To: All WRC Subscribers and purchasers of WC 537

From: WRC Publication Staff

Date: Friday, August 19, 2011

Subject: WRC Bulletin 537 Errata

The following errata have been reported.

Page	Section/Table/Figure	Description	Date Corrected
6	August 1965 Foreword	Correct range for beta from 0.375 to 0.5	5/31/2011
16	3.4	Page number for nondimensional curves for spherical shells should be page 43	5/31/2011
25	4.4.1	Page number for nondimensional curves for cylindrical shells should be page 91	5/31/2011
39	Table 5	Table 5 – for computation of Nø/(P/Rm) currently states 3C or 4C, should only State 3C – Note Figure 3C is properly labeled.	6/1/2011
39	Table 5	Table 5 – for computation of Nx/(P/Rm) currently states 3C or 4C, should only State 4C – Note Figure 4C is properly labeled	6/1/2011
51	Curve Fit Table for SP-1	Incorrect column name in last column currently shows My should show Ny	7/5/2011
54,55	Figure SP-3 and Curve Fit Table	Incorrect range for right side axis for NiT(RmT)1/2/Mcosq	6/21/2011
74,75	Figure SM-3 and Curve Fit Table	Curve fit for data was adjusted to prevent negative values for Y within valid range for X	7/22/2011
86	Figure SM-9	Adjusted the placement of the labels for Nx and My for easier reading	7/22/2011
89	Curve Fit Table for SM-10	Equation shown is not the equation used to calculate the curve fit	6/21/2011
101	Figure 4A and Curve Fit Table	Missing figure and table	2/28/2011
118	Figure 3B	Title is incorrect should be longituidinal moment not circumferential	5/31/2011
120	Figure 4B	Title is incorrect should be longituidinal moment not circumferential	5/31/2011
128, 129	Figure 1C-1 Original and Curve Fit Table	Incorrect range for Y	4/4/2011
130, 131	Figure 1C-1 Extrapolated and Curve Fit Table	Incorrect range for Y	4/4/2011
184	Figure B-2	Incorrect values for x axis	8/19/2011

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If any additional errata items are reported, this file will be updated. Please check http://www.forengineers.org/wrc/BULLETIN%20537_Errata_pages.pdf for any updates.

FOREWORD

To WRC Bulletin 107, March 1979 Update of August 1965 Original Version

Welding Research Council Bulletin No. 107 has been one of the most widely used bulletins ever published by WRC. The original bulletin was published in August 1965. Since that time, a revised printing was issued in December 1968; a second revised printing was issued in July 1970; a third revised printing was released in April 1972; and a June 1977 reprint of the third revised printing was issued. As sometimes happens with publications of this type, some errors were detected and then corrected in subsequent revised printings.

In this March 1979 Revision of Bulletin 107, there are some additional revisions and clarifications. The formulations for calculation of the combined stress intensity, S, in Tables 2, 3, and 5 have been clarified. Changes in labels in Figures 1C-1, 2C-1, 3C, and 4C have been made and the calculated stresses for Model "R" in Table A-3 and Model "C-l" in Table A-4 have been revised accordingly. The background for the change in labels is given in a footnote on p. 66.

Present plans call for a review and possible extension of curves to parameters which will cover the majority of openings in nuclear containment vessels and large storage tanks. Plans are to extend R/T from 300 to 600 and to extend d/D range from 0.003 to 0.10 for the new R/T range, review available test data to establish limits of applicability, and develop some guidance for pad reinforcements.

Long range plans are to review shell theory in general, and Bijlaard's method in particular. The goal is to extend the R/T up to 1200 for a d/D up to 0.1. This will include large deflection theory and other nonlinear effects. In addition, available computer programs will be studied in hope of developing one which will be an appropriate supplement to Bijlaard's method. Finally, a review will be made of limit loads related to large R/T and small d/D .

J.R, Farr, Chairman
PVRC Design Division

FOREWORD

To WRC Bulletin 107, August 1965 Original Version

Several years ago, the Pressure Vessel Research Committee sponsored an analytical and experimental research program aimed at providing methods of determining the stresses in pressure vessel nozzle connections subjected to various forms of external loading. The analytical portion of this work was accomplished by Prof. P. P. Bijlaard of Cornell University, and was reported in References 1 to 8 inclusive. Development of the theoretical solutions involved a number of simplifying assumptions, including the use of shallow shell theory for spherical vessels and flexible loading surfaces for cylindrical vessels. These circumstances limited the potential usefulness of the results to d_i / D_i, ratios of perhaps 0.33 in the case of spherical shells and 0.25 in the case of cylindrical shells. Since no data were available for the larger diameter ratios, Prof. Bijlaard later supplied data, at the urging of the design engineers, for the values of $\beta = 0.375$ and 0.50 (d_i / D_i, ratios approaching 0.60) for cylindrical shells, as listed on page 12 of Reference 10. In so doing, Prof. Bijlaard included a specific warning concerning the possible limitations of these data, as follows: "The values for these large loading surfaces were computed on request of several companies. It should be remembered, however, that they actually apply to flexible loading surfaces and, for radial load, to the center of the loading surface. It should be understood that using these values for the edge of the attachment, as was recommended for small loading surfaces, may be unconservative."

Following completion of the theoretical work, experimental work was undertaken in an effort to verify the theory, the results of which were published in References 17 and 18. Whereas this work seemingly provided reasonable verification of the theory, it was limited to relatively small d_i / D_i ratios-0.10 in the case of spherical shells and 0.126 in the case of cylindrical shells. Since virtually no data, either analytical or experimental, were available covering the larger diameter ratios, the Bureau of Ships sponsored a limited investigation of this problem in spheres, aimed at a particular design problem, and the Pressure Vessel Research Committee undertook a somewhat similar investigation in cylinders. Results of this work have recently become available emphasizing the limitations in Bijlaard's data on cylindrical shells, particularly as it applies to thin shells over the "extended range" (page 12 of Reference 10).

Incident to the use of Bijlaard's data for design purposes, it has become apparent that design engineers sometimes have difficulty in interpreting or properly applying this work. As a result of such experience, PVRC has felt it desirable that all of Bijlaard's work be summarized in convenient, "cook-book" form to facilitate its use by design engineers. However, before this document could be issued, the above mentioned limitations became apparent, presenting an unfortunate dilemma, viz., the test data indicate that the calculated data are partially inadequate, but the exact nature and magnitude of the error is not known, nor is any better analytical treatment of the problem available (for cylinders).

Under these circumstances, it was decided that the best course was to proceed with issuing the "cook-book," extending Bijlaard's curves as best we can on the basis of available test data. This decision was based on the premise that all of the proposed changes would be toward the conservative (or "safe") side and that design engineers would continue to use Bijlaard's extended range data unless some alternative were offered. The following paper is therefore presented in the hope that it will facilitate the use of Bijlaard's work by design engineers. Every effort has been made to point out any known limitations in the work and to explain the exact nature of the changes which have been made to Bijlaard's original curves and data; however, users are warned that the resulting work is not necessarily adequate for all cases. It is the hope of the Subcommittee that additional theoretical work can be undertaken to provide more adequate data on various phases of this problem.

F. S. G. Williams, Chairman

PVRC Subcommittee on Reinforced

Openings and External Loadings

3.3.2 Stresses Resulting From Overturning Moment, M

3.3.2.1 Radial Stresses (σ_x)

a) STEP 1. Using the applicable values of U, Υ, and ρ^*, read off the dimensionless membrane force $\left(N_x T\sqrt{R_m T} / M\right)$ from the applicable curve which will be found in one of the following figures: Figure SR-3 or SM-1 to SM-10, inclusive.

b) STEP 2. By the same procedure used in STEP 1 above, read off the value of dimensionless bending moment $\left(M_x\sqrt{R_m T} / M\right)$ from the applicable curve. This value will be found in the same figure used in STEP 1.

c) STEP 3. Using the applicable values of M, R_m, and T, calculate the radial membrane stress $\left(N_x / T\right)$ by:

$$\frac{N_x}{T}=\left(\frac{N_x T\sqrt{R_m T}}{M}\right)\left(\frac{M}{T^2\sqrt{R_m T}}\right) \qquad (12)$$

d) STEP 4. By a procedure similar to that used in STEP 3, calculate the radial bending stress $\left(6M_x/T^2\right)$, thus:

$$\frac{6M_x}{T^2}=\left(\frac{M_x\sqrt{R_m T}}{M}\right)\left(\frac{6M}{T^2\sqrt{R_m T}}\right) \qquad (13)$$

e) STEP 5. Combine the radial membrane and bending stresses by use of the general stress equation (paragraph 2) together with the proper choice of sign (see Table 1); i.e.,

$$\sigma_x = K_n\frac{N_x}{T} \pm K_b\frac{6M_x}{T^2} \qquad (14)$$

3.3.2.2 Tangential Stress (σ_y)

Follow the five steps outlined in 3.3.2.1, using the same figure to obtain $\left(N_y T\sqrt{R_m T} / M\right)$ and $\left(M_y\sqrt{R_m T} / M\right)$ used to obtain $\left(N_x T / P\right)$ and $\left(M_x / P\right)$. It follows that:

$$\frac{N_y}{T}=\left(\frac{N_y T\sqrt{R_m T}}{M}\right)\left(\frac{M}{T^2\sqrt{R_m T}}\right) \qquad (15)$$

$$\frac{6M_y}{T^2}=\left(\frac{M_y\sqrt{R_m T}}{M}\right)\left(\frac{6M}{T^2\sqrt{R_m T}}\right) \qquad (16)$$

$$\sigma_y = K_n\frac{N_y}{T} \pm K_b\frac{6M_y}{T^2} \qquad (17)$$

3.3.3 Stresses Resulting From Torsional Moment, M_T

In the case of a round attachment (such as a pipe), torsional moment is assumed to induce pure shear stresses, so that shear stress (τ) in the shell at the attachment-to-shell juncture is given by:

$$\tau_{yx} = \tau_{xy} = \frac{M_T}{2\pi r_0^2 T} \tag{18}$$

If only shear stresses are being considered, it is to be noted that the equivalent stress intensity is twice the above calculated shear stress.

In the case of rectangular attachments, torsional moment produces a complex stress field in the shell. Acceptable methods of analyzing this situation are not available at this time. If the designer has reason for concern, the problem should be resolved by testing in accordance with established code procedures.

3.3.4 Stresses Resulting From Shear Load, V

Bijlaard has proposed[14] that shear force (V) can be assumed transmitted to the shell entirely by membrane shear force. Therefore, stresses in the shell at the attachment-to-shell juncture can be approximated as follows:

3.3.4.1 Round Attachment

$$\tau_{xy} = \frac{V}{\pi r_0 T}\sin\theta \qquad \textit{(refer to Figure 1)} \tag{19}$$

3.3.4.2 Square Attachment

$$\tau_{xy} = \frac{V}{4c_1 T} \qquad (at\ \theta = 90^\circ\ and\ 270^\circ) \tag{20}$$

3.3.5 Stresses Resulting From Arbitrary Loading

In the general case, all applied loads and moments must be resolved (at the attachment-shell interface) in the three principal directions; i.e., they must be resolved into components $P, V_1, V_2, M_1, M_2, and\ M_T$.

If one then proceeds in the manner previously outlined, membrane, bending and shear stresses can be evaluated at eight distinct points in the shell at its juncture with the attachment. These eight points are shown in the sign convention chart, Table 1.

The numerous stress components can be readily accounted for, if a scheme similar to that shown in Table 2 and 3 is adopted. In using this scheme, it is to be noted that the Maximum Shear Theory has been used to determine equivalent stress intensities. Also, it is to be noted that evaluation of stresses resulting from internal pressure has been omitted.

Test work conducted by PVRC has shown that stresses attenuate rapidly at points removed from the attachment-to-shell juncture, the maximum stress frequently being located at the juncture.* However, in the general case of arbitrary loading, one has no assurance that the absolute maximum stress intensity in the shell will be located at one of the eight points considered in the above discussion.

3.4 List Of Nondimensional Curves For Spherical Shells

The nondimensional curves for solid and hollow attachments in spherical shells is shown on page 43 .

* Under certain conditions stresses may be higher in the nozzle wall than they are in the vessel wall. This possibility is most likely if the nozzle opening in not reinforced or if the reinforcement is placed on the vessel wall and not on the nozzle.

4.3.5.2 Rectangular Attachment

$$\tau_{x\phi} = \frac{V_c}{4c_1T} \tag{50}$$

$$\tau_{\phi x} = \frac{V_L}{4c_2T} \tag{51}$$

4.3.6 Stresses Resulting From Arbitrary Loading

In the general case, all applied loads and moments must be resolved (at the attachment-to-shell interface) in the three principal directions; i.e., they must be resolved into components $P,\ V_c,\ V_L,\ M_c, M_L,\ and\ M_T$. If one then proceeds in the manner previously outlined (e.g., paragraph 4.3.1.1), membrane, bending and shear stresses can be evaluated at eight points in the shell at its juncture with the attachment. These eight points are shown in the sign convention chart, Table 4.

