ABSTRACT

Local Stress Factors of Pipe-nozzle Due to Radial Load, Circumferential and Longitudinal Moments

by
Junyu Lin

This thesis presents a series of stress factor data which provide more detailed information for the calculation of local stresses at the nozzle region, as well as the pipe region, of a pipe-nozzle intersection, subjected to an external radial load, circumferential bending moment, and longitudinal bending moment, respectively.

The pipe and nozzle thicknesses are assumed to be identical. Numerical solutions are obtained through the use of the finite element method. In obtaining the numerical solutions via ANSYS, the quadrilateral element is used to simulate the thin shell pipe-nozzle geometries. The local stresses, at eight different points on both the pipe and the nozzle at the intersections of the pipe's symmetric planes (longitudinal and transverse) are investigated. The resulting circumferential and longitudinal stresses, on the pipe and the nozzle, respectively, are first resolved into the bending and membrane components, and then further normalized into stress factors by the geometric parameters, beta, β, (nozzle radius/pipe radius), and gamma, Υ, (pipe radius/pipe thickness).

Presented in this thesis are sixteen (16) stress factor plots for the external radial loading, P, and eight (8) plots for the external circumferential moment, M_C, and longitudinal bending moment, M_L. The values of beta vary from 0.1 to 0.9 with values for gamma varying from 10 to 300. However, in the nozzle stress factor plots, when the product of beta and gamma are less than ten the results are not included since they are not in the thin shell range.

LOCAL STRESS FACTORS OF PIPE-NOZZLE DUE TO RADIAL LOAD, CIRCUMFERENTIAL AND LONGITUDINAL MOMENTS

by
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A Thesis
Submitted to the Faculty of
the New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Engineering Science

Department of Mechanical Engineering

October 1993

This thesis is delicated to Philip M. Remington
who will always be the best part of my life

APPROVAL PAGE

Local Stress Factors of Pipe-nozzle Due to Radial Load, Circumferential and Longitudinal Moments

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ACKNOWLEDGEMENT

I would like to express my sincere gratitute to my advisor, Dr. Benedict C. Sun, for his guidance, and encouragement throughout the course of this work.

My special thanks to Professors Bernard Koplik, Rong-Yaw Chen and John Droughton for serving as members of the committee.

I am thankful to all my friends and family members for supporting and encouraging me to complete my work successfully.

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LIST OF NOMENCLATURE

$\alpha = \frac{L}{R_p}$, alpha

$\beta = \frac{R_n}{R_p}$, beta

$\Upsilon = \frac{R_p}{T}$, gamma

σ_i = normal stress in the ith direction on the surface of shell, psi

i = denotes direction (longitudinal and circumferential direction of shell)

ϕ = circumferential direction

x = longitudinal direction

j = denotes location (on the nozzle and pipe)

n = on the nozzle

p = on the pipe

K_m = membrane stress concentration factor

K_{mn} = membrane stress concentration factor of the nozzle

K_{mp} = membrane stress concentration factor of the pipe

K_b = bending stress concentration factor of the nozzle

K_{bn} = bending stress concentration factor of the nozzle

K_{bp} = bending stress concentration factor of the pipe

L = length of pipe, in

M_x = bending moment, in longitudinal direction, in-lb/in

M_{xn} = bending moment in longitudinal direction of the nozzle, in-lb/in

LIST OF NOMENCLATURE continue

M_{xp} = bending moment in longitudinal direction of the pipe, in-lb/in

M_{ϕ} = bending moment in circumferential direction, in-lb/in

$M_{\phi n}$ = bending moment in circumferential direction of the nozzle, in-lb/in

$M_{\phi p}$ = bending moment in circumferential direction of the pipe, in-lb/in

N_x = membrane force in longitudinal direction, lb/in

N_{xn} = membrane force in longitudinal direction of the nozzle, lb/in

N_{xp} = membrane force in longitudinal direction of the pipe, lb/in

N_{ϕ} = membrane force in circumferential direction, lb/in

$N_{\phi n}$ = membrane force in circumferential direction of the nozzle, lb/in

$N_{\phi p}$ = membrane force in circumferential direction of the pipe, lb/in

R_n = mean radius of the nozzle, in ($r_n = \beta\ R_p$ in this thesis)

R_p = mean radius of the pipe, in

t = wall thickness of the nozzle, in

T = wall thickness of the pipe, in

CHAPTER I
INTRODUCTION

The external loadings on a pressure vessel such as the vessel's weight, thermal expansion load, activation of safety/relief values, wind load, internal pressure, earthquake, water or steam, hammer phonomenon, and other effects can be resolved into six different generic load components with respect to the pipe-nozzle geometry. They are radial force P, circumferential moment, M_C, longitudinal moment, M_L, two shear forces, V_C, V_L and torsional moment, M_T, respectively as shown in Figure 1. The local stresses at the juncture of the pipe-nozzle connection due to these external loadings are always the major concerns for designers.

In this thesis, based on the finite element method, the ANSYS program is used to simulate the real geometry of pipe-nozzle connection under three major external loadings, P, M_C, M_L. The numerical stress results on both the circumferential and longitudinal directions of the pipe, as well as on the nozzle, are further resolved into the bending and membrane stress components. Finally, these stress components are normalized to obtain a series of stress factors. The final results of these stress factors are plotted and presented in this thesis as functions of pipe-nozzle geometrical parameters, beta, β, (nozzle radius/pipe radius) and gamma, Υ, (pipe radius/ pipe thickness). The gamma ranges from 10 to 300, the beta ranges from 0.1 to 0.9, which has been extented from 0.55 which is the upper limit of WRC 107 [1].

In 1988 and 1990, Sun and Sun [2] [3] published their stress factor results due to all the six external loadings. The have only reported the results on the pipe portion of the pipe-nozzle connection, under the assumption that the maximum stresses would occur only on the pipe portion of the connection due to the fact that frequently the nozzle has more material reserve than the pipe if one uses pressure stress criteria for the design. However, one finds that in certain combination of pipe-nozzle design the maximum stress does occur on the nozzle portion of the juncture. This thesis is aimed to address their issues that the stress factors on the nozzle are extensively investigated. Again, as assumed by Sun & Sun [2][3], the pipe and the nozzle are having the same thickness. Furthermore, this thesis reported the stress factors due to the radial load in more detail than what have been published by the previous authors.

Presented in this thesis are sixteen (16) stress factors due to the radial load, P, are eight (8) stress factors each due to the circumferential and longitudinal bending moments, respectively.

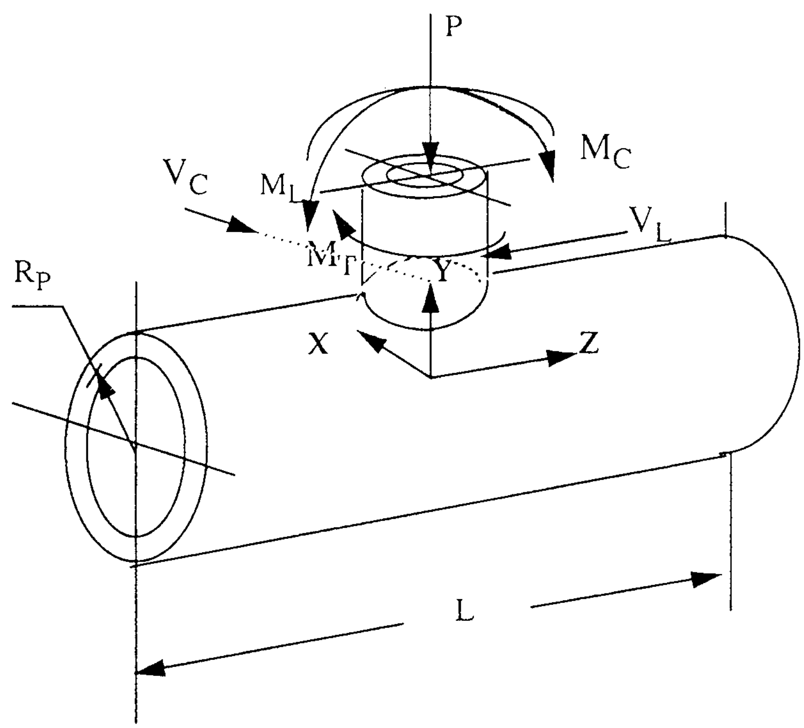


Figure 1. Typical configuration of pipe with a nozzle attachment subjeced to six components of loadings

CHAPTER II
THE DEVELOPMENT OF STRESS ANALYSIS ON THE PIPE-NOZZLE CONNECTION

2.1 THEORY AND EXPERIMENT

In 1955, Prof. Bijlaard [4] provided an analytical method for determining the stresses in pressure vessel nozzle connections subjected to various forms of external loadings. Bijlaard's work is based on thin-shell theory using a double Fourier series solution.

