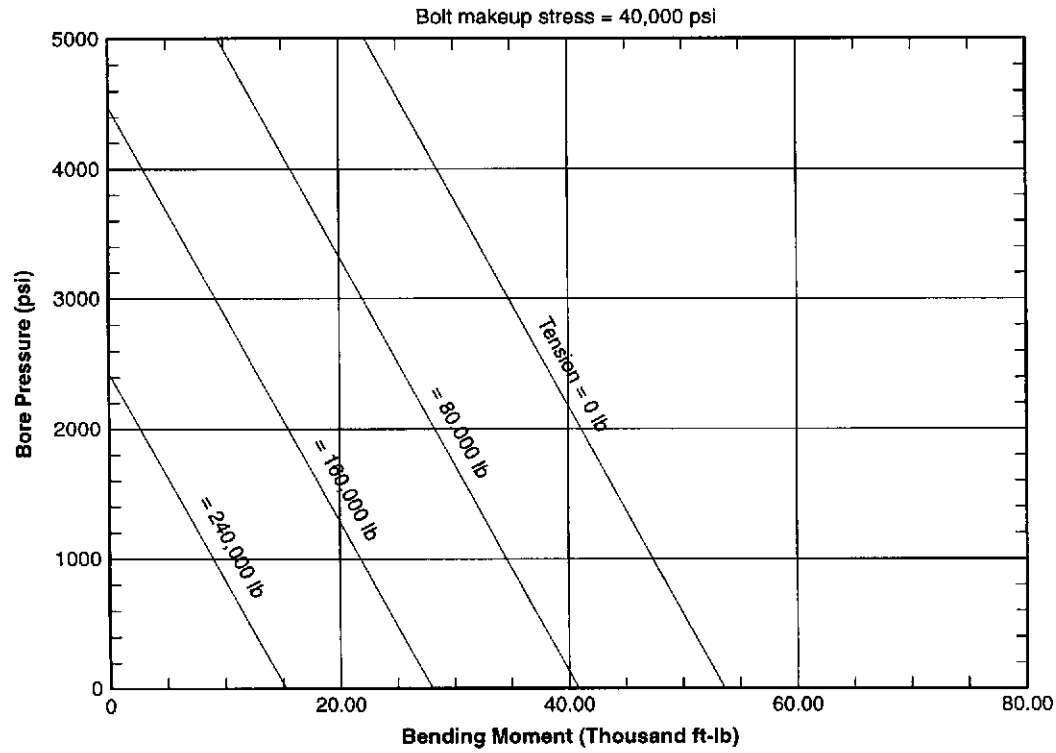


3⅛ IN. 5,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension

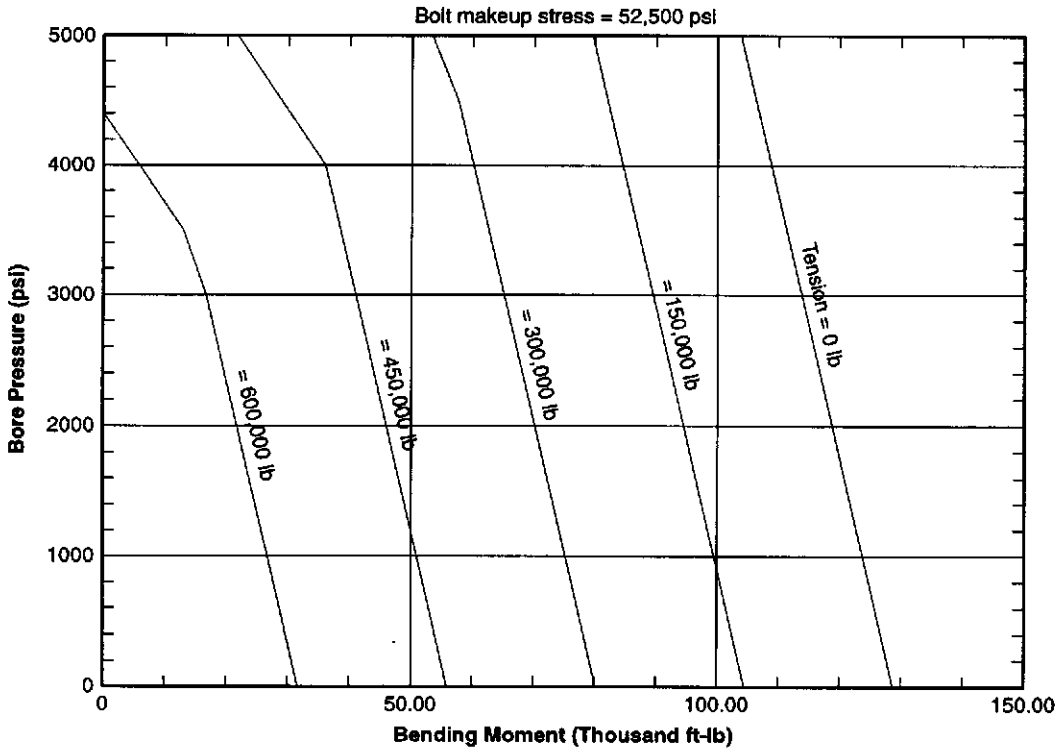


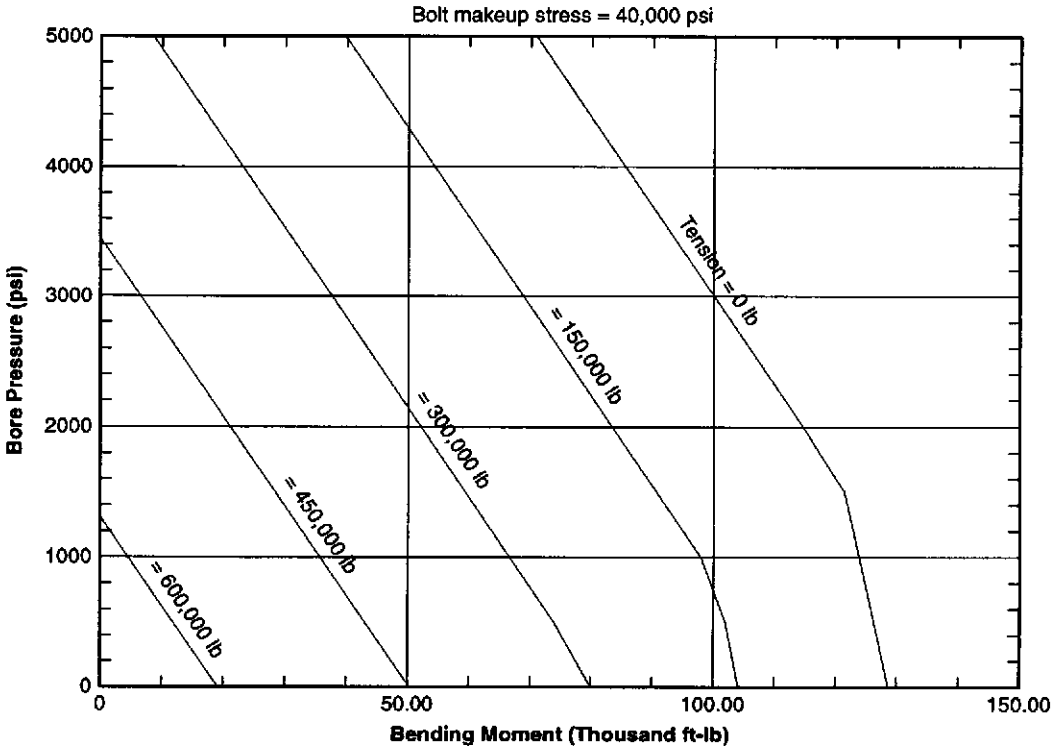




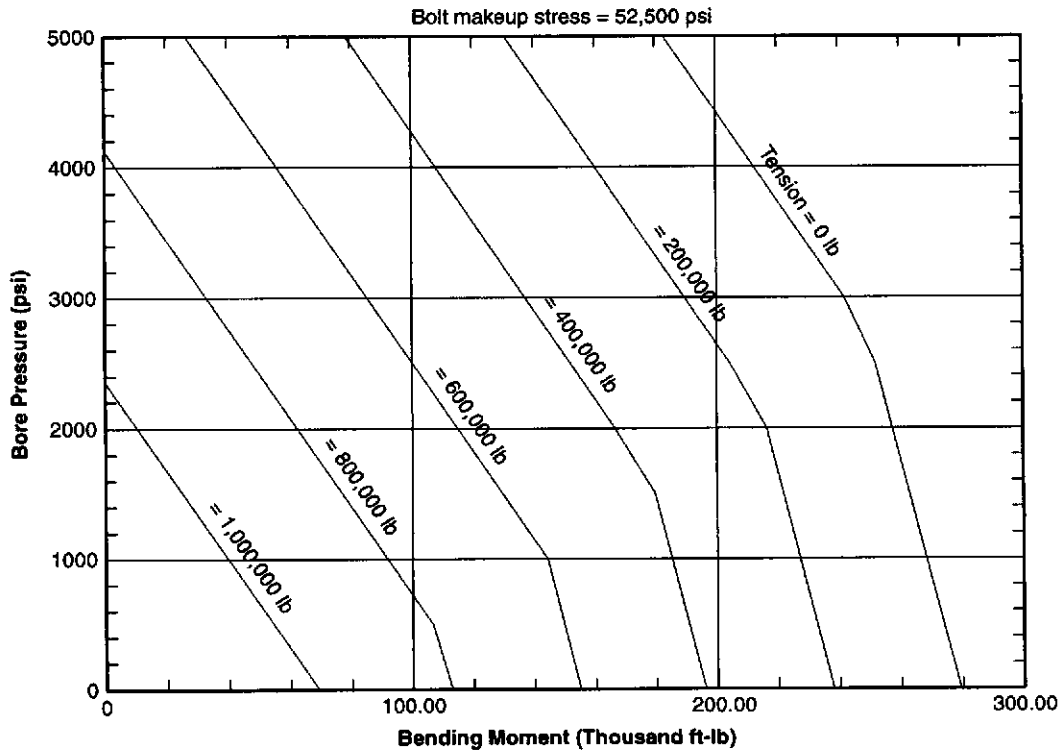


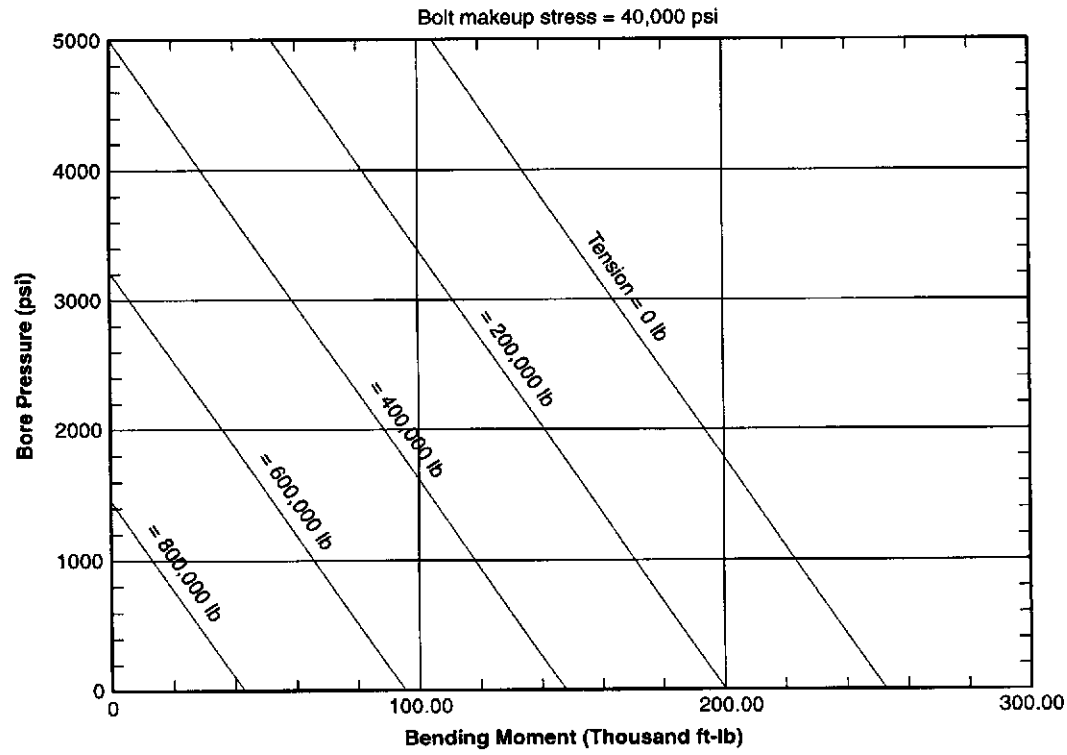
7 1/16 IN. 5,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension



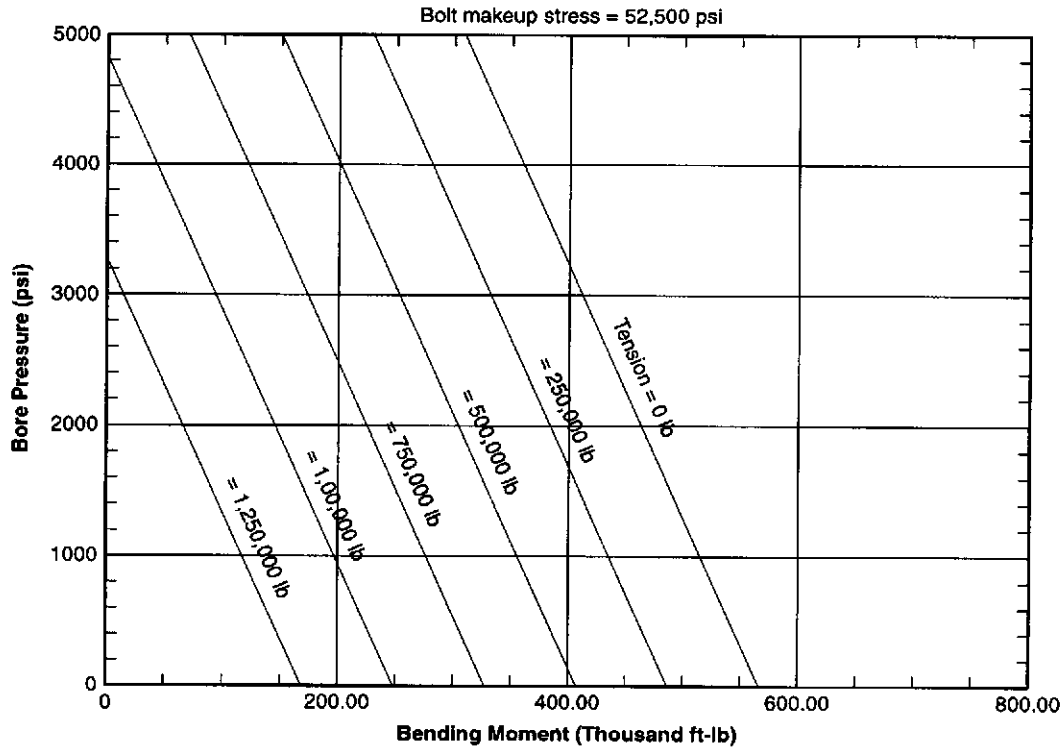


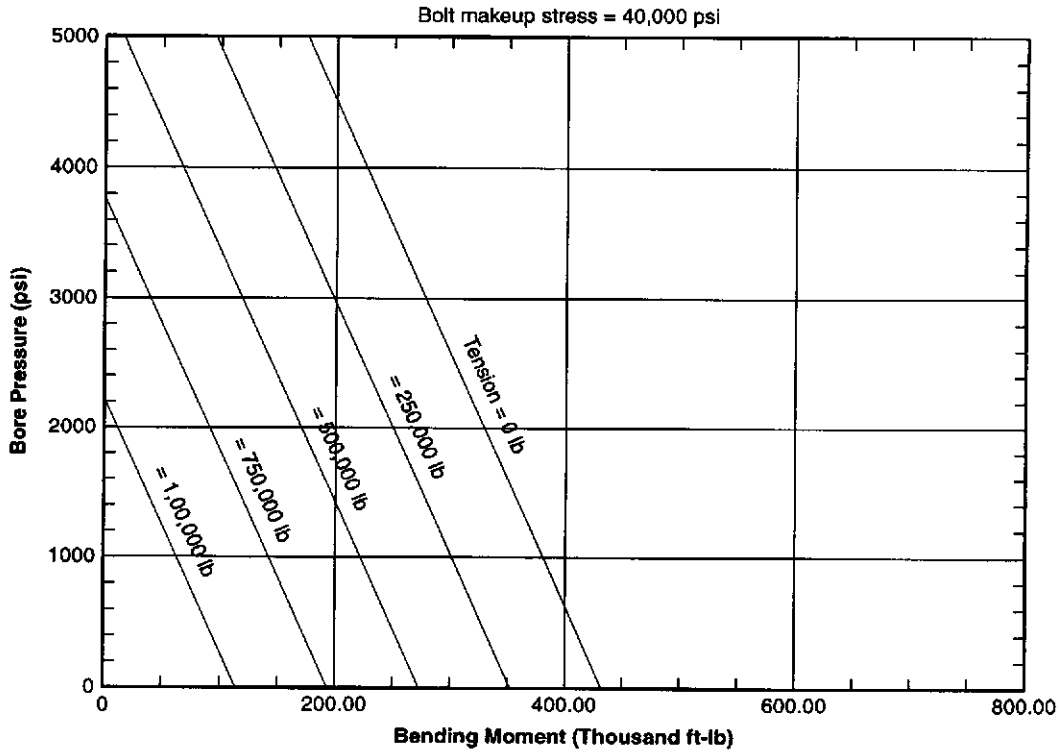
9 IN. 5,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension



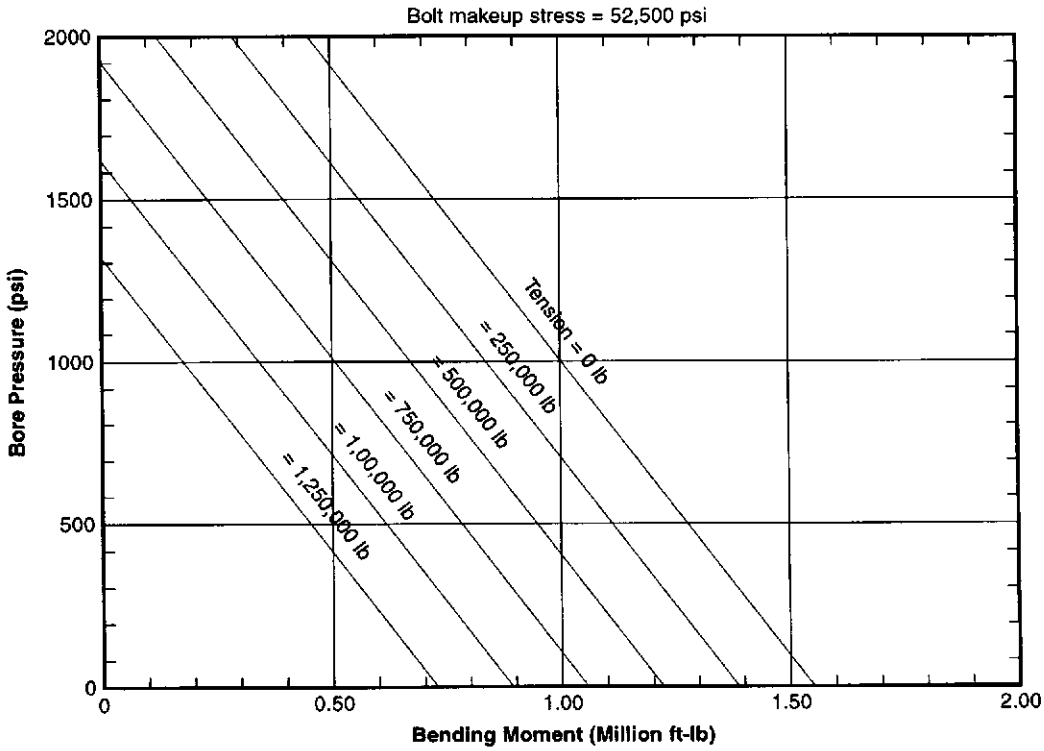


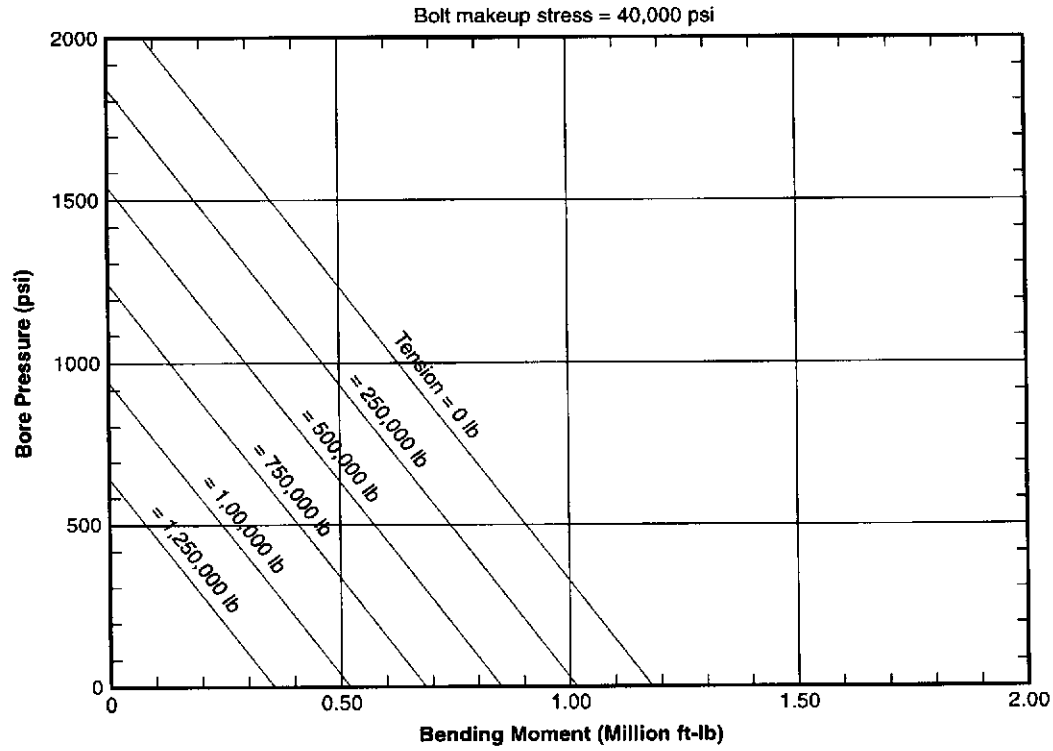
11 IN. 5,000 PSI API 6B FLANGE
Bore Pressure versus Bending Moment with Tension



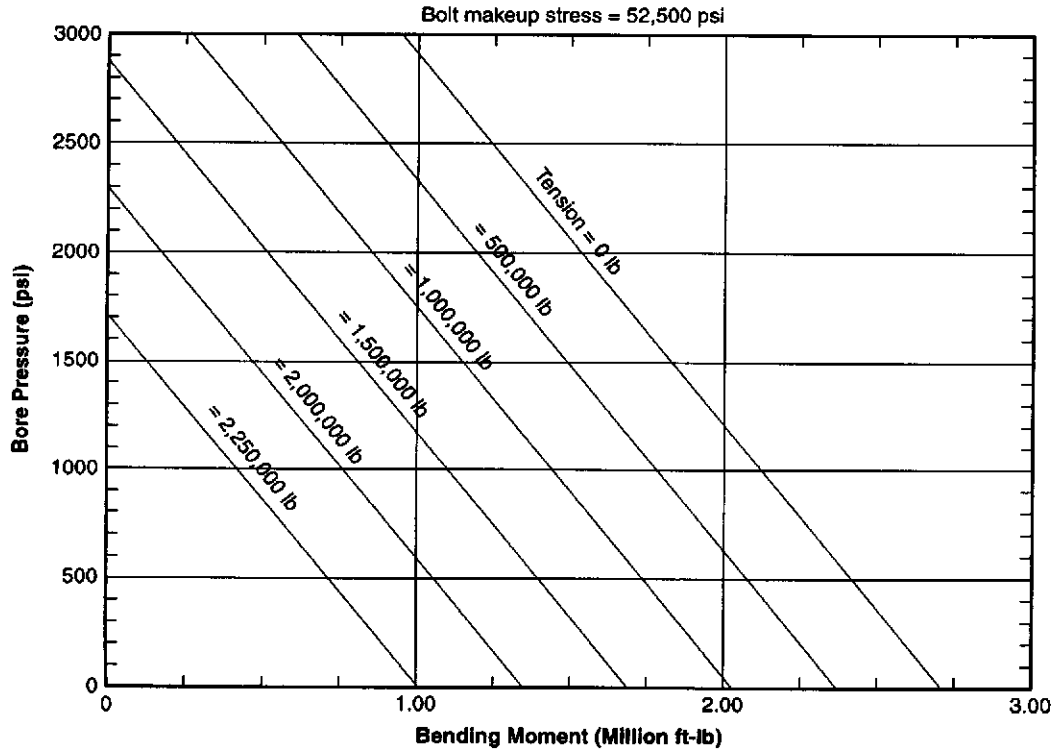


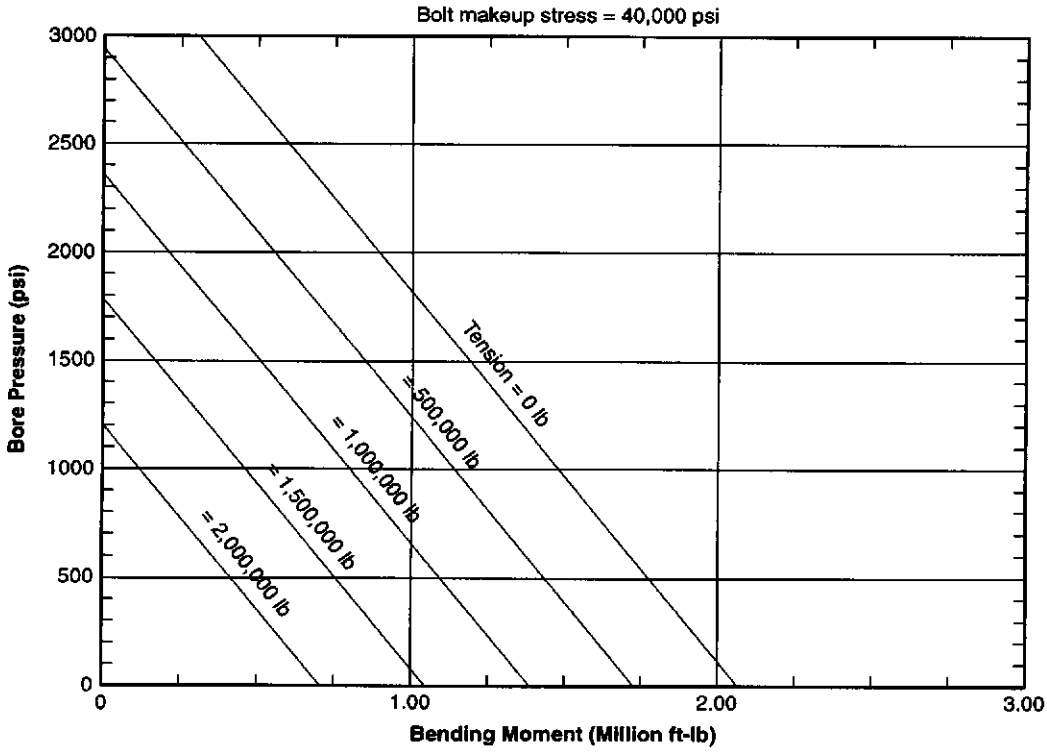
26¾ IN. 2,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