4.4 Nondimensional Curves For Cylindrical Shells

The nondimensional curves which follow constitute, in general, a replot of Bijlaard's data to a semilog scale in order that certain portions of the curves can be read with greater facility. Those portions of the curves which are taken directly from Bijlaard's work are shown as solid curves; those portions of the curves which have been modified on the basis of recent experimental data, as discussed in Appendix A, are shown as dotted curves.

In the case of longitudinal moment loading and axial loading (thrust), two sets of curves are shown for the bending components of stress-one set applying to the longitudinal axis, and the other applying to an area of maximum stress off the axes of symmetry (longitudinal moment), or to the transverse axis (thrust). In the latter case, a portion of the original curves has been deleted in order to emphasize that the curves should not be used beyond the limits indicated. This was done because the available data indicated that the "outer limits" of the curves were appreciably unconservative, with no feasible manner to "correct" them (as explained in Appendix A).

In the case of longitudinal moment , the exact location, of the maximum stress cannot be defined with certainty, but Figure A-14 will provide an estimate of its location (considering that the location of maximum stress under internal pressure and longitudinal moment was essentially the same on IIT model "C-1," as shown on Figures A-2 and A-3). It should also be noted that, to the best of our knowledge, the curves for "maximum stresses off the axes of symmetry" (Figures 1B-1 and 2B-1) would apply only to the case of a round, flexible nozzle connection; it is conceivable that a similar effect might apply to a rigid square or rectangular attachment, for which the shell at the outer edges of the attachment might take a greater part of the load than that portion of the shell adjacent to the longitudinal centerline. However, we know of no direct evidence to support such an assumption.

4.4.1 List Of Nondimensional Curves For Cylindrical Shells

The list of nondimensional curves for cylindrical shells is shown on page 91.

4.5 Limits On Application

Where relatively large attachments are considered, or when situations are encountered that deviate considerably from the idealized cases presented herein, the designer should refer to paragraph A.3 in Appendix A and to the original references to ascertain the limitations of applicability for the procedure used.

However, there are a few generalizations that can safely be made regarding vessel and attachment geometry.

4.5.1 External Radial Load

Stresses are affected very little by the ratio of shell length to shell radius (l/R_m). Therefore, no restriction is made on the point of load application except in very extreme cases. The curves included in this report are for an l/R_m ratio of 8, which is sufficient for most practical applications. On the basis of data presented in Bibliographical Reference 2, results based on an l/R_m ratio of 8 will be slightly conservative for lesser values of l/R_m ratio and unconservative for greater values of l/R_m ratio. However, the error involved does not exceed approximately 10% of all l/R_m values greater than 3, which should be sufficiently accurate for most calculations. Since for lesser values of l/R_m, the results are conservative, no restriction will ordinarily be necessary on l/R_m ratio or the point of load application. For extreme cases or for "off center" loading, one may make corrections by use of the curves presented on page 8 of Bibliographical Reference 2, if desired.

Results are not considered applicable in cases where the length of the cylinder (l) is less than its radius (R_m). This applies either to the case of an open ended cylinder or closed ended cylinder where the stiffness is appreciably modified from the case considered.

4.5.2 External Moment

Results are applicable in the case of longitudinally off center attachments (a more usual case) provided that the attachment is located at least half the shell radius $(0.5R_m)$ from the end of the cylinder.

4.5.3 Attachment Stresses

The foregoing procedure provides one with a tool to find stresses in the shell, but not in the attachment. Under certain conditions, stresses may be higher in the attachment than they are in the vessel. For example, in the case of a nozzle, it is likely that the stresses will be higher in the nozzle wall than they are in the vessel wall if the nozzle opening is unreinforced or if the reinforcement is placed on the vessel wall and not on the nozzle.

5 ACKNOWLEDGMENT

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6 REFERENCES

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5. Bijlaard, P. P., "Local Stresses in Spherical Shells from Radial or Moment Loadings," Welding Jnl., 36 (5), Research Supplement, 240-s to 243-s (1957).
6. Bijlaard, P. P., "Stresses in a Spherical Vessel from Radial Loads Acting on a Pipe," Welding Research Council Bulletin No. 49, 1-30 (April 1959).
7. Bijlaard, P. P., "Stresses in a Spherical Vessel from External Moments Acting on a Pipe," Ibid., No. 49, 31-62 (April 1959).

Table 5 Continued – Computation Sheet for Local Stresses in Cylindrical Shells

Reference Figure No.	Read Curves for	Calculate absolute values of stress and enter result	STRESSES - If load is opposite that shown, reverse signs shown							
			A_u	A_L	B_u	B_L	C_u	C_L	D_u	D_L
3C	$\frac{N_\phi}{P/R_m}=$	$K_n\left(\frac{N_\phi}{P/R_m}\right)\left(\frac{P}{R_m T}\right)=$	−	−	−	−	−	−	−	−
1C OR 2C-1	$\frac{M_\phi}{P}=$	$K_b\left(\frac{M_\phi}{P}\right)\left(\frac{6P}{T^2}\right)=$	−	+	−	+	−	+	−	+
3A	$\frac{N_\phi}{M_c/R_m^2\beta}=$	$K_n\left(\frac{N_\phi}{M_c/R_m^2\beta}\right)\left(\frac{M_c}{R_m^2\beta T}\right)=$					−	−	+	+
1A	$\frac{M_\phi}{M_c/R_m\beta}=$	$K_b\left(\frac{M_\phi}{M_c/R_m\beta}\right)\left(\frac{6M_c}{R_m\beta T^2}\right)=$					−	+	+	−
3B	$\frac{N_\phi}{M_L/R_m^2\beta}=$	$K_n\left(\frac{N_\phi}{M_L/R_m^2\beta}\right)\left(\frac{M_L}{R_m^2\beta T}\right)=$	−	−	+	+				
1B or 1B-1	$\frac{M_\phi}{M_L/R_m\beta}=$	$K_b\left(\frac{M_\phi}{M_L/R_m\beta}\right)\left(\frac{6M_L}{R_m\beta T^2}\right)=$	−	+	+	−				
Add algebraically for summation of ϕ stresses σ_ϕ		$\sigma_\phi=$								
4C	$\frac{N_x}{P/R_m}=$	$K_n\left(\frac{N_x}{P/R_m}\right)\left(\frac{P}{R_m T}\right)=$	−	−	−	−	−	−	−	−
1C-1 OR 2C	$\frac{M_x}{P}=$	$K_b\left(\frac{M_x}{P}\right)\left(\frac{6P}{T^2}\right)=$	−	+	−	+	−	+	−	+
4A	$\frac{N_x}{M_c/R_m^2\beta}=$	$K_n\left(\frac{N_x}{M_c/R_m^2\beta}\right)\left(\frac{M_c}{R_m^2\beta T}\right)=$					−	−	+	+
2A	$\frac{M_x}{M_c/R_m\beta}=$	$K_b\left(\frac{M_x}{M_c/R_m\beta}\right)\left(\frac{6M_c}{R_m\beta T^2}\right)=$					−	+	+	−
4B	$\frac{N_x}{M_L/R_m^2\beta}=$	$K_n\left(\frac{N_x}{M_L/R_m^2\beta}\right)\left(\frac{M_L}{R_m^2\beta T}\right)=$	−	−	+	+				
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta}=$	$K_b\left(\frac{M_x}{M_L/R_m\beta}\right)\left(\frac{6M_L}{R_m\beta T^2}\right)=$	−	+	+	−				
Add algebraically for summation of x stresses σ_x		$\sigma_x=$								
Shear stress due to Torsion, M_T		$\tau_{\phi x}=\tau_{x\phi}=\frac{M_T}{2\pi r_o^2 T}=$	+	+	+	+	+	+	+	+
Shear stress due to load V_C		$\tau_{x\phi}=\frac{V_C}{\pi r_o T}=$	+	+	−	−				
Shear stress due to load V_L		$\tau_{x\phi}=\frac{V_L}{\pi r_o T}=$					−	−	+	+
Add algebraically for summation of shear stresses τ		$\tau=$								

COMBINED STRESS INTENSITY - S

1) When σ_ϕ *and* σ_x have like signs $S=\frac{1}{2}\left[\sigma_\phi+\sigma_x\pm\sqrt{(\sigma_\phi-\sigma_x)^2+4\tau^2}\right]$ *or* $\sqrt{(\sigma_\phi-\sigma_x)^2+4\tau^2}$

2) When $\tau=0$, $S=$ largest absolute magnitude of either $S=\sigma_\phi,\ \sigma_x,\ or\ |\sigma_\phi-\sigma_x|$

3) When σ_ϕ *and* σ_x have unlike signs, $S=\sqrt{(\sigma_\phi-\sigma_x)^2+4\tau^2}$

Table 6 – Radial Load P

Parameter	N_ϕ	N_x	M_ϕ	M_x
K_1	0.91	1.68	1.76	1.2
K_2	1.48	1.2	0.88	1.25
Note: Above holds approximately within limits $4 \geq \frac{\beta_1}{\beta_2} \geq 0.25$				

Table 7 – Circumferential Moment M_c

β_1 / β_2	γ	K_c for θ	K_c for M_ϕ	K_c for M_x	C_c for N_ϕ	C_c for N_x
0.25	15	1.09	1.31	1.84	0.31	0.49
	50	1.04	1.24	1.62	0.21	0.46
	100	0.97	1.16	1.45	0.15	0.44
	300	0.92	1.02	1.17	0.09	0.46
0.5	15	1.00	1.09	1.36	0.64	0.75
	50	0.98	1.08	1.31	0.57	0.75
	100	0.94	1.04	1.26	0.51	0.76
	300	0.95	0.99	1.13	0.39	0.77
2	15	(1.00)	(1.20)	(0.97)	(1.7)	(1.3)
	100	1.19	1.10	0.95	1.43	1.12
	300	---	(1.00)	(0.90)	(1.3)	(1.00)
4	15	(1.00)	(1.47)	(1.08)	(1.75)	(1.31)
	100	1.49	1.38	1.06	1.49	0.81
	300	---	(1.27)	(0.98)	(1.36)	(0.74)
Note: The values in parenthesis determined by an approximate solution.						

Curve Fit Coefficients for Figure SP-1

$$Y = \left(a + cU + eU^2 + gU^3 + iU^4\right) / \left(1 + bU + dU^2 + fU^3 + hU^4 + jU^5\right)$$

Coefficients	M_i			N_i		
	M_x	M_y	$M_{y(\max)}$	N_x	$N_{x(\max)}$	N_y
a	3.7231311E+00	1.9182958E+00	-5.3669486E+01	2.1322836E-01	2.1858968E-01	2.4586502E-01
b	1.8671976E+02	7.1931150E+02	-1.2516166E+04	4.2050448E+00	-2.5343227E+00	2.0008949E+02
c	2.6436830E+01	7.4335393E+01	2.2431247E+02	1.0916995E-01	-1.0771993E+00	4.8408477E+01
d	1.4194954E+03	2.6452748E+03	2.2926371E+05	5.4913965E+00	-3.6522378E+00	2.5345658E+02
e	6.4800756E+02	-4.5736180E+01	1.5781341E+04	1.4080117E+00	1.5900589E+00	-2.5034168E+01
f	9.7346418E+03	9.1388566E+02	1.0511173E+05	2.4926977E+01	1.1261041E+01	1.5866437E+01
g	-1.6034796E+02	-5.3218355E+00	4.7741439E+03	-2.4401880E-01	-4.6485921E-01	5.4387020E+00
h	0	-2.5983370E+03	2.2746897E+06	0	0	0
i	0	5.7654597E+00	2.2544280E+04	0	0	0
j	0	7.9658446E+02	8.0828856E+04	0	0	0