From Bijlaard 's study, K. R. Wichman, A. G. Hopper and J. L. Mershon published WRC Bulletin No. 107 [1], in 1965. It suggests a procedure to calculate the local stresses in spherical and cylindrical shells due to external loadings.

Gwaltney et al [5] in 1976, published some experimental data for cylinder-to cylinder shell models in "Experimental stress analysis of cylinder-to-cylinder shell models and comparison with the theoretical predictions."

Brown et al [6] in 1977, published "Analytical and experimental stress analysis of a cylinder-to-cylinder structure."

Early researches by either analytical or experimental method, due to the mathematical limitations on Bijlaard's solution and experimental conditions (cost, material, and instrumentation limitation), were not possible for a larger nozzle radius , namely β (nozzle radius/pipe radius) greater than 0.5.

2.2 FINITE ELEMENT METHOD

With the development of computer method, local stress on a pipe-nozzle connection can be evaluated by the finite element method with computer programs.

Sadd and Avent [7] in 1982 studied a trunnion pipe anchor by the finite element method. The model is analyzed for the case of internal pressure and moment loadings.

Tabone and Mallett [8] in 1987 established a finite element model of a nozzle on a cylindrical shell subjected to internal pressure, out-of-plane moment, and a combination of internal pressure plus out-of-plane moment. The model used ANSYS three-dimensional finite elements and considered inelastic behavior at small displacements.

Mirza and Gupgupogu [9] in 1988 introduced 17-node doubly curved shell finite elements to simulate the case of longitudinal moments applied at discrete points around the circumference of the pipe.

Sun and Sun [2] in 1988 published the local stresses on piping-nozzle connections due to radial load, circumferential and longitudinal moments obtained by the finite element approach.

In 1990, Sun and Sun [3] extended their previous studies to the area of torsion and shear loading under the condition that the nozzle and pipe have the same wall thickness. That is t=T. In both Sun and Sun's publications, the ANSYS software package are used. The ANSYS vision 4.4 [10] has been proven in industry and school to provide the geometry model generation and the stress caculation efficiently and accurately.

CHAPTER III
BASIC EQUATION

3.1 STRESS AND STRESS FACTORS

According to WRC 107, each stress has two components, the internal membrane force and bending moment, which can be expressed by the following:

$$\sigma_i = K_n \frac{N_i}{T} \pm K_b \frac{6M_i}{T^2}$$

where K_n and K_b = stress concentration constants,

T = thickness of the pipe, also the nozzle.

i = x (longitudinal direction) or ϕ (circumferential direction)

as shown in Figure 2.

The membrane and bending stresses due to external radial load force P, are presented as:

$$\frac{N_i}{T} = \left[\frac{N_i}{P/R_j}\right] \cdot \left[\frac{P}{R_j \cdot T}\right] \text{ and } \frac{6M_i}{T^2} = \left[\frac{M_i}{P}\right] \cdot \left[\frac{6P}{T^2}\right]$$

the stress factors are $\left[\frac{N_i}{P/R_j}\right]$ and $\left[\frac{M_i}{P}\right]$

where j = p (pipe) or n (nozzle) as shown in Figure 2.

The membrane and bending stresses due to the external bending moment loadings are similarly normalized as:

$$\frac{N_i}{T} = \left[\frac{N_i}{M/(R_j^2\beta)}\right] \cdot \left[\frac{M}{R_j^2 T\beta}\right] \text{ and } \frac{6M_i}{T^2} = \left[\frac{M_i}{M/(R_j\beta)}\right] \cdot \left[\frac{6M}{R_j T^2\beta}\right]$$

the stress factors are $\left[\dfrac{N_i}{M/(R_j^2\beta)}\right]$ and $\left[\dfrac{M_i}{M/(R_j\beta)}\right]$

where M = M_C circumferential bending moment, in-lb,

M_L longitudinal bending moment, in-lb.

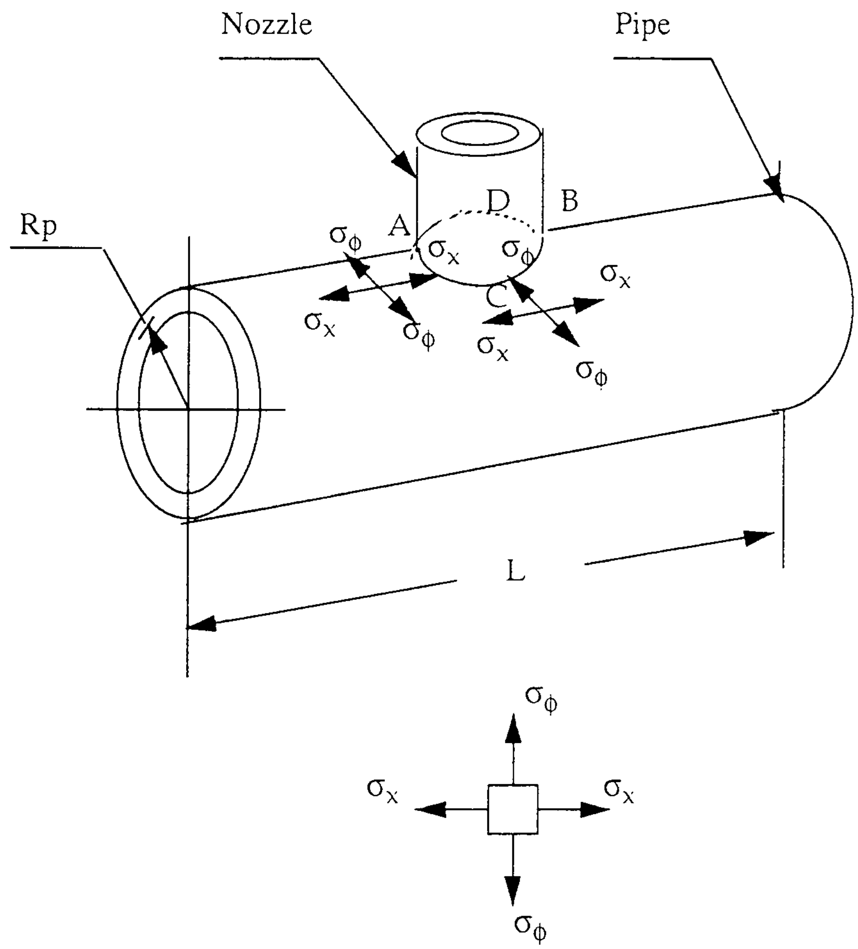


Figure 2. Stress directions at the pipe-nozzle connection

The definitions of stress factors on the pipe are summarized in Table 1 and those for the nozzle are summarized in Table 2.