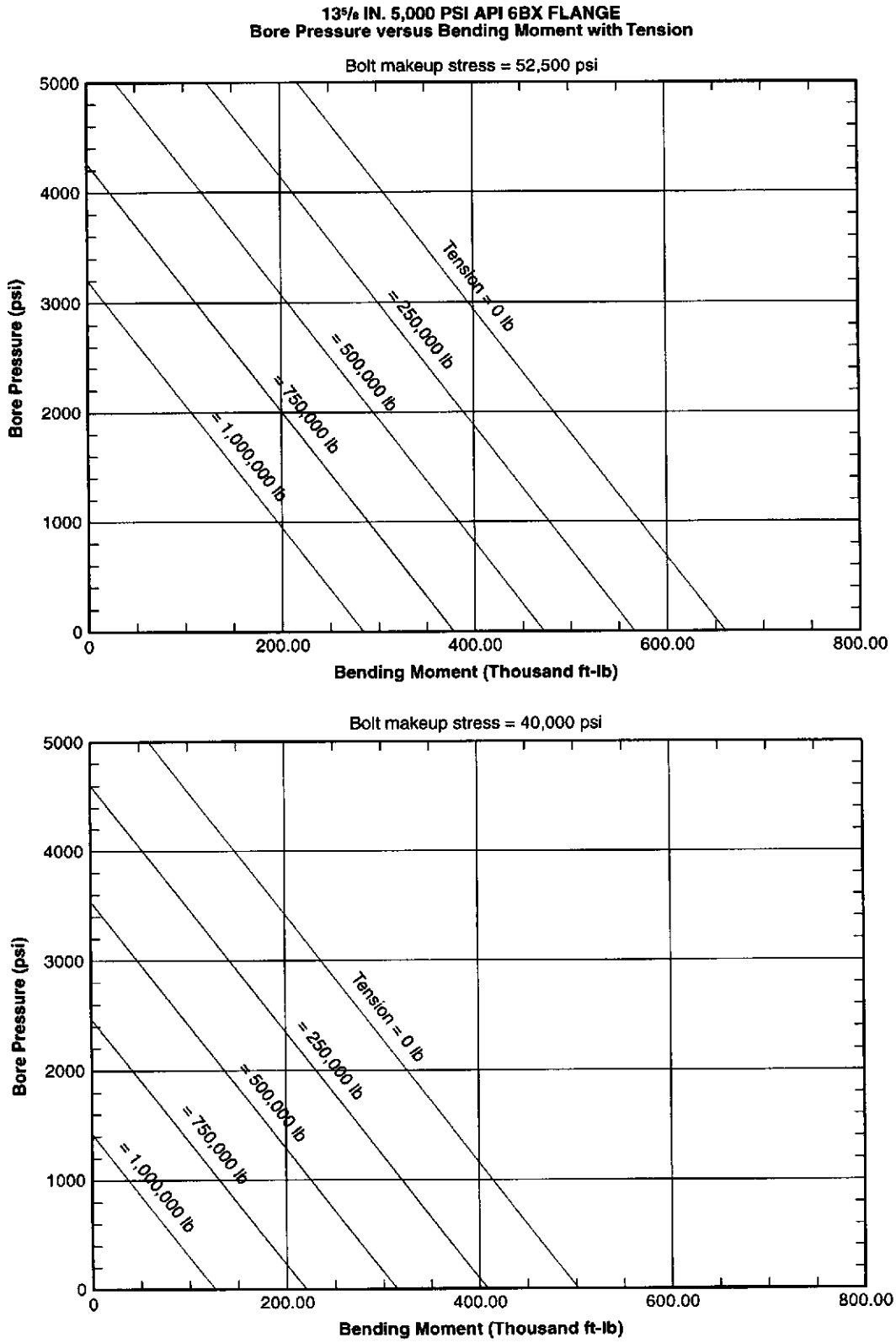




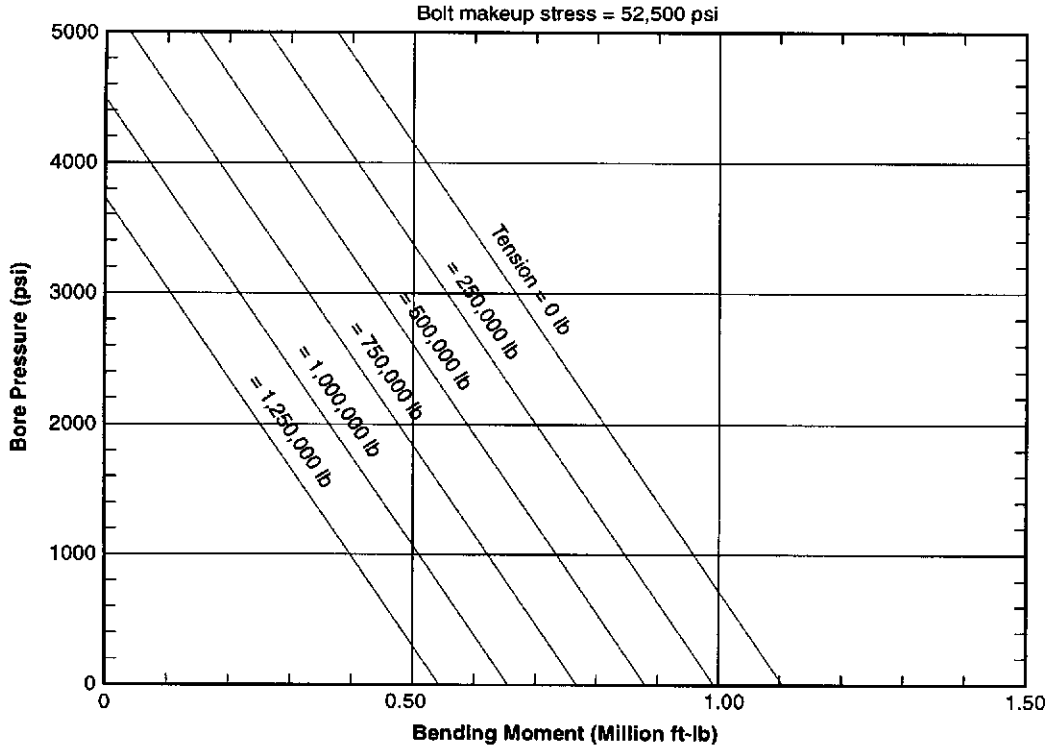
26¾ IN. 3,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

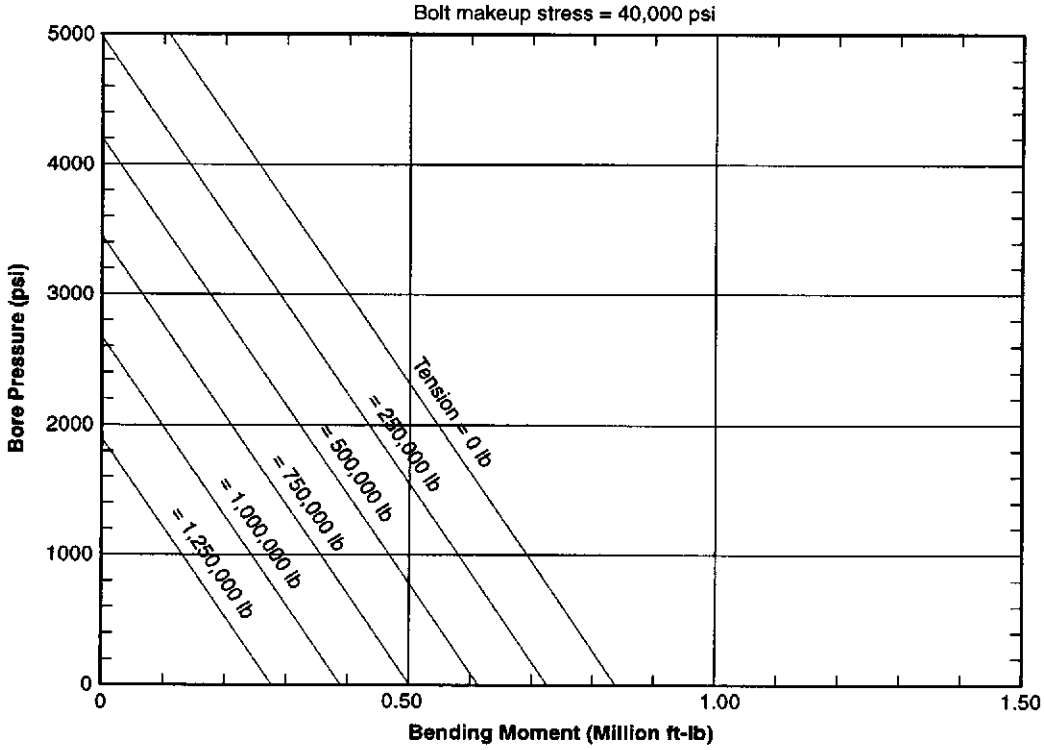


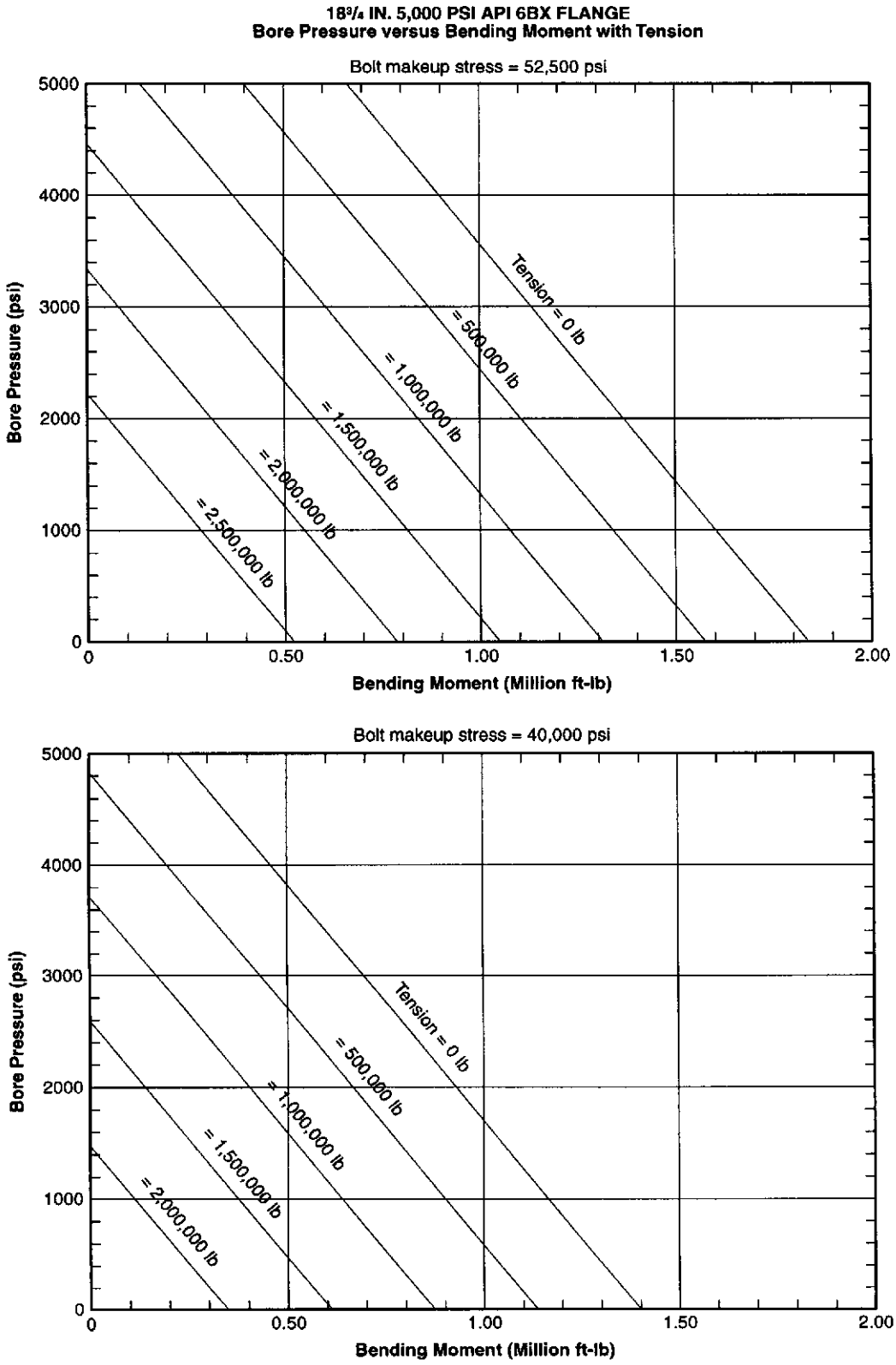




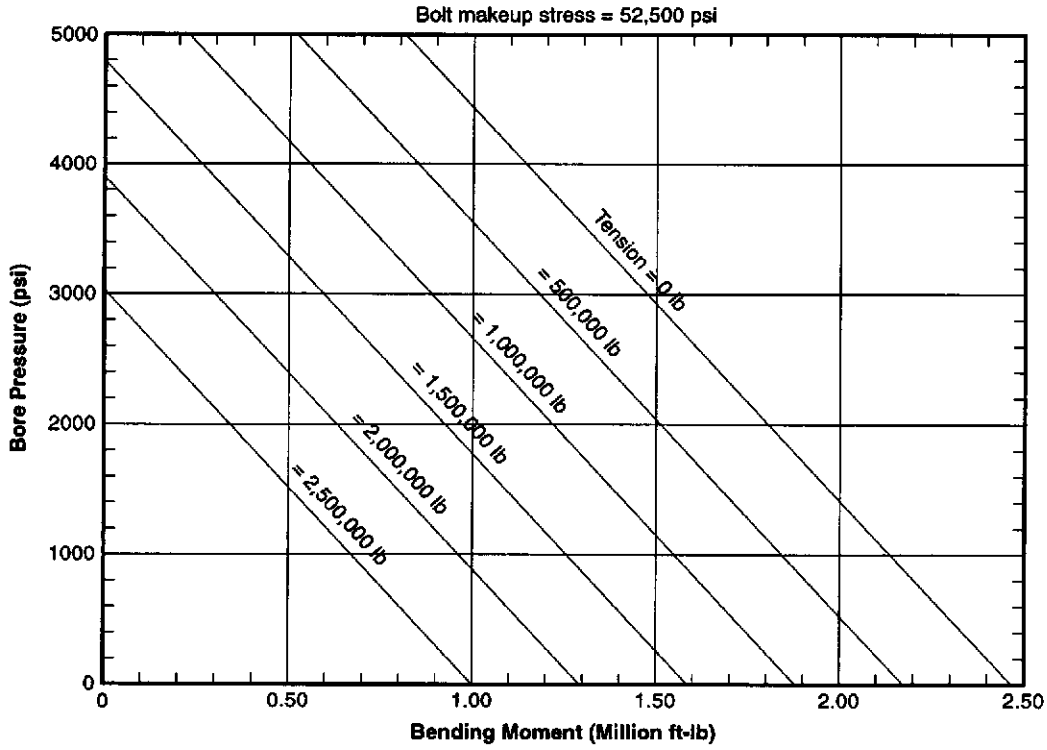
16¾ IN. 5,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

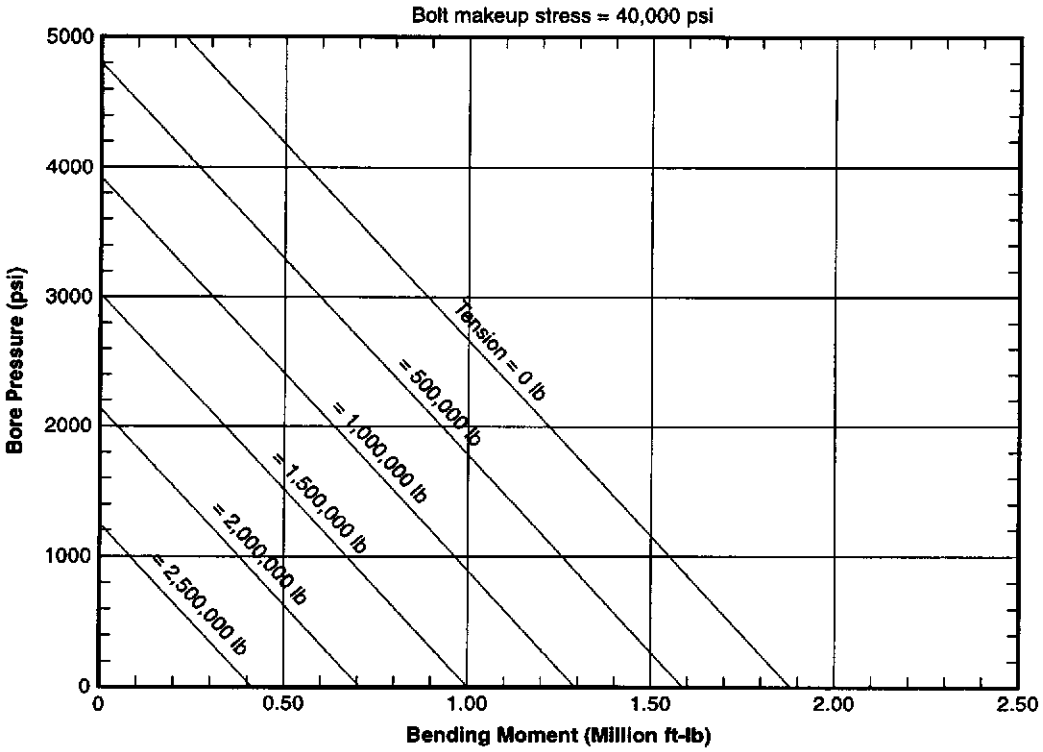




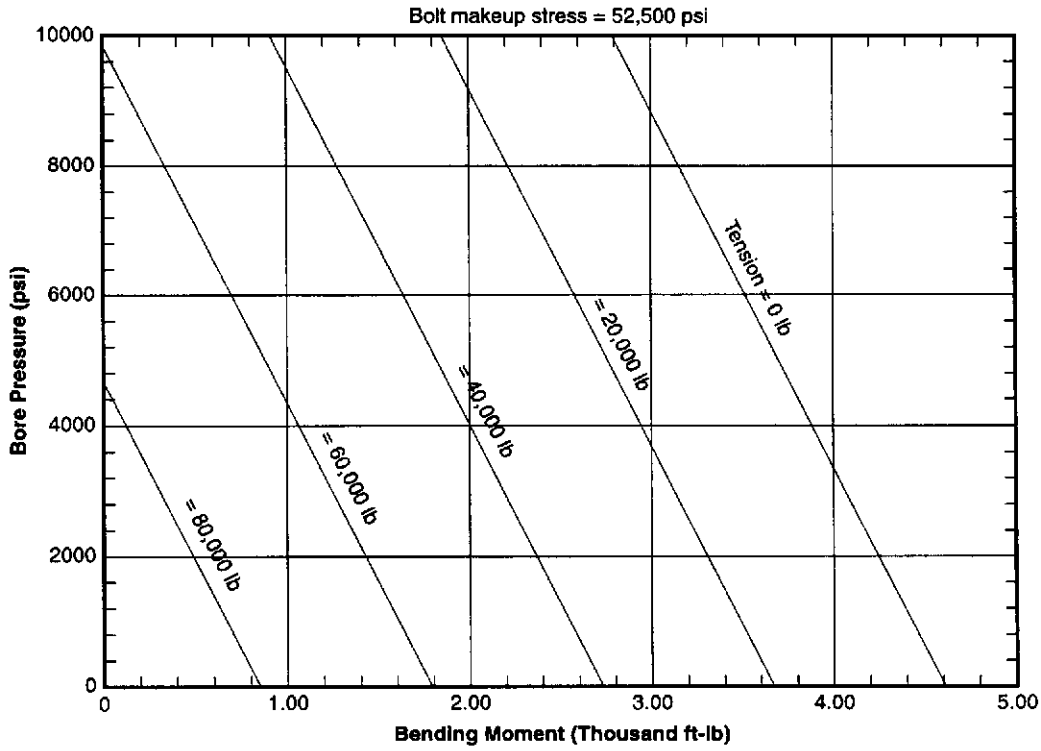


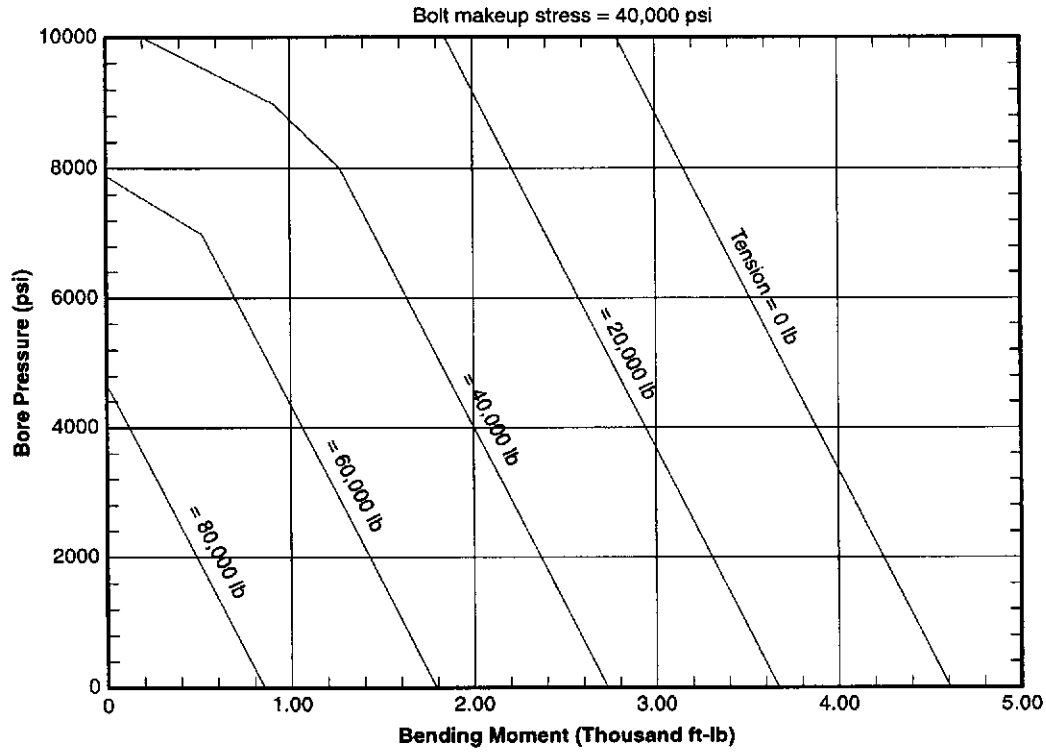
21¼ IN. 5,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



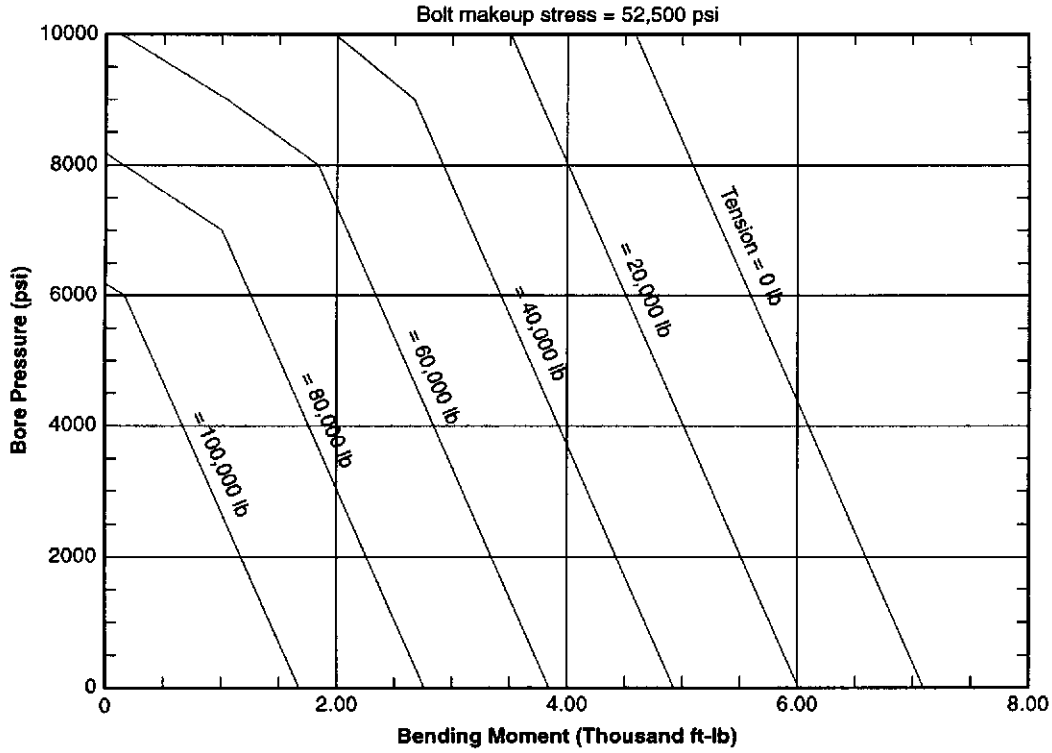


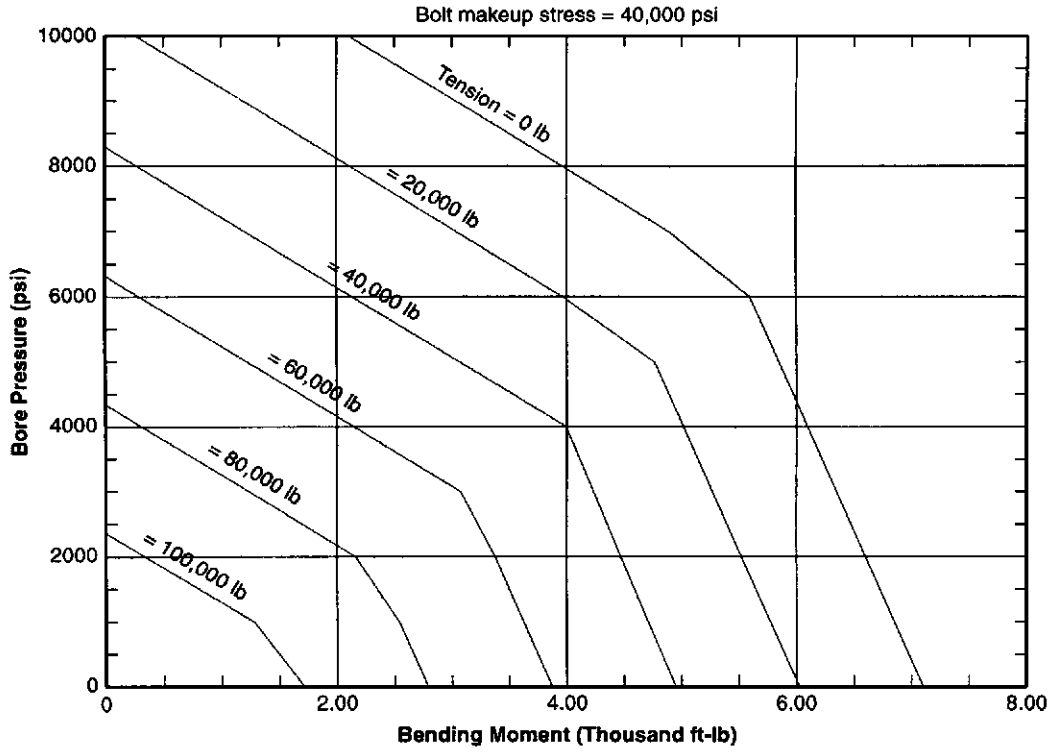
1 13/16 IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