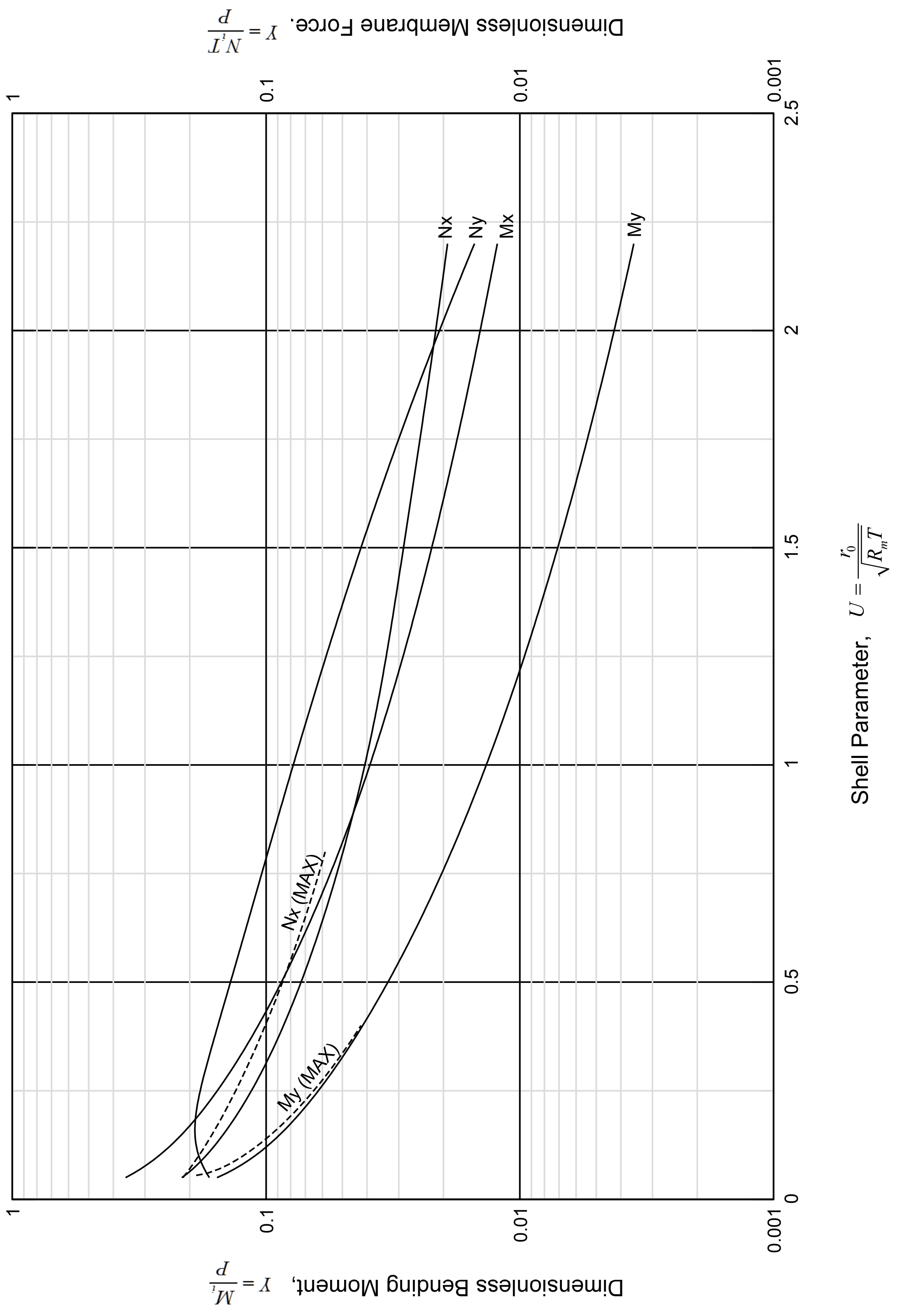

Figure SP - 2 Stresses in Spherical Shell Due to a Radial Load P on Nozzle Connection

Curve Fit Coefficients for Figure SP-2

$$Y = \left(a + cU + eU^2 + gU^3 + iU^4\right) / \left(1 + bU + dU^2 + fU^3 + hU^4 + jU^5\right)$$

Coefficients	M_i			N_i		
	M_x	M_y	$M_{y(\max)}$	N_x	$N_{x(\max)}$	N_y
a	6.2106583E-01	3.6266539E-01	-3.1810115E+02	4.2439923E+00	2.5272151E-01	1.4696948E-01
b	2.1627265E+01	4.4962773E+01	-1.2824607E+05	2.9097533E+03	4.4206642E+00	-1.6443301E+00
c	2.9618619E+00	3.7254224E+00	-1.7399420E+04	6.7064837E+02	1.4138993E-01	1.2384743E-01
d	2.9230883E+01	9.8034596E+01	1.7045745E+06	7.8830399E+03	3.3747209E+00	2.9842988E+01
e	2.1842087E+00	-2.7044035E-01	4.9959536E+05	-1.0252729E+03	8.3253656E-01	5.3815760E+00
f	8.6140607E+01	1.3759214E+02	1.7739591E+07	-1.5335935E+04	1.6937757E+01	6.1433221E+00
g	-3.8731112E-01	0	-2.0079910E+05	4.8289898E+02	0	-3.3272374E+00
h	0	0	2.2634886E+06	6.9349360E+03	0	1.2596850E+00
i	0	0	0	-3.4862622E+01	0	5.3508405E-01
j	0	0	0	0	0	0

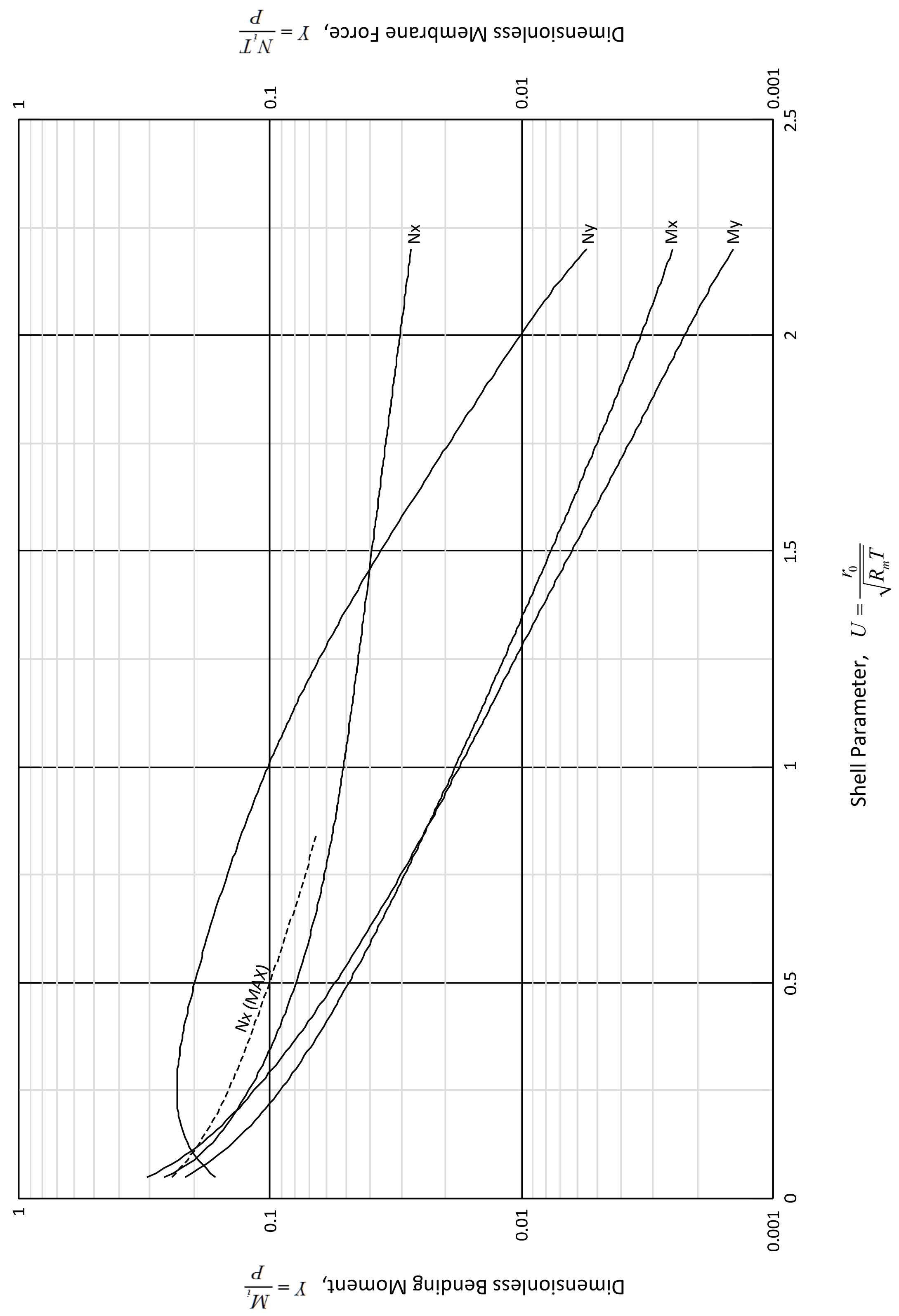

Figure SP-3 – Stresses in Spherical Shell Due to a Radial Load P on Nozzle Connection

Curve Fit Coefficients for Figure SP-3

$$Y = \left(a + cU + eU^2 + gU^3 + iU^4\right) / \left(1 + bU + dU^2 + fU^3 + hU^4 + jU^5\right)$$

Coefficients	M_i		N_i		
	M_x	M_y	N_x	$N_{x(\max)}$	N_y
a	3.6561314E-01	6.9239341E-01	1.9468982E+02	3.4042688E-01	1.1688293E-01
b	2.0761038E+01	4.1459886E+01	3.5425743E+04	5.9056469E+01	4.8475808E-02
c	2.1174399E+00	6.5648389E+00	6.7126521E+03	1.5213241E+01	1.0834266E+00
d	3.9890351E+01	5.6965733E+01	6.7541613E+04	1.1073094E+02	6.5637891E+00
e	-1.5403305E+00	-1.0362019E+01	-7.0766023E+03	-3.1746355E+01	-1.4491092E+00
f	6.0841929E+00	5.0303340E+01	-3.8750208E+04	-3.6344661E+02	-8.5621782E+00
g	3.0035995E-01	5.2068393E+00	7.1274907E+03	5.2139514E+01	6.6329377E-01
h	0	-1.2484335E+02	5.2813192E+04	8.3510139E+02	4.7650686E+00
i	0	-8.5063401E-01	-9.7664276E+02	0	-1.0585206E-01
j	0	4.5914601E+01	0	0	-7.8865952E-01

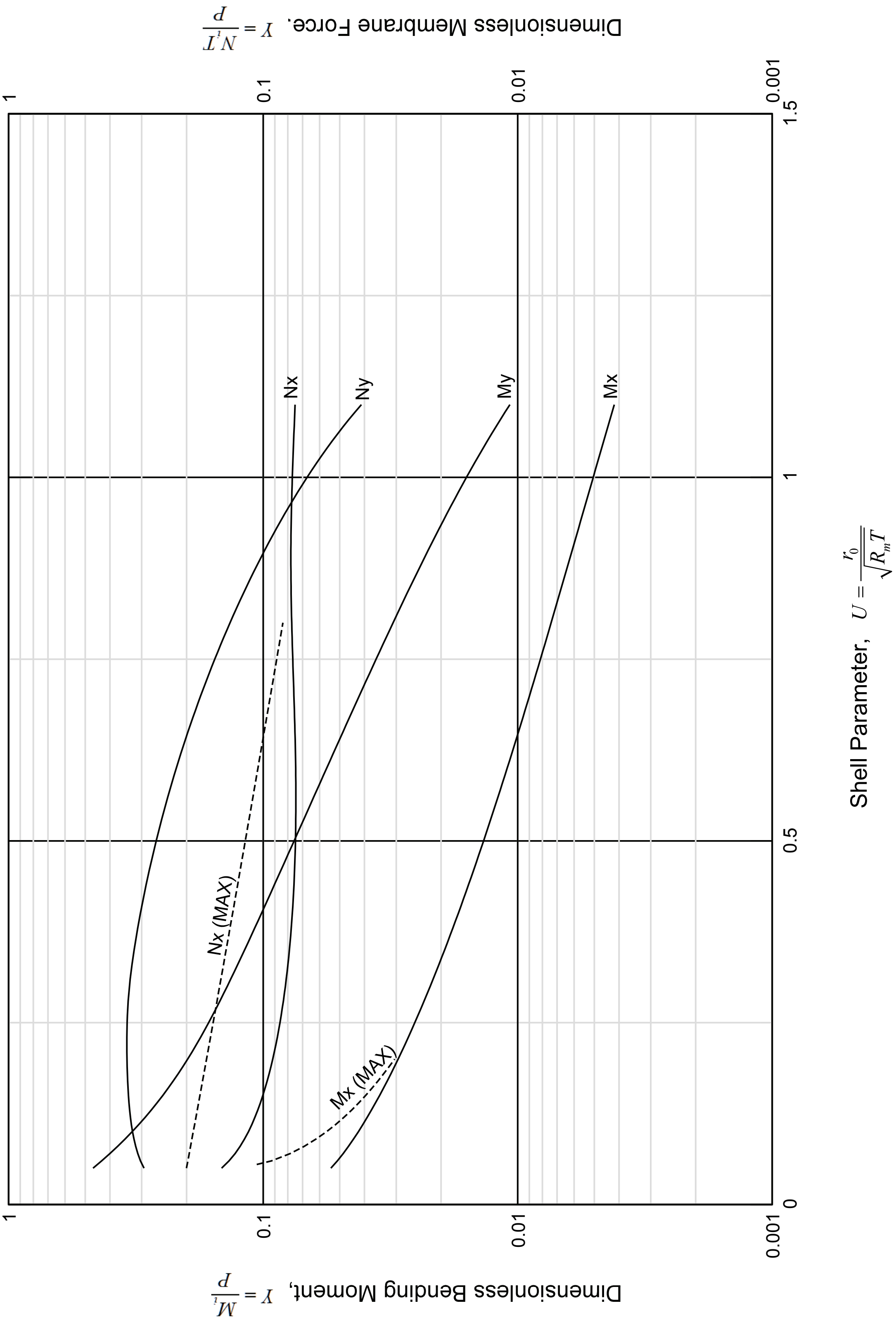

Figure SP-4 – Stresses in Spherical Shell Due to a Radial Load P on Nozzle Connection