Table 1: Computation sheet for local stresses on the pipe

Figure	Stress factor	Stress component	Stress direction
3P 7P	$\dfrac{N_{\phi p}}{P/R_p}$	$K_{mp}\left[\dfrac{N_{\phi p}}{P/R_p}\right]\cdot\dfrac{P}{R_p\cdot T}$	ϕ
1P 5P	$\dfrac{M_{\phi p}}{P}$	$K_{bp}\left[\dfrac{M_{\phi p}}{P}\right]\cdot\dfrac{6P}{T^2}$	ϕ
4P 8P	$\dfrac{N_{xp}}{P/R_p}$	$K_{mp}\left[\dfrac{N_{xp}}{P/R_p}\right]\cdot\dfrac{P}{R_p\cdot T}$	x
2P 6P	$\dfrac{M_{xp}}{P}$	$K_{bp}\left[\dfrac{M_{xp}}{P}\right]\cdot\dfrac{6P}{T^2}$	x
$3M_C$ $3M_L$	$\dfrac{N_{\phi P}}{M_i/(R_P^2\beta)}$	$K_{mP}\left[\dfrac{N_{\phi P}}{M_i/(R_P^2\beta)}\right]\cdot\dfrac{M_i}{R_P^2 T\beta}$	ϕ
$1M_C$ $1M_L$	$\dfrac{M_{\phi P}}{M_i/(R_P\beta)}$	$K_{bP}\left[\dfrac{M_{\phi P}}{M_i/(R_P\beta)}\right]\cdot\dfrac{6M_i}{R_P T^2\beta}$	ϕ
$4M_C$ $4M_L$	$\dfrac{N_{xP}}{M_i/(R_P^2\beta)}$	$K_{mP}\left[\dfrac{N_{xP}}{M_i/(R_P^2\beta)}\right]\cdot\dfrac{M_i}{R_P^2 T\beta}$	x
$2M_C$ $2M_L$	$\dfrac{M_{xP}}{M_i/(R_P\beta)}$	$K_{bP}\left[\dfrac{M_{xP}}{M_i/(R_P\beta)}\right]\cdot\dfrac{6M_i}{R_P T^2\beta}$	x

Table 2: Computation sheet for local stresses on the nozzle

Figure	Stress factor	Stress component	Stress direction
11P 15P	$\frac{N_{\phi n}}{P/r_n}$	$K_{mn}\left[\frac{N_{\phi n}}{P/r_n}\right]\cdot\frac{P}{r_n\cdot t}$	ϕ
9P 13P	$\frac{M_{\phi n}}{P}$	$K_{bn}\left[\frac{M_{\phi n}}{P}\right]\cdot\frac{6P}{t^2}$	ϕ
12P 16P	$\frac{N_{xn}}{P/r_n}$	$K_{mn}\left[\frac{N_{xn}}{P/r_n}\right]\cdot\frac{P}{r_n\cdot t}$	x
10P 14P	$\frac{M_{xn}}{P}$	$K_{bn}\left[\frac{M_{xn}}{P}\right]\cdot\frac{6P}{t^2}$	x
$7M_C$ $7M_L$	$\frac{N_{\phi n}}{M_i/(R_n^2\beta)}$	$K_{mn}\left[\frac{N_{\phi n}}{M_i/(R_n^2\beta)}\right]\cdot\frac{M_i}{R_n^2T\beta}$	ϕ
$5M_C$ $5M_L$	$\frac{M_{\phi n}}{M_i/(R_n\beta)}$	$K_{bn}\left[\frac{M_{\phi n}}{M_i/(R_n\beta)}\right]\cdot\frac{6M_i}{R_nT^2\beta}$	ϕ
$8M_C$ $8M_L$	$\frac{N_{xn}}{M_i/(R_n^2\beta)}$	$K_{mn}\left[\frac{N_{xn}}{M_i/(R_n^2\beta)}\right]\cdot\frac{M_i}{R_n^2T\beta}$	x
$6M_C$ $6M_L$	$\frac{M_{xn}}{M_i/(R_n\beta)}$	$K_{bn}\left[\frac{M_{xn}}{M_i/(R_n\beta)}\right]\cdot\frac{6M_i}{R_nT^2\beta}$	x

3.3 SIGN CONVENTION

Sign convention on the nozzle, different from that on the pipe, is discussed in the following:

3.3.1. Sign conventions on the pipe

In the ANSYS model, the radial load P is acting from nozzle to pipe inward which causes a compressive membrane stress. Furthermore, the local bending occur so that the tensile bending stresses are observed on the inside wall of the pipe i.e. A_L, B_L, C_L, D_L while the compressive bending stresses result on the outside wall i.e. A_u, B_u, C_u, and D_u.

In the cases of M_C and M_L, the applied moments are considered to act as couples composed of equal and opposite radial forces. Hence, the tensile membrane stresses are obtained at B and D while the compressive membrane stresses obtained at A and C. As in the radial load case, the tensile bending stresses are obtained at A and C on the inside wall of the pipe i.e. A_L, C_L , and at B and D on the outside wall of the pipe i.e. B_u, D_u (Figure 3).

3.3.2. Sign conventions on the nozzle

An external radial loading P acts similarly to a local external pressure on the nozzle causing compressive membrane stresses and bending stresses on both sides of the nozzle at E, F, G, H, (as shown) in Figure 4.

In the case of M_C, while tensile membrane stresses result at H (inside and outside wall), compressive membrane stresses result at G (inside and outside wall), tensile bending stresses result at G (inside wall) and H (outside wall), compressive bending stresses result at G (outside wall) and H (inside wall).

In the case of M_L, while tensile membrane stresses result at F (inside and outside wall), compressive membrane stresses result at E (inside and outside wall), tensile bending stresses result at E (inside wall) and F (outside wall), compressive bending stresses result at E (outside wall) and F (inside wall).

Sign notations on the pipe and the nozzle are summarized in Table 3. and Table 4.