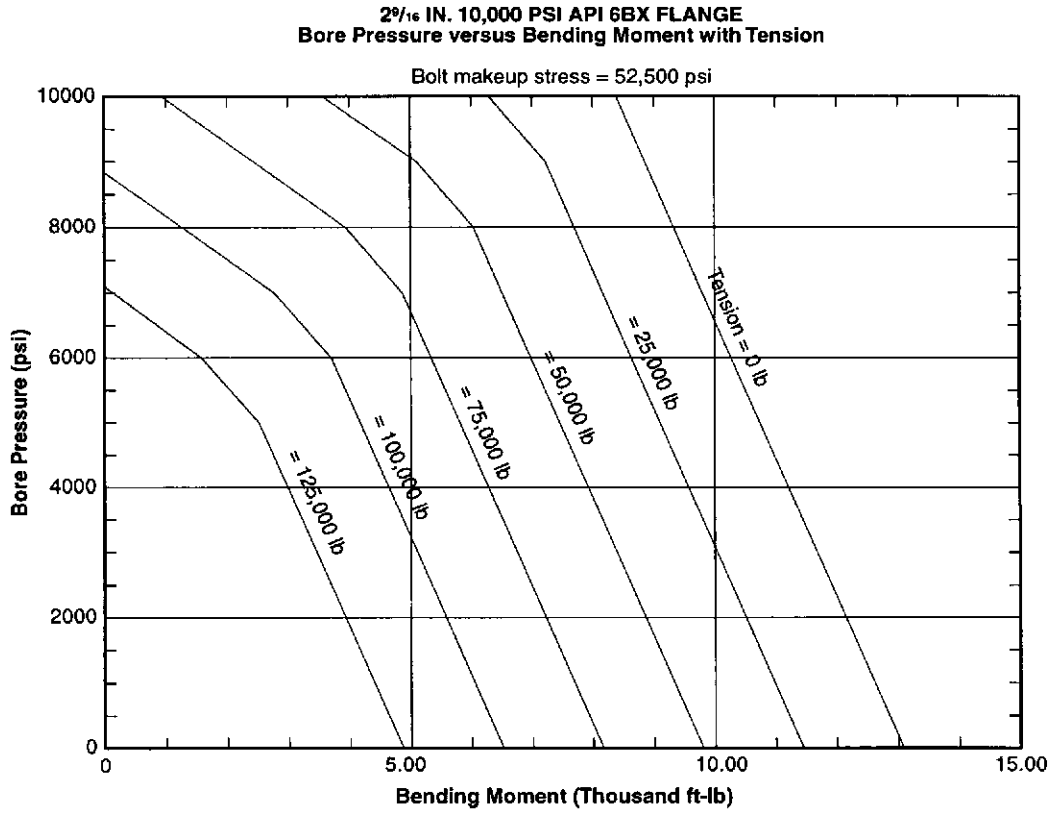


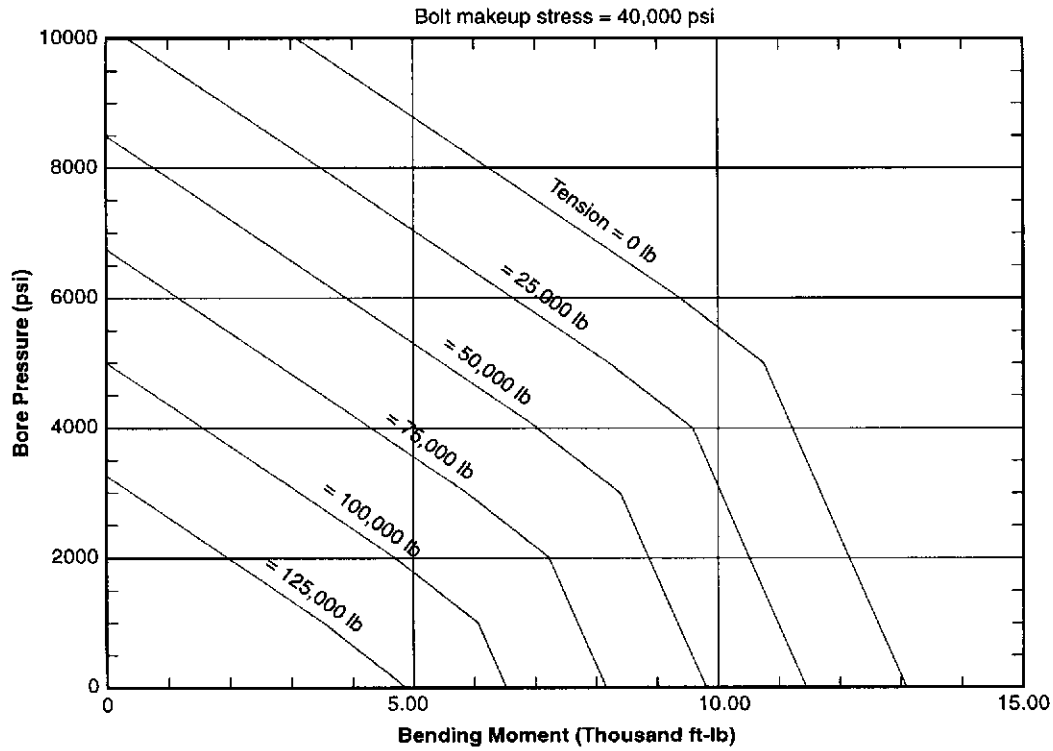


2 1/16 IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

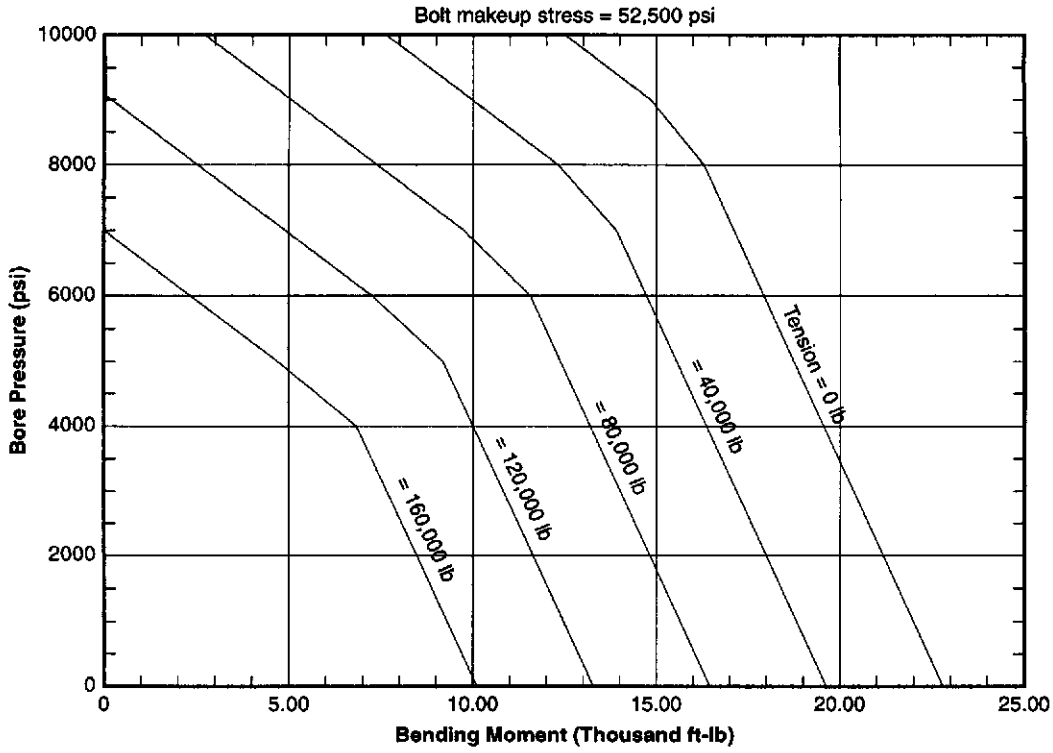


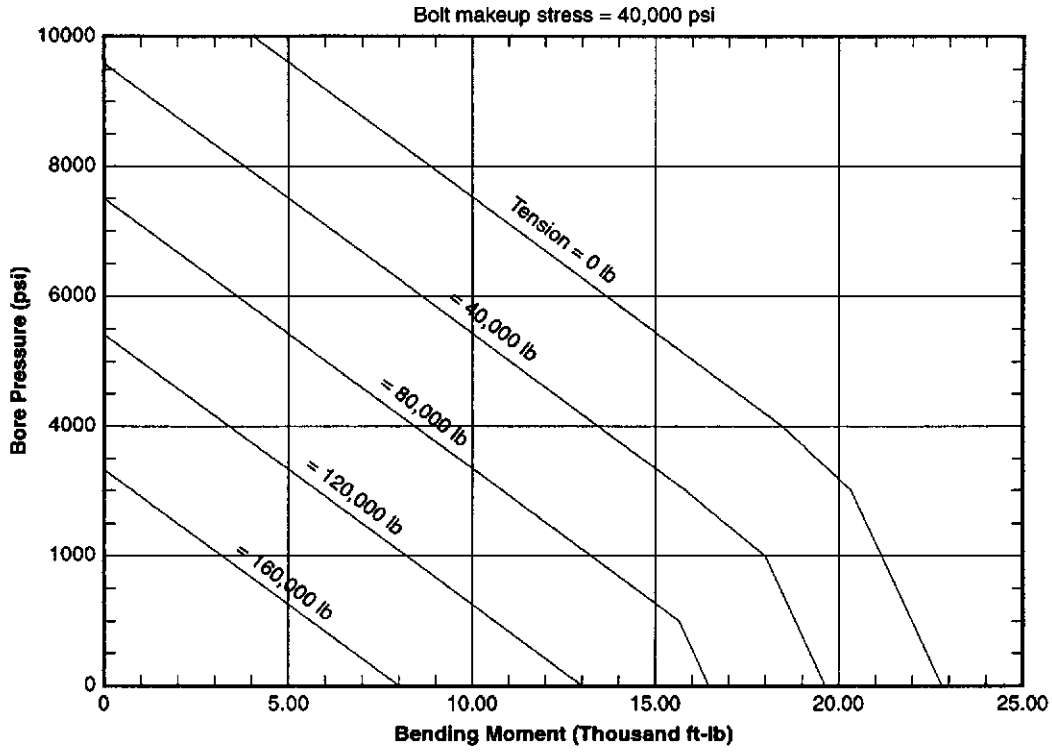


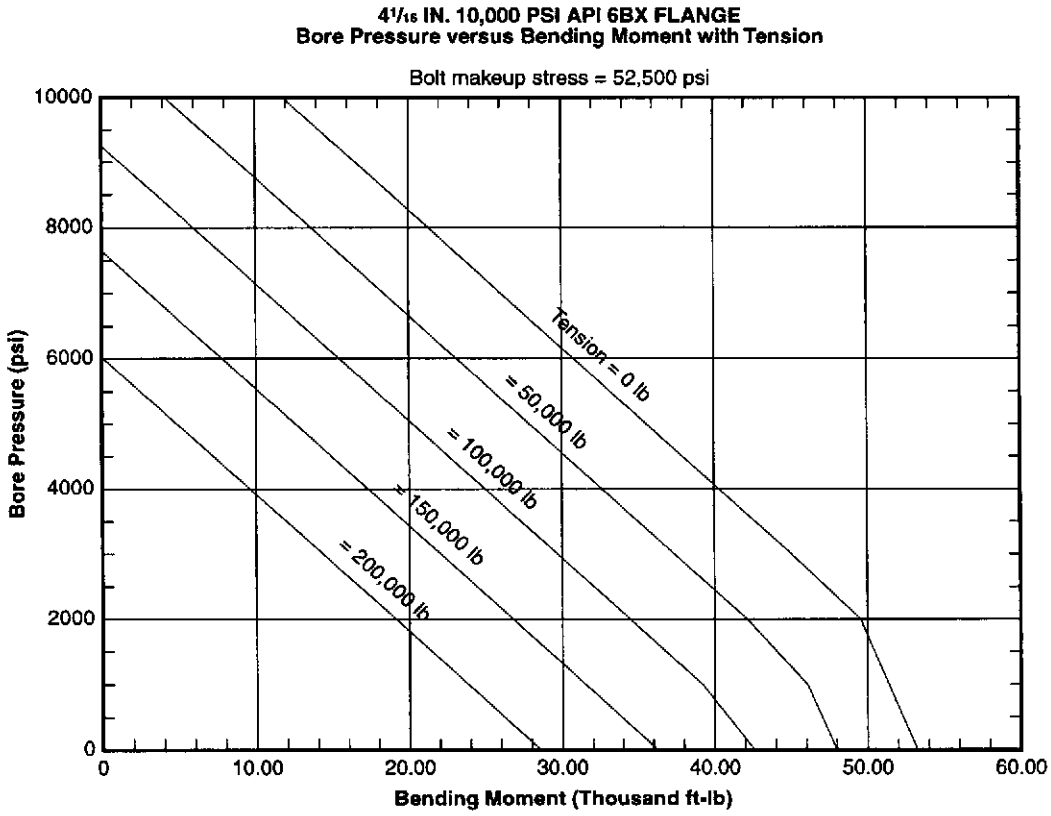


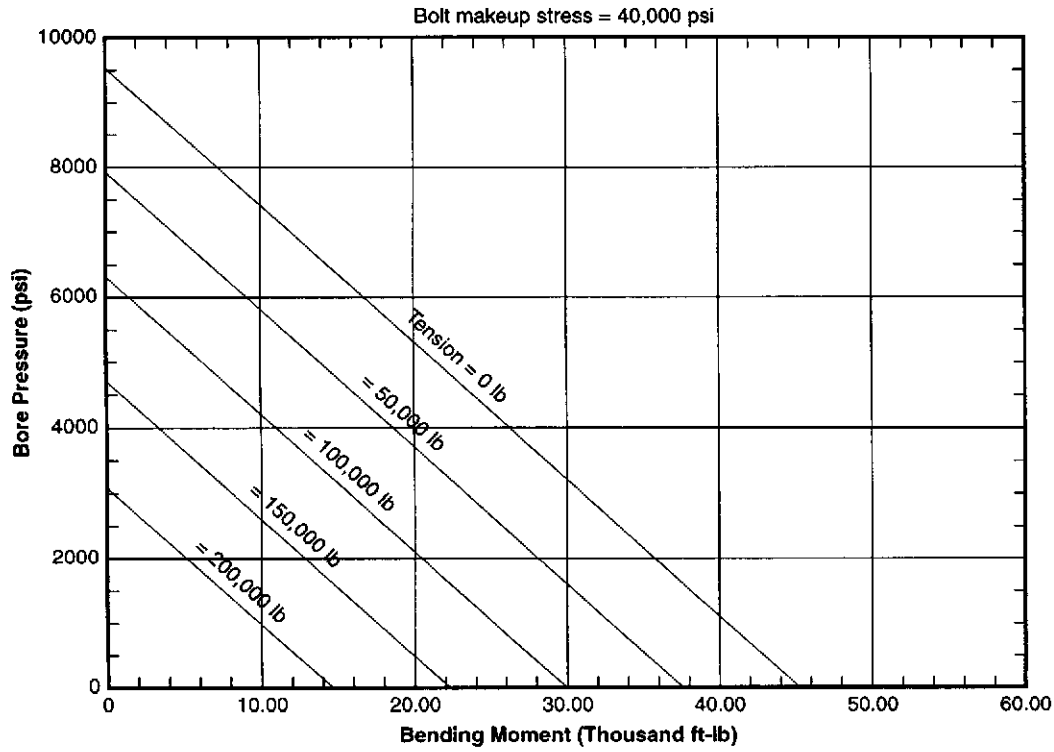


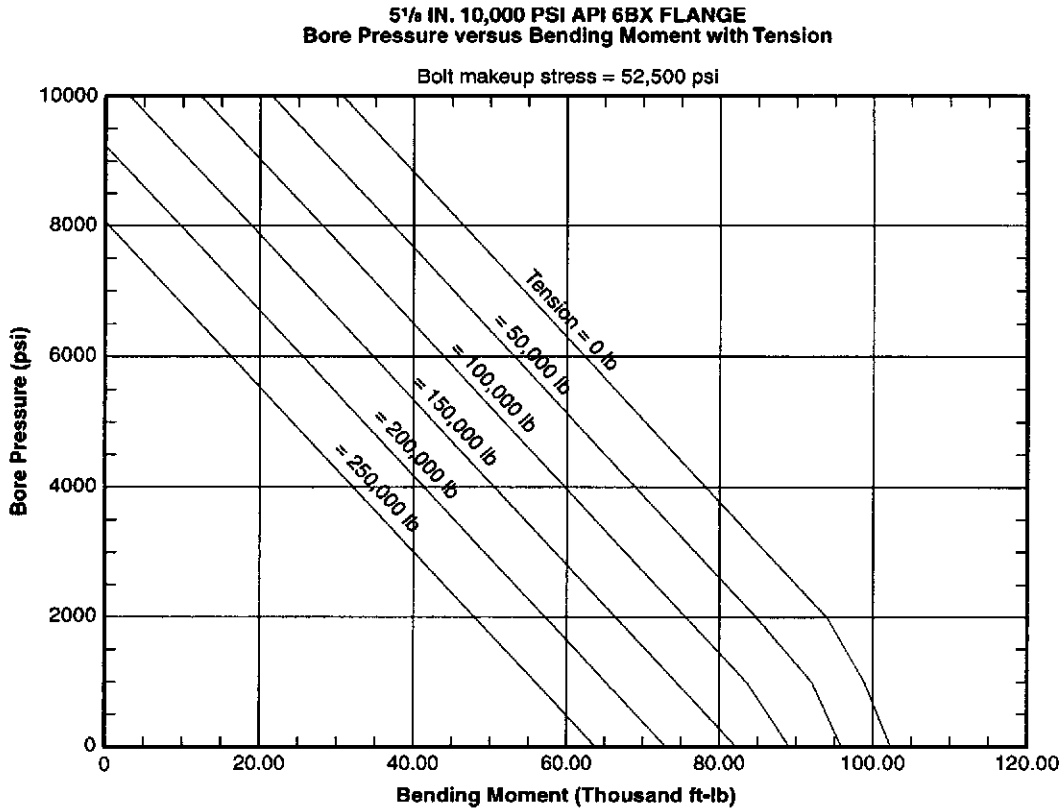
3 1/16 IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

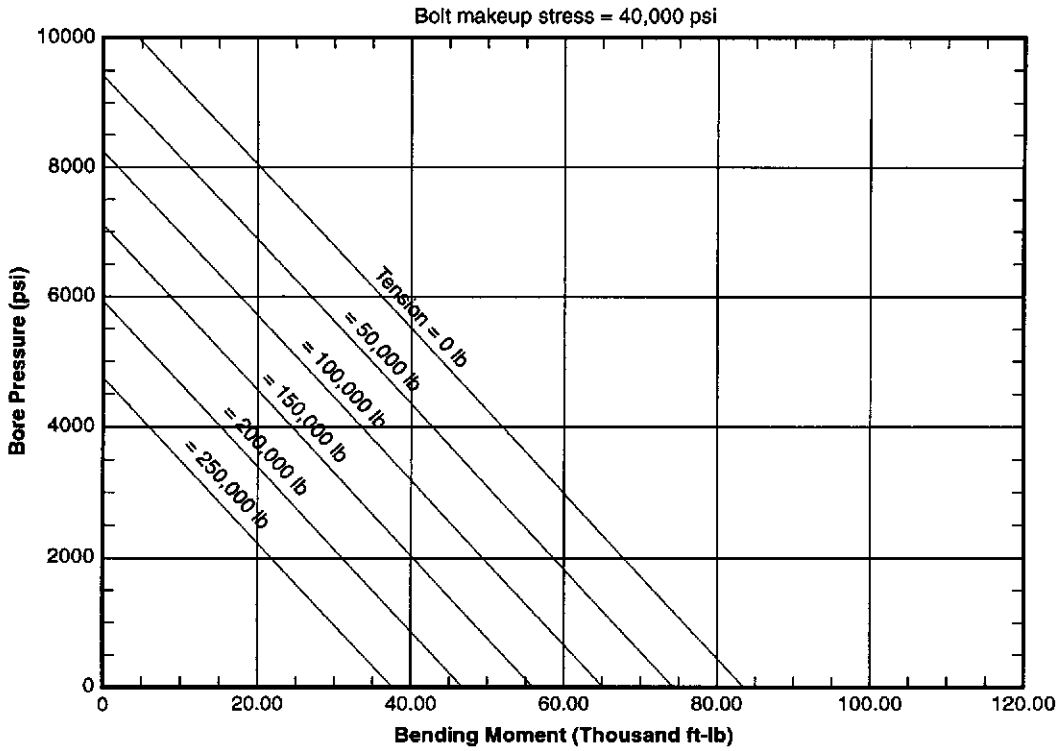




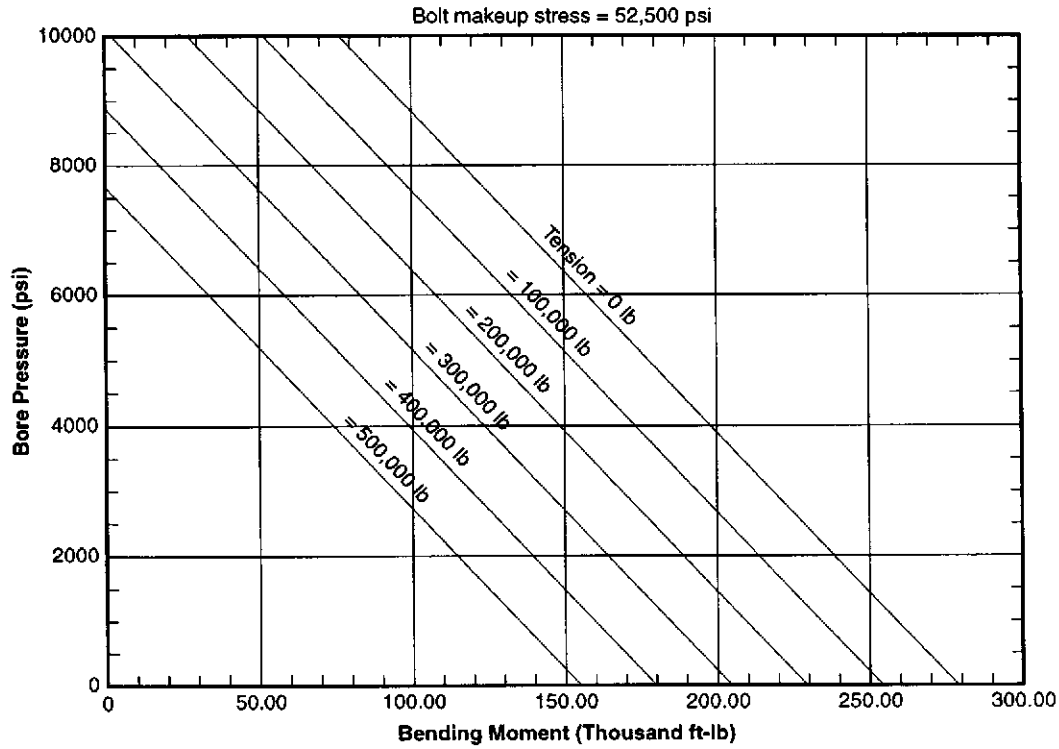


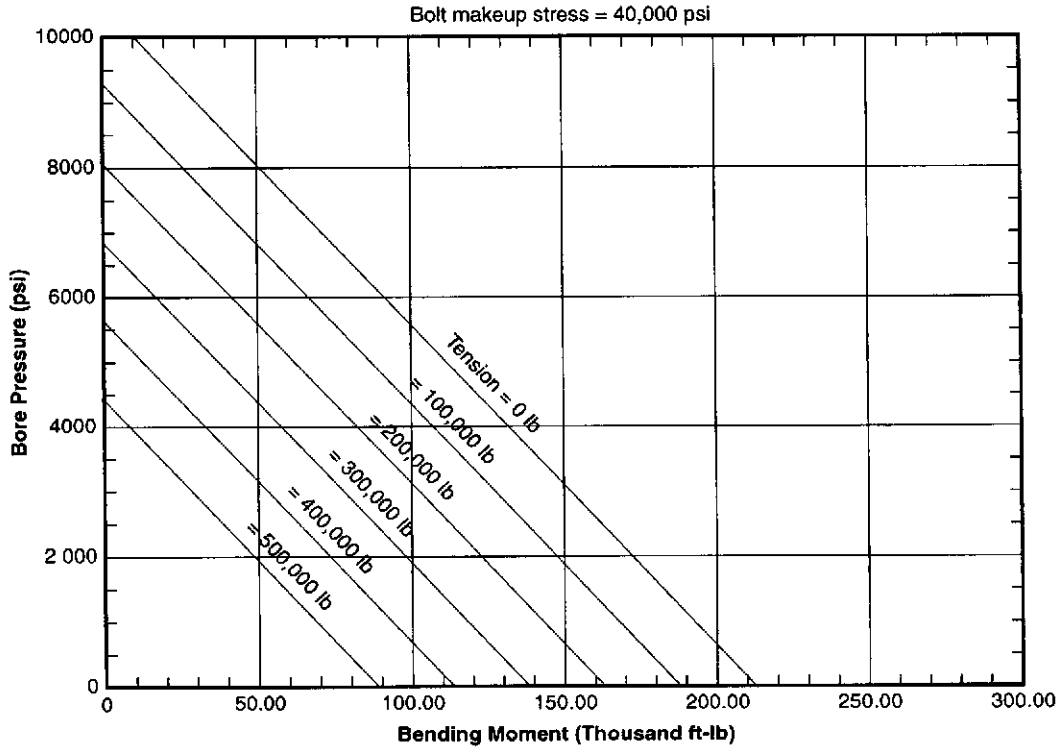




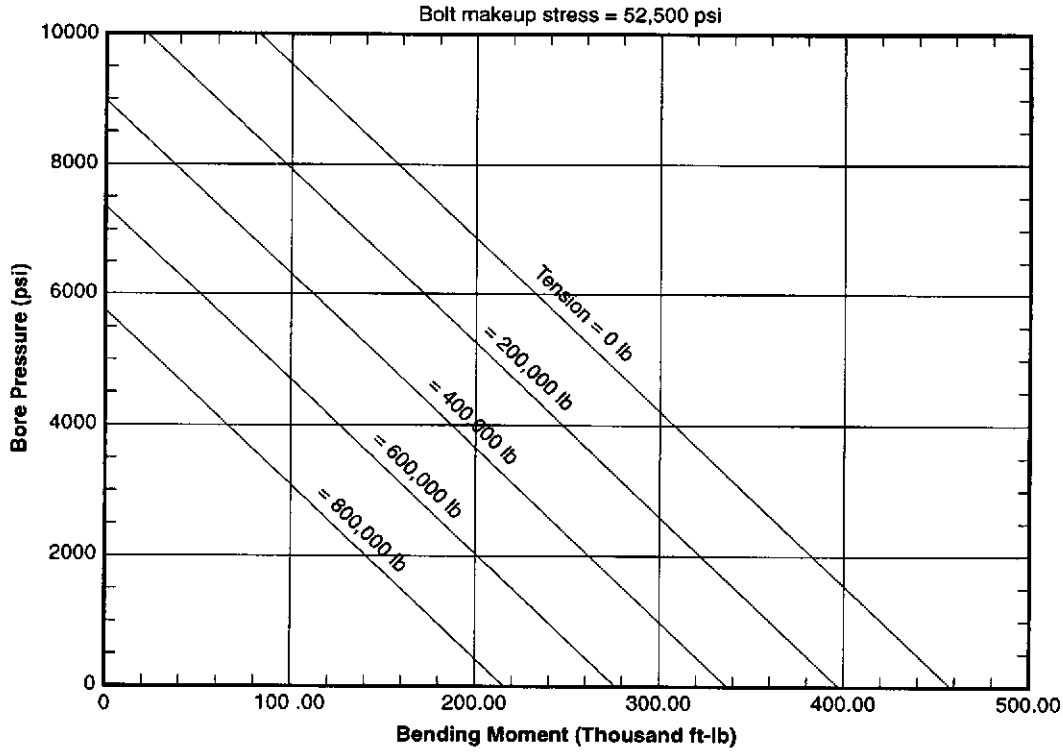


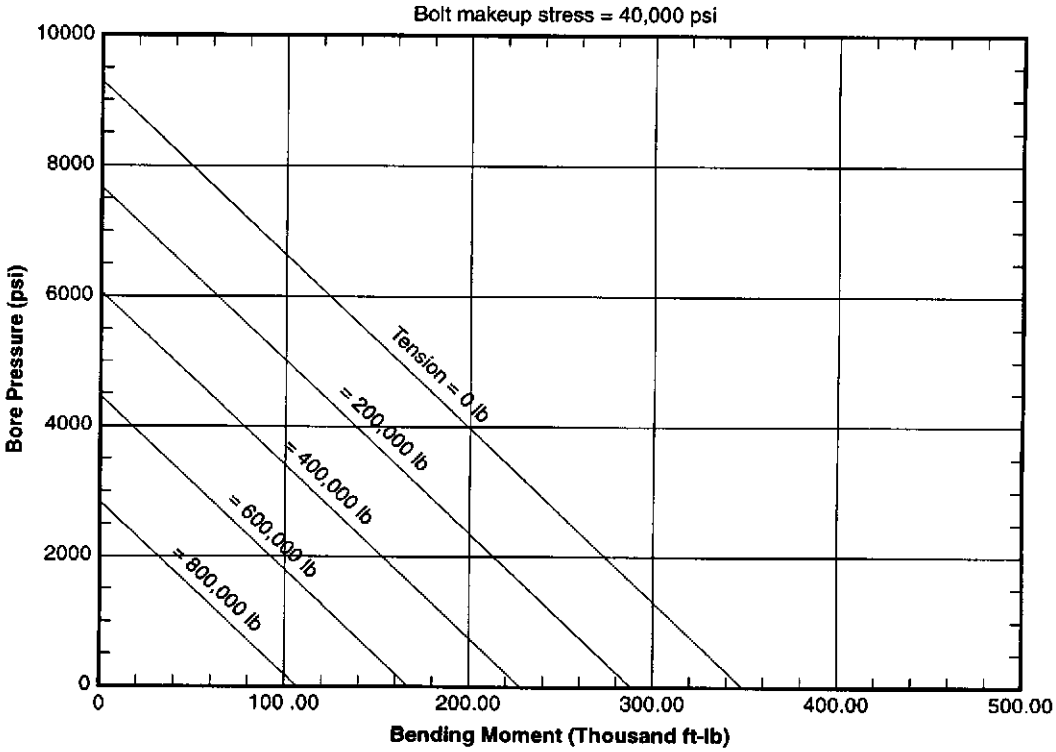
7 1/16 IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



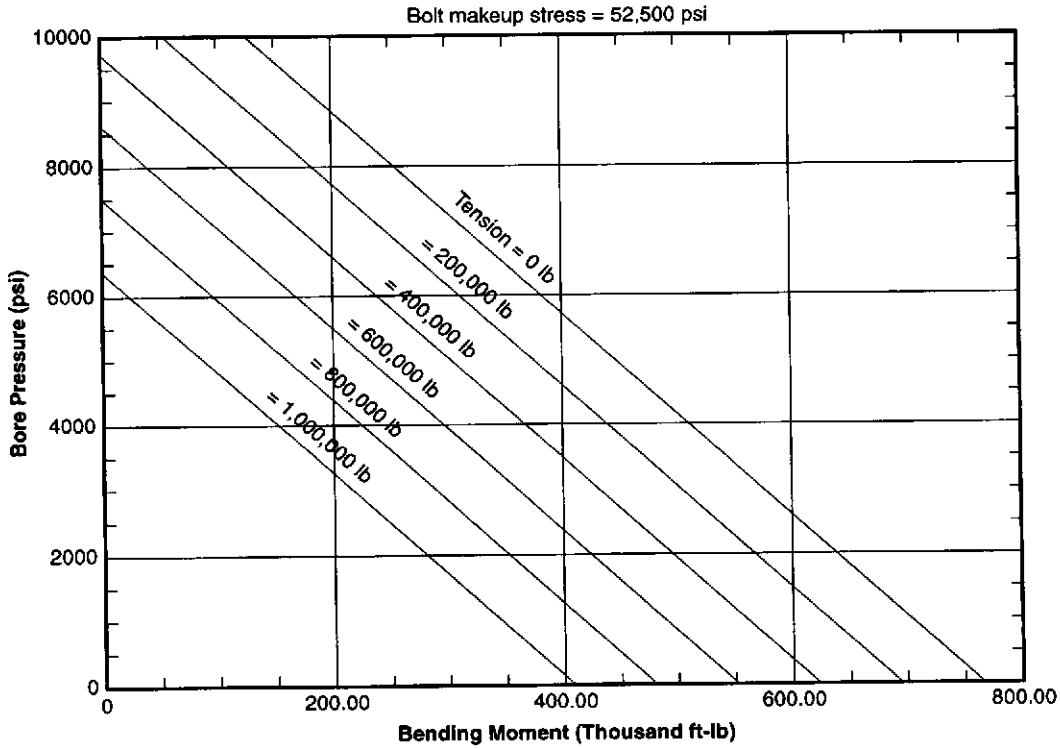


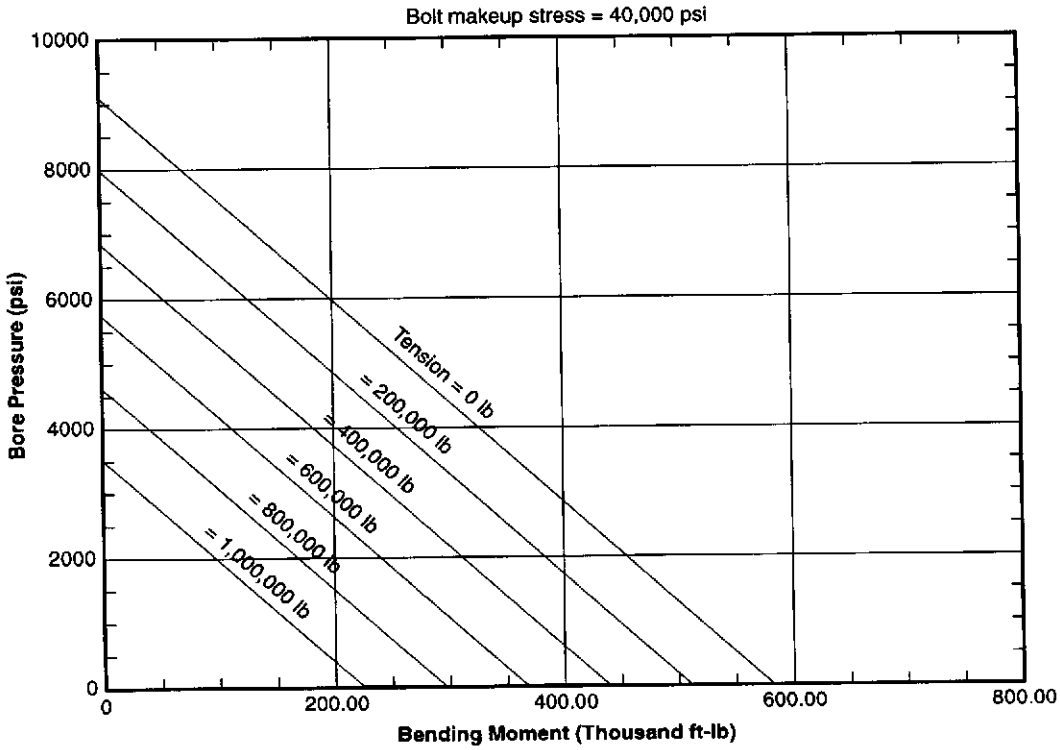
9 IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