Curve Fit Coefficients for Figure SM-2

$$Y = \left(a + cU + eU^2 + gU^3 + iU^4\right) / \left(1 + bU + dU^2 + fU^3 + hU^4 + jU^5\right)$$

Coefficients	M_i		N_i		
	M_x	M_y	N_x	N_y	$N_{y(\max)}$
a	1.1646993E+01	3.0505431E+00	2.3257601E+00	-6.0791980E-02	2.5370654E-01
b	4.4812600E+01	1.8715738E+01	7.2895751E+00	-4.1860737E+00	-2.8999797E-01
c	-2.1554201E+02	-1.3822104E+01	-1.0621217E+01	3.3386300E-01	-3.8957216E-01
d	-9.9067850E+02	-1.9097632E+01	4.6172276E+01	9.0988534E+00	-8.1897073E-01
e	1.2067112E+03	2.4613474E+01	2.3782398E+01	-3.7291406E-01	2.0136812E-01
f	5.0631144E+03	-1.0817593E+02	-1.9822983E+02	-7.5883117E+00	8.8819248E-01
g	-3.9867125E+02	-6.4013986E+00	1.8276664E+01	2.1355625E-01	0
h	5.2285657E+03	3.7344372E+02	7.6711959E+02	2.6114456E+00	0
i	0	0	0	-4.2183167E-02	0
j	0	0	0	0	0

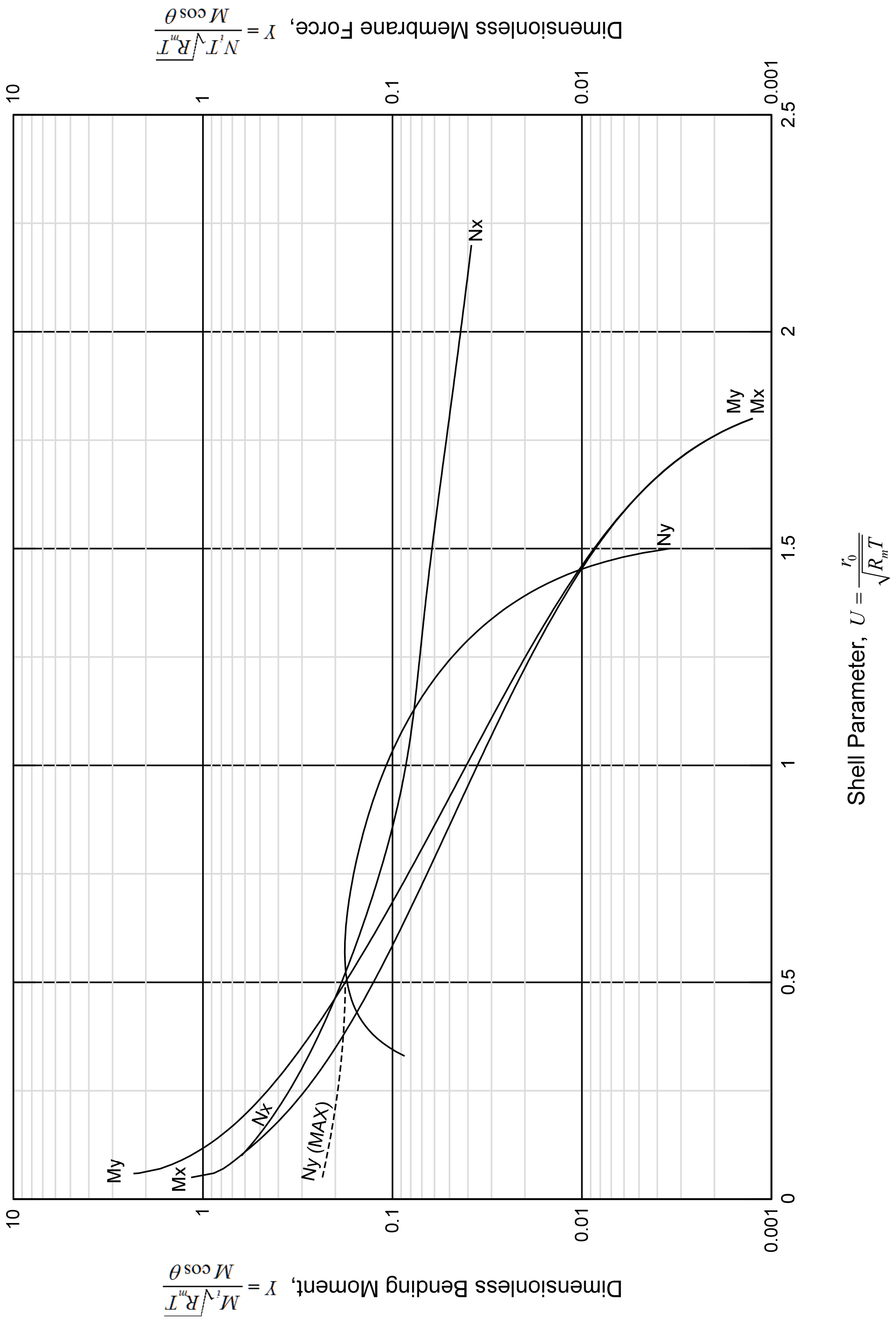

Figure SM-3 – Stresses in Spherical Shell Due to Overturning Moment M on a Nozzle Connection

Curve Fit Coefficients for Figure SM-3

$$Y = \left(a + cU + eU^2 + gU^3 + iU^4\right) / \left(1 + bU + dU^2 + fU^3 + hU^4 + jU^5\right)$$

Coefficients	M_i		N_i		
	M_x	M_y	N_x	N_y	$N_{y(\max)}$
a	3.5758953E+03	-1.6128152E+03	1.1657748E+00	-2.5119924E-01	2.4792063E-01
b	1.8337834E+04	-1.6367035E+04	6.6118950E+00	-4.0064481E+00	3.3862786E-01
c	-1.4840283E+05	1.9145704E+04	-1.8023351E+00	1.2060395E+00	-2.1239925E-01
d	-1.1131498E+06	2.3171093E+05	-7.5795472E+00	1.1601141E+01	4.1233137E-01
e	1.8083402E+06	1.7410382E+05	7.8509789E-01	-9.1529815E-01	3.3566529E-01
f	1.9219473E+07	9.6988029E+05	-5.6021012E-01	-1.0414986E+01	0
g	-1.2126461E+05	7.4723918E+04	4.0155458E-02	1.5287720E-01	0
h	4.8680620E+06	1.3653286E+06	2.7493072E+00	3.6042497E+00	0
i	-4.2794108E+05	-9.1957244E+04	0	0	0
j	8.2865245E+06	1.7291098E+06	0	0	0

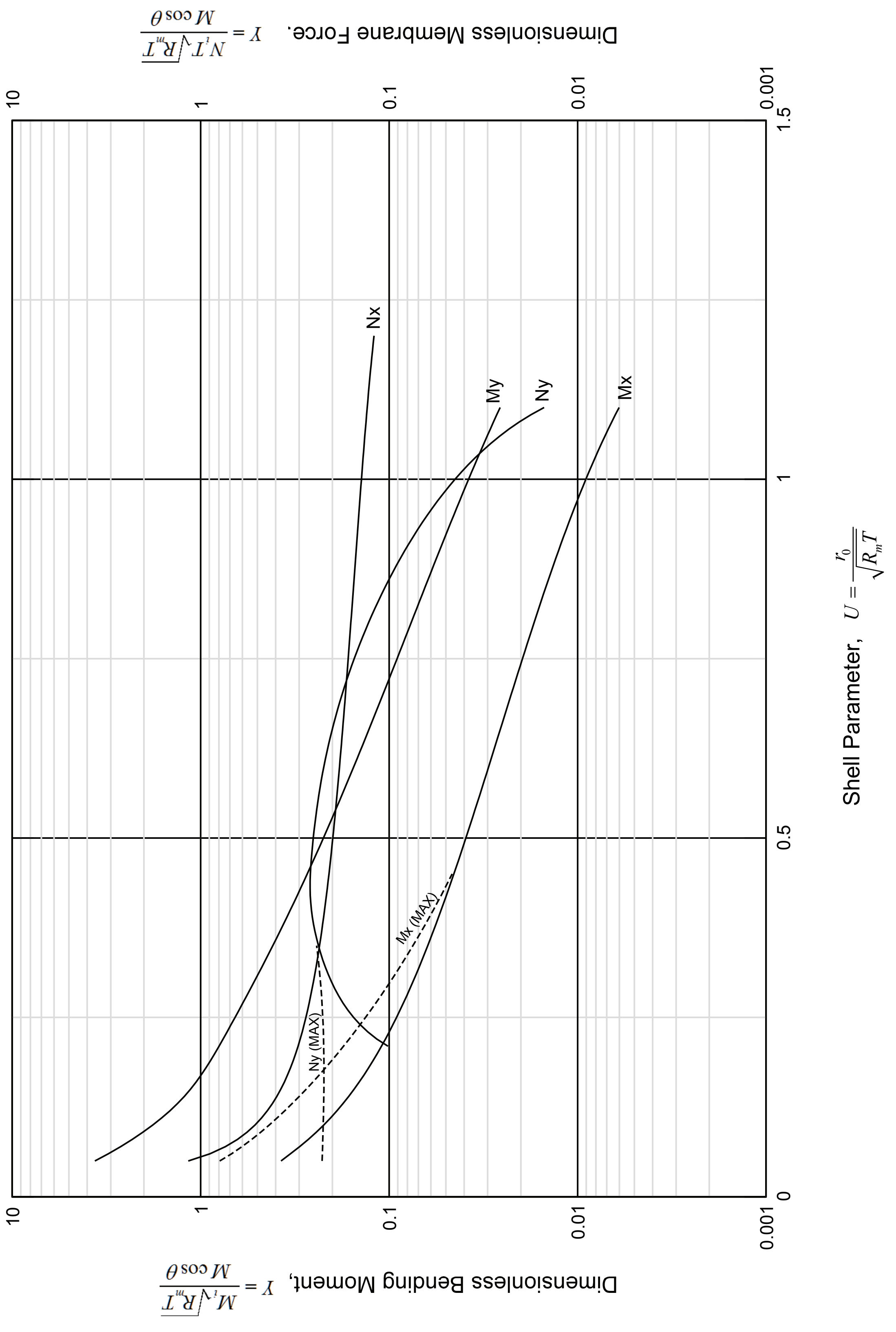

Figure SM-4 – Stresses in Spherical Shell Due to Overturning Moment M on a Nozzle Connection

Curve Fit Coefficients for Figure SM-8

$$Y = \left(a + cU + eU^2 + gU^3 + iU^4\right) / \left(1 + bU + dU^2 + fU^3 + hU^4 + jU^5\right)$$

Coefficients	M_i			N_i		
	M_x	$M_{x(\max)}$	M_y	N_x	$N_{x(\max)}$	N_y
a	4.4733666E-01	5.7533123E+00	5.8264907E+00	-4.7164570E+00	-3.9918460E-01	-3.4872177E-02
b	7.8610698E+01	1.1086142E+02	2.5265382E+00	-5.9701208E+02	6.2212419E+01	-2.3803483E+00
c	-8.3839589E+00	-2.5938122E+01	-1.1258135E+02	1.6151819E+02	1.3584827E+01	1.8887817E+00
d	-1.8016236E+03	-3.1144926E+02	-3.6871966E+02	1.8269051E+04	-2.7280298E+02	6.6619028E+00
e	7.5876319E+00	3.9969232E+01	8.1597594E+01	9.2708144E+02	-5.3559232E+01	-3.4378049E+00
f	1.6414093E+03	3.2943438E+02	-1.6649828E+02	-9.9025503E+03	4.2276461E+02	-8.1245389E+00
g	-2.1271960E+00	-2.0938374E+01	0	3.8766373E+02	8.0220652E+01	1.9493159E+00
h	-8.1344676E+02	-1.5170605E+02	0	6.7598529E+02	-2.1963519E+02	3.3624721E+00
i	0	0	0	-6.9623849E+01	-4.1668059E+01	-3.1426692E-01
j	0	0	0	2.9426661E+03	0	0