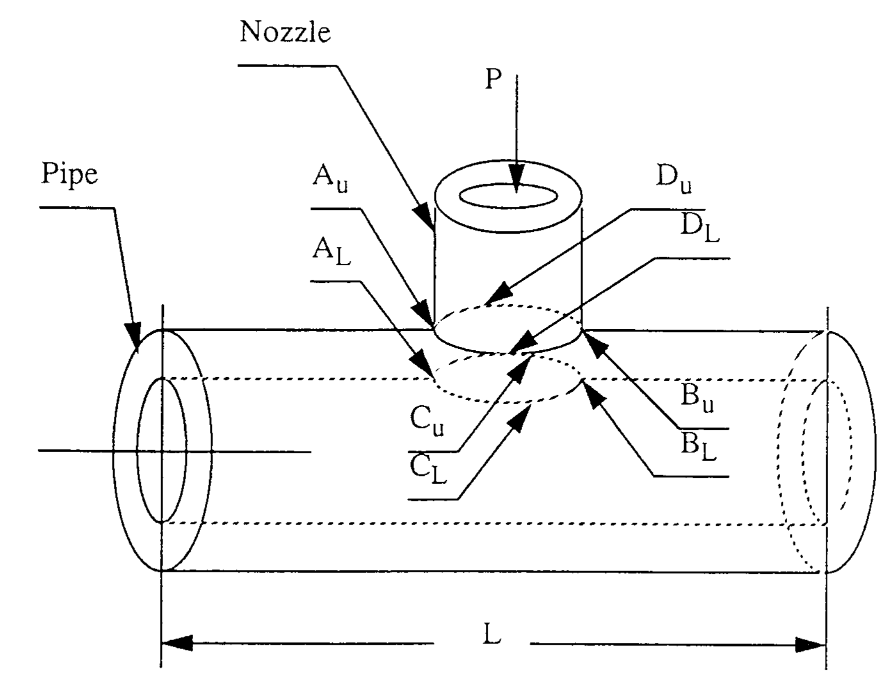


Figure 3. Stress location on the pipe

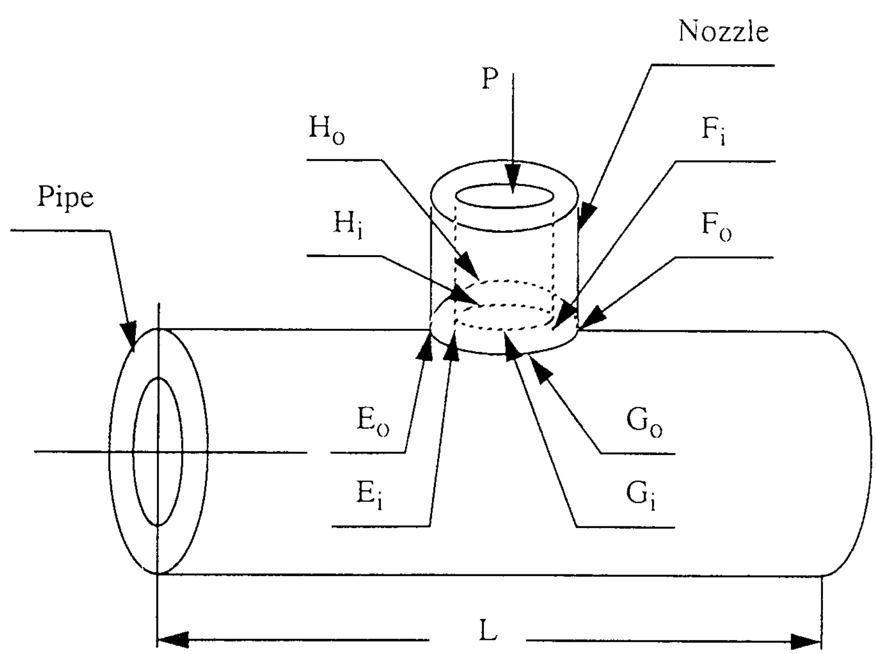


Figure 4. Stress location on the nozzle

Table 3: **Sign Convention on the Pipe for Stresses Factor Resulting**

Stress factor	Location	Sign convention
Membrane stress factor from P load $\frac{N_{xp}}{P/R_P}$ and $\frac{N_{\phi p}}{P/R_P}$	A_u, A_L B_u, B_L C_u, C_L D_u, D_L	- - - -
Bending stress factor from P load $\frac{M_{xp}}{P}$ and $\frac{M_{\phi p}}{P}$	A_u, B_u C_u, D_u A_L, B_L C_L, D_L	- - + +
Membrane stress factor from M_C $\frac{N_{xP}}{M_C/(R_P^2\beta)}$ and $\frac{N_{\phi P}}{M_C/(R_P^2\beta)}$	C_u, C_L D_u, D_L	- +
Bending stress factor from M_C $\frac{M_{xP}}{M_C/(R_P\beta)}$ and $\frac{M_{\phi P}}{M_C/(R_P\beta)}$	C_u, D_L C_L, D_u	- +
Membrane stress factor from M_L $\frac{N_{xP}}{M_L/(R_P^2\beta)}$ and $\frac{N_{\phi P}}{M_L/(R_P^2\beta)}$	A_u, A_L B_u, B_L	- +
Bending stress factor from M_L $\frac{M_{xP}}{M_L/(R_P\beta)}$ and $\frac{M_{\phi P}}{M_L/(R_P\beta)}$	A_u, B_L A_L, B_u	- +

u----- upper surface of the pipe   L-------lower surface of the pipe

Table 4: Sign Convention on the Nozzle for Stresses Factor Resulting

Stress factor	Location	Sign convention
Membrane stress from P load $\frac{N_{xn}}{P/R_n}$ and $\frac{N_{\phi n}}{P/R_n}$	E_o, E_i F_o, F_i G_o, G_i H_o, H_i	- - - -
Bending stress from P load $\frac{M_{xn}}{P}$ and $\frac{M_{\phi n}}{P}$	E_o, E_i F_o, F_i G_o, G_i H_o, H_i	- - - -
Membrane stress from M_C load $\frac{N_{xn}}{M_C/(R_n^2\beta)}$ and $\frac{N_{\phi n}}{M_C/(R_n^2\beta)}$	G_o, G_i H_o, H_i	– +
Bending stress from M_C load $\frac{M_{xn}}{M_C/(R_n\beta)}$ and $\frac{M_{\phi n}}{M_C/(R_n\beta)}$	G_o, H_i G_i, H_o	- +
Membrane stress from M_L load $\frac{N_{xn}}{M_L/(R_n^2\beta)}$ and $\frac{N_{\phi n}}{M_L/(R_n^2\beta)}$	E_o, E_i F_o, F_i	- +
Bending stress from M_L load $\frac{M_{xn}}{M_L/(R_n\beta)}$ and $\frac{M_{\phi n}}{M_L/(R_n\beta)}$	E_o, F_i E_i, F_o	- +

o------outside surface of the nozzle   i-------inside surface of the nozzle

CHAPTER IV
FINITE ELEMENT MODEL

The ANSYS program is a self-contained general purpose finite element program developed and maintained by Swanson Analysis Systems, Inc. [11]. The program contains many routines, all inter-related, and all for the main purpose of achieving a solution to an engineering problem by the finite element method.

4.1 ESTABLISHMENT OF THE PIPE-NOZZLE MODEL

The ANSYS program models the pipe-nozzle connection by a quadrilateral thin shell element (STIF 63, shell element) for a wide range of beta and gamma in this thesis. Since the geometry of the model, elastic properties, and support conditions are symmetric to the x-y plane and the y-z plane (see Figure 1), only one quarter of the geometry is necessary if a loading applied to the model is symmetric or uniformly distributed (see Figure 5) . A symmetry structure can carry either symmetric or anti-symmetric loads.

In ANSYS program, a mesh can be formed after the appropriate point, line, area are defined. In this thesis, the subroutine called PREP7 is used to generate the geometry. The mesh is defined by subdiving the region into elments with 17 key-points in 9 areas, A1 and A2 are generated with one cylidrical coordinate system and A3 to A9 are generated with another cylindrical coordinate system. (Figure 6). Element type STIF 63 is used to generate the model which is a quadrilateral in shape with one node at each corner.

For the analysis of this model, the following assumptions are used, thus

A. The material is assumed to be homogeneous, and in the elastic range, it obeys Hooke's Law. The resulting stresses and strains are within the proportional limit of the material.

B. The internal pressure is not taken into account.

C. The influences of material, weight and temperature are neglected.

D. There are no transitions, fillets, or reinforcing at the juncture.

E. The length of the pipe, L, is adopted as such that the dimensionless ratio of α (L/R_P) is equal to 4.0, this is consistent with the WRC 107, [1] that the boundary of the pipe-nozzle model does not have a significant effect on the local stresses under external loadings.