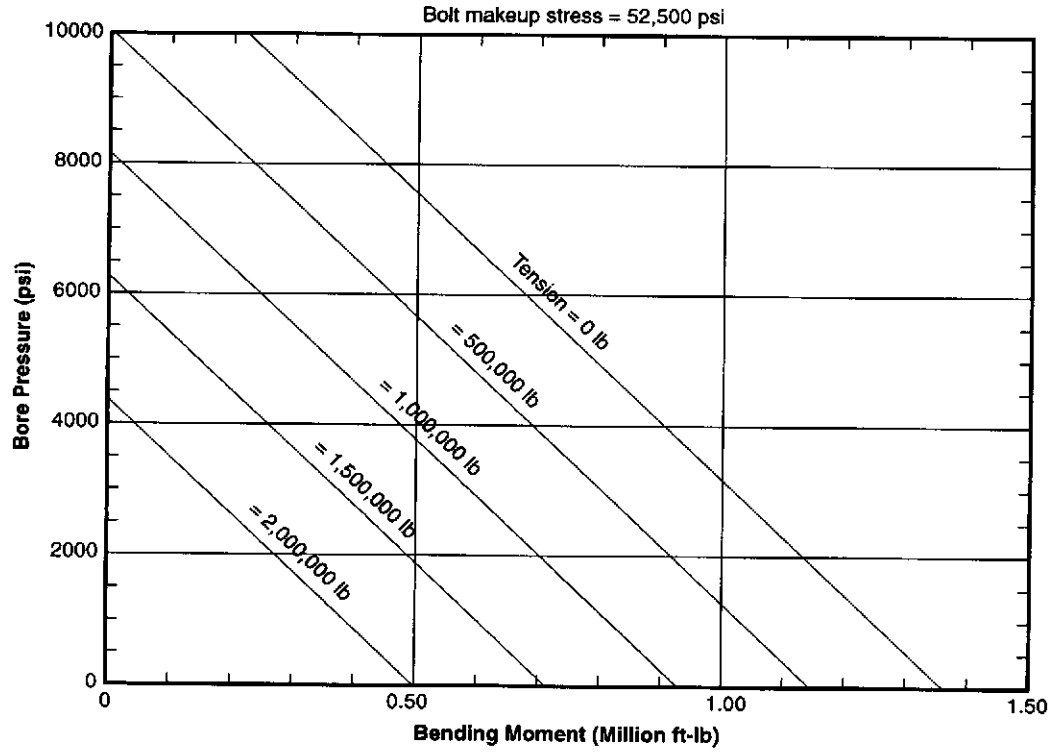


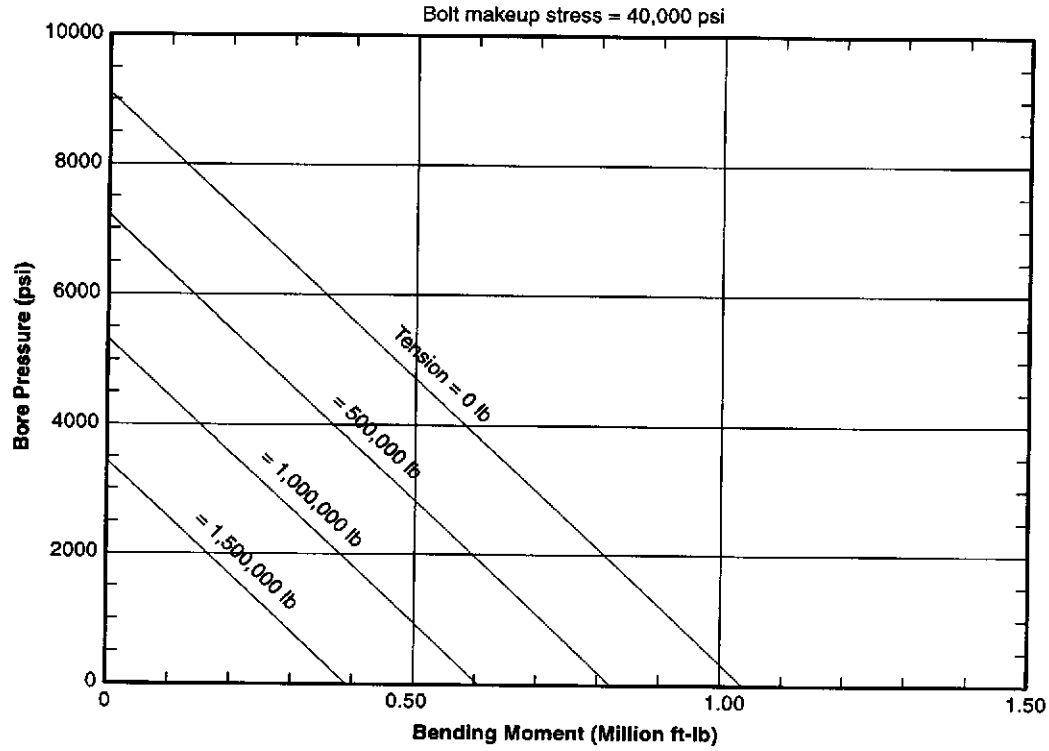
11 IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

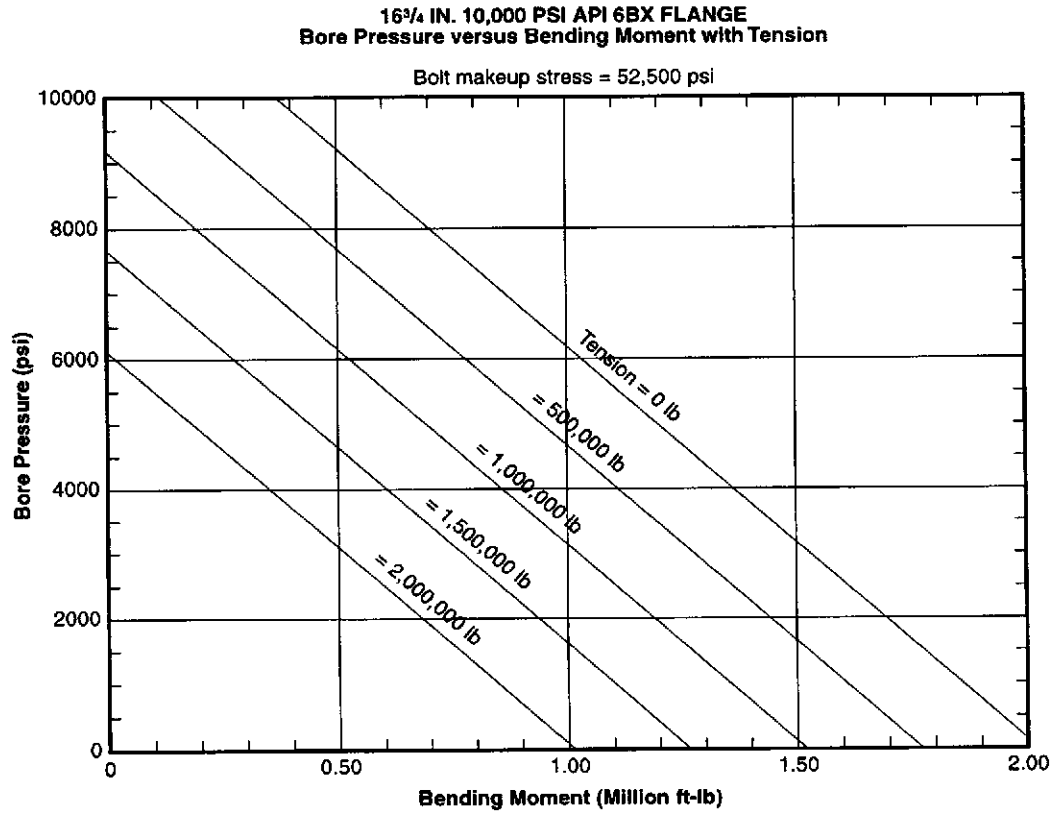


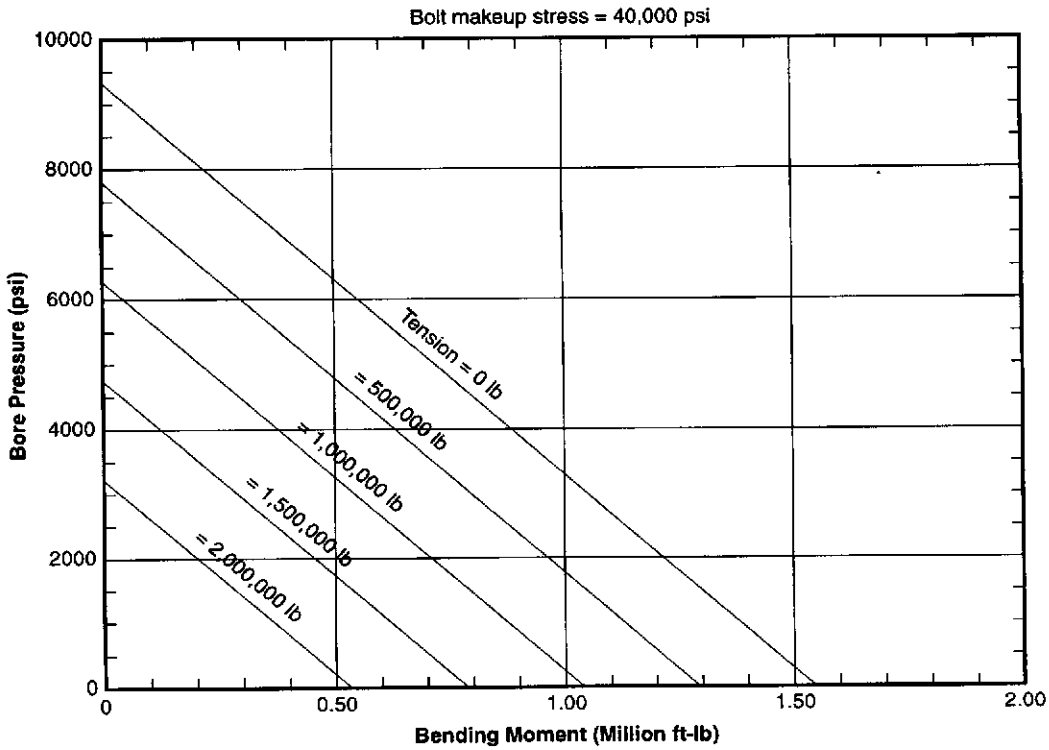


13⅝ IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

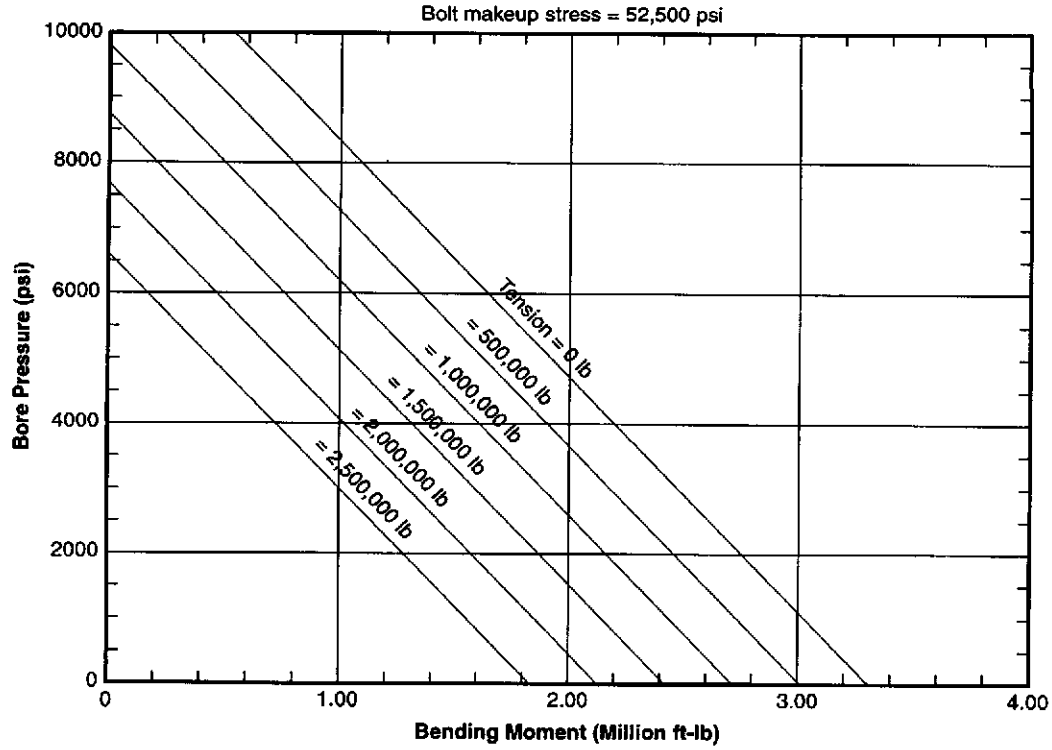


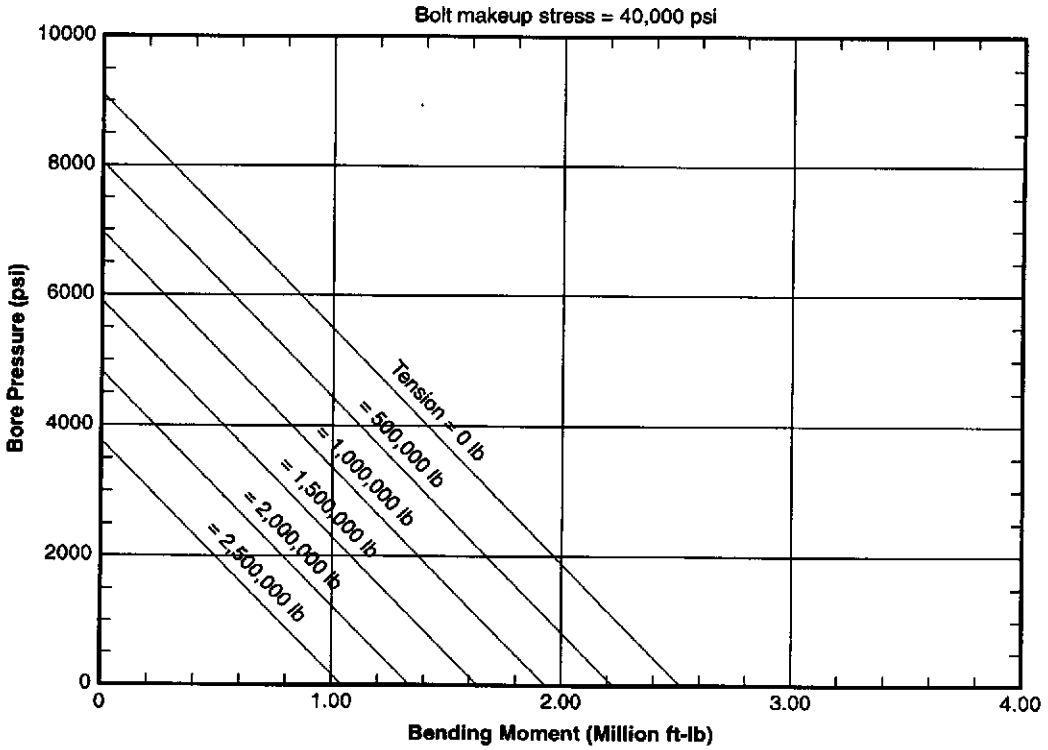




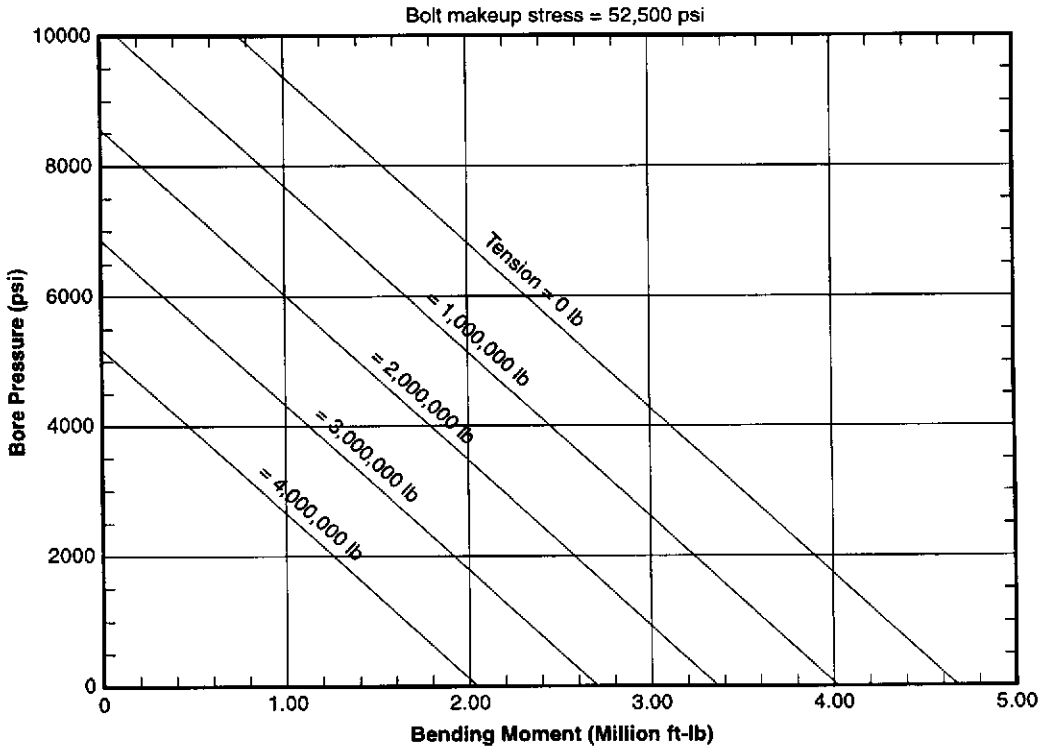


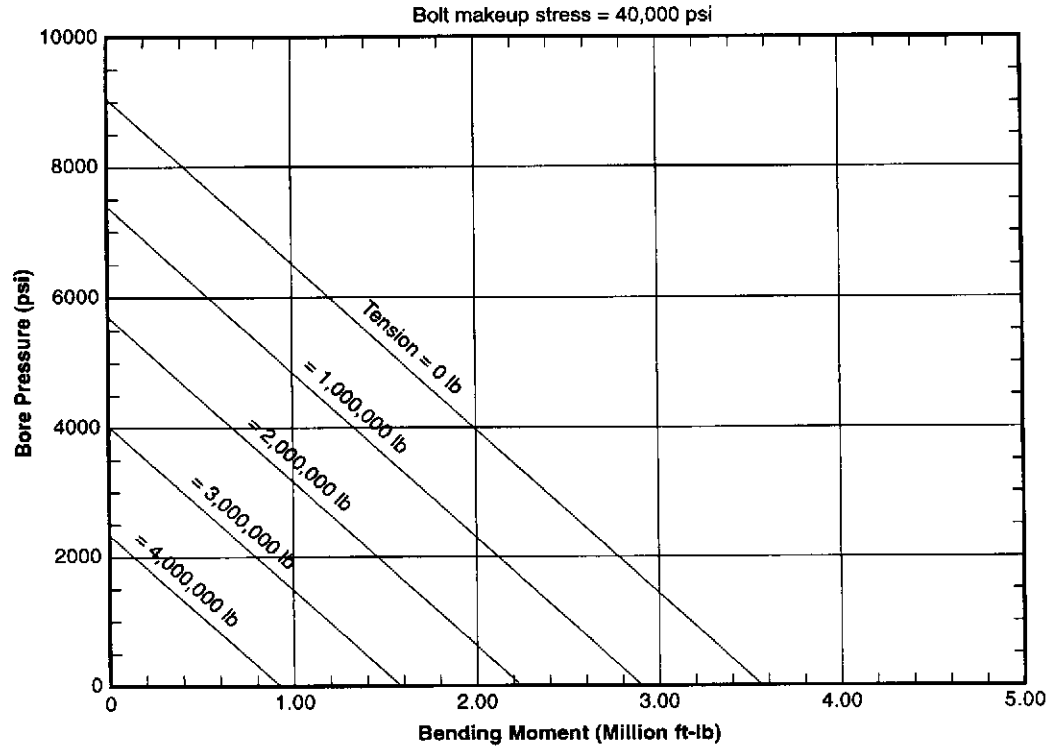
18¾ IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



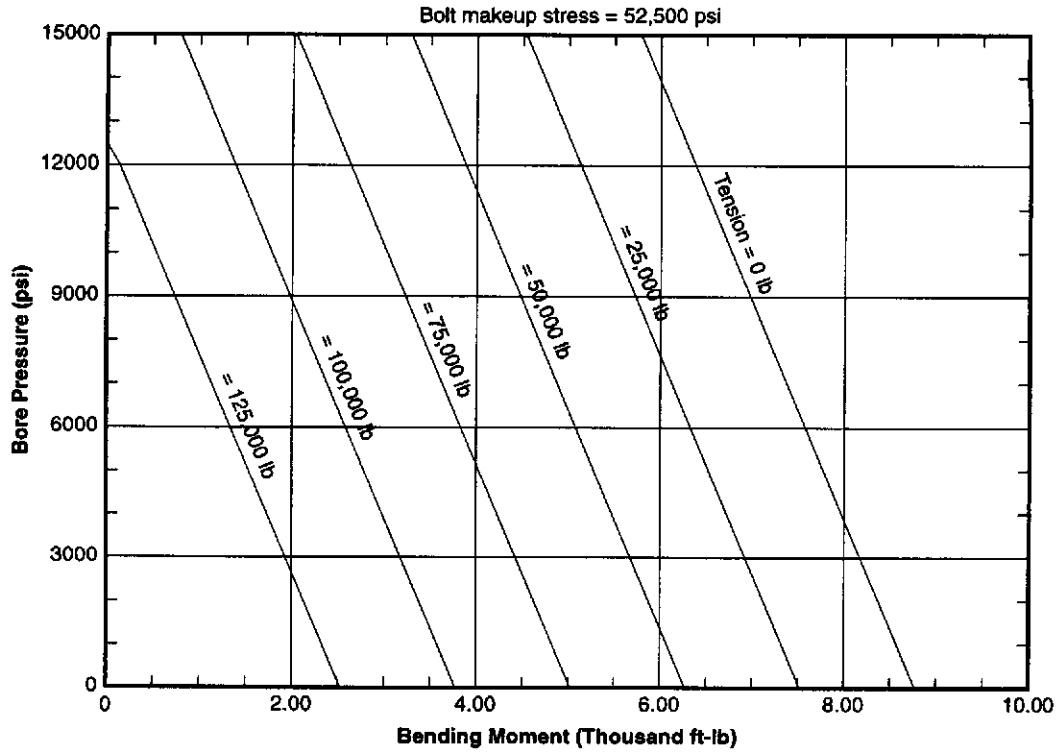


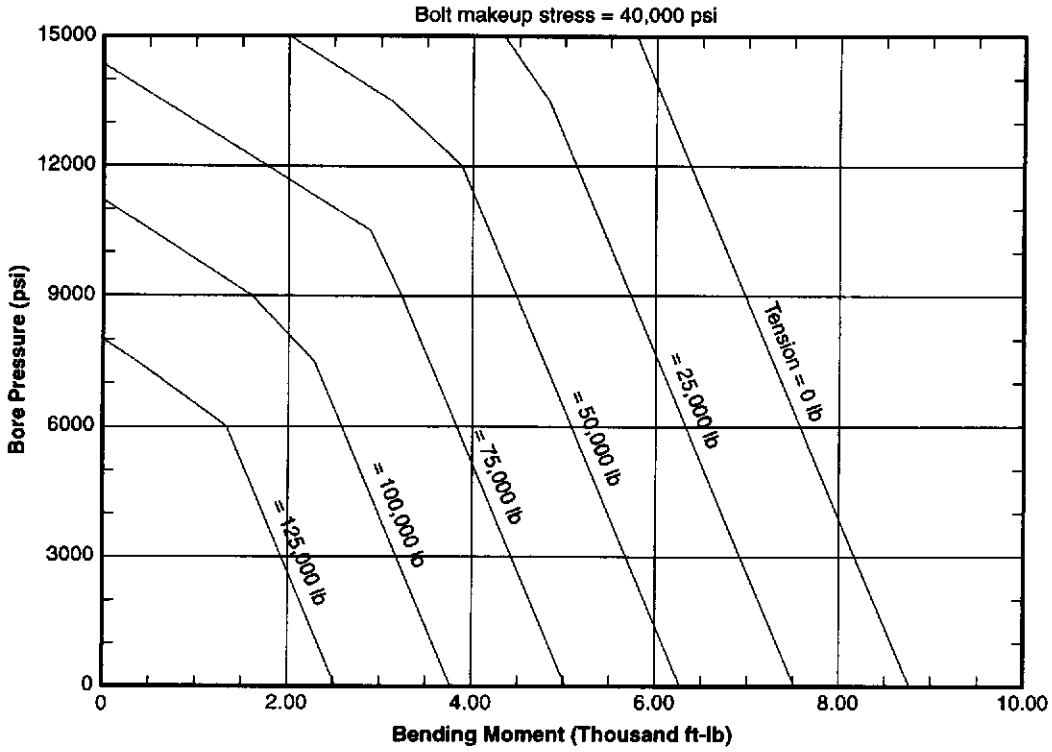
21¼ IN. 10,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