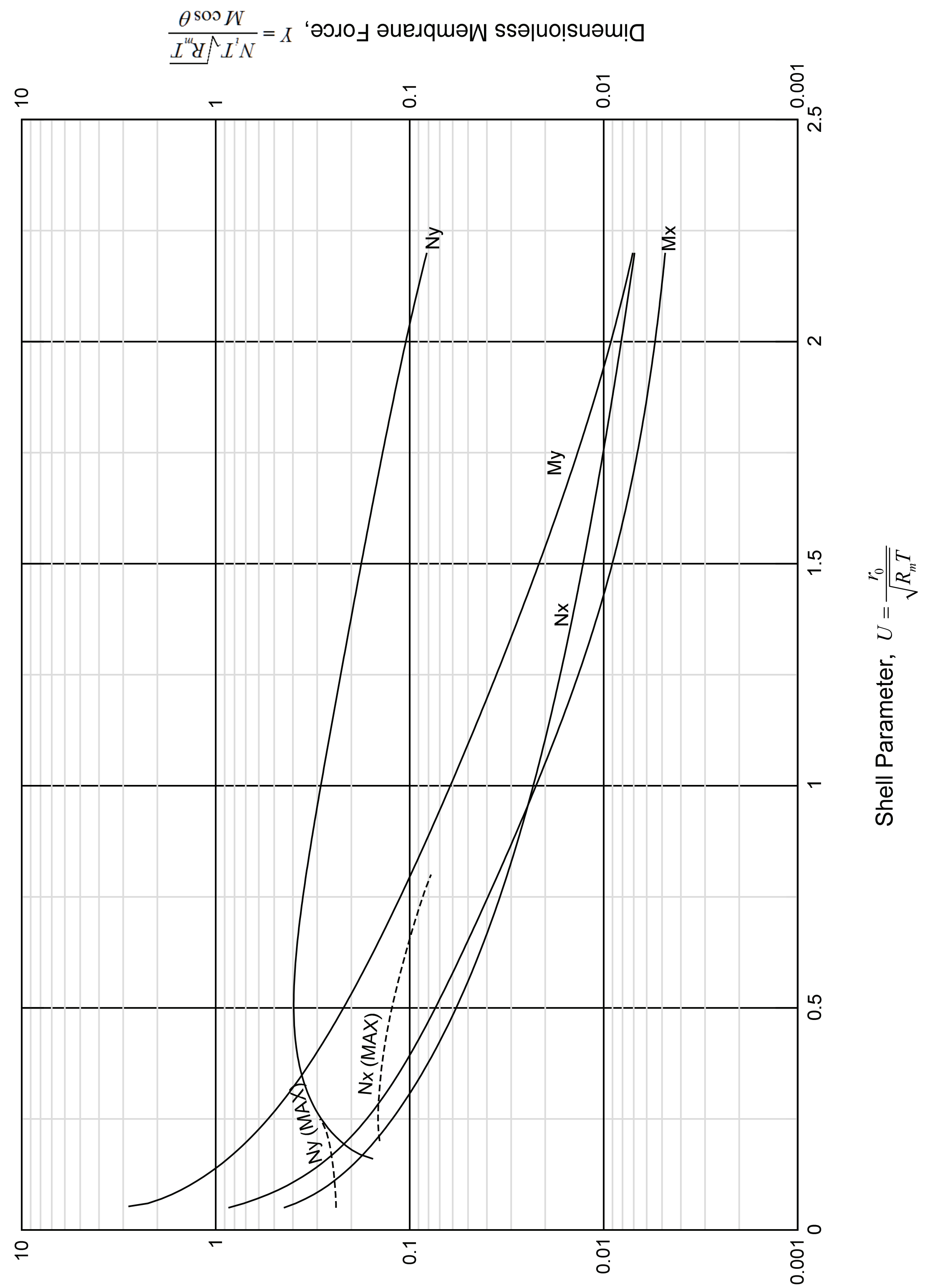

Figure SM-9 – Stresses in Spherical Shell Due to Overturning Moment M on a Nozzle Connection

Curve Fit Coefficients for Figure SM-10

$$Y=\left(a+cU+eU^2+gU^3+iU^4\right)/\left(1+bU+dU^2+fU^3+hU^4+jU^5\right)$$

Coefficients	M_i			N_i		
	M_x	$M_{x(\max)}$	M_y	N_x	$N_{x(\max)}$	N_y
a	-2.8953612E-01	3.7438322E+00	-1.1507646E-01	3.6486425E-01	2.4147461E-01	-2.4765961E+02
b	-2.3969828E+02	4.6553411E+01	-3.6469314E+01	1.5251530E+01	-6.0878947E+00	1.3279704E+04
c	2.8154560E+01	-2.6472881E+01	6.8407551E+01	-5.9161742E+00	-2.1522051E+00	6.0502227E+03
d	8.7047434E+03	-2.2290514E+02	6.7643978E+02	-4.9050816E+02	2.9258704E+01	-7.6294446E+03
e	1.6233457E+02	7.0363289E+01	2.5082547E+02	5.8078798E-01	9.5636687E+00	-8.5879675E+03
f	1.0939479E+04	3.2906011E+02	-5.1126097E+02	1.9508997E+02	-1.6150711E+00	8.8654767E+04
g	-9.4525620E+01	-8.3408410E+01	-1.0601931E+02	-3.8109676E+00	-6.2859846E+00	1.0378873E+05
h	1.2376590E+04	-3.1498891E+02	2.5611251E+03	-1.1959366E+01	1.8565963E+01	2.0192673E+04
i	1.7167907E+01	3.7929431E+01	0	1.5998571E+00	1.3048984E+00	-4.2585861E+04
j	0	4.0136563E+02	0	0	-6.2293872E+00	3.1275025E+04

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Curve Fit Coefficients for Figure 3A – *Extrapolated*

$$Y = \left(a + c\beta + e\beta^2 + g\beta^3 + i\beta^4\right) / \left(1 + b\beta + d\beta^2 + f\beta^3 + h\beta^4 + j\beta^5\right)$$

Shell Parameter γ	Coefficients									
	a	b	c	d	e	f	g	h	i	j
5	-1.451139E-03	-1.035899E+01	2.650327E-01	9.166767E+01	-1.895453E+00	-1.323582E+02	3.062425E+01	1.812153E+02	0.000000E+00	0.000000E+00
7.5	-1.403441E-03	-1.198365E+01	3.360175E-01	9.109319E+01	-7.708523E-01	-2.745443E+02	1.673266E+01	4.116683E+02	-3.207802E+01	-2.887586E+02
10	1.977358E-03	1.726468E+00	-1.036820E-01	4.467894E+01	3.139516E+01	-1.988610E+02	-9.907324E+01	2.724253E+02	9.384576E+01	-8.086119E+01
15	-1.424719E-02	-8.542087E+00	3.061791E+00	6.886452E+02	-1.405058E+02	2.247020E+02	3.732610E+03	3.055907E+03	-3.858723E+03	-2.066650E+03
25	-2.098695E-02	-1.402968E+01	3.346873E+00	1.437985E+02	-7.573819E-01	-4.856585E+02	9.718657E+01	8.701394E+02	7.064534E+01	0.000000E+00
35	-3.847029E-02	7.173794E+00	4.074958E+00	6.829491E+01	2.416726E+02	-2.057620E+02	-3.965408E+02	1.116052E+03	-1.977746E+02	-2.084064E+03
50	-5.914460E-02	-1.910455E+01	1.356950E+01	1.289748E+02	-1.593822E+02	-1.973228E+02	9.293769E+01	-1.387348E+03	4.801930E+03	1.160375E+04
75	-1.661500E-01	-1.415320E+01	3.192937E+01	1.145019E+02	-3.027891E+02	-5.504676E+02	8.217625E+02	1.072565E+03	-3.161649E+02	0.000000E+00
100	-1.244246E-01	-4.216117E+01	3.554631E+01	8.057370E+02	-9.341817E+02	-5.792720E+03	1.243407E+04	2.692923E+04	3.126918E+03	0.000000E+00
150	-1.431212E+00	7.204012E+01	2.007445E+02	-1.137065E+03	1.971052E+03	1.084690E+04	-1.543698E+04	-4.080601E+04	3.187912E+04	5.973328E+04
200	-7.282994E-01	-1.225348E+01	1.694251E+02	1.560004E+02	-1.642413E+03	-1.021341E+03	5.109293E+03	2.417154E+03	-2.425999E+03	1.144195E+03
300	-1.235952E+01	2.248684E+02	1.763915E+03	-4.401423E+03	-5.885038E+02	4.801349E+04	-1.103392E+05	-2.621259E+05	4.029191E+05	5.529536E+05

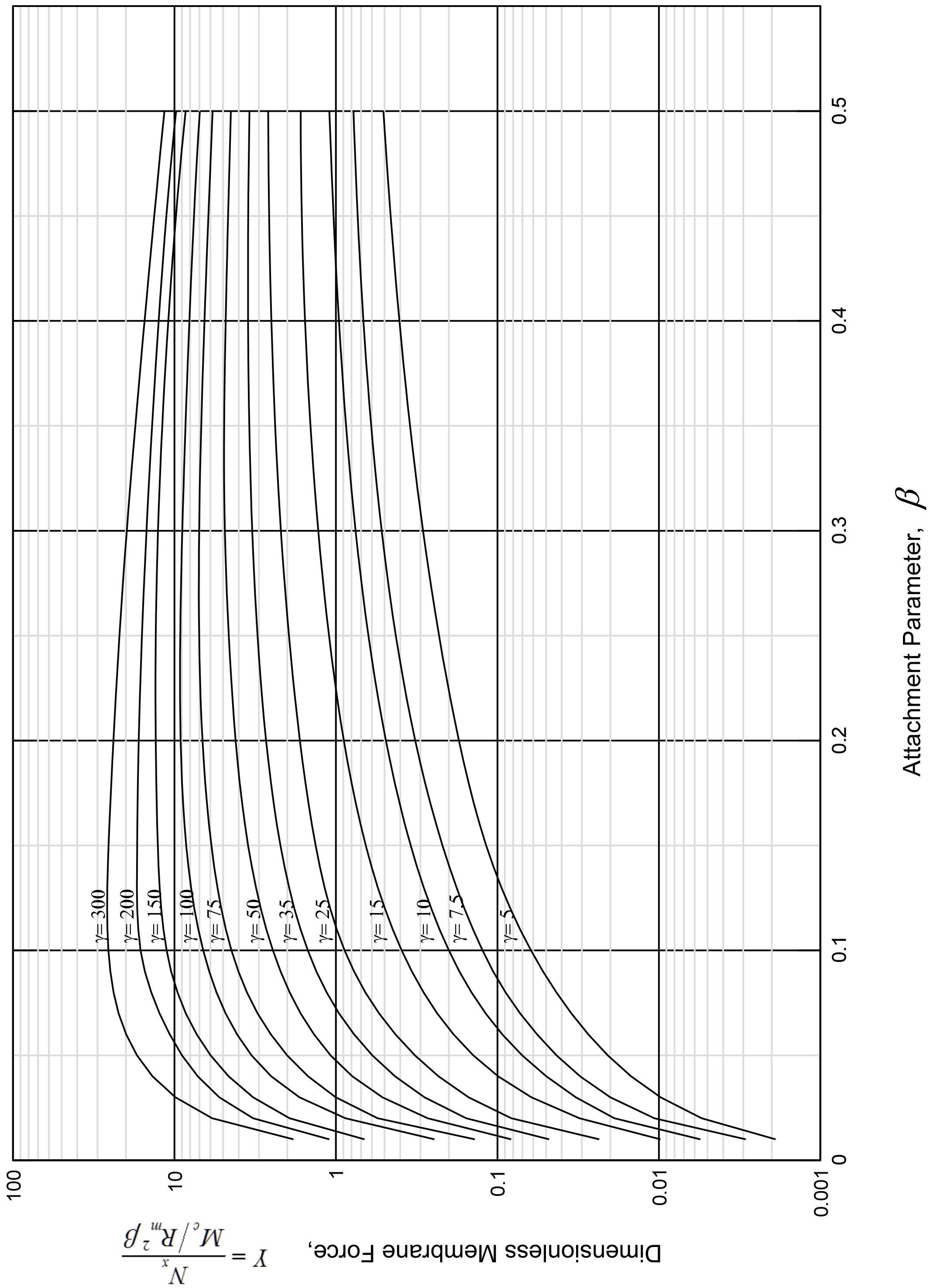

Figure 4A – Moment $\dfrac{N_\phi}{\left(M_c / R_m^2 \beta\right)}$ Due to an External Circumferential Moment M_c on a Circular Cylinder – *Original*