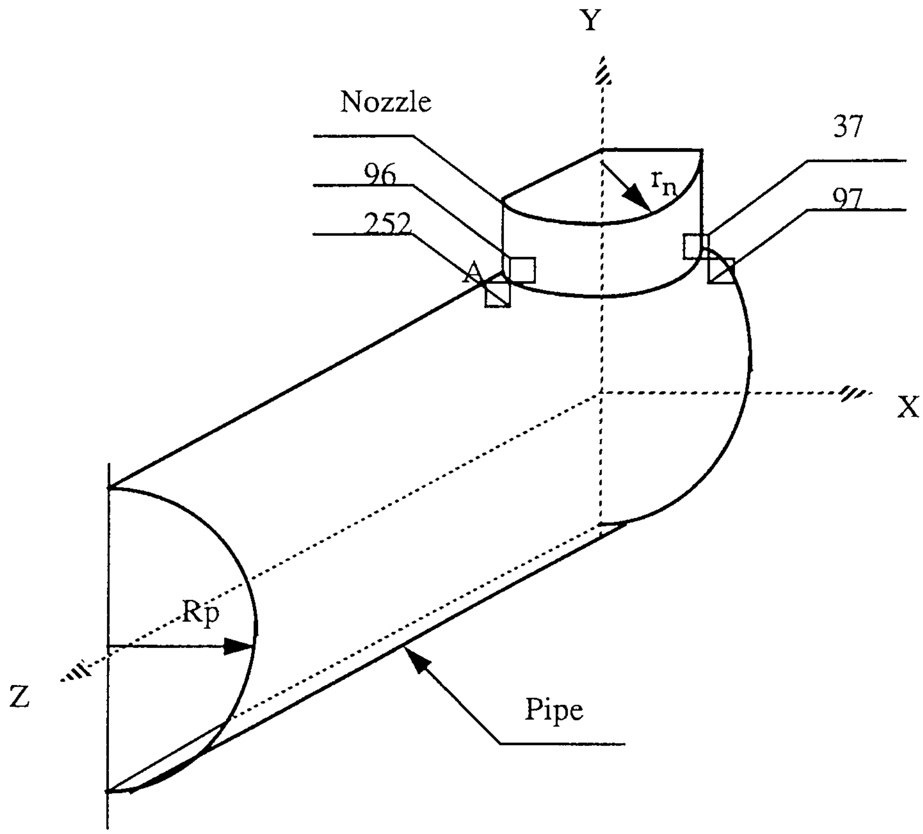


Figure 5. A quarter model of the nozzle-pipe juncture

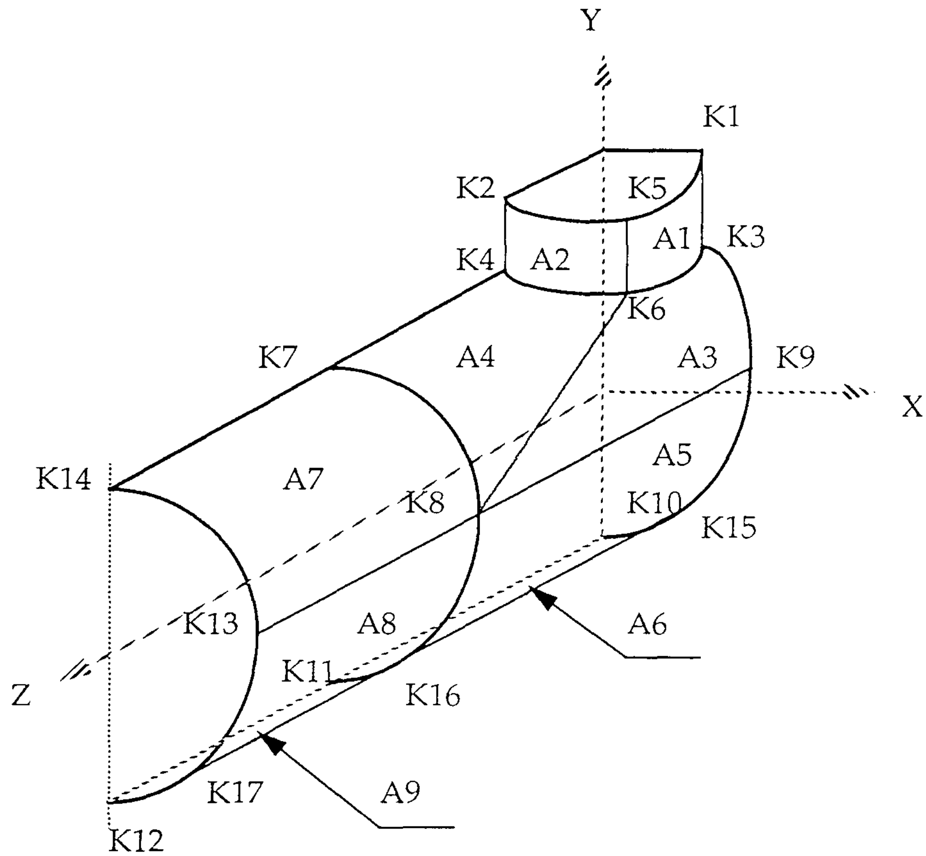


Figure 6. Areas and Keypoints at edge of the model

4.2 BOUNDARY CONDITIONS AND LOADINGS

4.2.1. Radial force

Since the radial force is uniformly distributed in the negative y direction from the top of the nozzle, the geometry of the structure and the applied loading are symmetric with respect to the x-y and y-z planes, therefore the displacement in z direction for all nodes on the x-y plane and the displacement in x direction for all nodes on the y-z plane are restrained. Correspondingly, rotations around the x, y, and the z-axis are zero.

On the top edge of the nozzle, there are totally 25 nodes (24 elements) to insure convergence [3]. The radial force P is distributed equally at these nodes, except for two nodes located on the planes of symmetry at each end (see Figure 7 (b)). The values on these two points should be the half of the others. For example, when P=1000lbs, the loading on the each nodes is 10.416667lbs and the each ends is 5.208333lbs.

4.2.2. Bending moment

For the purpose of simulating real moment loading, a linearly distributed nodal force is applied at top of the nozzle as shown in Figure 7 (c) and 7 (d) for circumferential and longitudinal moments, respectively.

The boundary conditions at the pipe-nozzle symmetric planes for circumferential moment are summarized as the following:

- Nodes on the x-y plane, symmetric boundary, DZ, ROTY, ROTX are zero.
- Nodes on the y-z plane, anti-symmetric boundary, DZ, DY, ROTX are zero.

The boundary conditions at the pipe-nozzle symmetric planes for longitudinal moment are summarized as the following:

- Nodes on the x-y plane, anti-symmetric boundary, DY, DX, ROTZ are zero.
- Nodes on the y-z plane, symmetric boundary, DZ, ROTZ, ROTY are zero.

If the moment is 1000 in-lb, for a quarter model, the following equations represent the loading at each node:

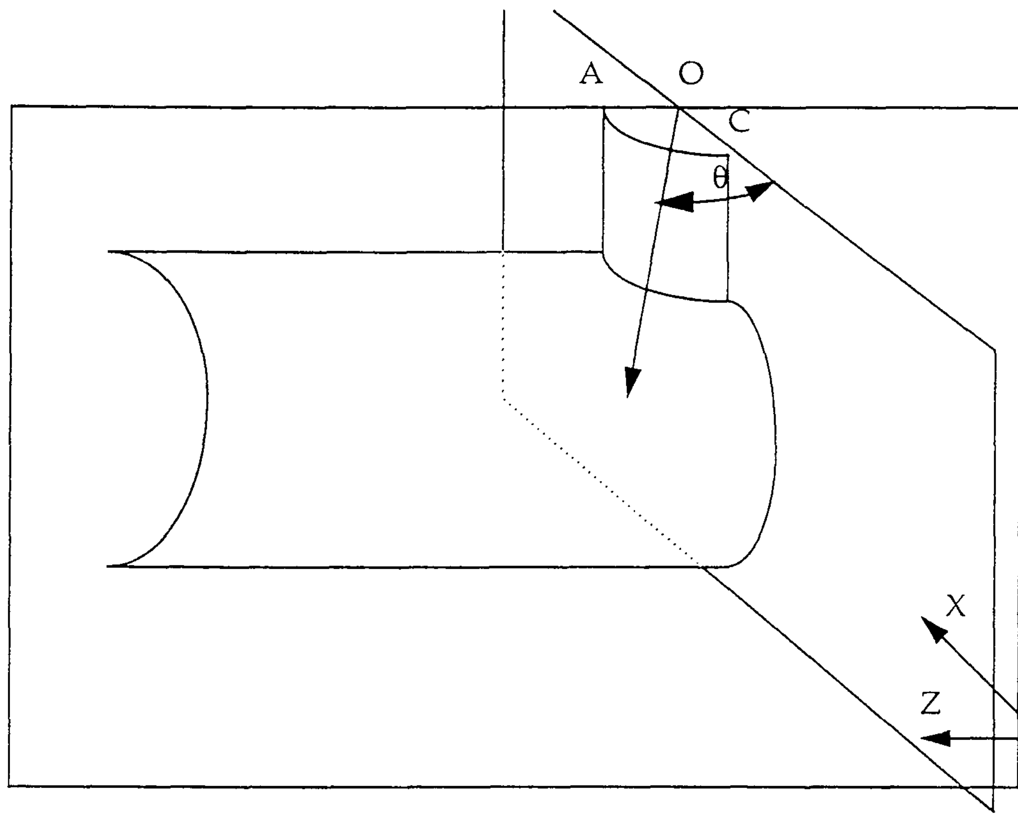
$$\frac{M_C}{4} = \sum_{\theta_i = 0^o}^{90^o} f\cos\theta_i \cdot R_n \cdot \cos\theta_i \qquad \theta_i = 0^o, 3.75^o, 7.5^o, \quad \cdot \quad \cdot \quad \cdot$$

or $f = \dfrac{M_C}{48 \cdot R_n}$ where f is maximum nodal force at the node located at zero degree position.

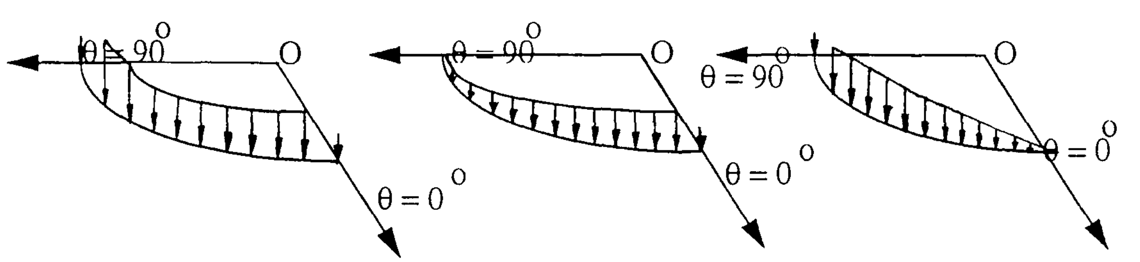
For the longitudinal moment loading:

$$\frac{M_L}{4} = \sum_{\theta_i = 0^o}^{90^o} f \sin\theta_i \cdot R_n \cdot \sin\theta_i \qquad \theta_i = 0^o, 3.75^o, 7.5^o, \quad \cdot \quad \cdot \quad \cdot$$

or $f = \dfrac{M_L}{48 \cdot R_n}$ where f is the maximum nodal force at the node located at ninety degree. The nodes are at angular increment of 3.75 degree.



(a) Quarter model of the pipe-nozzle juncture, x-y plane and y-z plane



(b)Radial force (c) Circumferential moment (d)Longitudinal moment

Figure 7. Loadings and boundary conditions for shell model due to Radial force, circumferential and longitudinal moment

CHAPTER V
COMPARISON AND CONCLUSION

Table 5: Results of the plots

No.	Stress Point	Location/ Direction	Plot designation	Stress factor
1	A	pipe/circumferential	1P	bending moment $M_{\phi p}/P$ on the pipe
2	A	pipe/longitudinal	2P	bending moment M_{xp}/P on the pipe
3	A	pipe/circumferential	3P	Membrane force $N_{\phi p}/(P/R_p)$ on the pipe
4	A	pipe/longitudinal	4P	Membrane force $N_{xp}/(P/R_p)$ on the pipe
5	C	pipe/circumferential	5P	Bending moment $M_{\phi p}/P$ on the pipe
6	C	pipe/longitudinal	6P	Bending moment M_{xp}/P on the pipe
7	C	pipe/circumferential	7P	Membrane force $N_{\phi p}/(P/R_p)$ on the pipe
8	C	pipe/longitudinal	8P	Membrane force $N_{xp}/(P/R_p)$ on the pipe
9	E	nozzle/circumferential	9P	Bending moment $M_{\phi n}/P$ on the nozzle
10	E	nozzle/longitudinal	10P	Bending moment M_{xn}/P on the nozzle
11	E	nozzle/circumferential	11P	Membrane force $N_{\phi n}/(P/R_n)$ on the nozzle
12	E	nozzle/longitudinal	12P	Membrane force $N_{xn}/(P/R_n)$ on the nozzle

Table 5 continue

No.	Stress Point	Location/ Direction	Plot designation	Stress factor
13	G	nozzle/circumferential	13P	Bending moment $M_{\phi n}/P$ on the nozzle
14	G	nozzle/longitudinal	14P	Bending moment M_{xn}/P on the nozzle
15	G	nozzle/circumferential	15P	Membrane force $N_{\phi n}/(P/R_n)$ on the nozzle
16	G	nozzle/longitudinal	16P	Membrane force $N_{xn}/(P/R_n)$ on the nozzle
17	C	pipe/circumferential	$1M_C$	Bending moment $\dfrac{M_{\phi P}}{M_C/(R_P\beta)}$ on the pipe
18	C	pipe/longitudinal	$2M_C$	Bending moment $\dfrac{M_{xP}}{M_C/(R_P\beta)}$ on the pipe
19	C	pipe/circumferential	$3M_C$	Membrane force $\dfrac{N_{\phi P}}{M_C/(R_P^2\beta)}$ on the pipe
20	C	pipe/longitudinal	$4M_C$	Membrane force $\dfrac{N_{xP}}{M_C/(R_P^2\beta)}$ on the pipe
21	G	nozzle/circumferential	$5M_C$	Bending moment $\dfrac{M_{\phi n}}{M_C/(R_n\beta)}$ on the nozzle

Table 5 continue

No.	Stress Point	Location/ Direction	Plot designation	Stress factor
22	G	nozzle/longitudinal	$6M_C$	Bending moment $\frac{M_{xn}}{M_C/(R_n\beta)}$ on the nozzle
23	G	nozzle/circumferential	$7M_C$	Membrane force $\frac{N_{\phi n}}{M_C/(R_n^2\beta)}$ on the nozzle
24	G	nozzle/longitudinal	$8M_C$	Membrane force $\frac{N_{xn}}{M_C/(R_n^2\beta)}$ on the nozzle
25	A	pipe/circumferential	$1M_L$	Bending moment $\frac{M_{\phi p}}{M_L/(R_p\beta)}$ on the pipe
26	A	pipe/longitudinal	$2M_L$	Bending moment $\frac{M_{xp}}{M_L/(R_p\beta)}$ on the pipe
27	A	pipe/circumferential	$3M_L$	Membrane force $\frac{N_{\phi p}}{M_L/(R_p^2\beta)}$ on the pipe
28	A	pipe/longitudinal	$4M_L$	Membrane force $\frac{N_{xp}}{M_L/(R_p^2\beta)}$ on the pipe

Table 5 continue

No.	Stress Point	Location/ Direction	Plot designation	Stress factor
29	E	nozzle/circumferential	$5M_L$	Bending moment $\frac{M_{\phi n}}{M_L/(R_p\beta)}$ on the nozzle
30	E	nozzle/longitudinal	$6M_L$	Bending moment $\frac{M_{xn}}{M_L/(R_n\beta)}$ on the nozzle
31	E	nozzle/circumferential	$7M_L$	Membrane force $\frac{N_{\phi n}}{M_L/(R_n^2\beta)}$ on the nozzle
32	E	nozzle/longitudinal	$8M_L$	Membrane force $\frac{N_{xn}}{M_L/(R_n^2\beta)}$ on the nozzle

5. 1. NUMARICAL EXAMPLE

5.1.1. BETA =.125, GAMMA = 200, Kn = 1.0. Kb = 1.0.

A vessel with outside diameter of 100.25 inches and thickness of 0.25 in. intersects a 12 in. pipe (O.D. = 12.75 in.) acting as a nozzle, whose thickness is also 0.25 in. It is subjected to a radial force of 400 lbs., and circumferential and longitudinal moments of 500 in-lb. each.