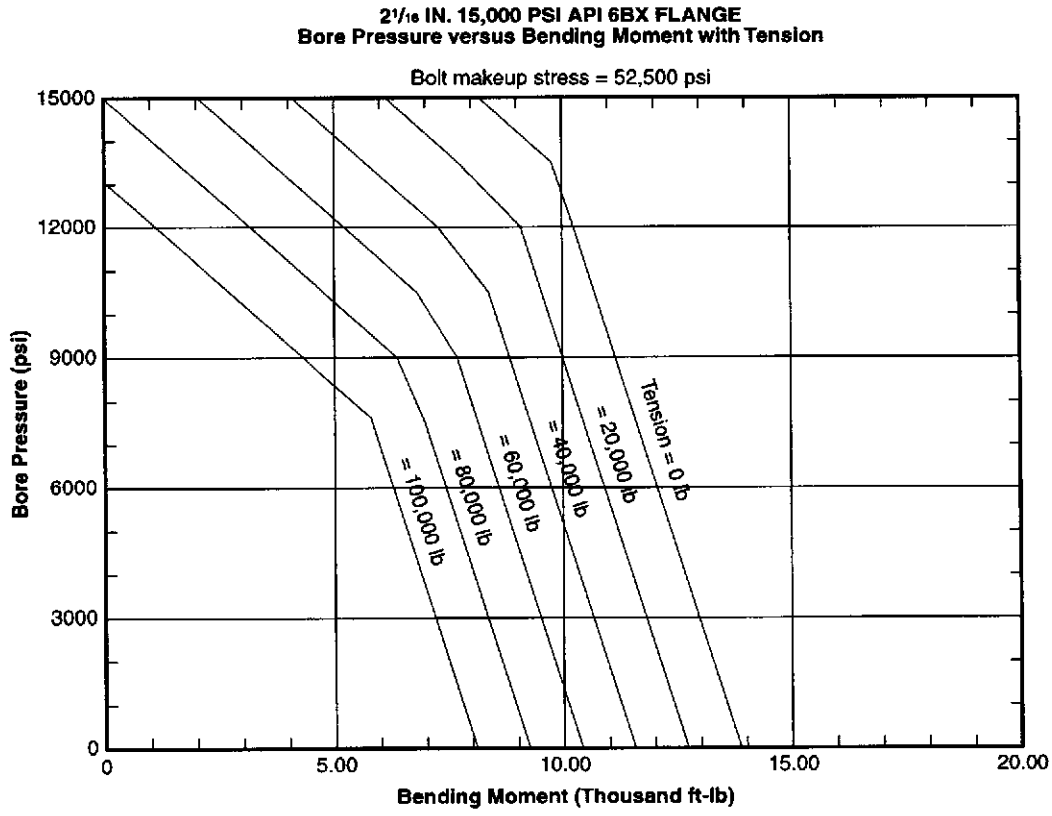


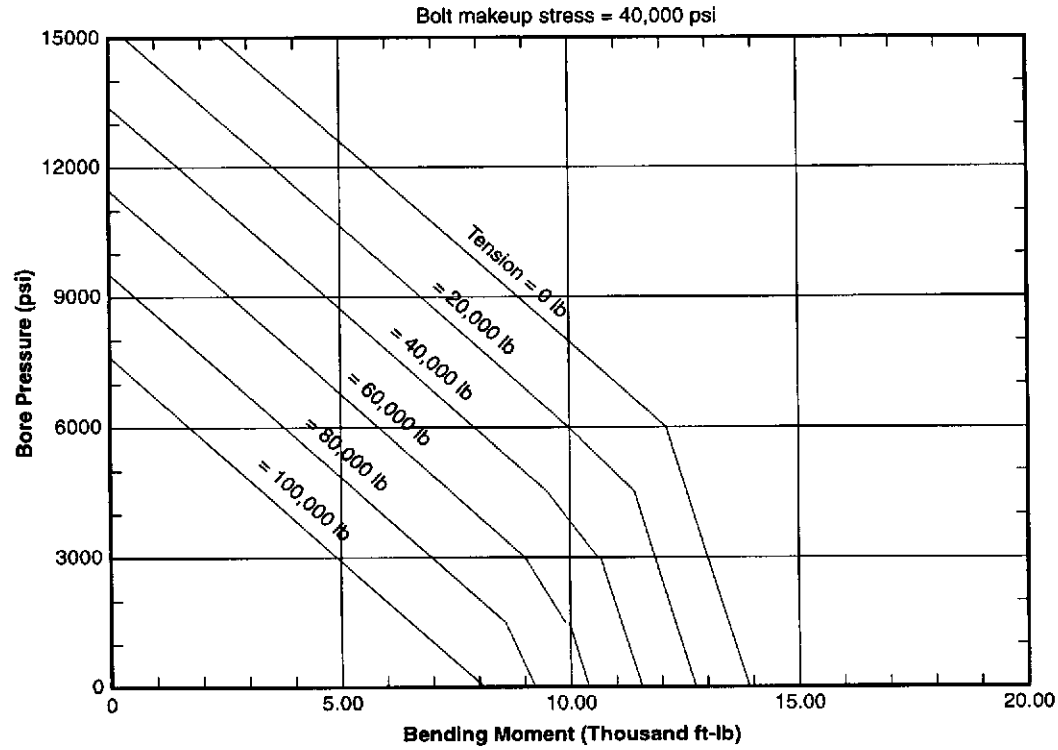


1 13/16 IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

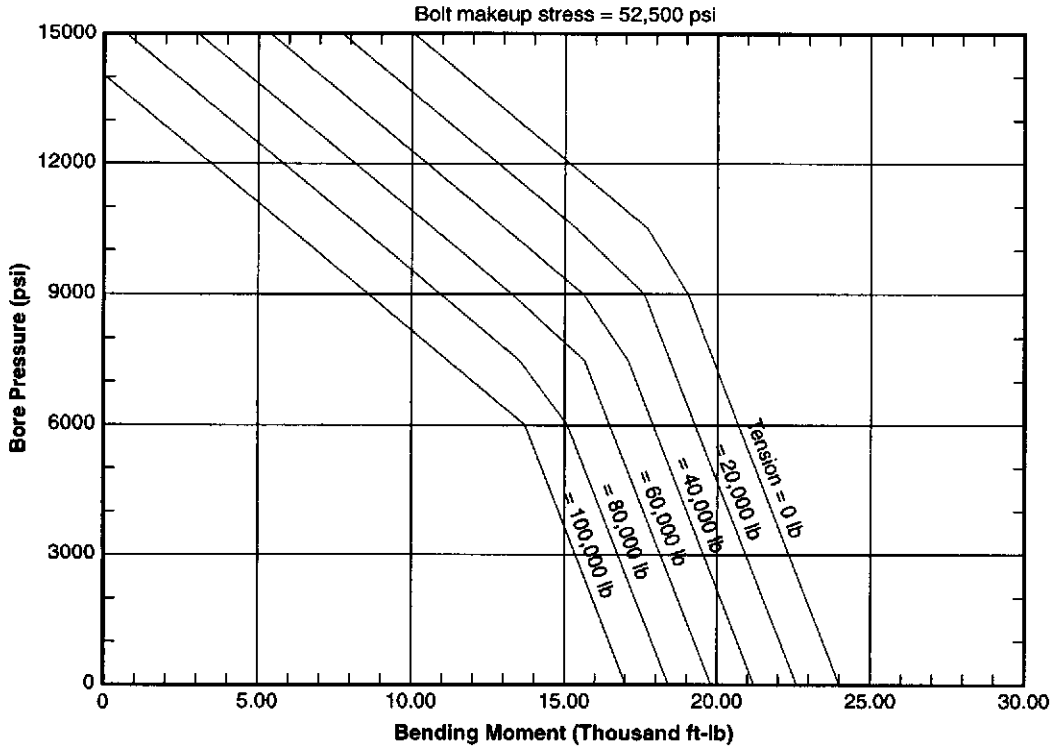


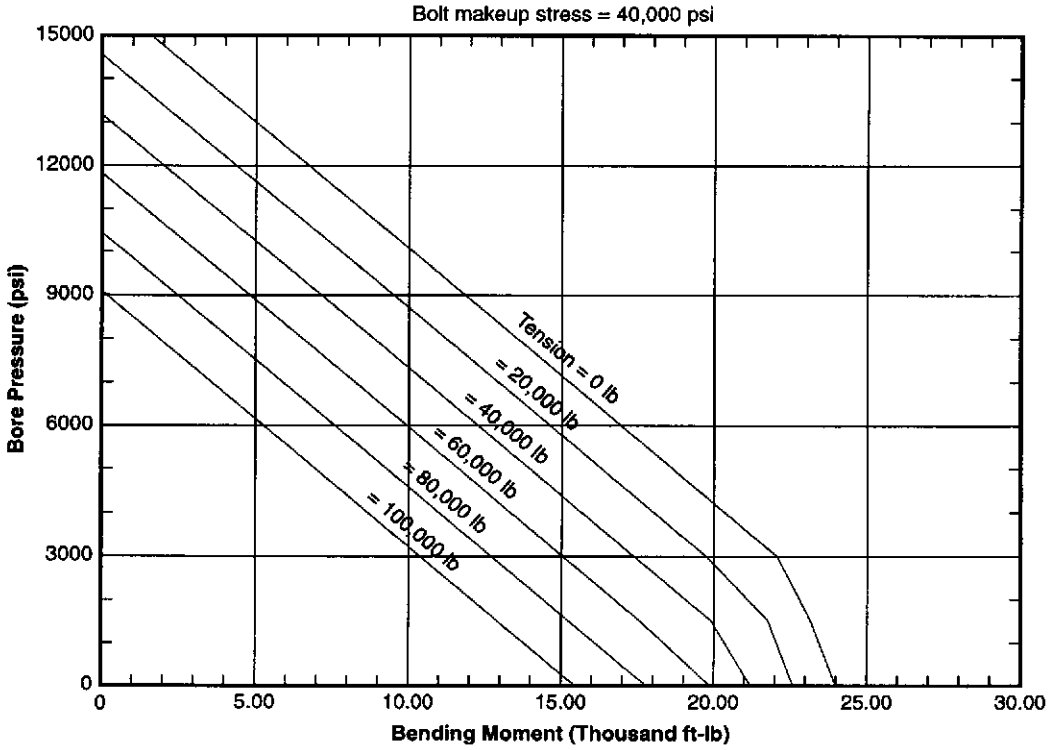


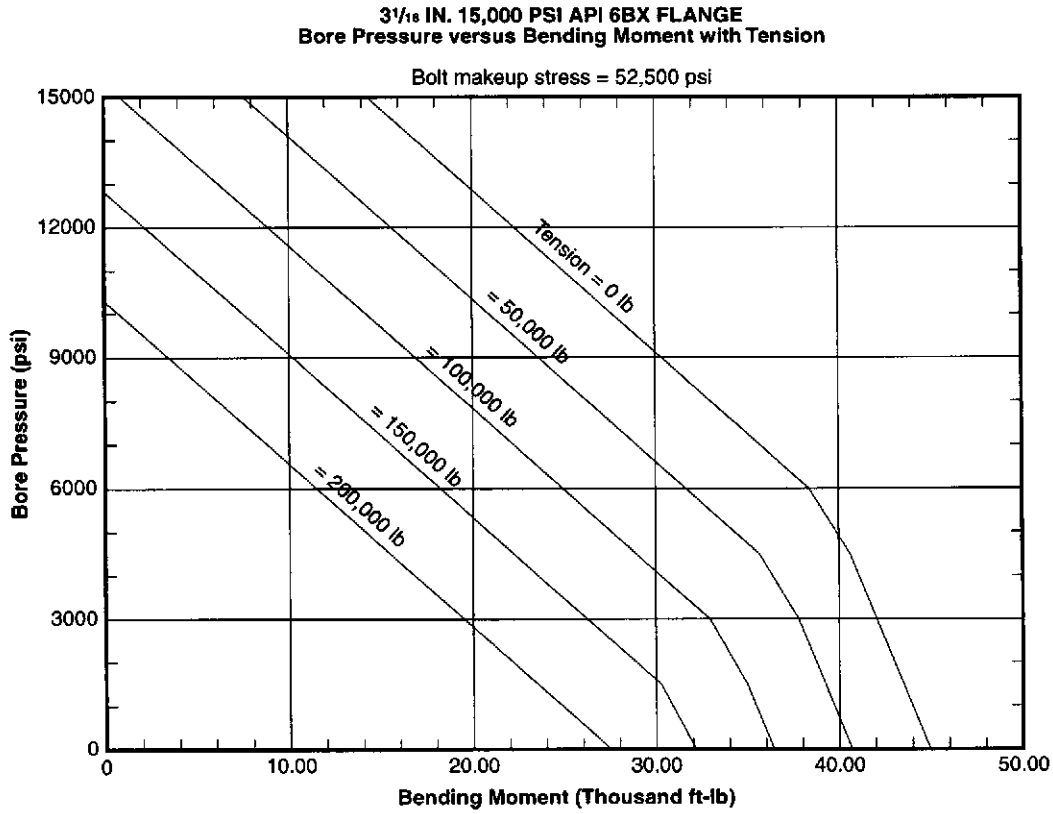


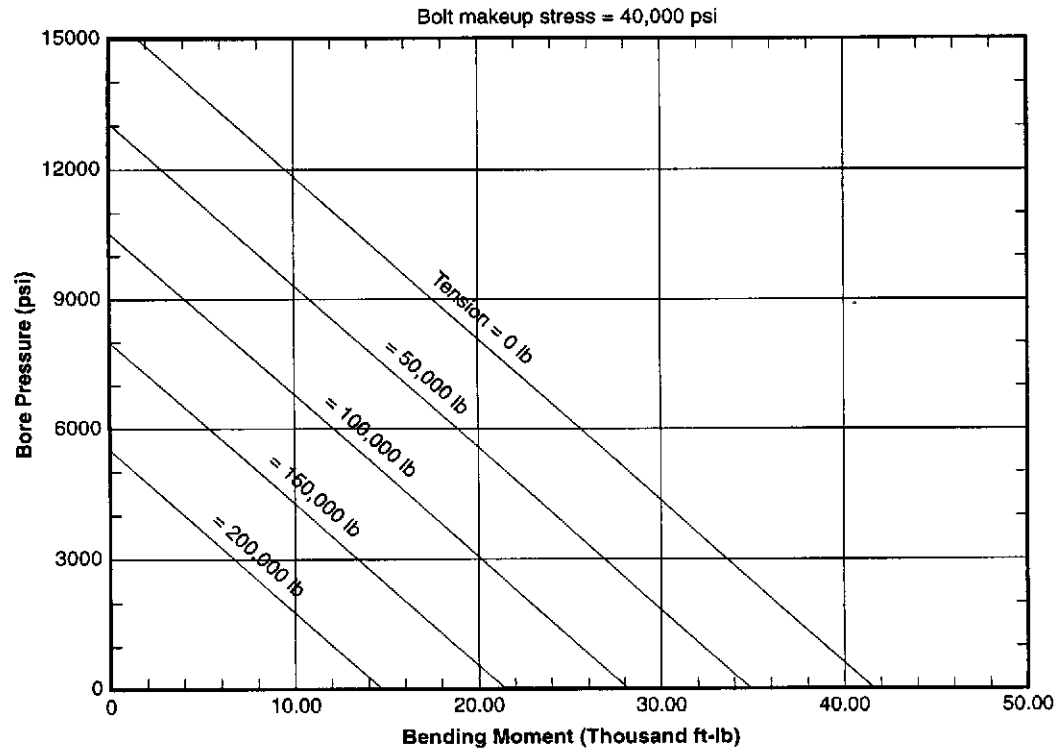


2⁹/₁₆ IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

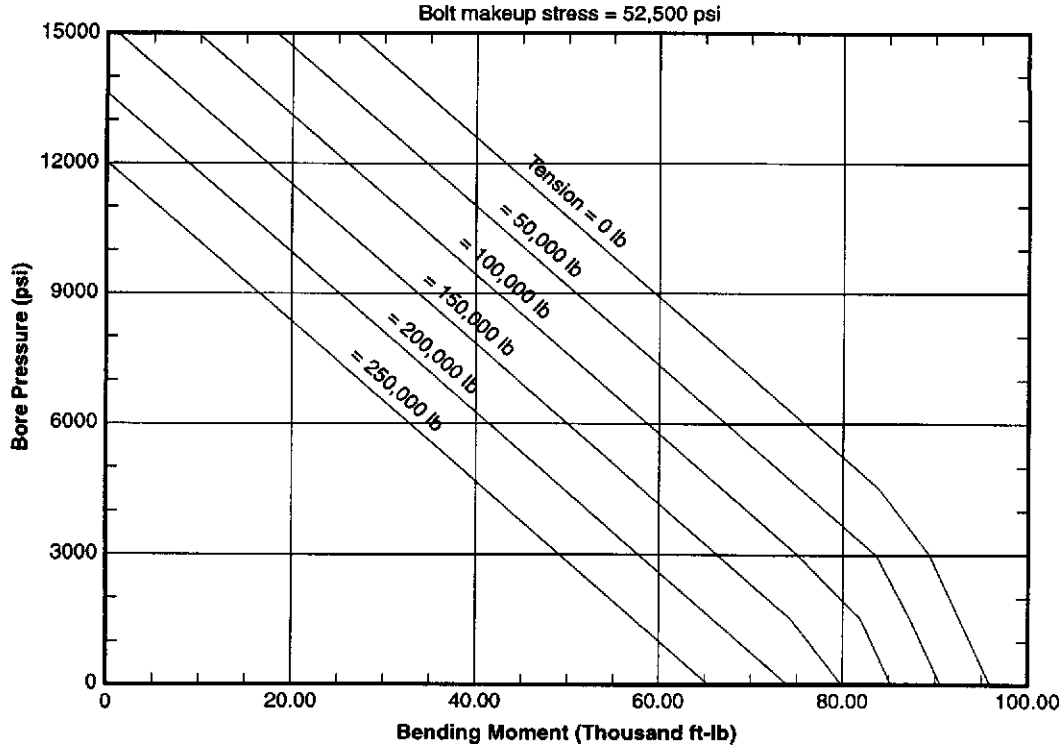


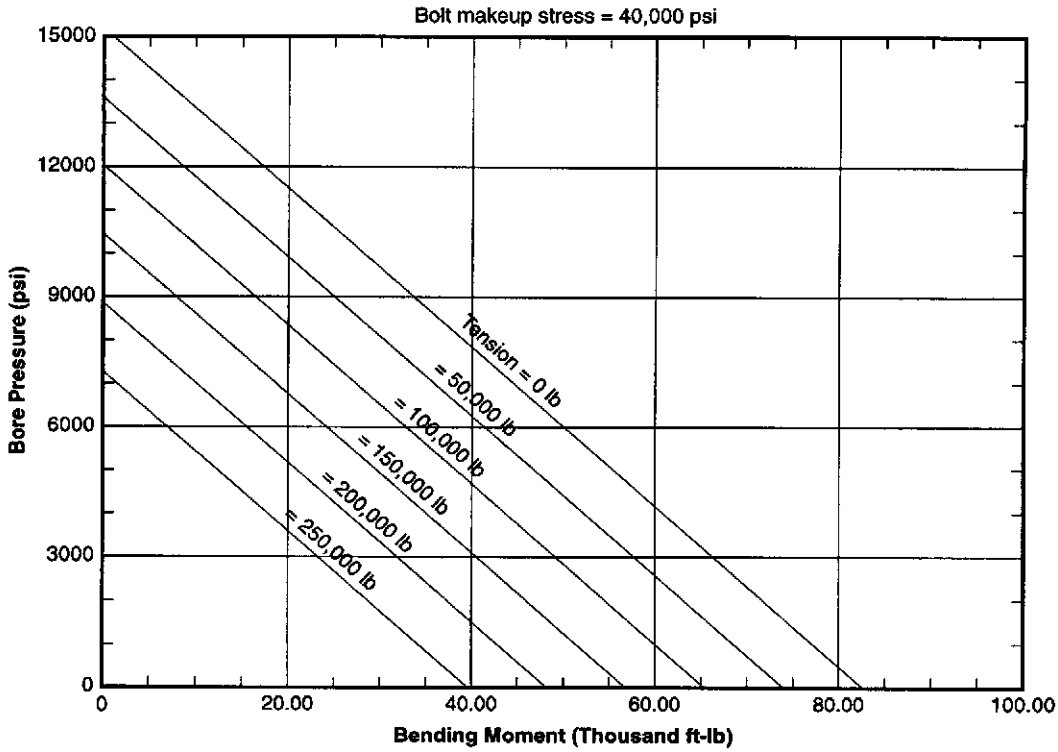




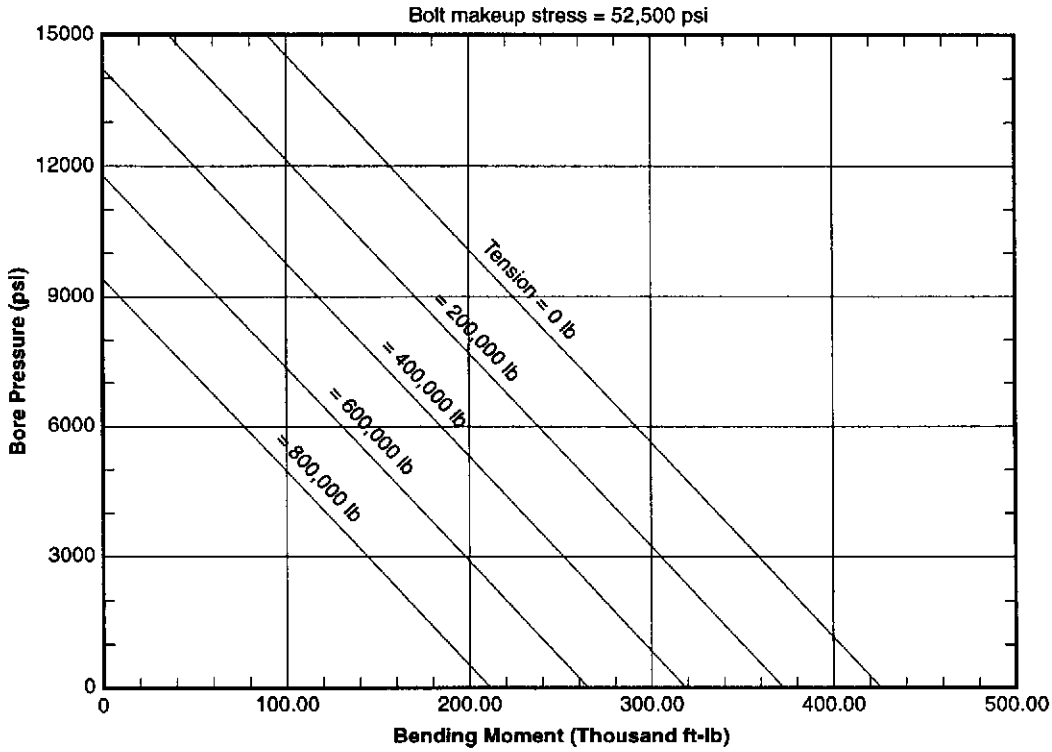


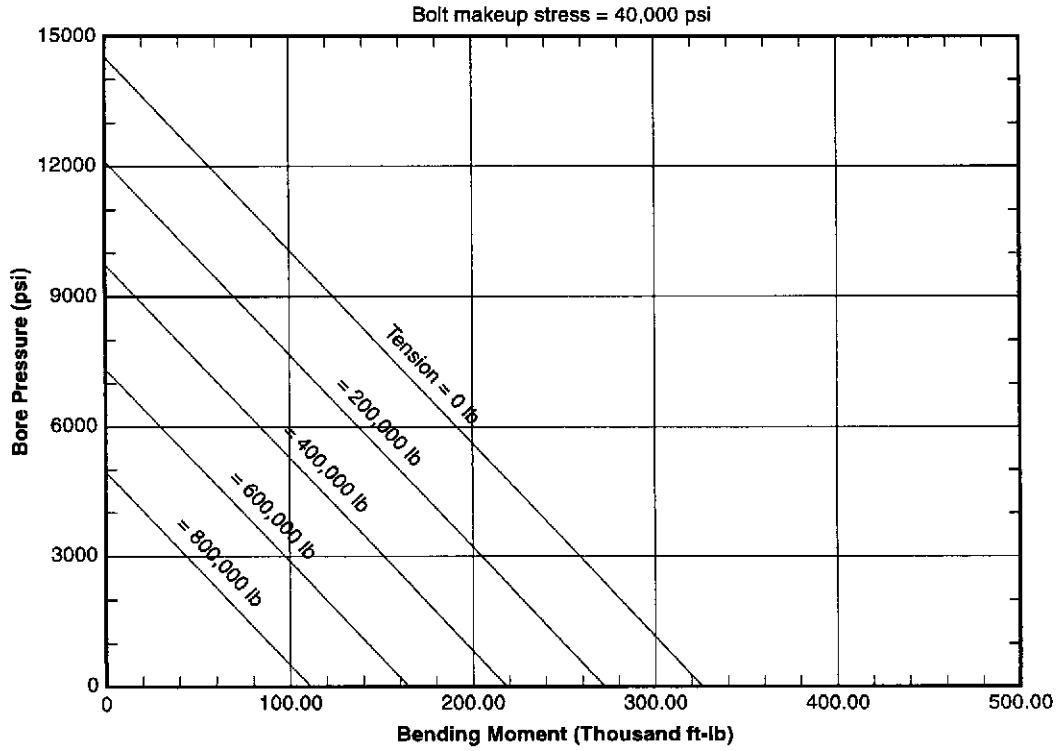
4 1/16 IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



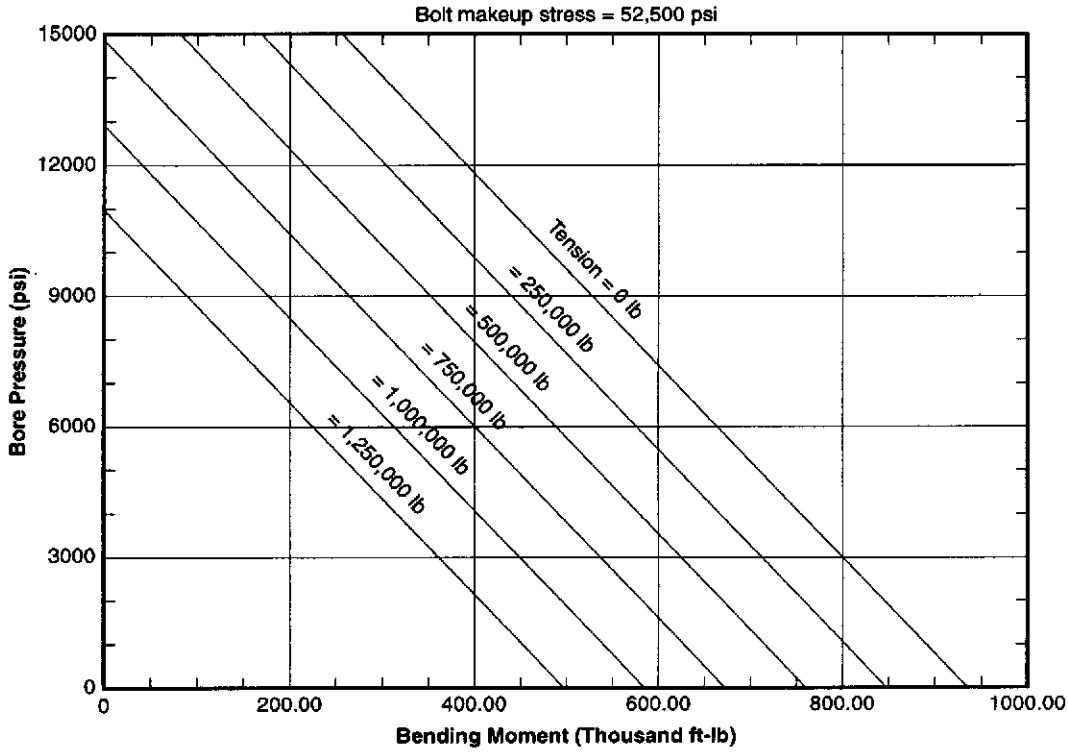


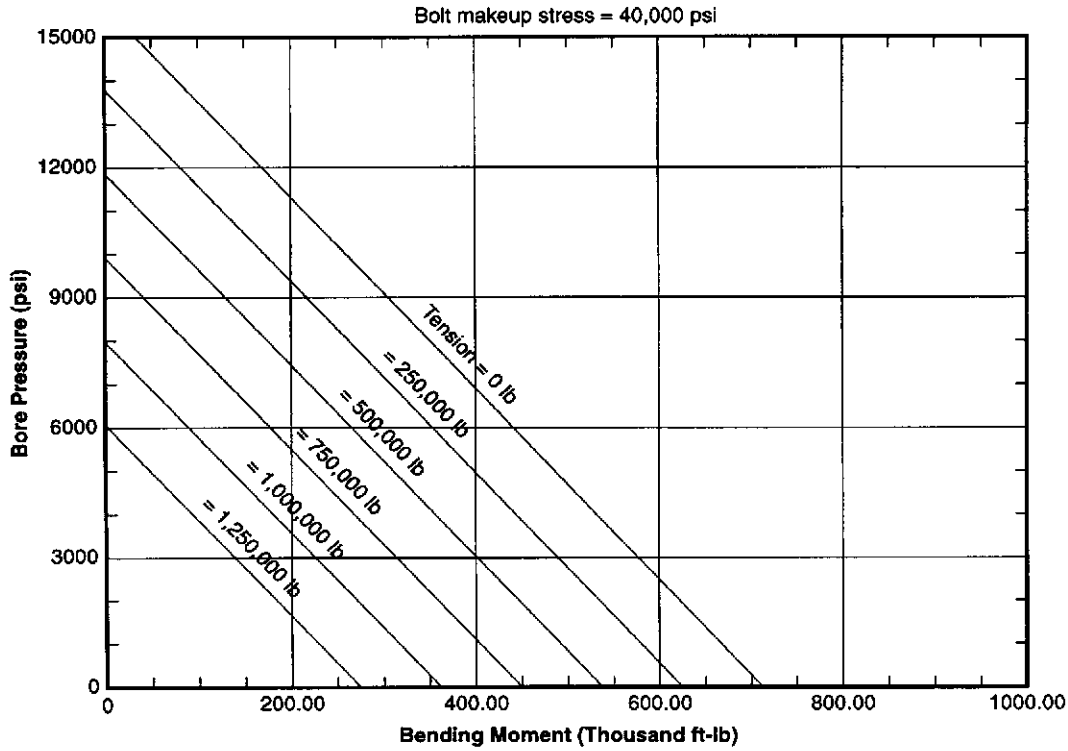
7 1/16 IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



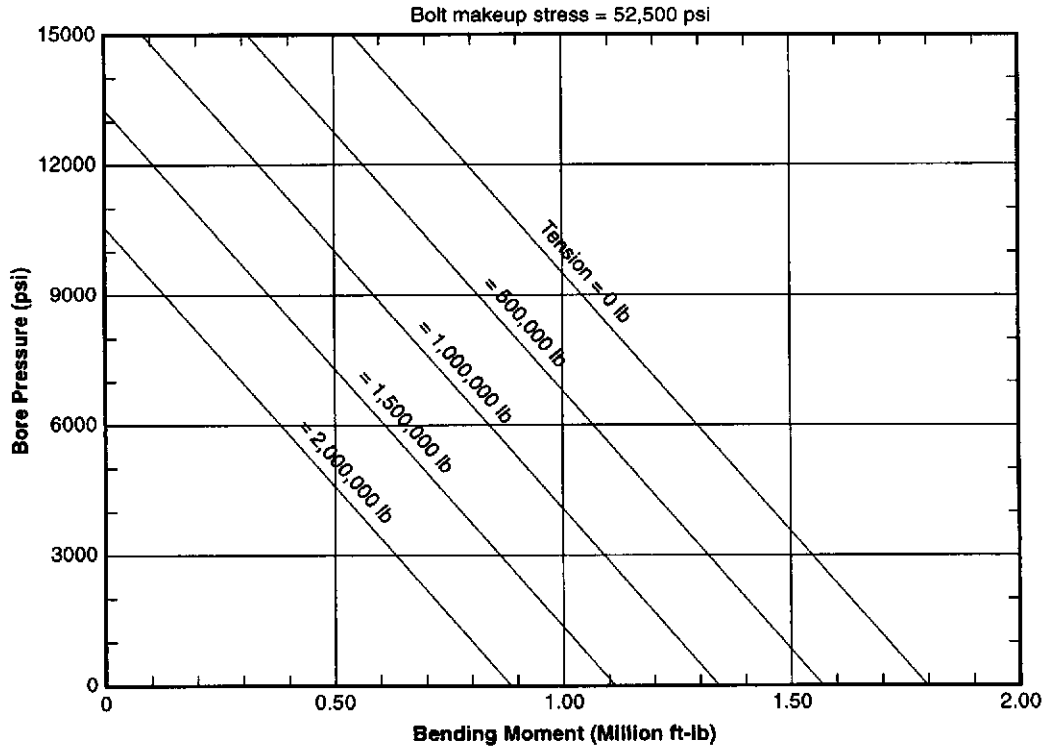


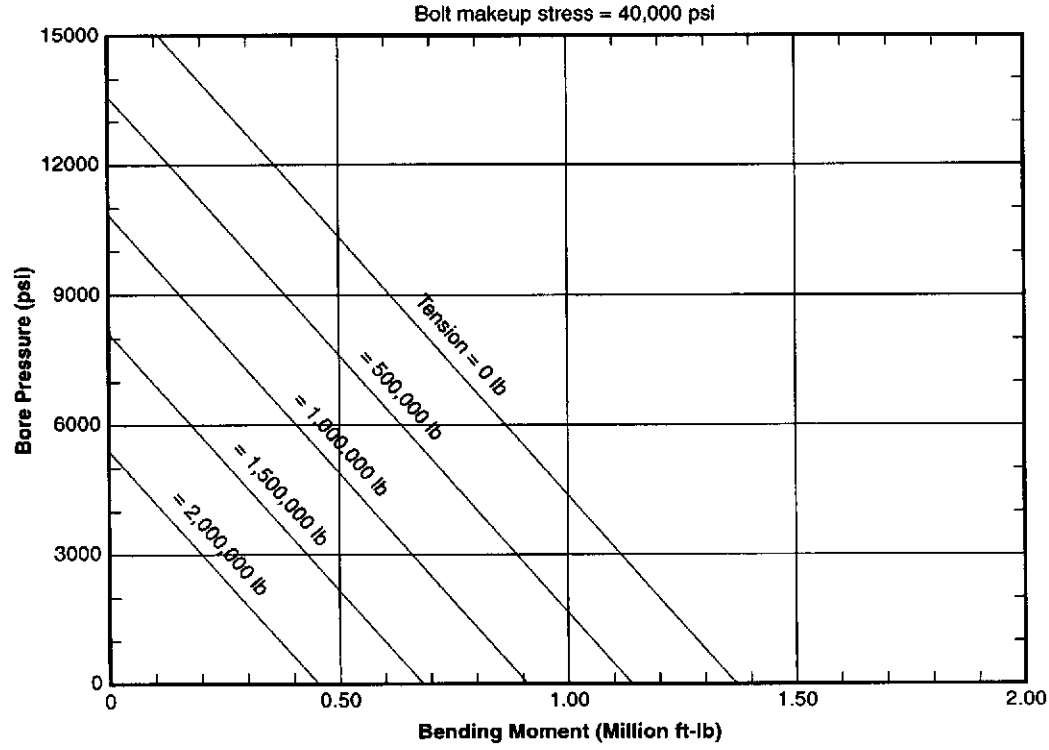
9 IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