Curve Fit Coefficients for Figure 4A – *Original*

Shell Parameter γ	$Y = \left(a + c\beta + e\beta^2 + g\beta^3 + i\beta^4\right) / \left(1 + b\beta + d\beta^2 + f\beta^3 + h\beta^4 + j\beta^5\right)$									
	Coefficients									
	a	b	c	d	e	f	g	h	i	j
5	-8.9588077E-04	-1.0457970E+01	2.5061533E-01	4.3031174E+01	1.1824023E+00	-5.2395915E+01	-2.7046982E+01	1.7696115E+02	1.2691723E+02	-4.0346310E+01
7.5	-3.3140260E-03	-2.1220032E+01	6.1100156E-01	1.2389299E+02	-3.7332931E+00	6.6891240E+01	-1.1638340E+02	4.9003857E+02	1.2555121E+03	6.6886838E+02
10	-1.1648336E-02	-1.4431293E+01	2.1639922E+00	7.1439732E+02	-6.5047324E+01	-1.4489682E+03	1.6405458E+03	3.2001690E+03	-8.5424030E+02	-2.1431786E+03
15	2.0637923E-03	1.7628487E+01	-8.9435633E-02	-3.5074928E+01	1.0285314E+02	4.1110651E+02	2.6541337E+01	-8.8879784E+02	2.6936808E+02	9.8642922E+02
25	-2.7228028E-02	-1.2363871E+01	5.0597456E+00	9.9070478E+01	-3.0140077E+01	-9.6383083E+01	3.7715102E+02	2.2341567E+02	4.8679924E+02	1.9450443E+02
35	-4.5336152E-02	-6.0281082E+00	9.0094840E+00	9.5109514E+01	-7.6383456E+00	1.8550518E+02	1.4383657E+03	-6.6824710E+01	7.8227326E+02	8.4985885E+02
50	6.9545543E-03	2.1013063E+01	-1.2520239E+00	-1.2197355E+02	1.1081457E+03	3.6889967E+02	-6.9319584E+03	-1.5521239E+03	1.2001421E+04	3.3806300E+03
75	-2.4044856E-01	-1.2299088E+01	3.9096093E+01	9.2010582E+01	-3.0031771E+02	8.6894638E+01	1.6416270E+03	3.1442550E+02	1.4725438E+04	4.3460455E+03
100	4.4165576E+01	7.5148226E+03	-9.5857906E+03	-1.3832738E+04	7.1082532E+05	2.0168647E+05	-9.9722279E+05	-3.8741927E+05	-3.2653494E+05	8.6665726E+04
150	-5.4249899E-01	-1.3950711E+01	1.2479865E+02	1.0971178E+02	-1.3365378E+03	-3.3930352E+02	7.4189398E+03	1.0909387E+03	-8.1851989E+03	-9.7272639E+02
200	-1.2159205E+00	-1.4951902E+01	2.5720616E+02	7.0819294E+01	-4.4129430E+03	-1.3547617E+02	2.7292632E+04	2.2687676E+03	-3.2082704E+04	-2.9454074E+03
300	-1.9533000E+00	-1.1589980E+01	3.8412396E+02	1.4555168E+02	-2.5265943E+03	-6.8417326E+02	1.0045023E+04	1.9247450E+03	-9.9041899E+03	-1.5832995E+03

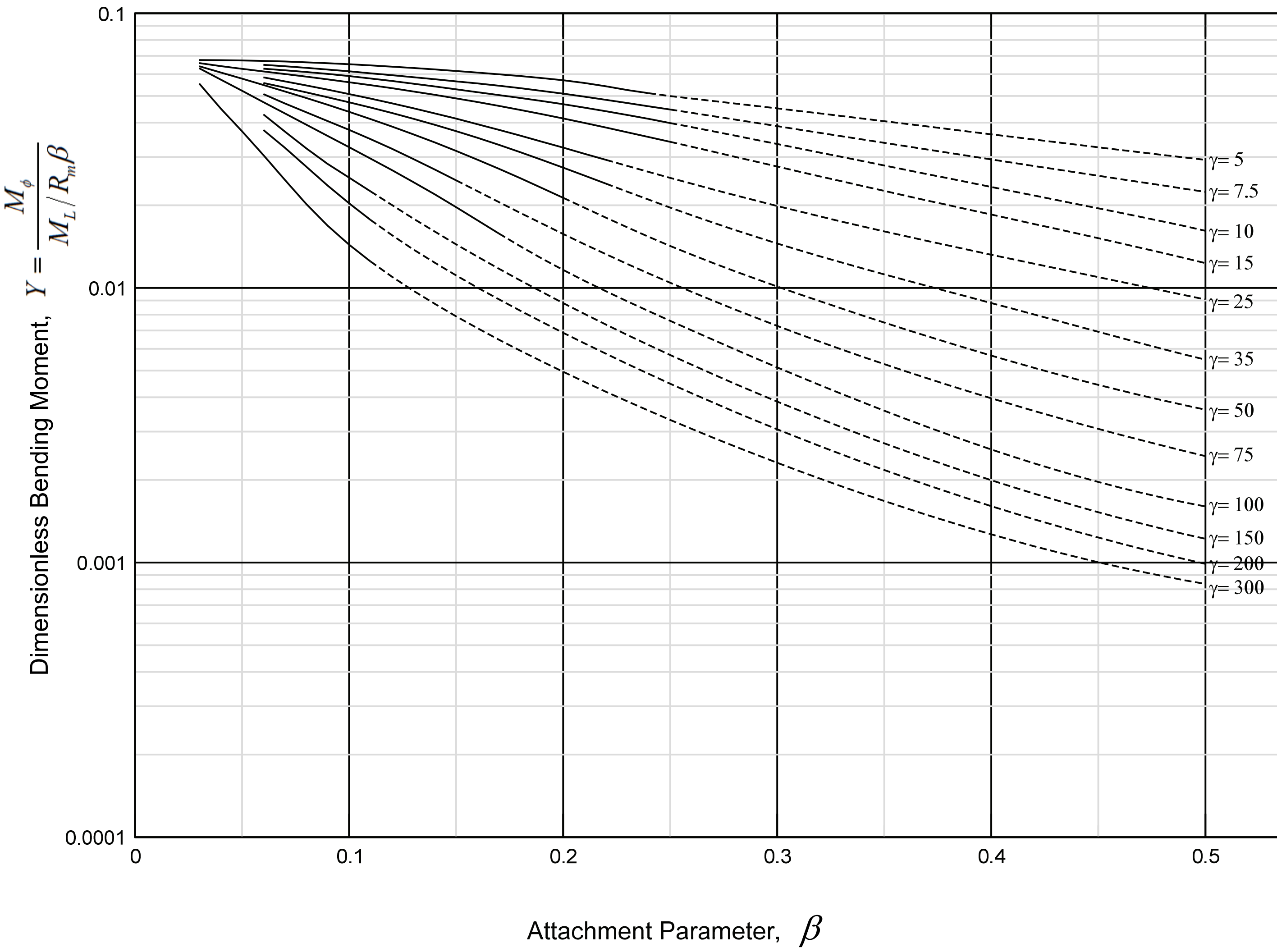

Figure 1B – Moment $\frac{M_\phi}{(M_L / R_m \beta)}$ Due to an External Longitudinal Moment M_L on a Circular Cylinder (Stress on the Longitudinal Plane of Symmetry) – *Original*

Curve Fit Coefficients for Figure 2B-1 – *Extrapolated*

$$Y = \left(a + c\beta + e\beta^2 + g\beta^3 + i\beta^4\right) \Big/ \left(1 + b\beta + d\beta^2 + f\beta^3 + h\beta^4 + j\beta^5\right)$$

Shell Parameter γ	Coefficients									
	a	b	c	d	e	f	g	h	i	j
5	1.0123714E-01	2.8998068E+01	3.8378637E+00	2.6540347E+01	-6.1909603E+00	4.8105428E+01	2.4515777E+01	3.6140331E+02	-2.9669235E+01	-6.4424335E+02
7.5	1.1486497E-01	-1.0047536E+01	-1.2865145E+00	3.3458060E+01	5.0707609E+00	-3.6637248E+01	-7.4990182E+00	3.6468690E+01	4.5588220E+00	0.0000000E+00
10	1.1489487E-01	-1.1244590E+01	-1.3847729E+00	4.3802996E+01	5.1190723E+00	-1.1568066E+02	-4.8191382E+00	3.7649094E+02	-7.9590164E-01	-4.4248426E+02
15	1.1703035E-01	-1.0329079E+01	-1.3861493E+00	4.8925062E+01	6.6122794E+00	-8.5219683E+01	-7.0034434E+00	4.3181446E+02	1.0826428E+00	-4.3207921E+02
25	1.1506739E-01	3.0785023E-01	-7.1024642E-02	3.7454421E+01	7.5831012E-01	1.5255140E+02	2.8161721E+01	1.4641336E+03	-3.5665596E+01	-1.4981279E+03
35	1.2445631E-01	-4.7477282E-01	-6.2098418E-01	2.9230583E+01	6.9633595E+00	5.0272736E+02	3.0479673E+00	2.4204448E+02	-7.5002285E+00	0.0000000E+00
50	1.3782476E-01	-4.2166215E+00	-2.0121769E+00	-8.1163911E+01	1.5125192E+01	1.3894849E+03	-3.9674044E+01	-4.3839143E+03	4.1526585E+01	5.1558656E+03
75	1.2303863E-01	-4.6436945E+00	-1.3818761E+00	-2.2430957E+00	1.1688304E+01	1.2070655E+03	-4.0276783E+01	-5.5776135E+03	6.6508093E+01	1.0366662E+04
100	1.1483769E-01	-1.0697336E+01	-1.5792381E+00	1.0297098E+02	1.0801728E+01	-1.8576448E+02	-3.7715197E+01	-1.1431360E+03	6.3491193E+01	6.3609195E+03
150	1.1325087E-01	-1.1061693E+01	-1.8069913E+00	9.1953655E+01	1.3223496E+01	1.1161123E+02	-4.6919265E+01	-3.2696681E+03	6.7913784E+01	8.9011590E+03
200	1.1584080E-01	-5.3416948E+00	-1.6456791E+00	1.1686466E+01	1.0764330E+01	7.2815813E+02	-1.5998281E+01	3.3436221E+03	3.4555682E+01	0.0000000E+00
300	1.2088872E-01	-8.8461349E+00	-1.7016322E+00	3.3336060E+02	1.7078437E+01	2.4075841E+02	-7.1413948E+01	-9.9440697E+03	1.1072960E+02	2.4864860E+04

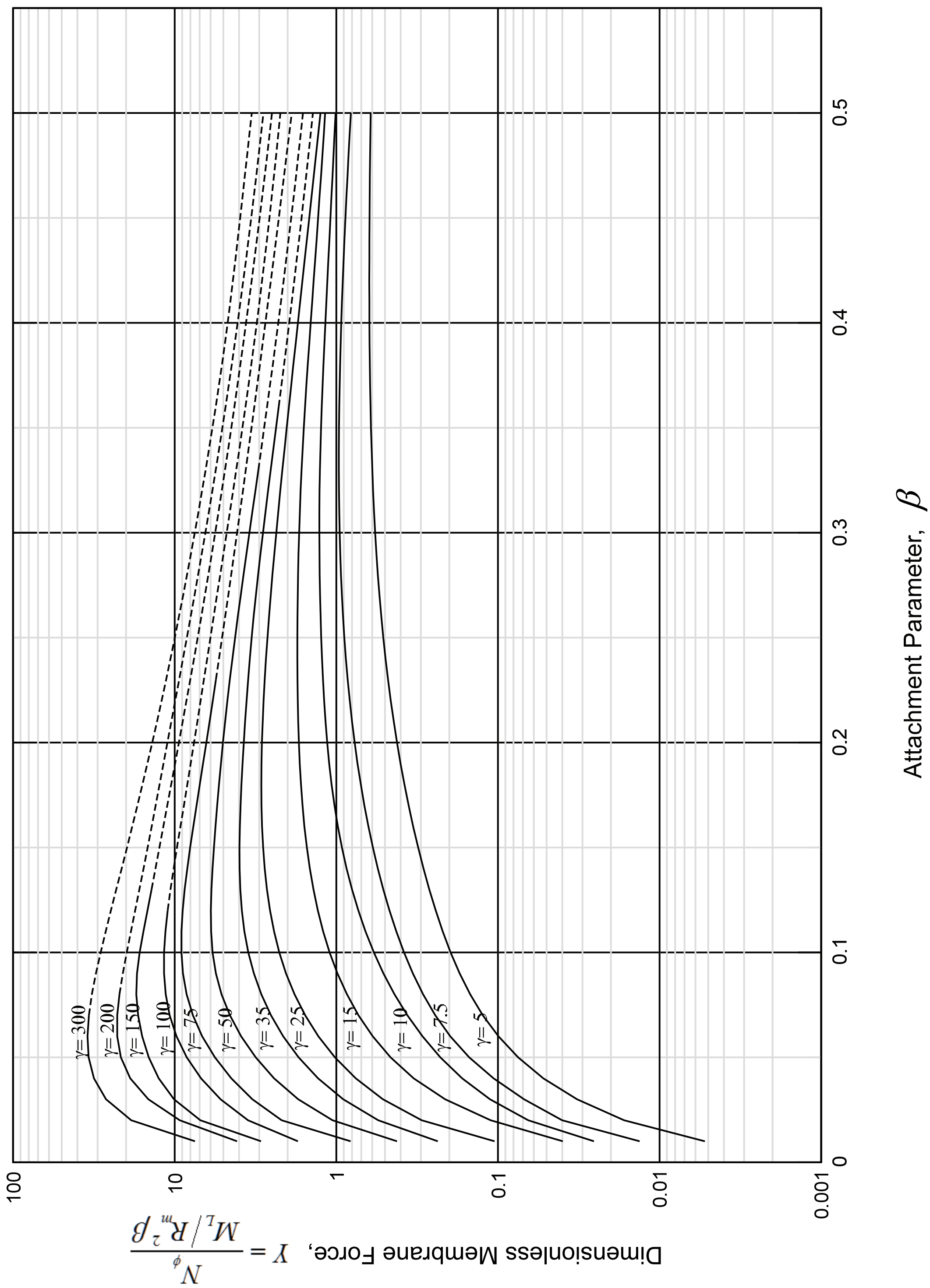

Figure 3B – Membrane Force $\frac{N_\phi}{\left(M_L / R_m^2 \beta\right)}$ **Due to an External Longitudinal Moment** M_L **on a Circular Cylinder –** ***Original***