The mean radius of the pipe is $R_P = 50.0$ in. and the mean radius of the nozzle is $R_n = 6.25$ in. The geometrical parameters are beta, $\beta = R_n/R_P = 0.125$, and gamma, $\Upsilon = R_P/T = 200.0$. From the stress factors plots one obtains the stress factors and calculates the stress components for both the pipe and the nozzle. These data are shown in Table 6 through Table 13. For the completeness of the local stress tabulation, additional external loading components (torsional moment, shear forces and internal pressure) are assigned with numerical values. The circumferential and longitudinal pressure stresses are calculated from PR/T and PR/(2T) respectively. The shear stresses calculation follows WRC 107, [1] as $M_T/(2\pi R_o^2 T)$, $V_C/(\pi R_o T)$, and $V_L/(\pi R_o T)$, respectively. One notices that the maximum stresses do not always occur on the pipe portion of the juncture even when the same thickness is assumed.

Radial load, P = 400 lbs,

Table 6: Local stresses on the pipe at point A due to radial load, P

	Fig.	Value from Figure	Stress
BZPPA	1P	$\frac{M_\phi}{P} = 0.0160$	$\sigma_\phi = K_b \cdot (0.0160) \frac{6P}{T^2} = 614$
BXPPA	2P	$\frac{M_x}{P} = 0.0300$	$\sigma_x = K_b \cdot (0.0300) \frac{6P}{T^2} = 1152$
MZPPA	3P	$\frac{N_\phi}{P/R_p} = 5.130$	$\sigma_\phi = K_n \cdot (5.130) \frac{P}{R_P \cdot T} = 164$
MXPPA	4P	$\frac{N_x}{P/R_p} = 5.700$	$\sigma_x = K_n \cdot (5.700) \frac{P}{R_P \cdot T} = 182$

Table 7: Local stresses on the pipe at point C due to radial load, P

	Fig.	Value from Figure	Stress
BZPPC	5P	$\frac{M_\phi}{P} = 0.0520$	$\sigma_\phi = K_b \cdot (0.0520) \frac{6P}{T^2} = 1997$
BXPPC	6P	$\frac{M_x}{P} = 0.0220$	$\sigma_x = K_b \cdot (0.0220) \frac{6P}{T^2} = 845$

Table 7 continue

	Fig.	Value from Figure	Stress
MZPPC	7P	$\frac{N_\phi}{P/R_p} = 5.020$	$\sigma_\phi = K_n \cdot (5.020)\frac{P}{R_P \cdot T} = 161$
MXPPC	8P	$\frac{N_x}{P/R_p} = 22.00$	$\sigma_x = K_n \cdot (22.00)\frac{P}{R_P \cdot T} = 704$

Table 8: Local stresses on the nozzle at point A due to radial load, P

	Fig.	Value from Figure	Stress
BZPNA	9P	$\frac{M_\phi}{P} = 0.0120$	$\sigma_\phi = K_b \cdot (0.0120)\frac{6P}{T^2} = 461$
BYPNA	10P	$\frac{M_x}{P} = 0.3400$	$\sigma_x = K_b \cdot (0.3400)\frac{6P}{T^2} = 1306$
MZPNA	11P	$\frac{N_\phi}{P/R_n} = 0.6000$	$\sigma_\phi = K_n \cdot (0.6000)\frac{P}{R_n \cdot T} = 154$
MYPNA	12P	$\frac{N_x}{P/R_n} = 0.0700$	$\sigma_x = K_n \cdot (0.0700)\frac{P}{R_n \cdot T} = 18$

Table 9: Local stresses on the nozzle at point C due to radial load, P

	Fig.	Value from Figure	Stress
BZPNC	13P	$\frac{M_\phi}{P} = 0.050$	$\sigma_\phi = K_b \cdot (0.050)\frac{6P}{T^2} = 1920$

Table 9 continue

	Fig.	Value from Figure	Stress
BYPNC	14P	$\frac{M_x}{P} = 0.0130$	$\sigma_x = K_b \cdot (0.0130) \frac{6P}{T^2} = 499$
MZPNC	15P	$\frac{N_\phi}{P/R_n} = 0.190$	$\sigma_\phi = K_n \cdot (0.1900) \frac{P}{R_n \cdot T} = 49$
MYPNC	16P	$\frac{N_x}{P/R_n} = 3.400$	$\sigma_x = K_n \cdot (3.400) \frac{P}{R_n \cdot T} = 870$

Circumferential bending moment, M_C = 500 in-lb

Table 10: Local stresses on the pipe at point C due to moment, M_C

	Fig.	Value from Figure	Stress
BZM_CPC	$1M_C$	$\frac{M_\phi}{M_C/(R_P\beta)} = 0.800$	$\sigma_\phi = K_b \cdot (0.800) \frac{6M_C}{R_P\beta T^2} = 614$
BXM_CPC	$2M_C$	$\frac{M_x}{M_C/(R_P\beta)} = 0.030$	$\sigma_x = K_b \cdot (0.030) \frac{6M_C}{R_P\beta T^2} = 230$
MZM_CPC	$3M_C$	$\frac{N_\phi}{M_C/(R_P^2\beta)} = 3.30$	$\sigma_\phi = K_n \cdot (3.30) \frac{M_C}{R_P^2\beta T} = 21$
MXM_CPC	$4M_C$	$\frac{N_x}{M_C/(R_P^2\beta)} = 11.6$	$\sigma_x = K_n \cdot (11.6) \frac{M_C}{R_P^2\beta T} = 74$

Table 11: Local stresses on the nozzle at point C due to moment, M_C

	Fig.	Value from Figure	Stress
BZM_CNC	$5M_C$	$\frac{M_\phi}{M_C/(R_n\beta)} = 0.009$	$\sigma_\phi = K_b \cdot (0.009)\frac{6M_C}{R_n\beta T^2} = 553$
BYM_CNC	$6M_C$	$\frac{M_x}{M_C/(R_n\beta)} = 0.003$	$\sigma_x = K_b \cdot (0.003)\frac{6M_C}{R_n\beta T^2} = 184$
MZM_CNC	$7M_C$	$\frac{N_\phi}{M_C/(R_n^2\beta)} = 0.05$	$\sigma_\phi = K_n \cdot (0.05)\frac{M_C}{R_n^2\beta T} = 20$
MYM_CNC	$8M_C$	$\frac{N_x}{M_C/(R_n^2\beta)} = 0.30$	$\sigma_x = K_n \cdot (0.30)\frac{M_C}{R_n^2\beta T} = 123$