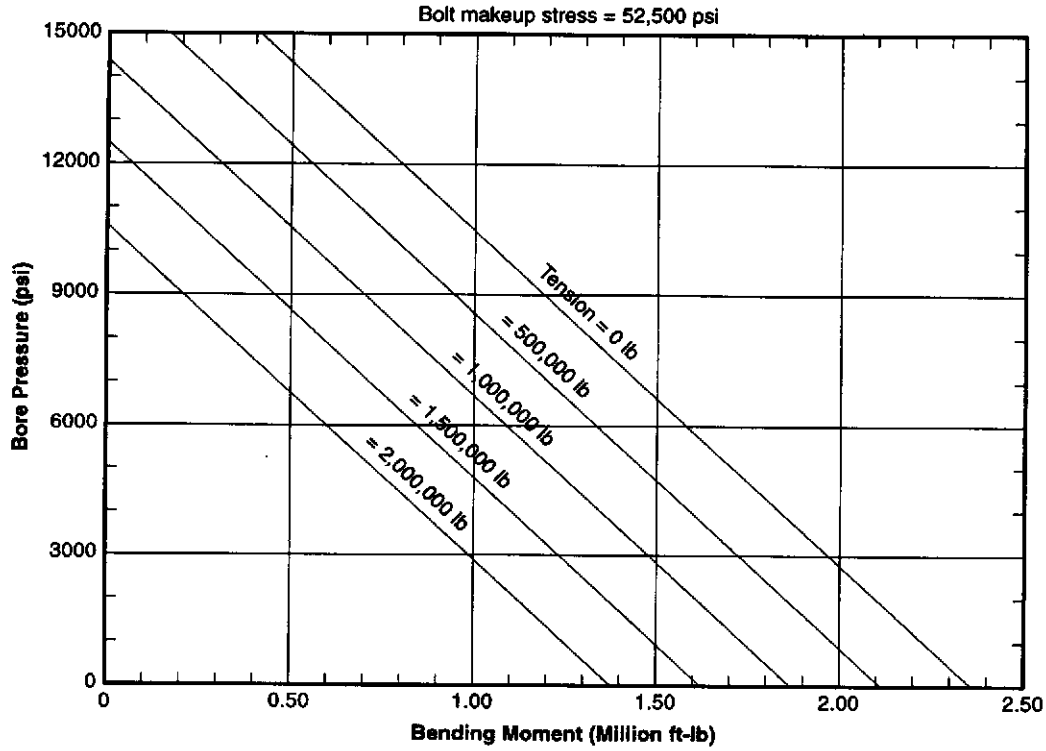


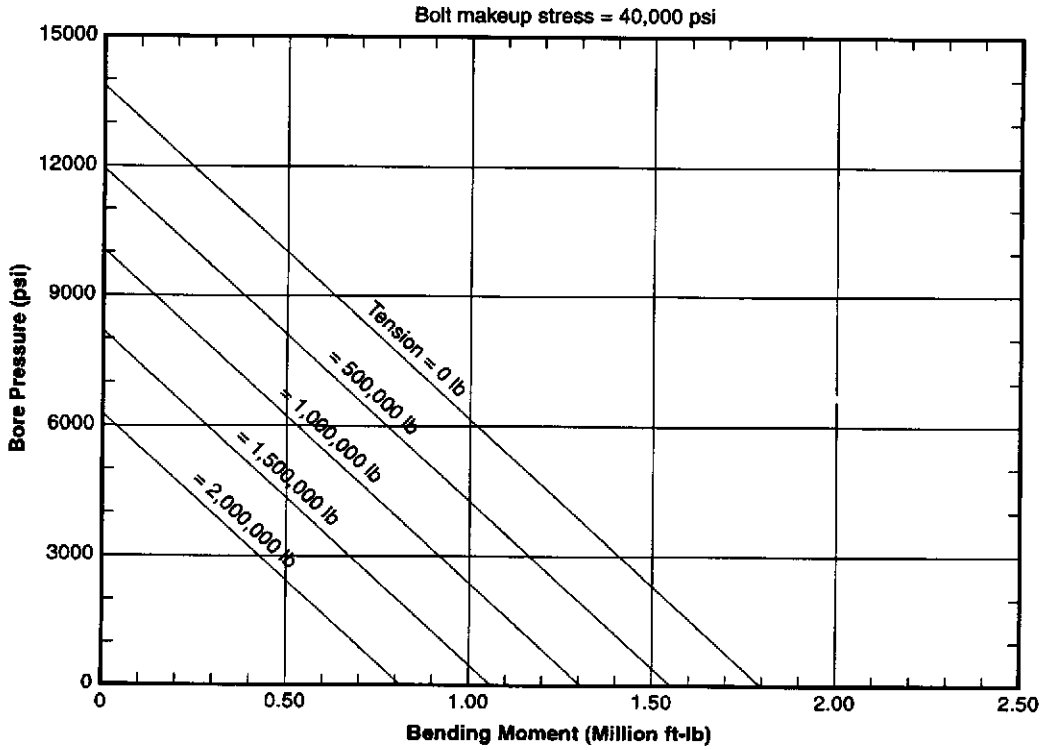
11 IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