Curve Fit Coefficients for Figure 1C – *Extrapolated*

$$Y = \left(a + c\beta + e\beta^2 + g\beta^3 + i\beta^4\right) \Big/ \left(1 + b\beta + d\beta^2 + f\beta^3 + h\beta^4 + j\beta^5\right)$$

Shell Parameter γ	Coefficients									
	a	b	c	d	e	f	g	h	i	j
5	4.582270E-01	5.945634E+00	-3.036431E+00	-1.016941E+02	1.974035E+00	3.250149E+02	1.389091E+01	-4.688659E+02	-2.694221E+00	8.825230E+02
7.5	4.207004E-01	1.510403E+01	1.581305E+00	-3.103491E+01	-2.453742E+01	-3.171388E+02	5.948403E+01	7.262875E+02	-2.131462E+01	5.502750E+02
10	3.816180E-01	4.523298E+01	1.621814E+01	8.837445E+02	9.259331E+01	-6.151990E+01	-4.159127E+02	-2.192796E+03	4.484787E+02	2.261068E+03
15	4.080761E-01	-3.924850E+00	-7.485687E+00	-1.398097E+02	4.669771E+01	1.347686E+03	-3.824180E+01	-2.726180E+02	0.000000E+00	0.000000E+00
25	4.115648E-01	-2.101055E+01	-1.563479E+01	8.617374E+01	2.615038E+02	6.200437E+03	-9.988138E+02	-2.263490E+04	1.489572E+03	4.166938E+04
35	3.859407E-01	6.798425E+00	-3.924144E+00	1.228247E+02	8.954075E+01	2.298680E+03	-3.296632E+02	-5.234970E+03	4.272916E+02	2.278665E+03
50	3.968700E-01	2.580834E+01	1.098581E+00	7.378094E+01	-1.762546E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
75	3.026954E-01	1.709219E+01	5.222633E+00	8.885274E+02	9.243128E+01	4.226790E+03	-1.752356E+02	0.000000E+00	0.000000E+00	0.000000E+00
100	3.564371E-01	-3.674019E+01	-2.115102E+01	6.030078E+01	5.167269E+02	2.635962E+04	-2.725685E+03	-1.272093E+05	4.635827E+03	1.657965E+05
150	4.245751E-01	1.486043E+01	-1.055510E+01	-7.373358E+02	7.462081E+01	5.026256E+03	-1.051835E+02	0.000000E+00	0.000000E+00	0.000000E+00
200	5.482515E-01	5.676207E+01	-1.008116E+01	-1.299505E+03	4.813893E+01	6.665867E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
300	1.913899E-01	-5.104412E+01	-6.325633E+00	1.733490E+03	1.066215E+02	-2.290056E+04	8.879816E+02	4.018972E+05	0.000000E+00	0.000000E+00

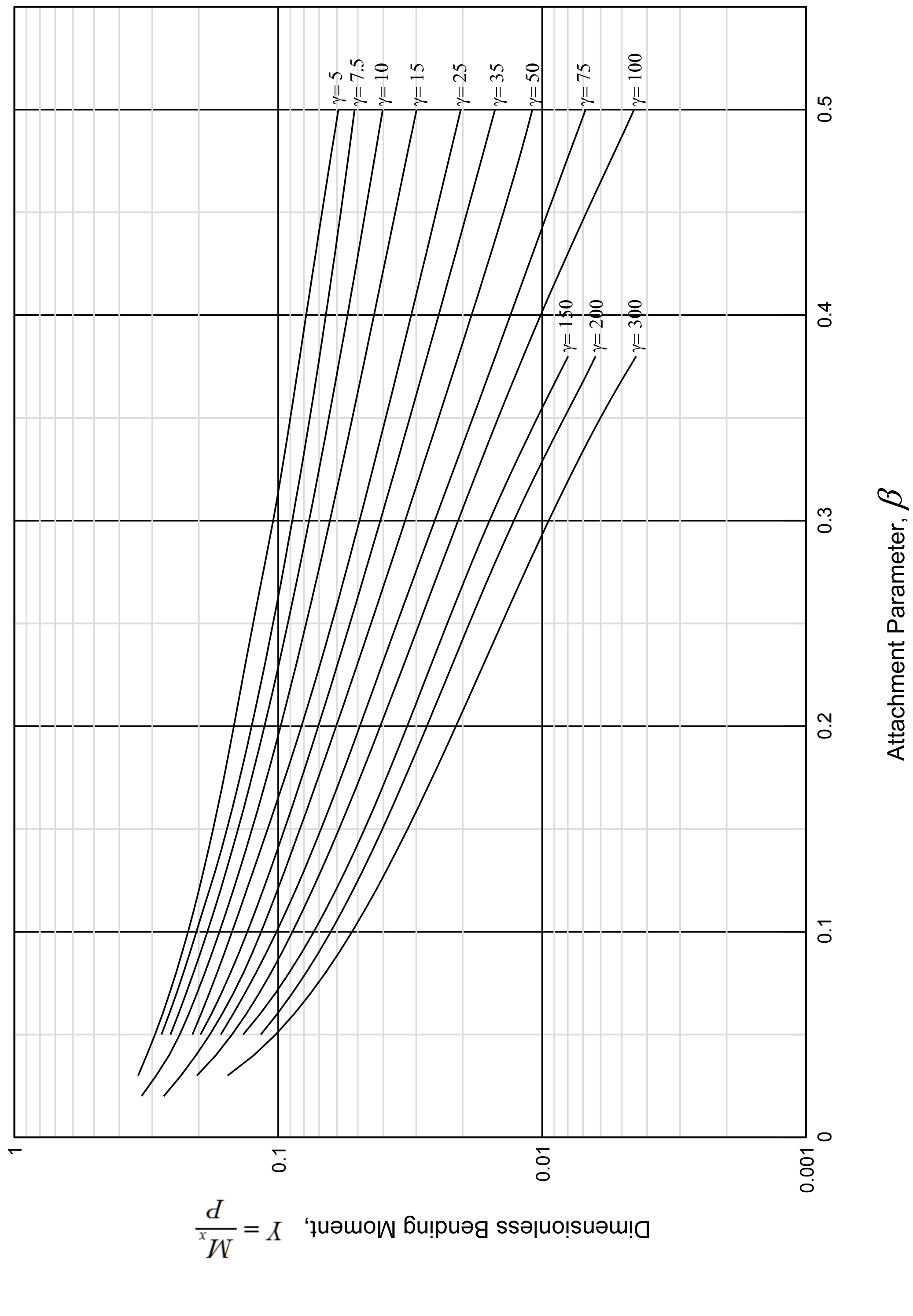

Figure 1C-1 – Bending Moment $\frac{M_x}{P}$ Due to an External Radial Load P on a Circular Cylinder (Longitudinal Axis) – *Original*

Curve Fit Coefficients for Figure 1C-1 – *Original*

$$Y = \left(a + c\beta + e\beta^2 + g\beta^3 + i\beta^4\right) \Big/ \left(1 + b\beta + d\beta^2 + f\beta^3 + h\beta^4 + j\beta^5\right)$$

Shell Parameter γ	Coefficients									
	a	b	c	d	e	f	g	h	i	j
5	4.517367E-01	5.192574E+00	-2.715021E+00	-7.248822E+01	1.804063E+00	1.586297E+02	1.242687E+01	7.063613E-01	-1.251545E+01	0.000000E+00
7.5	4.186608E-01	-7.724277E+00	-7.389790E+00	-7.400667E+01	3.981936E+01	7.172621E+02	-4.910547E+01	-5.439525E+02	1.954846E+01	0.000000E+00
10	-7.719173E+00	1.024379E+04	4.359326E+03	1.096056E+05	-3.456152E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
15	4.256644E-01	-2.430119E+01	-1.585255E+01	2.239148E+02	2.807819E+02	7.453039E+03	-2.677806E+02	0.000000E+00	0.000000E+00	0.000000E+00
25	3.304192E-01	-1.674973E+00	-4.029073E+00	-5.707889E+01	1.892740E+01	3.563050E+02	-2.832513E+01	-1.740556E+02	1.425430E+01	0.000000E+00
35	2.974847E+00	9.726975E+02	2.048642E+02	4.834287E+03	-3.711770E+02	5.629210E+03	1.888550E+02	0.000000E+00	0.000000E+00	0.000000E+00
50	3.889337E-01	6.508102E+00	-5.445882E+00	-1.054809E+02	4.929533E+01	1.536730E+03	-1.153045E+02	-1.470909E+03	8.437472E+01	0.000000E+00
75	3.213964E-01	9.792806E+00	-2.088793E+00	-3.522464E+01	6.035543E+00	-2.141044E+01	-4.944556E+00	4.815189E+02	0.000000E+00	0.000000E+00
100	1.474589E+00	5.574128E+02	1.187201E+02	6.129536E+03	-3.961479E+02	-8.038623E+03	3.345792E+02	0.000000E+00	0.000000E+00	0.000000E+00
150	4.871399E-01	4.148437E+01	-3.071165E+00	-2.147145E+02	6.822400E+00	3.148886E+02	-5.121609E+00	0.000000E+00	0.000000E+00	0.000000E+00
200	3.842791E-01	3.635368E+01	-2.202977E+00	-1.610413E+02	4.093503E+00	1.749817E+02	-2.386633E+00	0.000000E+00	0.000000E+00	0.000000E+00
300	2.114371E+00	6.377731E+02	8.888538E+01	1.026265E+04	-2.454726E+02	-2.470237E+03	1.194422E+02	0.000000E+00	0.000000E+00	0.000000E+00

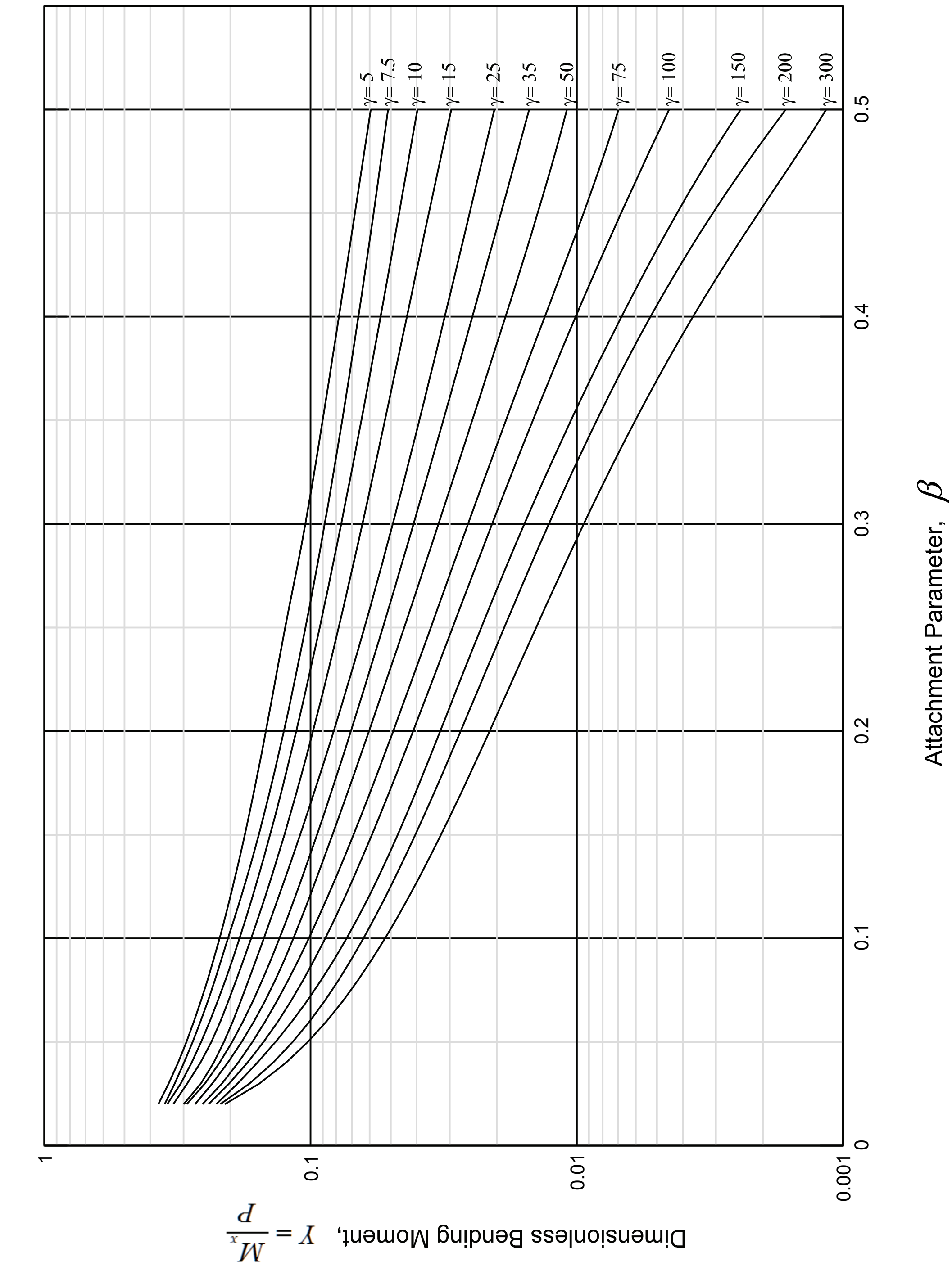

Figure 1C-1 – Bending Moment $\frac{M_x}{P}$ Due to an External Radial Load P on a Circular Cylinder (Longitudinal Axis) – *Extrapolated*