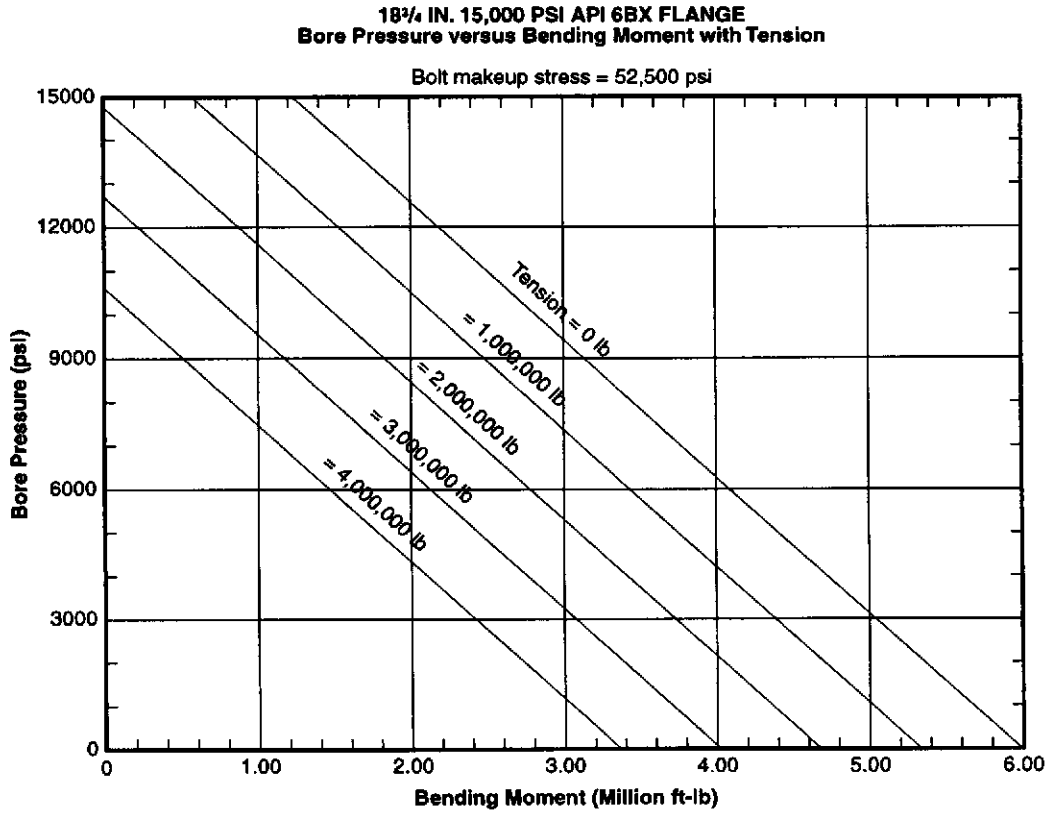


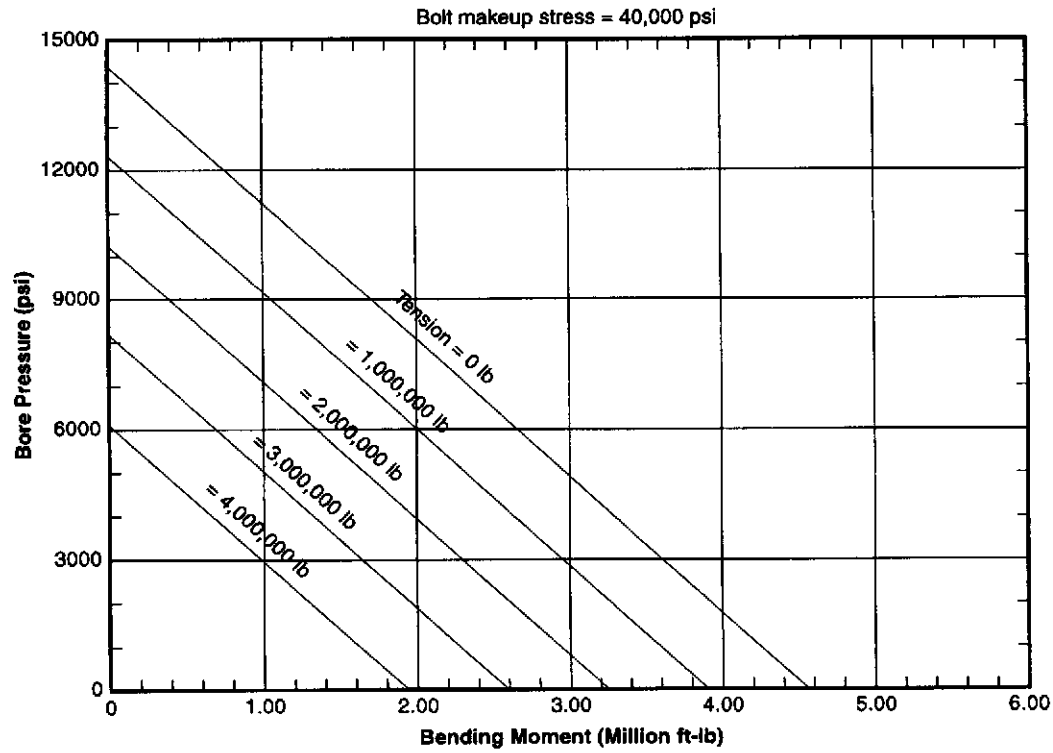


13⅝ IN. 15,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

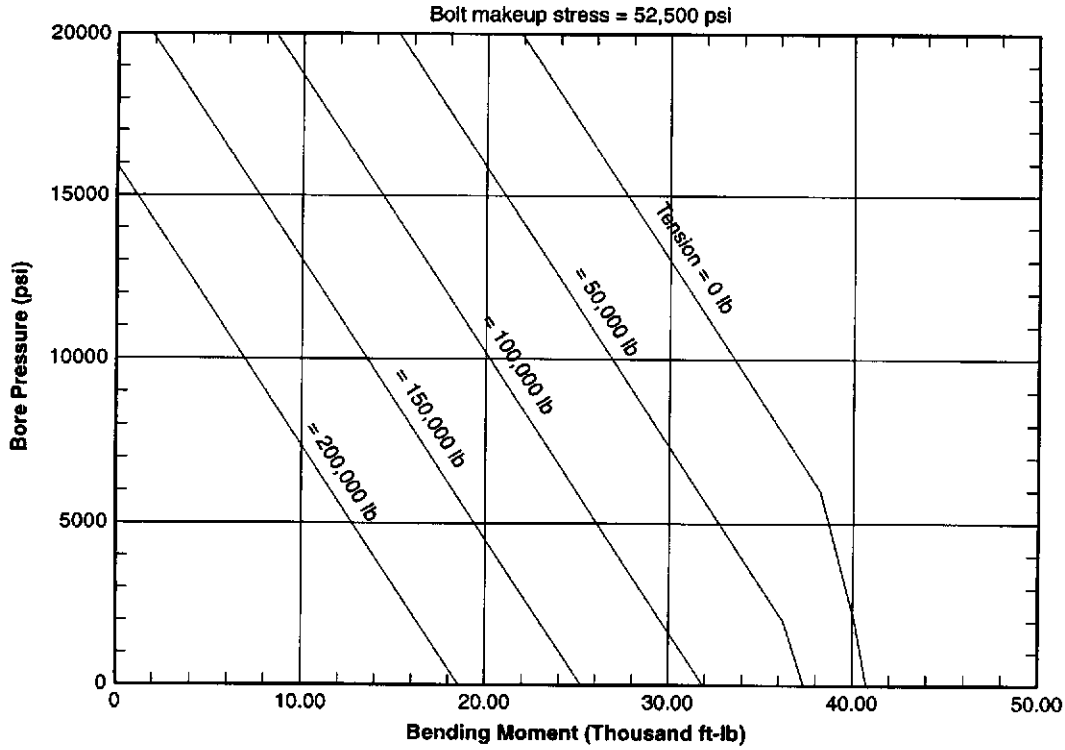


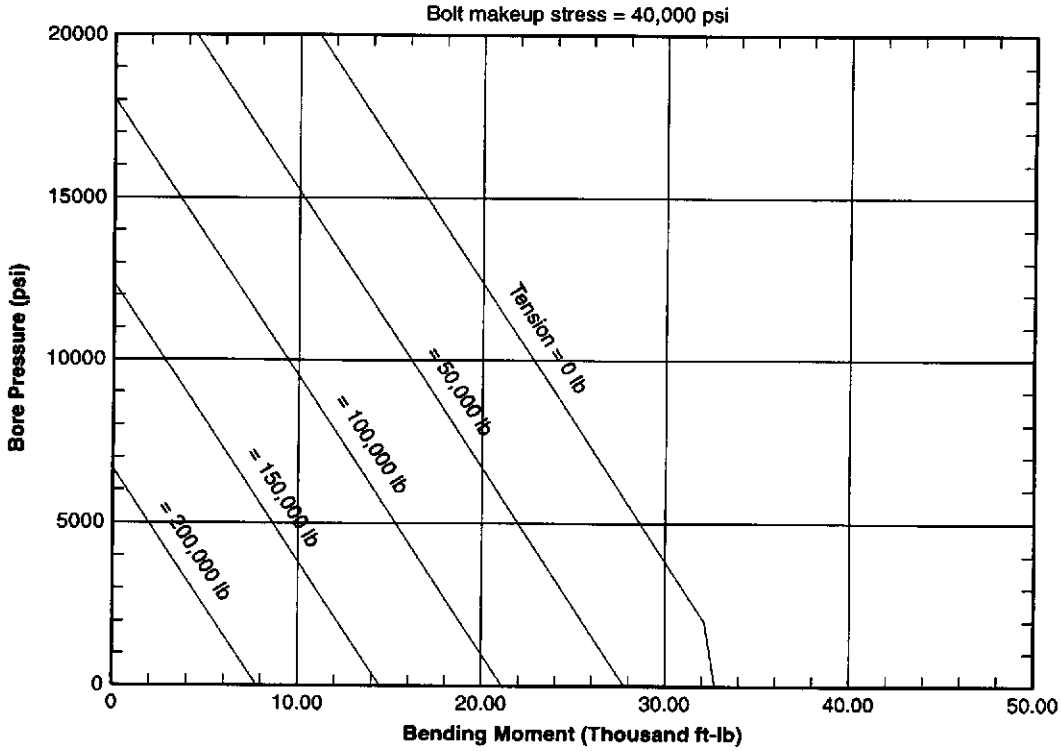


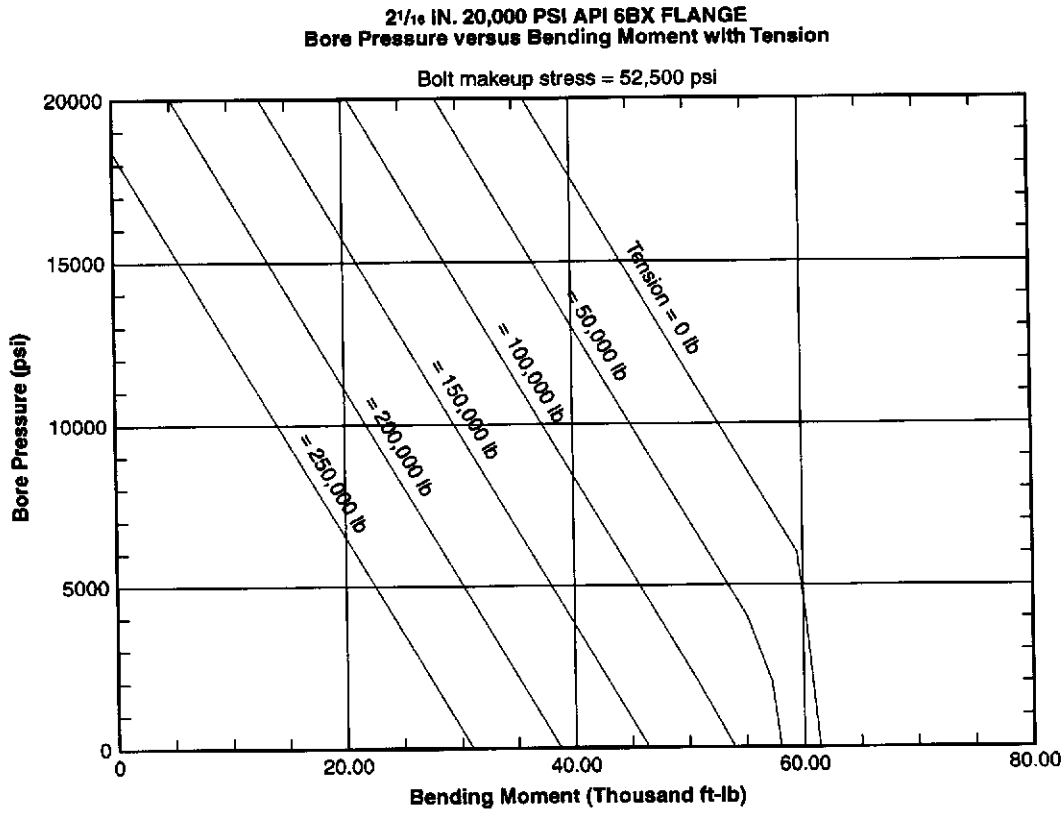


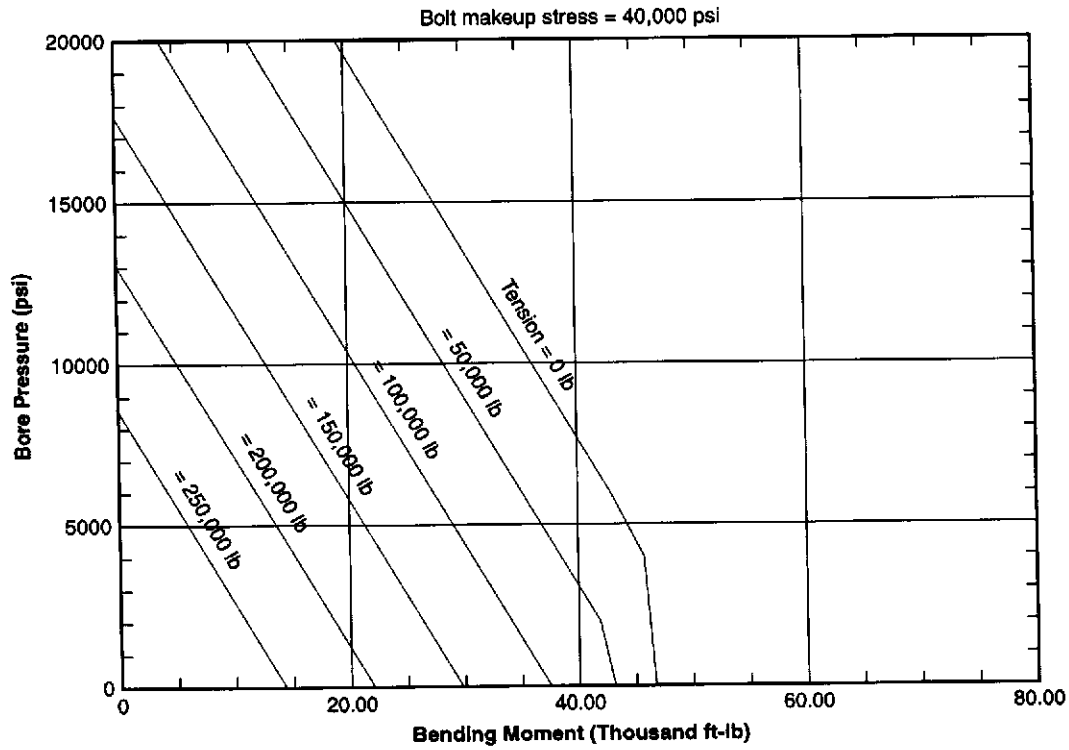


1 13/16 IN. 20,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

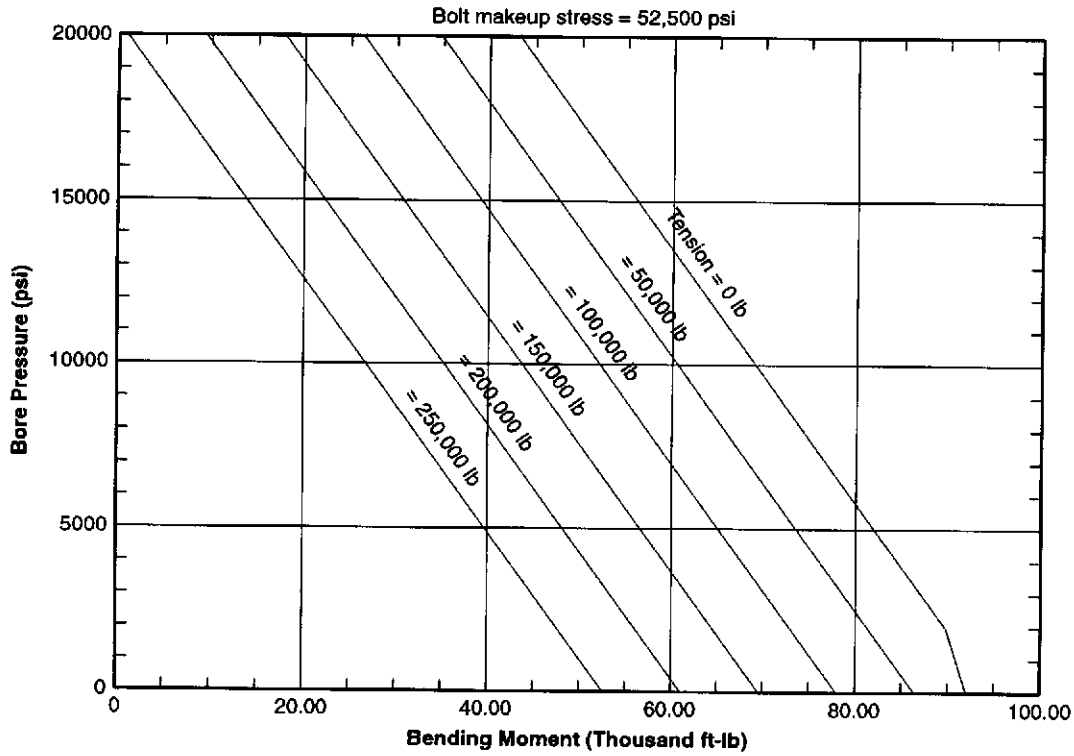


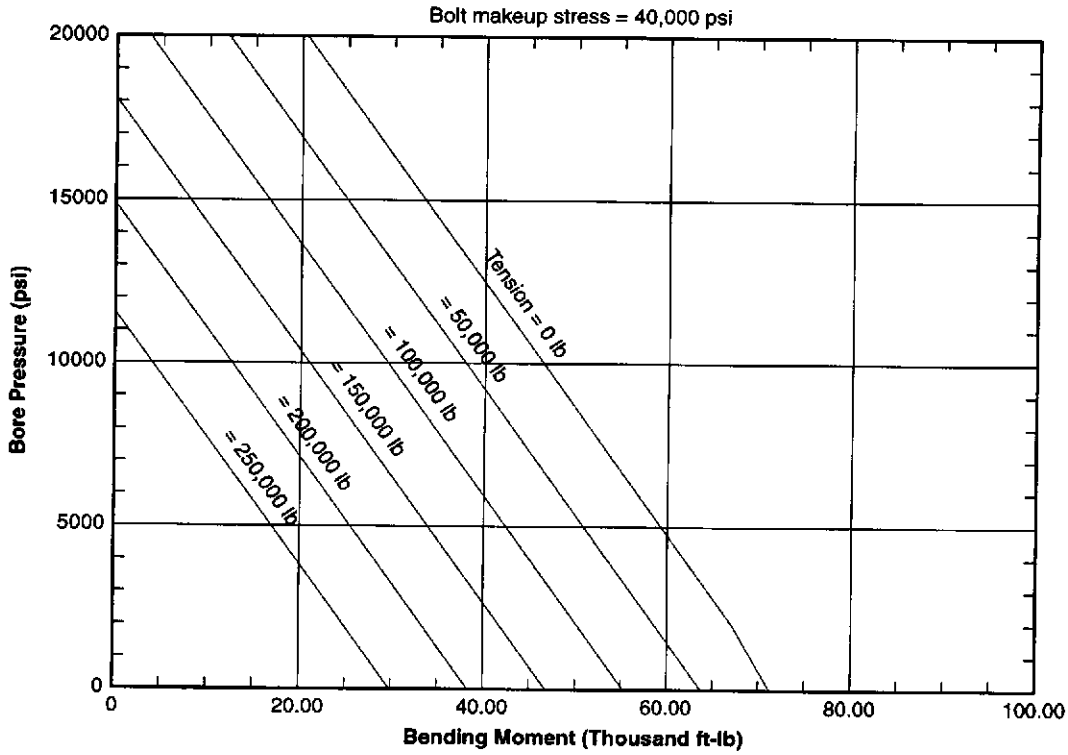


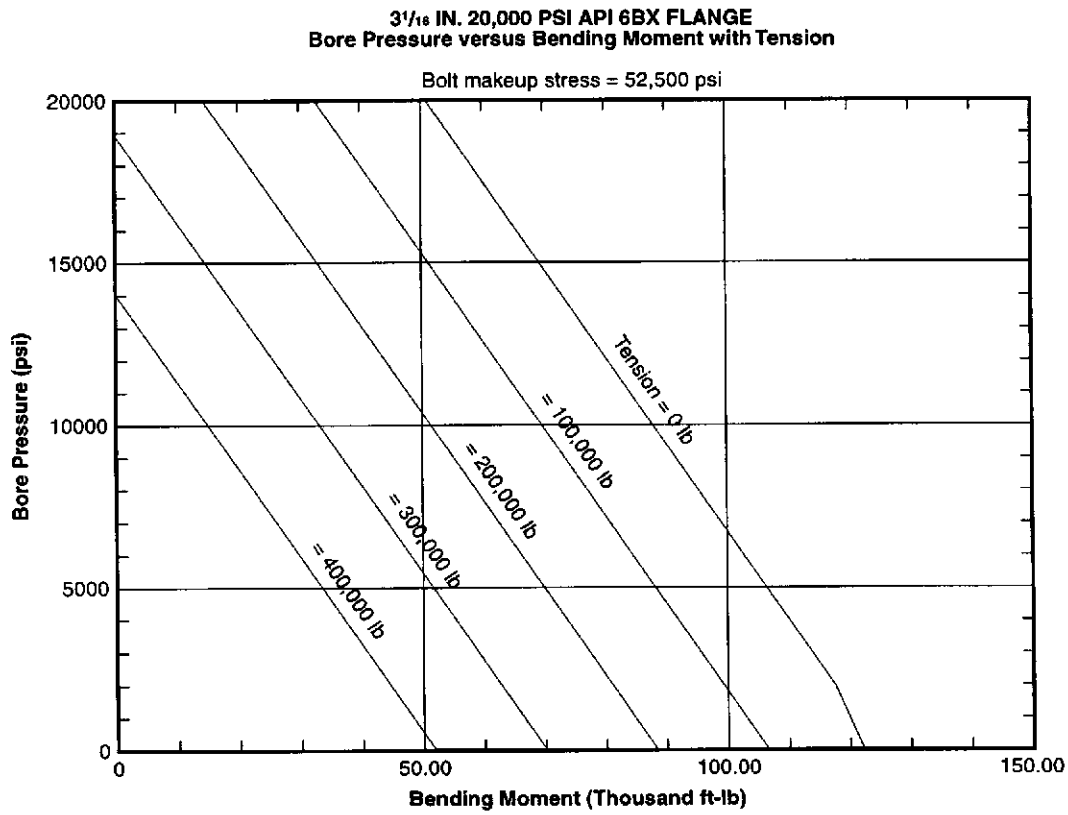


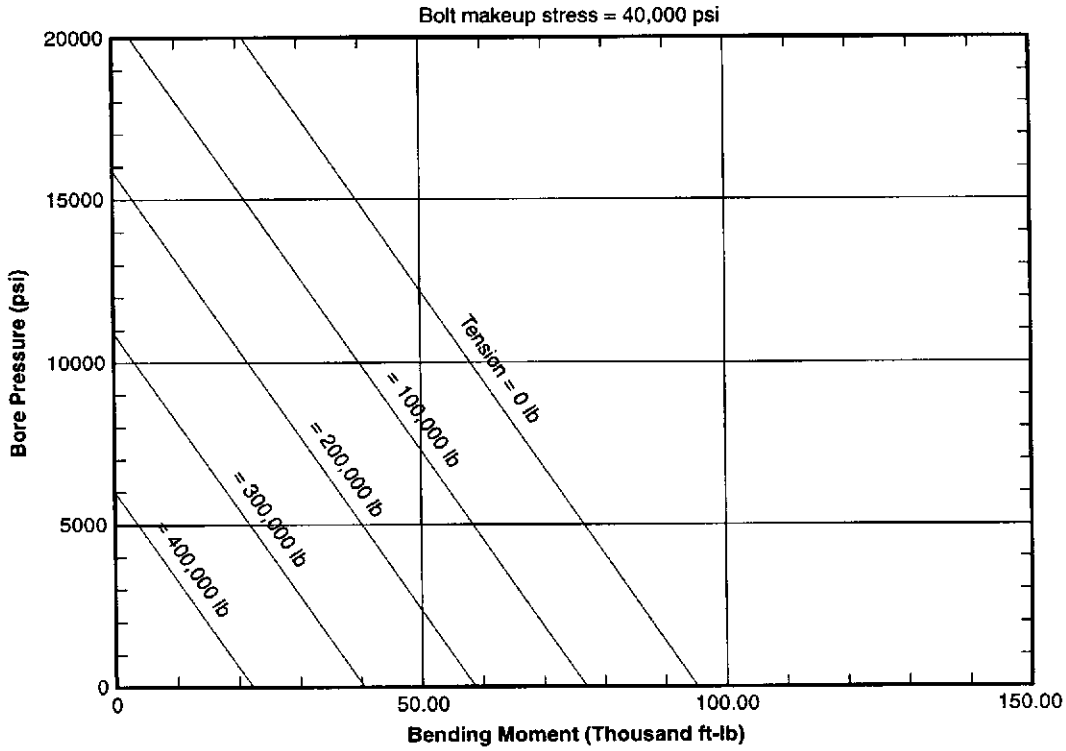


2 9/16 IN. 20,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

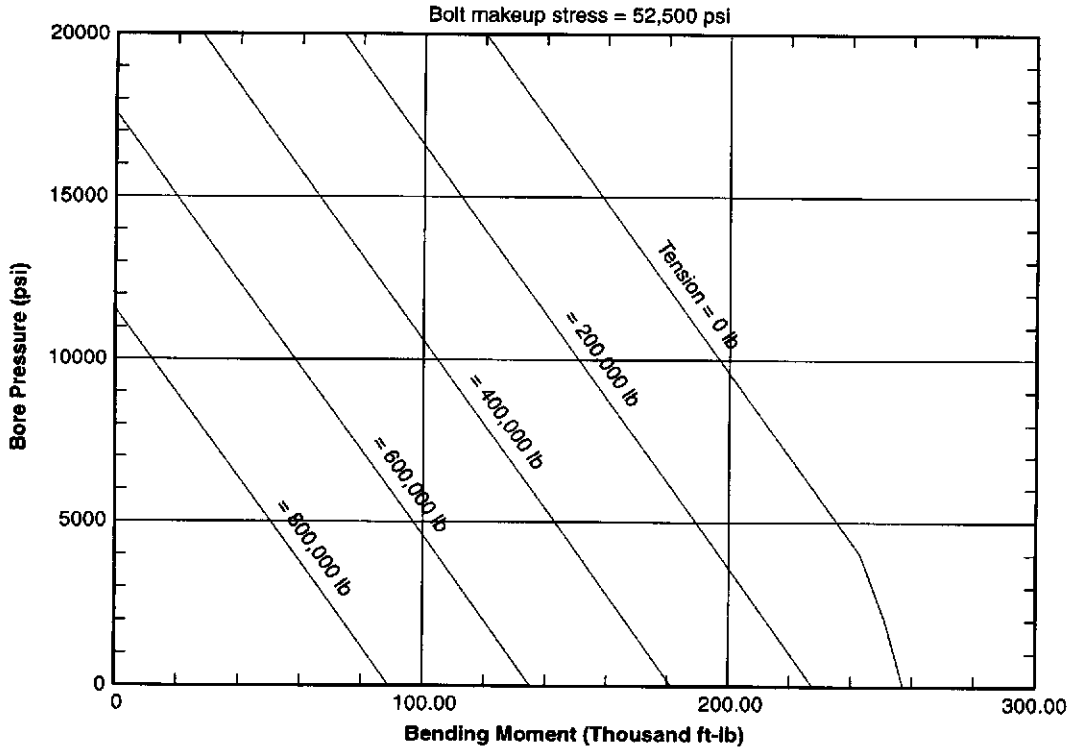


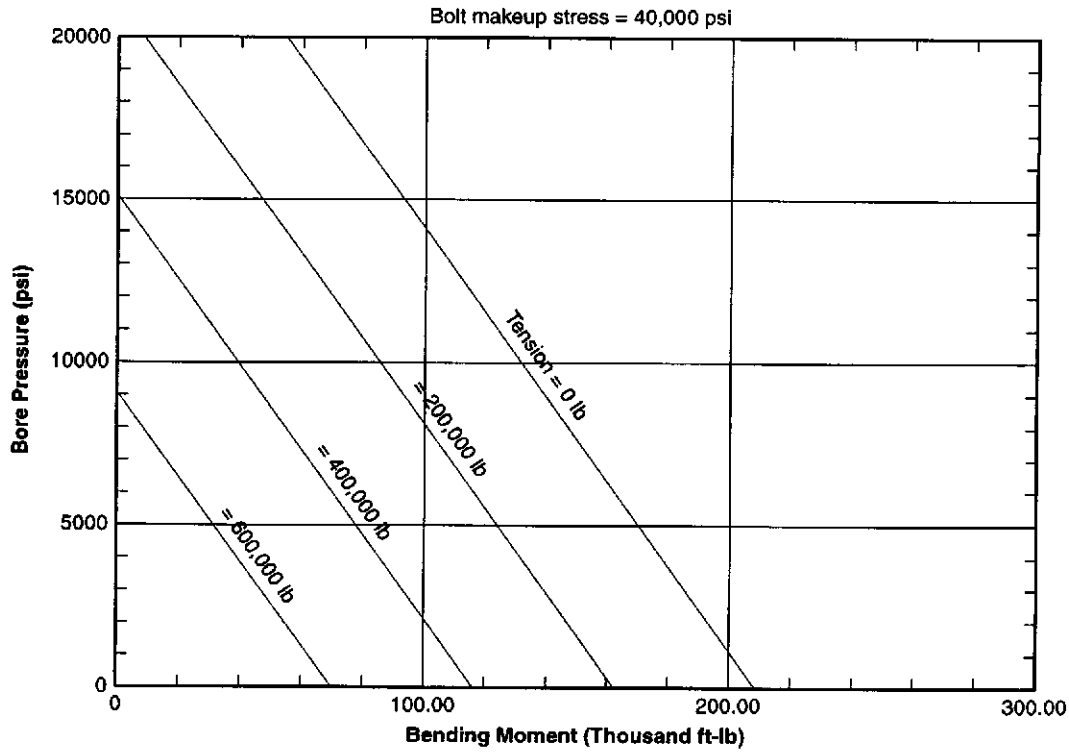


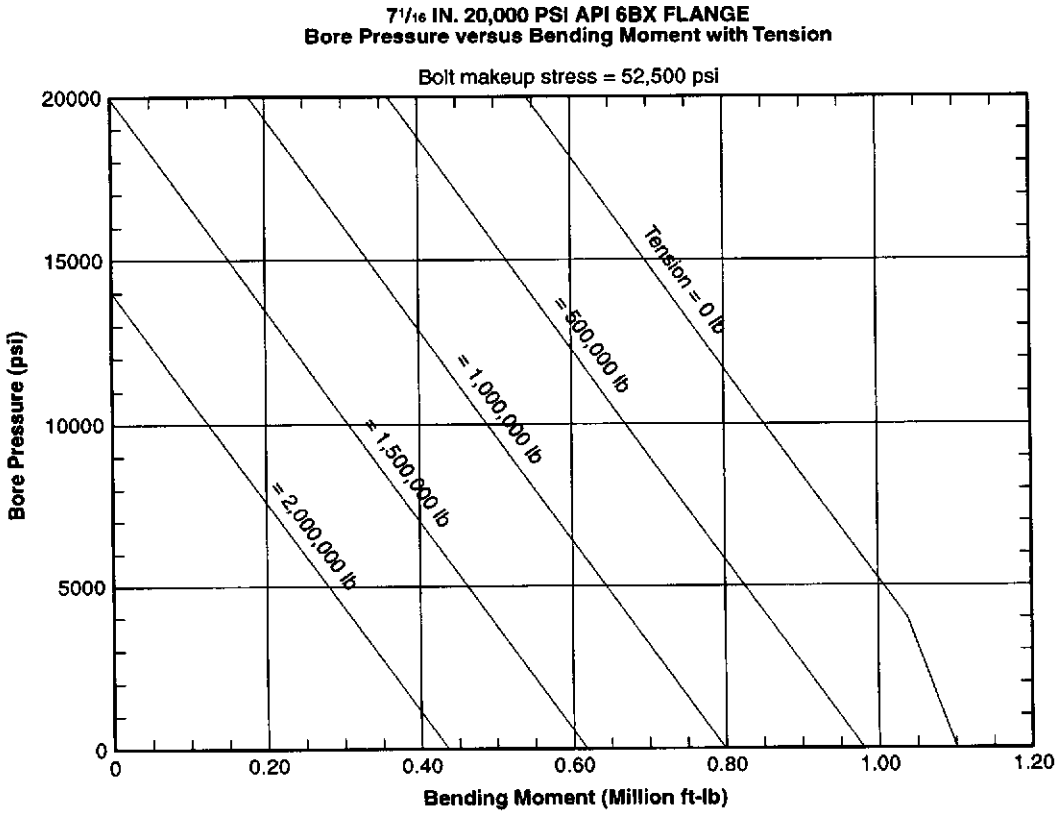


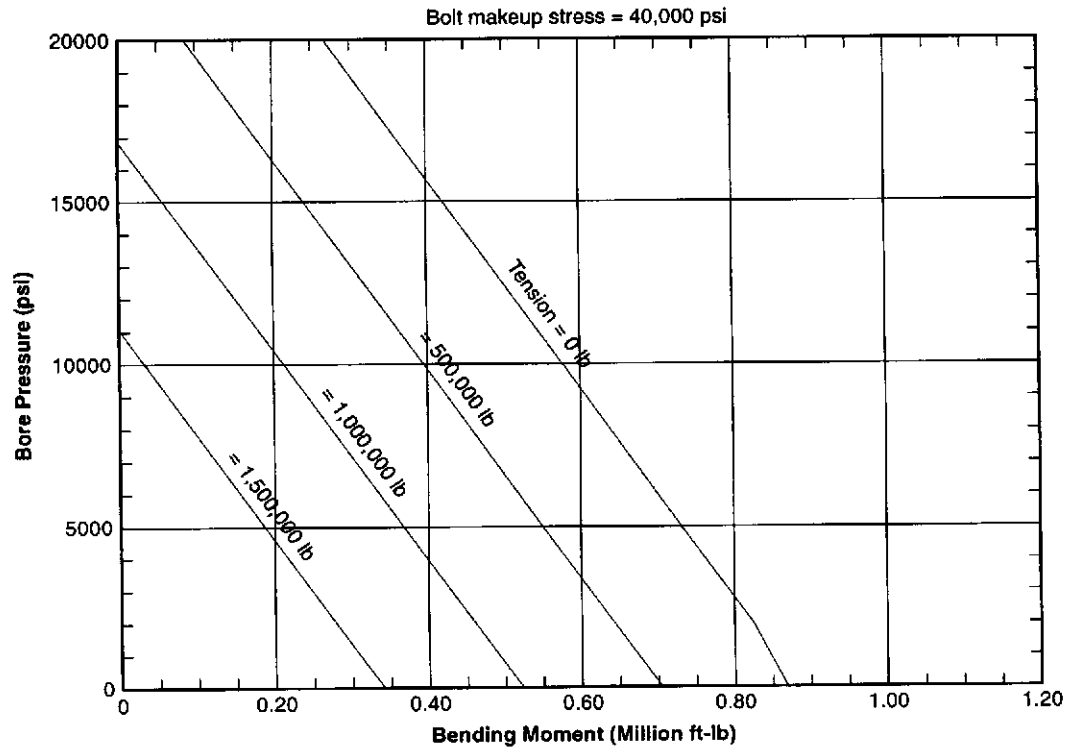


4 1/16 IN. 20,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

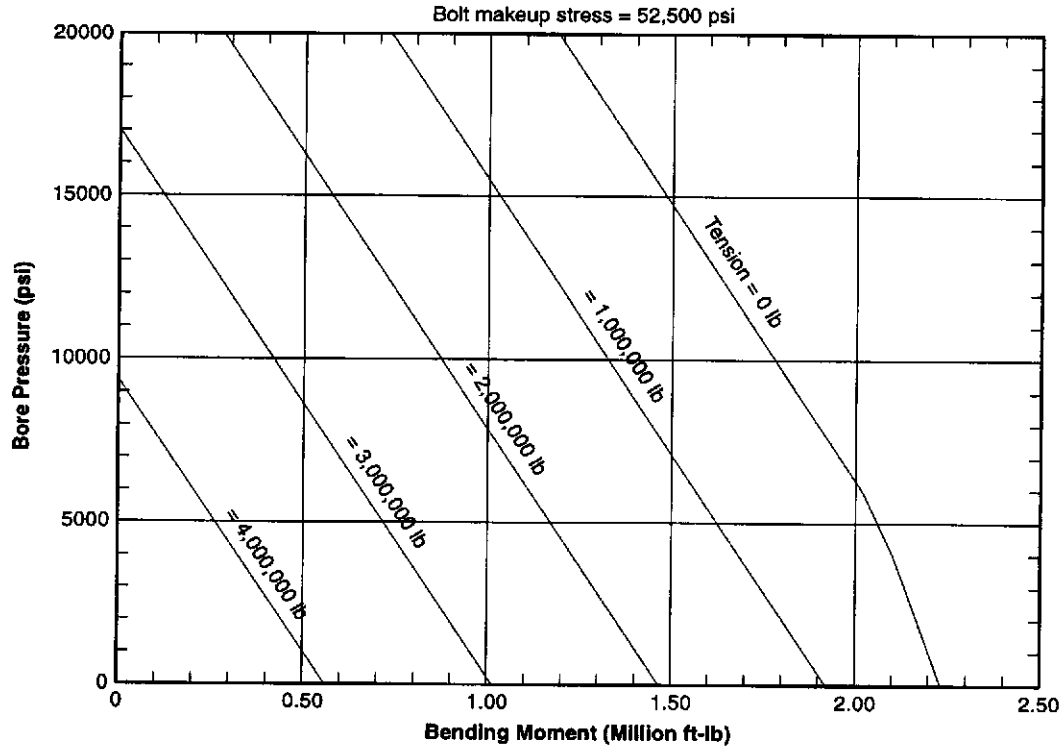


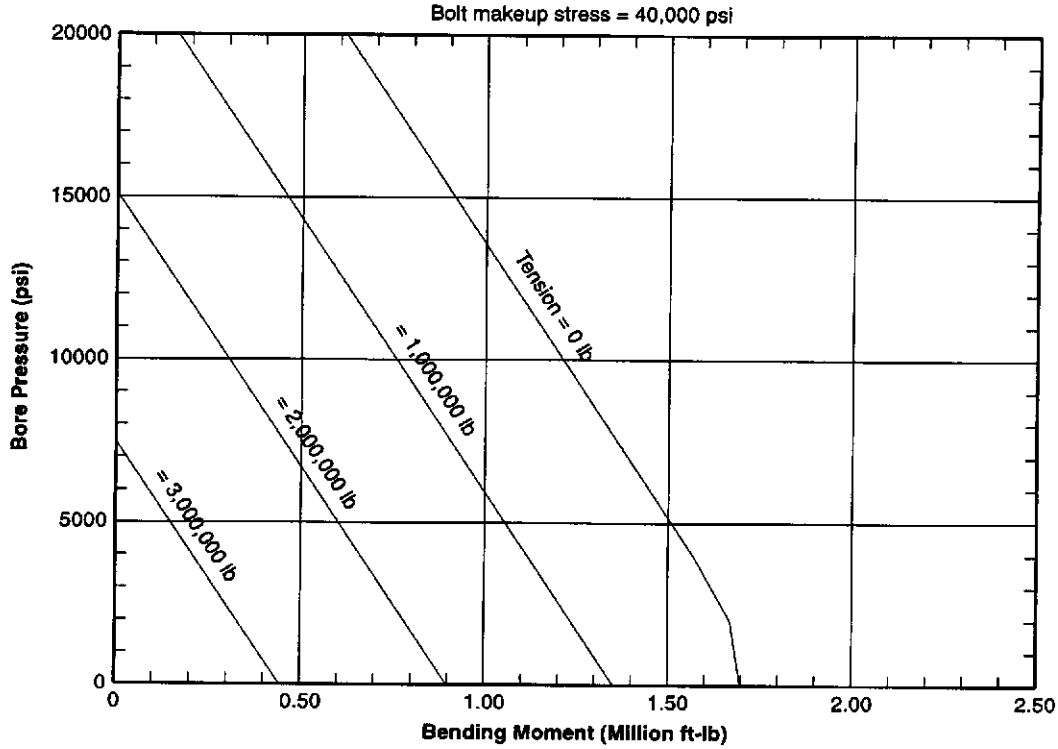


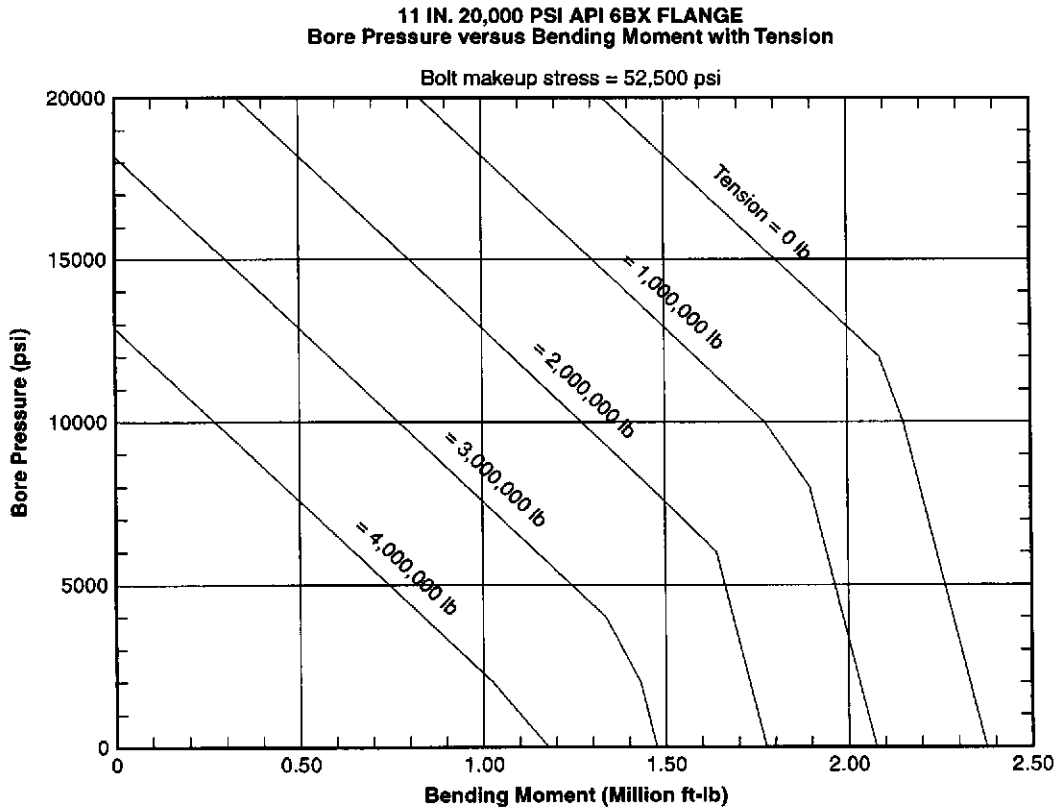


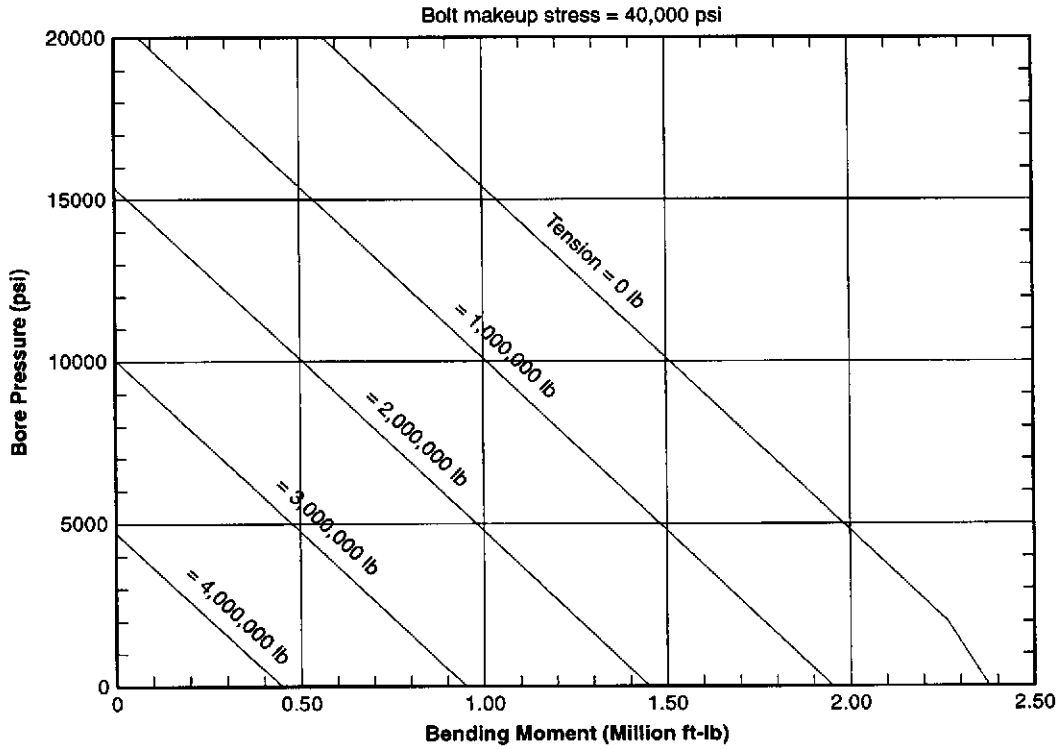


9 IN. 20,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

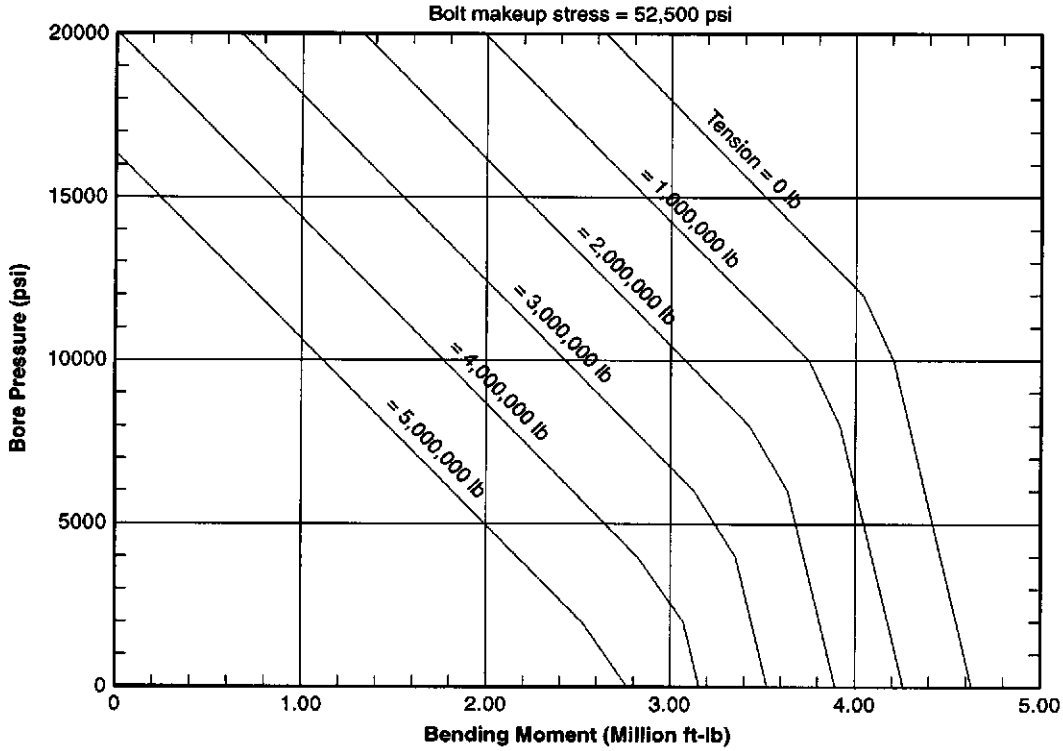


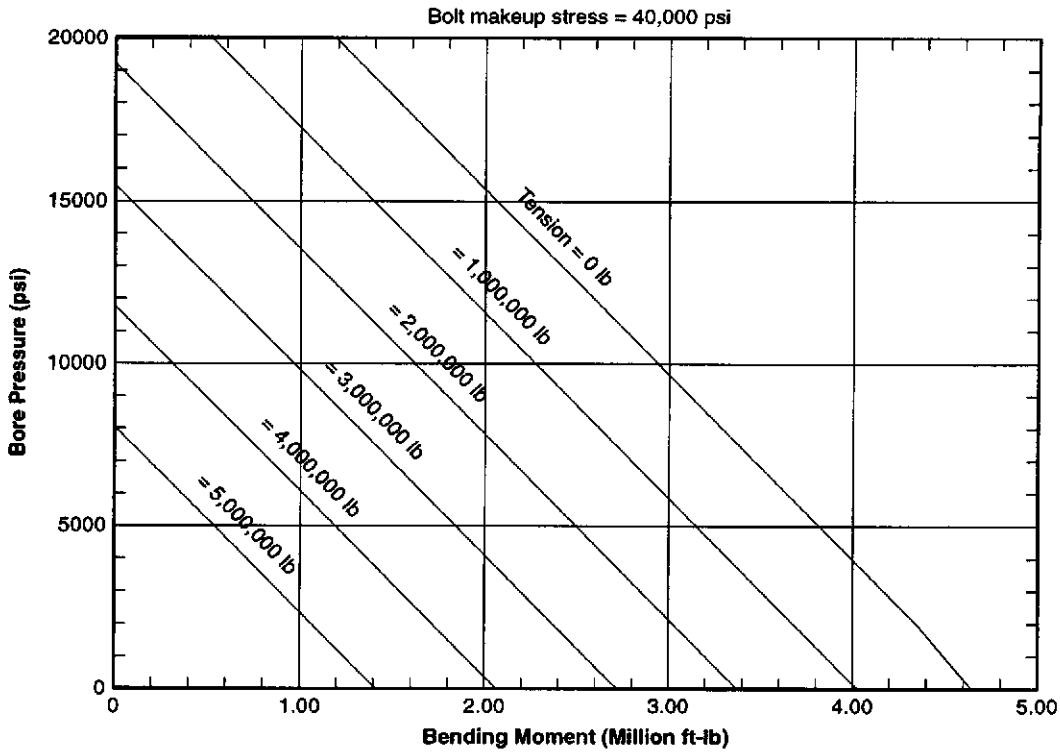




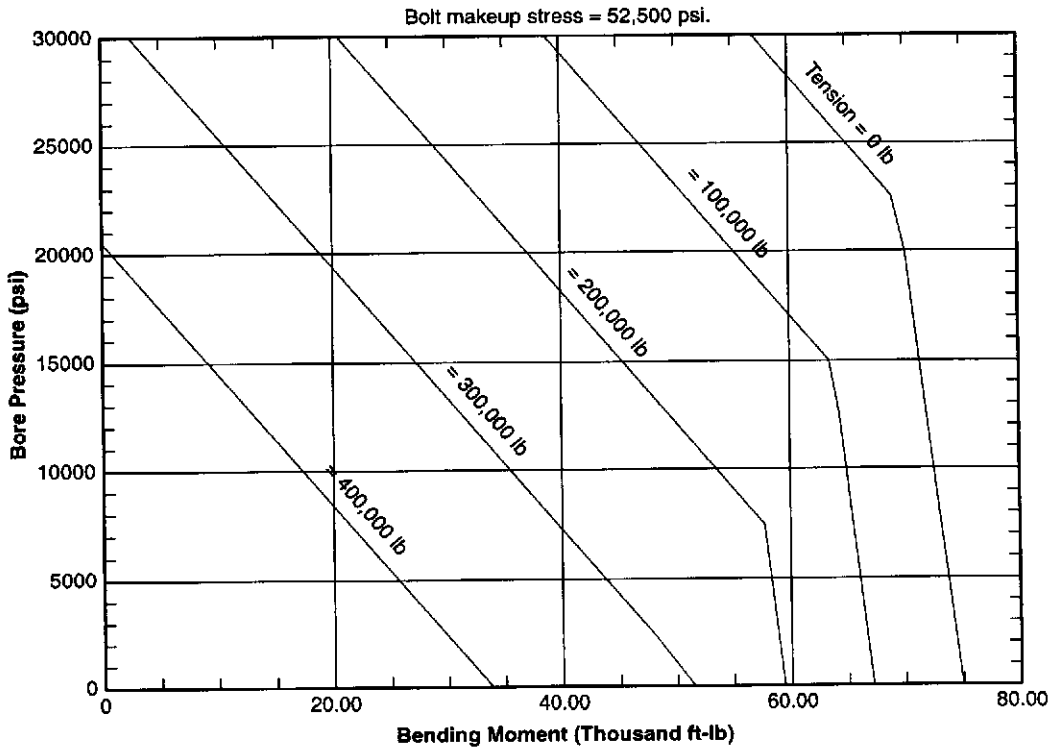


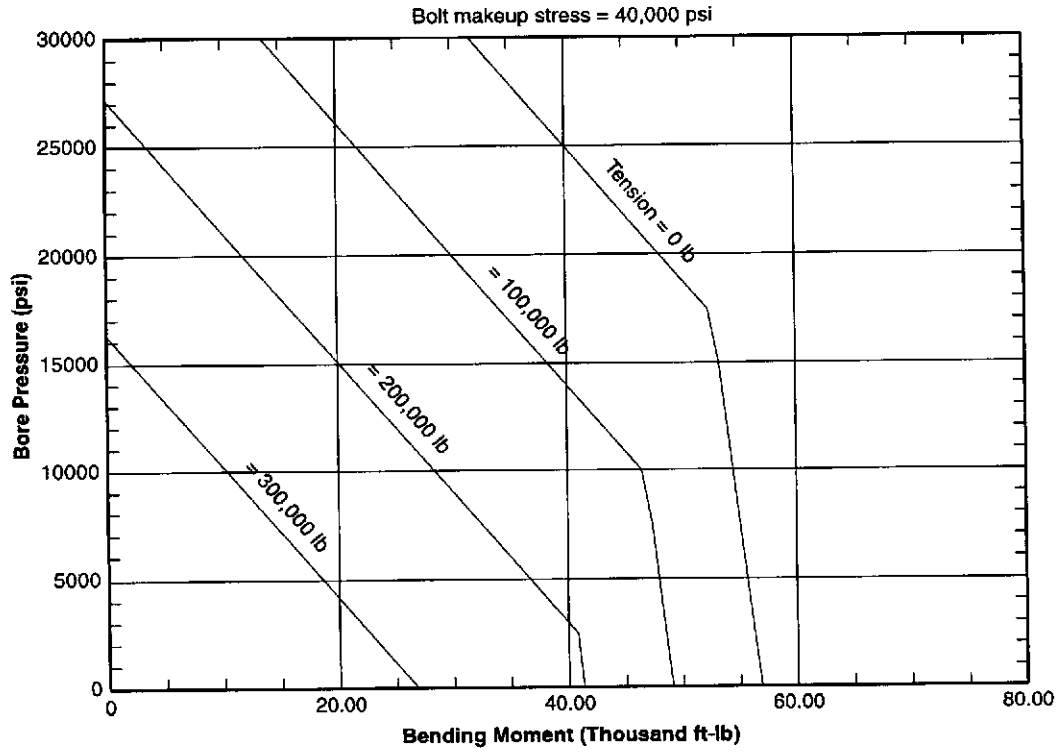
13⅝ IN. 20,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension



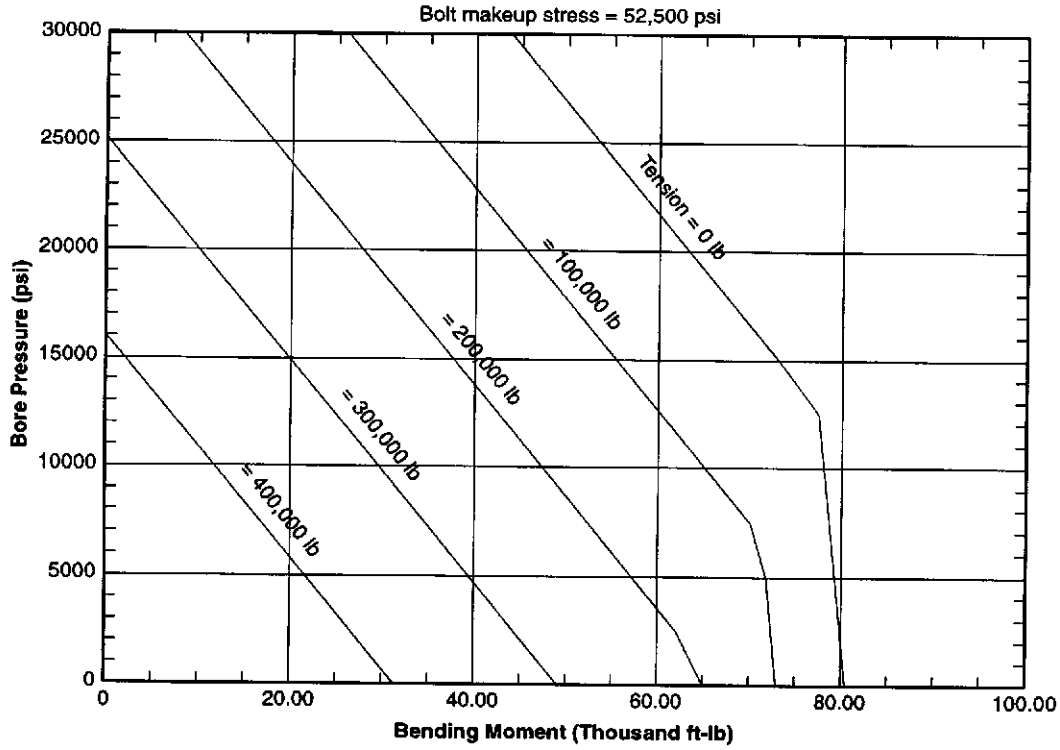


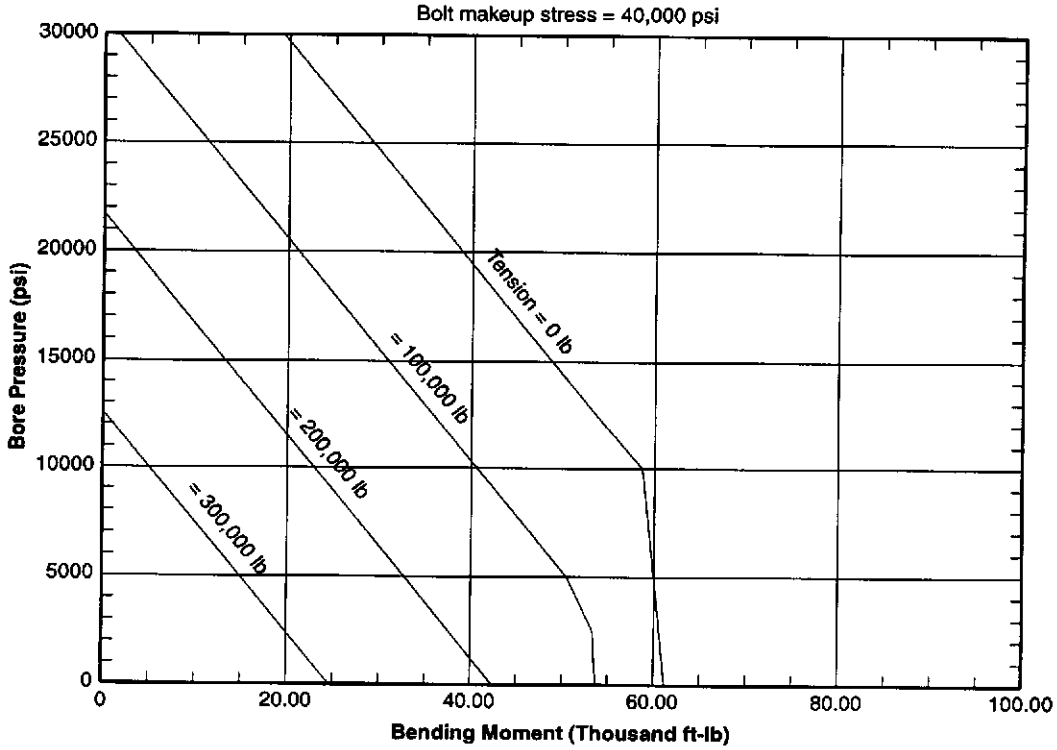
$1^{13}/_{16}$ IN. 30,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

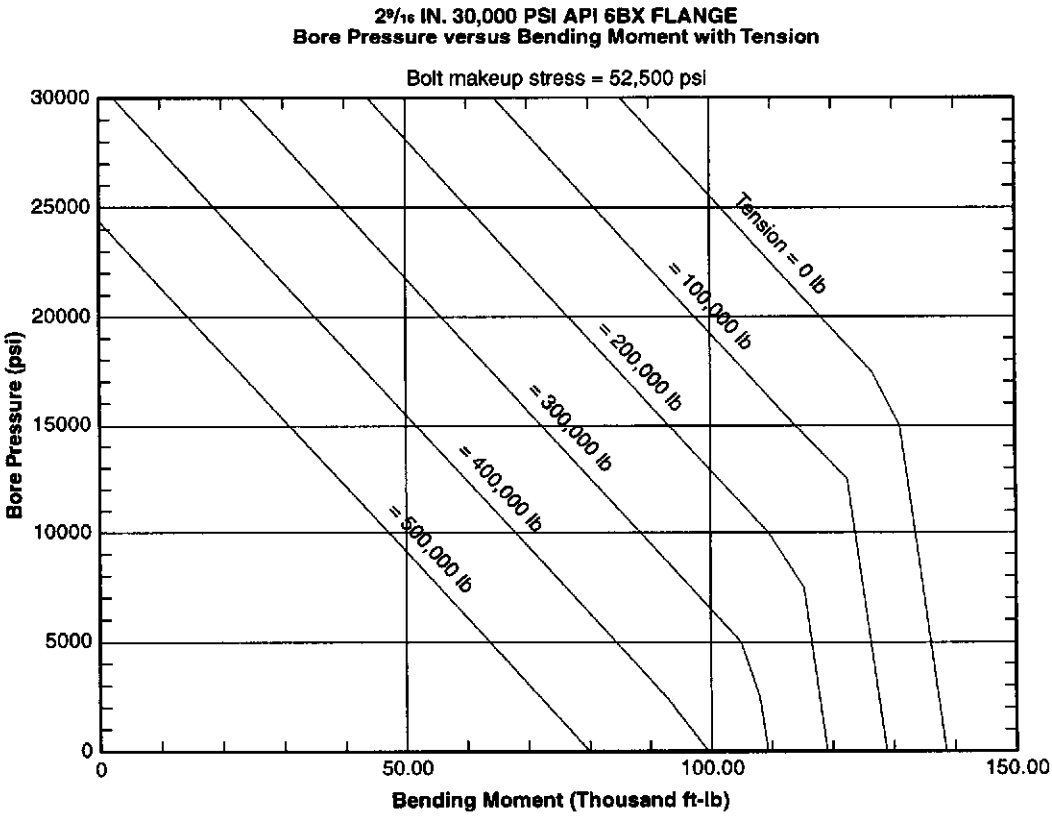


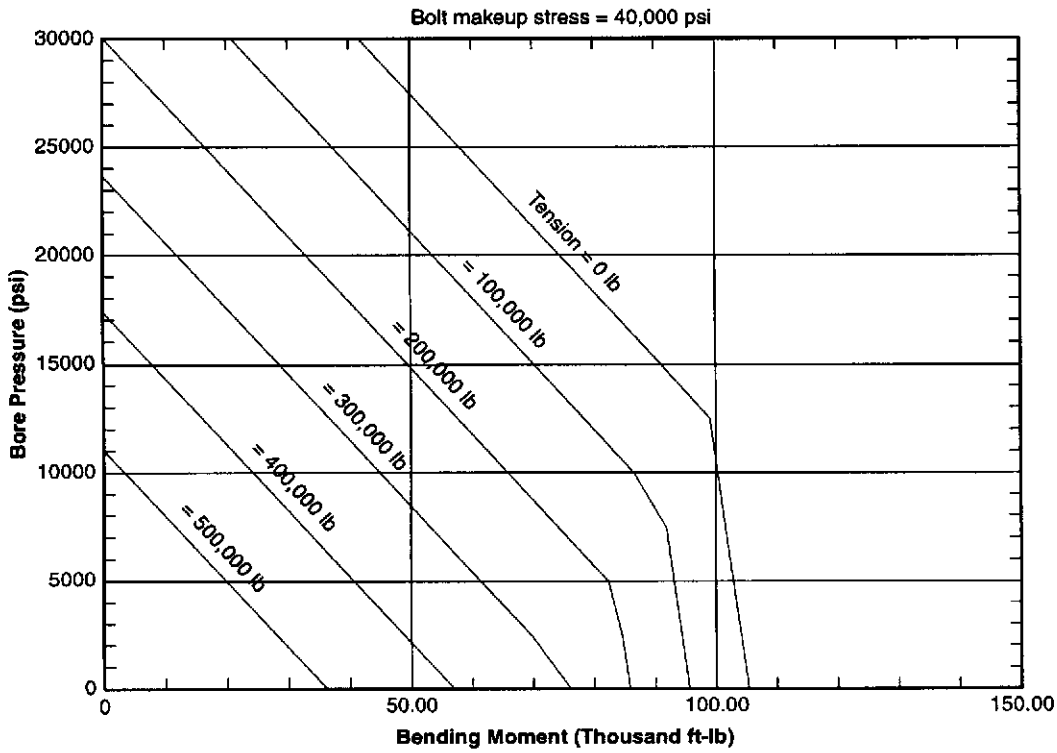


2 1/16 IN. 30,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

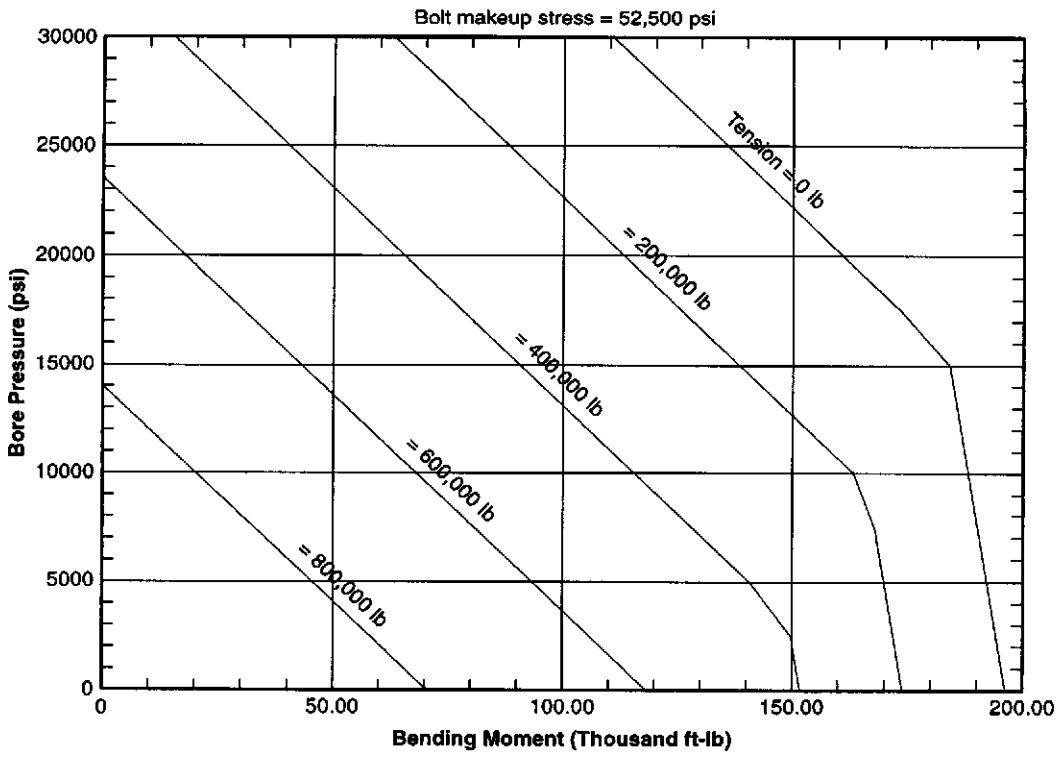


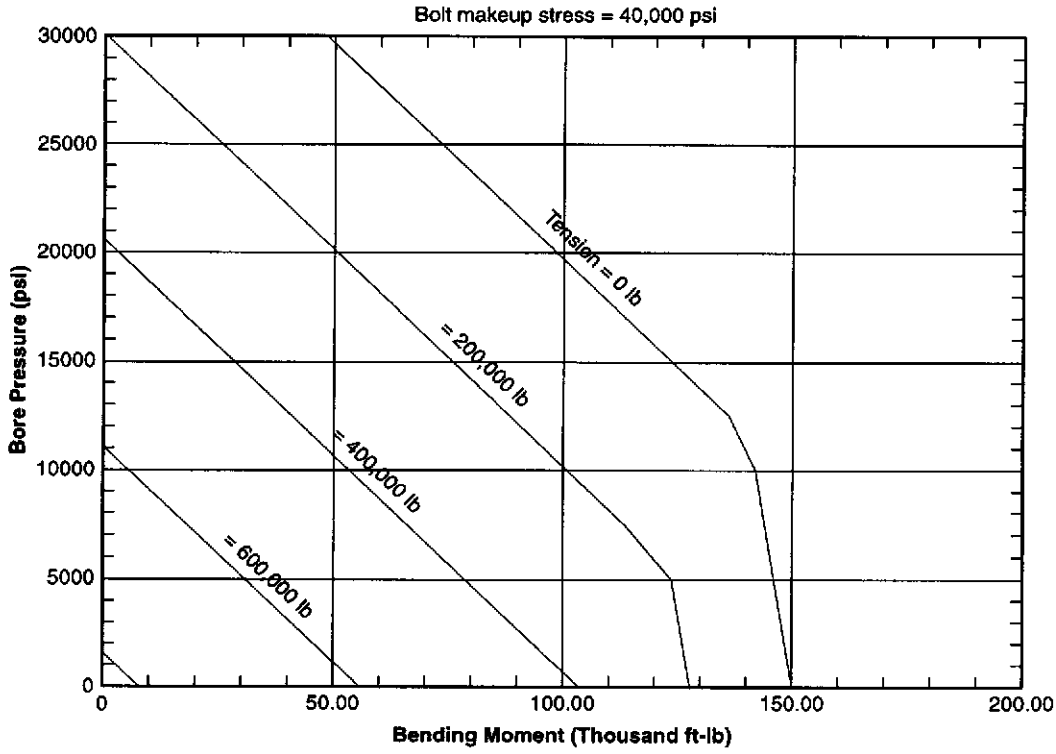


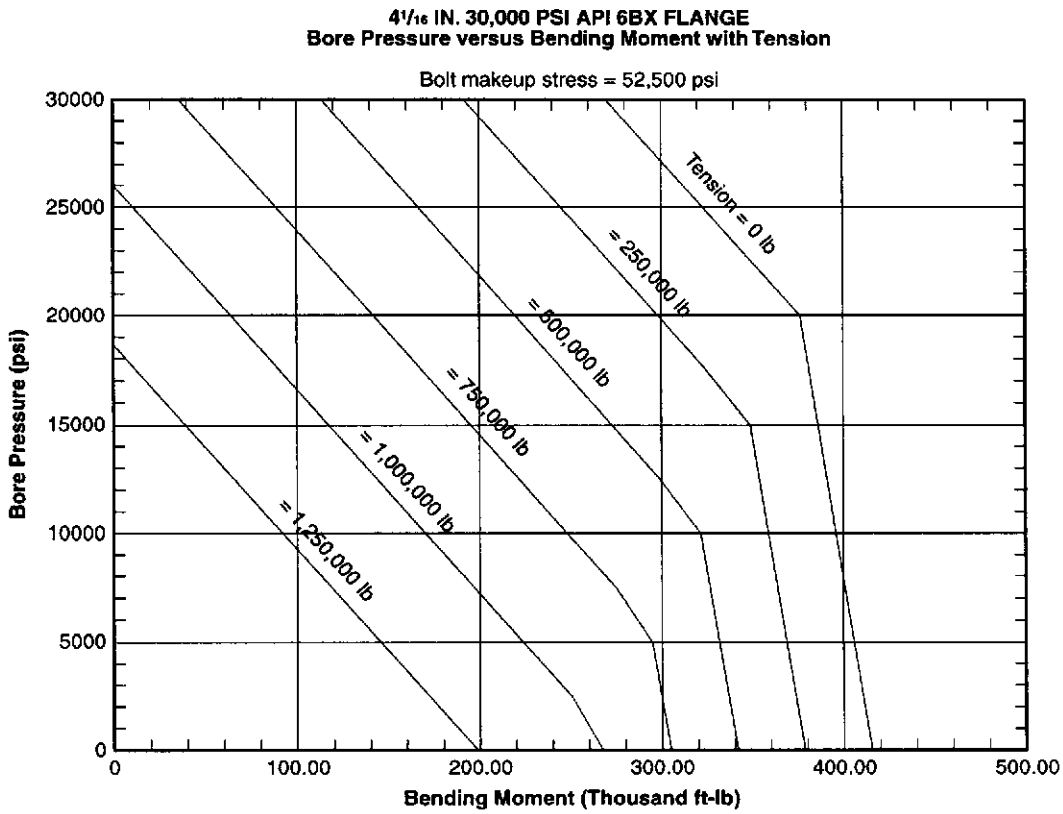


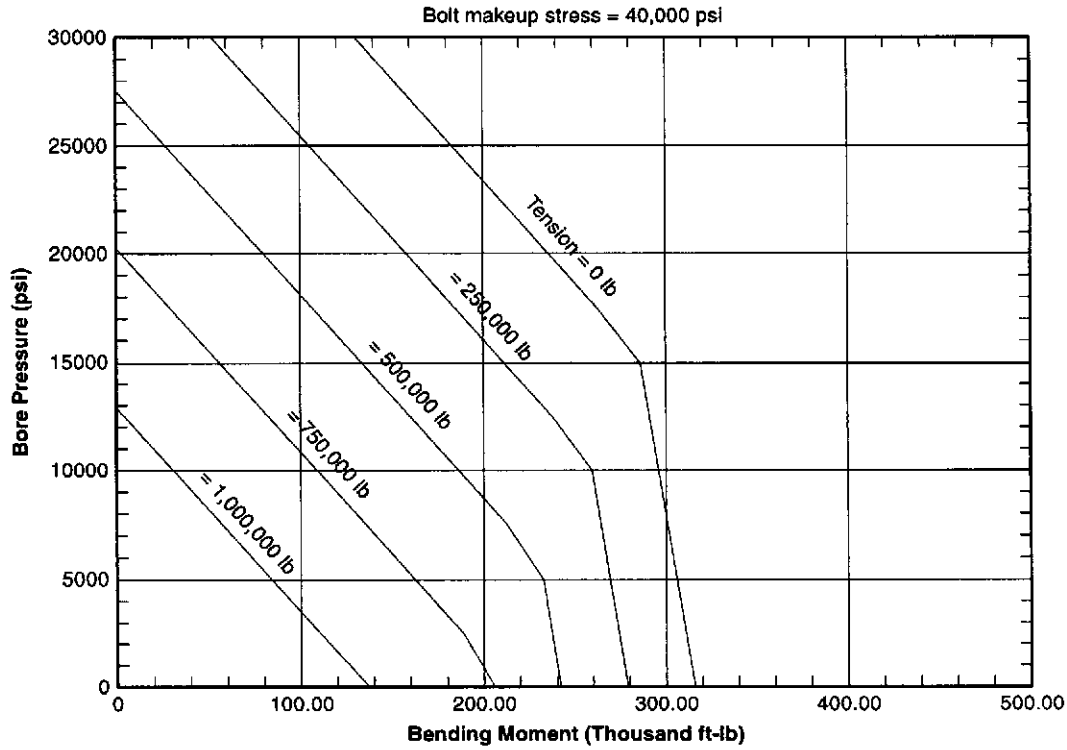


3 1/16 IN. 30,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension

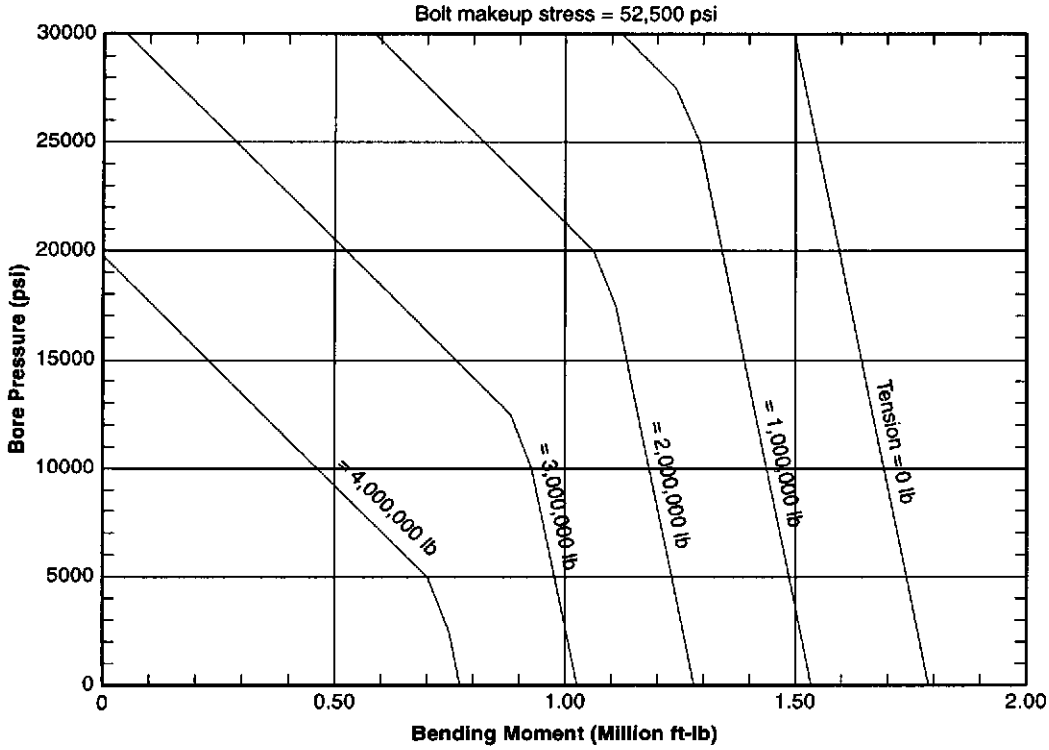


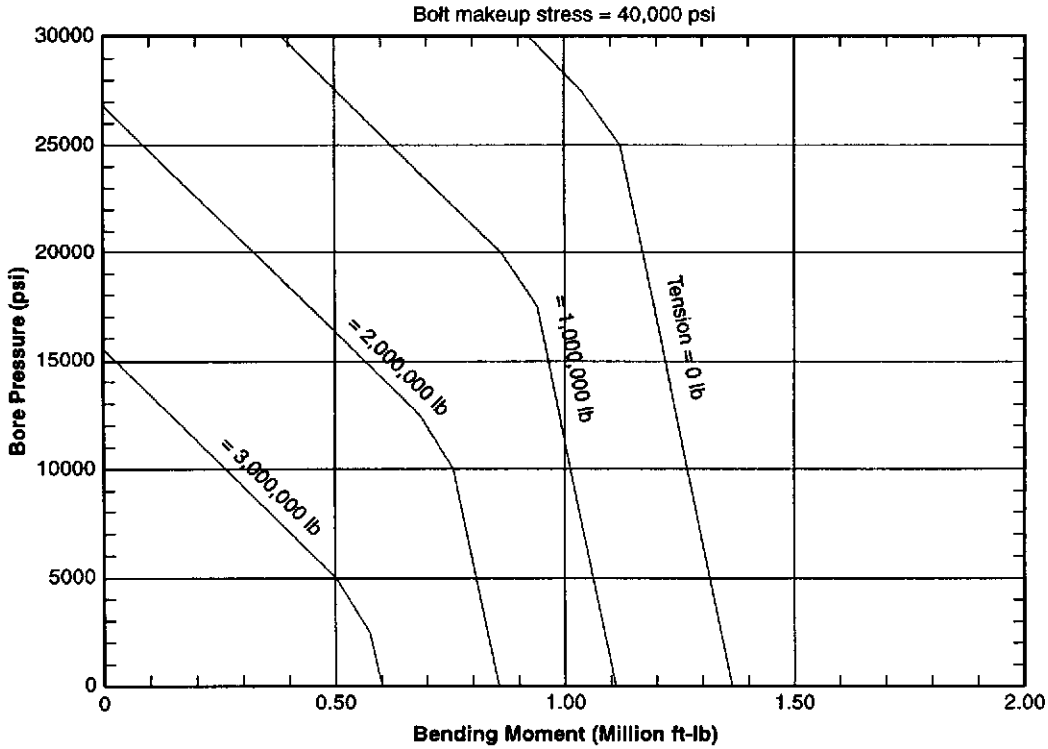






7 1/16 IN. 30,000 PSI API 6BX FLANGE
Bore Pressure versus Bending Moment with Tension





ADDITIONAL COPIES AVAILABLE FROM
PUBLICATIONS AND DISTRIBUTION
(202) 682-8375

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

Order No. G06AF2