Curve Fit Coefficients for Figure 1C-1 – *Extrapolated*

$$Y = \left(a + c\beta + e\beta^2 + g\beta^3 + i\beta^4\right) / \left(1 + b\beta + d\beta^2 + f\beta^3 + h\beta^4 + j\beta^5\right)$$

Shell Parameter γ	Coefficients									
	a	b	c	d	e	f	g	h	i	j
5	4.675856E-01	1.271036E+01	-3.019087E-01	-9.136649E+01	-1.925547E+01	-2.558630E+01	6.455719E+01	5.713301E+02	-4.097683E+01	0.000000E+00
7.5	4.305934E-01	-9.235515E+00	-8.643296E+00	-8.991981E+01	5.281817E+01	1.099504E+03	-5.321053E+01	-6.825396E+02	1.366495E+01	0.000000E+00
10	7.182745E+00	7.484312E+03	2.730789E+03	6.388901E+04	-2.335382E+03	1.207436E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
15	4.263580E-01	-2.088461E+01	-1.497780E+01	-3.454976E+01	1.873126E+02	5.456111E+03	-1.217226E+02	-2.801459E+01	-7.911066E+01	0.000000E+00
25	5.300847E-01	4.951161E+01	1.987806E+00	4.366512E+00	9.877498E+01	4.734774E+03	-1.087733E+02	0.000000E+00	0.000000E+00	0.000000E+00
35	5.115379E-01	6.556593E+01	9.842398E+00	2.197823E+02	-1.654114E+01	4.620082E+02	7.311933E+00	0.000000E+00	0.000000E+00	0.000000E+00
50	3.889337E-01	6.508102E+00	-5.445882E+00	-1.054809E+02	4.929533E+01	1.536730E+03	-1.153045E+02	-1.470909E+03	8.437472E+01	0.000000E+00
75	6.218270E-01	3.148776E+02	8.725021E+01	4.050083E+03	-2.851998E+02	-7.046104E+03	2.479753E+02	4.404018E+03	0.000000E+00	0.000000E+00
100	3.548798E-01	4.564454E+01	1.047946E+01	1.281204E+03	7.390799E+01	2.965646E+03	-2.856638E+02	-5.364185E+01	2.374103E+02	0.000000E+00
150	3.424816E-01	1.982243E+01	-7.766049E-01	1.542565E+02	3.975535E+00	-6.481954E+02	-5.721169E+00	2.043710E+03	0.000000E+00	0.000000E+00
200	5.794145E-01	1.313955E+02	2.277730E+01	2.780940E+03	1.771193E+01	2.646138E+03	-2.612651E+02	-3.553070E+03	2.830585E+02	0.000000E+00
300	9.221079E-01	2.277546E+02	2.811653E+01	3.417187E+03	-1.072404E+02	-5.784664E+03	9.926064E+01	4.053793E+03	0.000000E+00	0.000000E+00

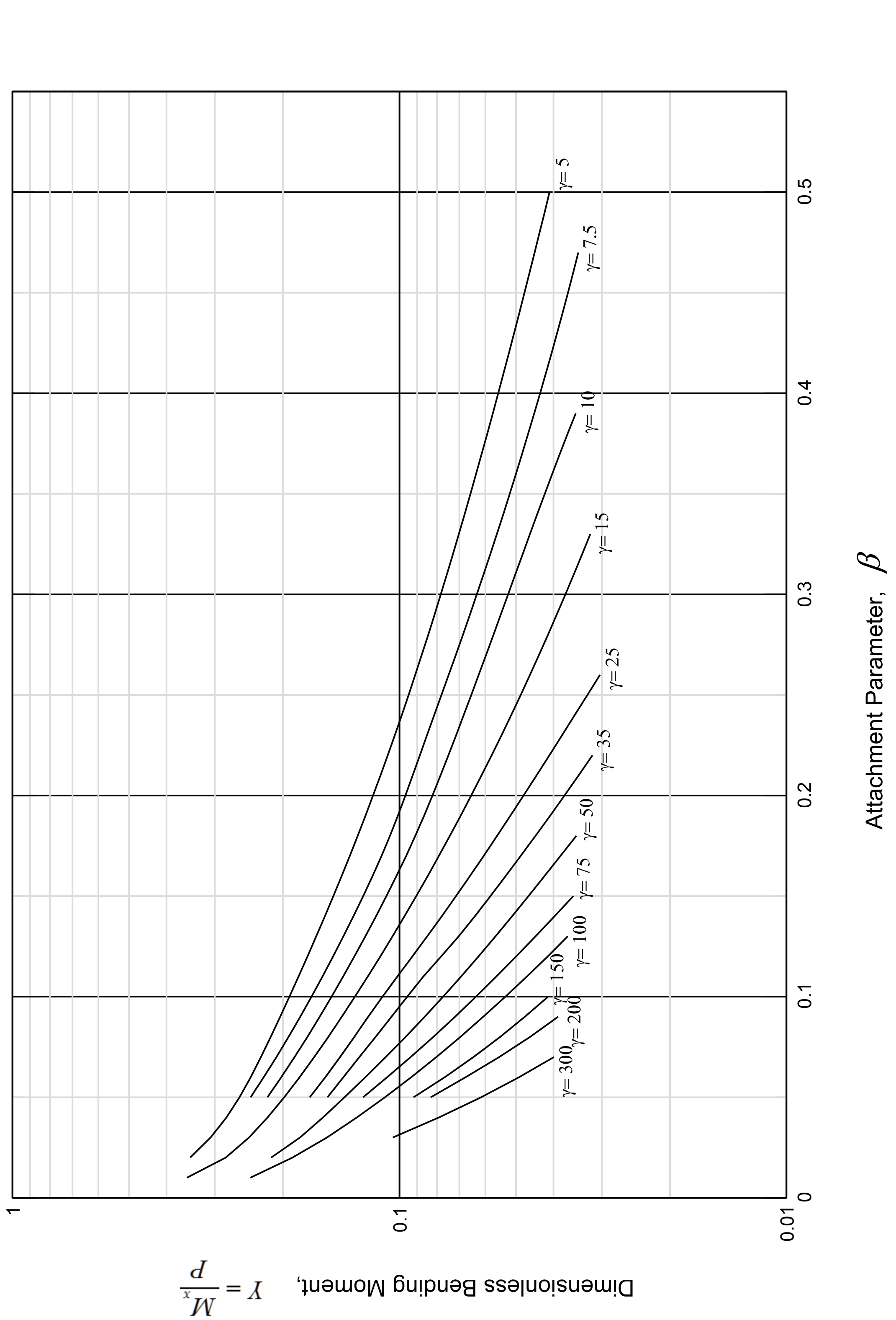

Figure 2C – Bending Moment $\frac{M_x}{P}$ Due to an External Radial Load P on a Circular Cylinder (Transverse Axis) – ***Original***

B.6 Figures

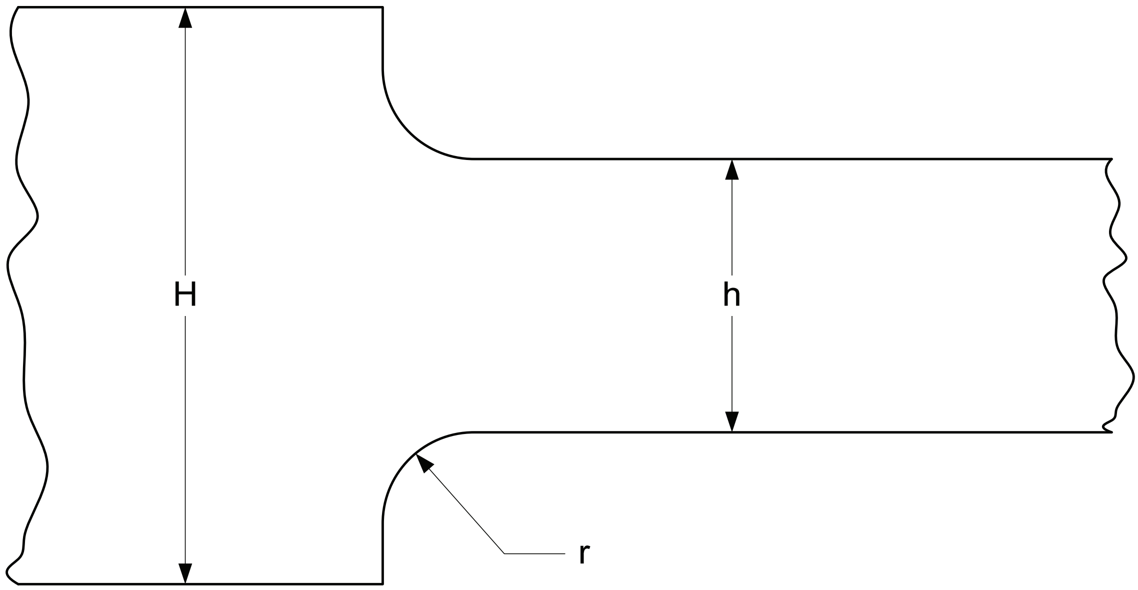

Figure B-1 – Stepped Bar

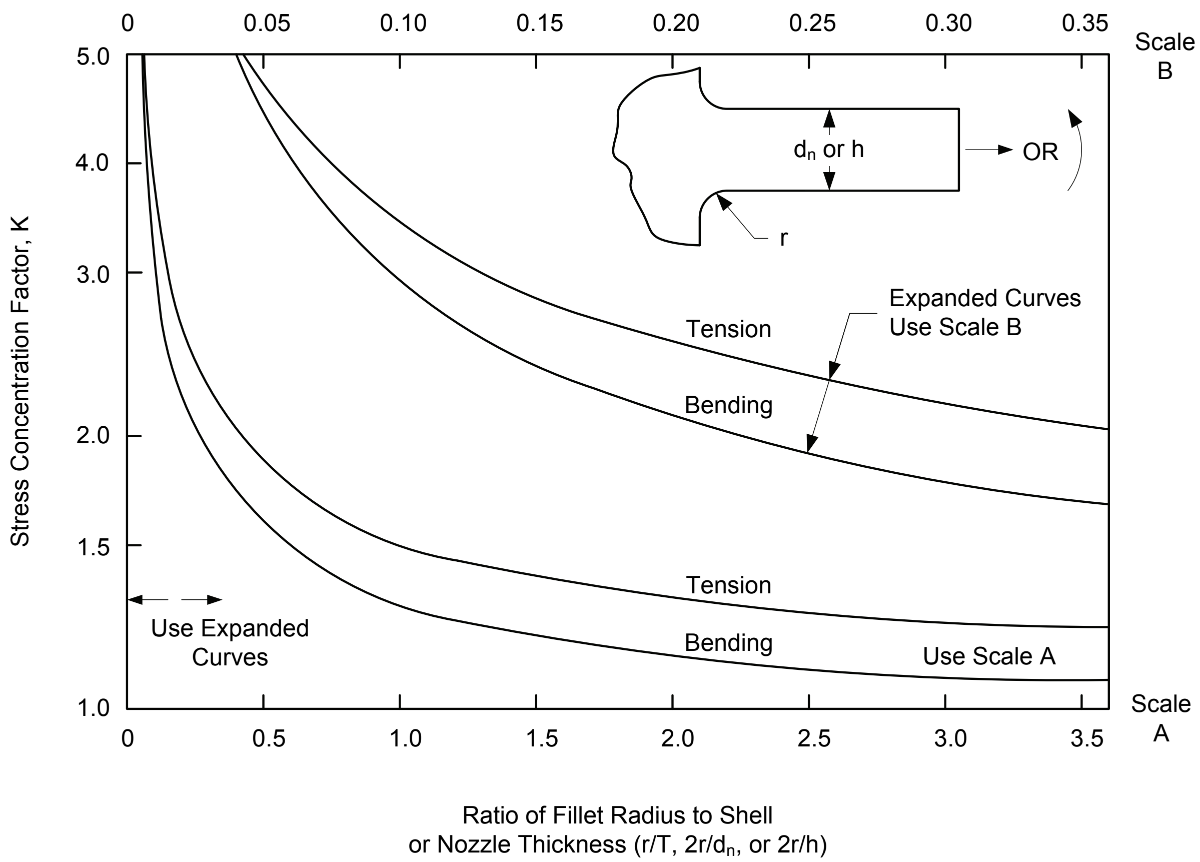

Figure B-2 – Stress Concentration Factors for $D >> d$