Longitudinal bending moment M_L = 500 in-lb

Table 12: Local stresses on the pipe at point A due to moment, M_L

	Fig.	Value from Figure	Stress
BZM_LPA	$1M_L$	$\frac{M_\phi}{M_L/(R_P\beta)} = 0.013$	$\sigma_\phi = K_b \cdot (0.013)\frac{6M_L}{R_P\beta T^2} = 100$
BXM_LPA	$2M_L$	$\frac{M_x}{M_L/(R_P\beta)} = 0.030$	$\sigma_x = K_b \cdot (0.030)\frac{6M_L}{R_P\beta T^2} = 230$
MZM_LPA	$3M_L$	$\frac{N_\phi}{M_L/(R_P^2\beta)} = 15.4$	$\sigma_\phi = K_n \cdot (15.4)\frac{M_L}{R_P^2\beta T} = 99$

Table 12 continue

	Fig.	Value from Figure	Stress
MXM$_L$PA	4M$_L$	$\frac{N_x}{M_L/(R_P^2\beta)} = 6.40$	$\sigma_x = K_n \cdot (6.40)\frac{M_L}{R_P^2\beta T} = 41$

Table 13: Local stresses on the nozzle at point A due to moment, M$_L$

	Fig.	Value from Figure	Stress
BZM$_L$NA	5M$_L$	$\frac{M_\phi}{M_L/(R_n\beta)} = 0.0014$	$\sigma_\phi = K_b \cdot (0.0014)\frac{6M_L}{R_n\beta T^2} = 86$
BYM$_L$NA	6M$_L$	$\frac{M_x}{M_L/(R_n\beta)} = 0.0042$	$\sigma_x = K_b \cdot (0.0042)\frac{6M_L}{R_n\beta T^2} = 258$
MZM$_L$NA	7M$_L$	$\frac{N_\phi}{M_L/(R_n^2\beta)} = 0.273$	$\sigma_\phi = K_n \cdot (0.273)\frac{M_L}{R_n^2\beta T} = 110$
MYM$_L$N A	8M$_L$	$\frac{N_x}{M_L/(R_n^2\beta)} = 0.04$	$\sigma_x = K_n \cdot (0.04)\frac{M_L}{R_n^2\beta T} = 16$

5.1.2. STRESSES COMPARISON WITH WRC 297

Using the same beta and gamma values from the above example, the stress resultant from various figures of WRC Bulletin 297 [11] are shown in Table 14, and the comparison of nozzle and pipe local stresses with finite element method (F. E. M.) are shown in Table 15 in which the F. E. M. stresses are the combination of maximum normal and bending stresses components at either point A or point C from Tables 9 and 10. One observes that the theoretical results from the WRC Bulletin 297, [2] are very conservative than the finite element method.

Table 14: Tabulation of stress resultant from WRC297

Stress resultant	d/t	Fig. for P	Value from Figure	Fig. for M_C	Value from Figure	Fig. for M_L	Value from Figure
m_r	50	6	0.118	25	0.25	43	0.11
n_r	50	11	0.036	30	0.065	48	0.037
m_θ	50	16	0.038	34	0.088	52	0.035
n_θ	50	21	0.13	39	0.14	57	0.18

Table 15: Comparison of pipe-nozzle stresses with WRC297

Stress for P	Pipe $\sigma_r = \sigma_x$ (psi)	Pipe $\sigma_\theta = \sigma_\phi$ (psi)	Nozzle $\sigma_a = \sigma_x$ (psi)	Nozzle $\sigma_c = \sigma_\phi$ (psi)
From WRC297	4761 or -4300	2291 or -627	3929 or -3900	832
From F.E.M.*	(1549)	(2158)	(1369)	(1940)
Stress for M_C				
From WRC297	800 or -706	333 or -188	655 or -636	73
From F.E.M.*	(304)	(634)	(307)	(572)
Stress for M_L				
From WRC207	348 or -311	195 or -15	284 or -265	90
From F.E.M.*	(271)	(198)	(273)	(198)

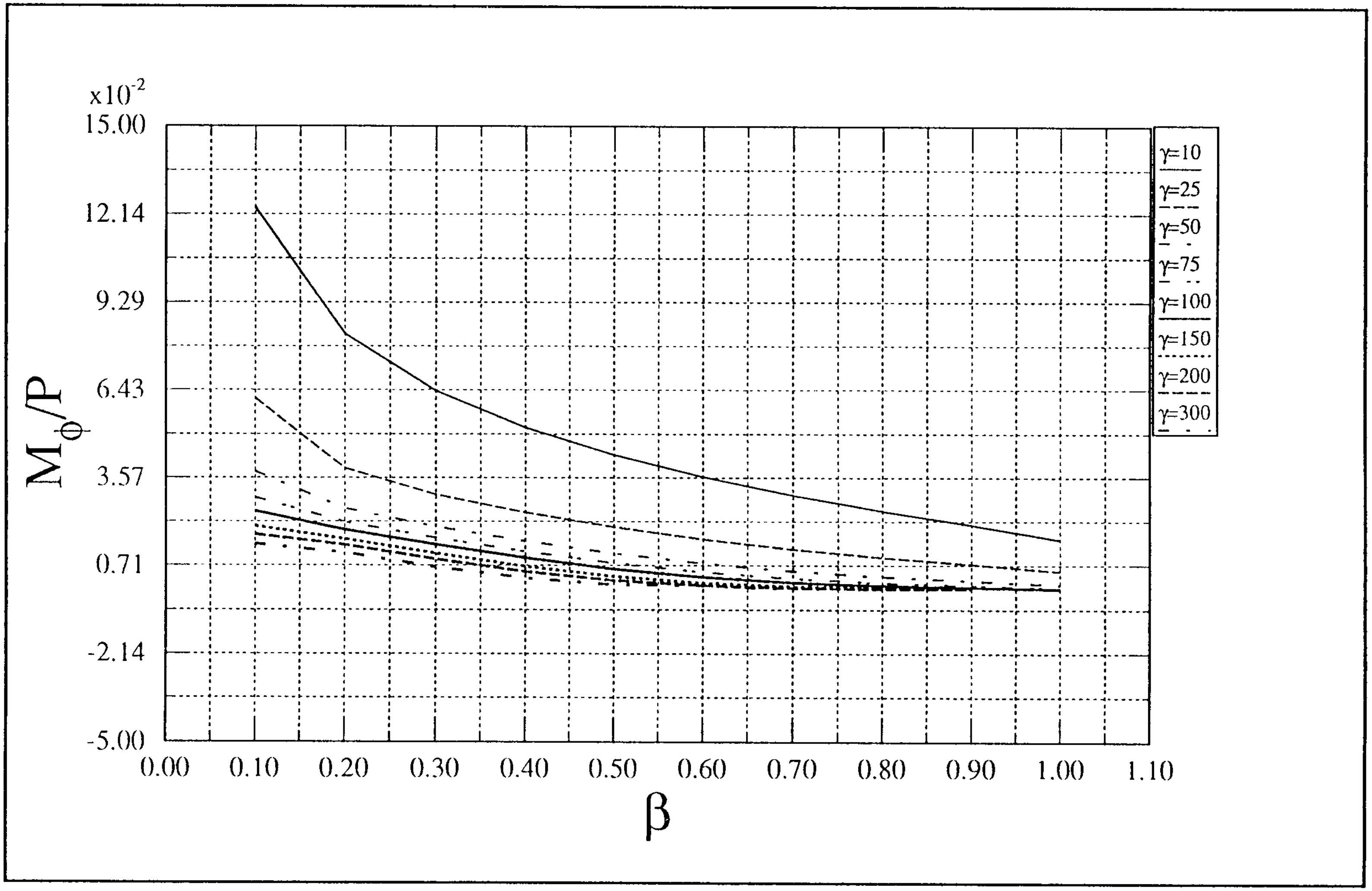


Figure 1P. Bending stress factor in circumferential direction due to radial load, P, on the pipe at point A (BZPPA)

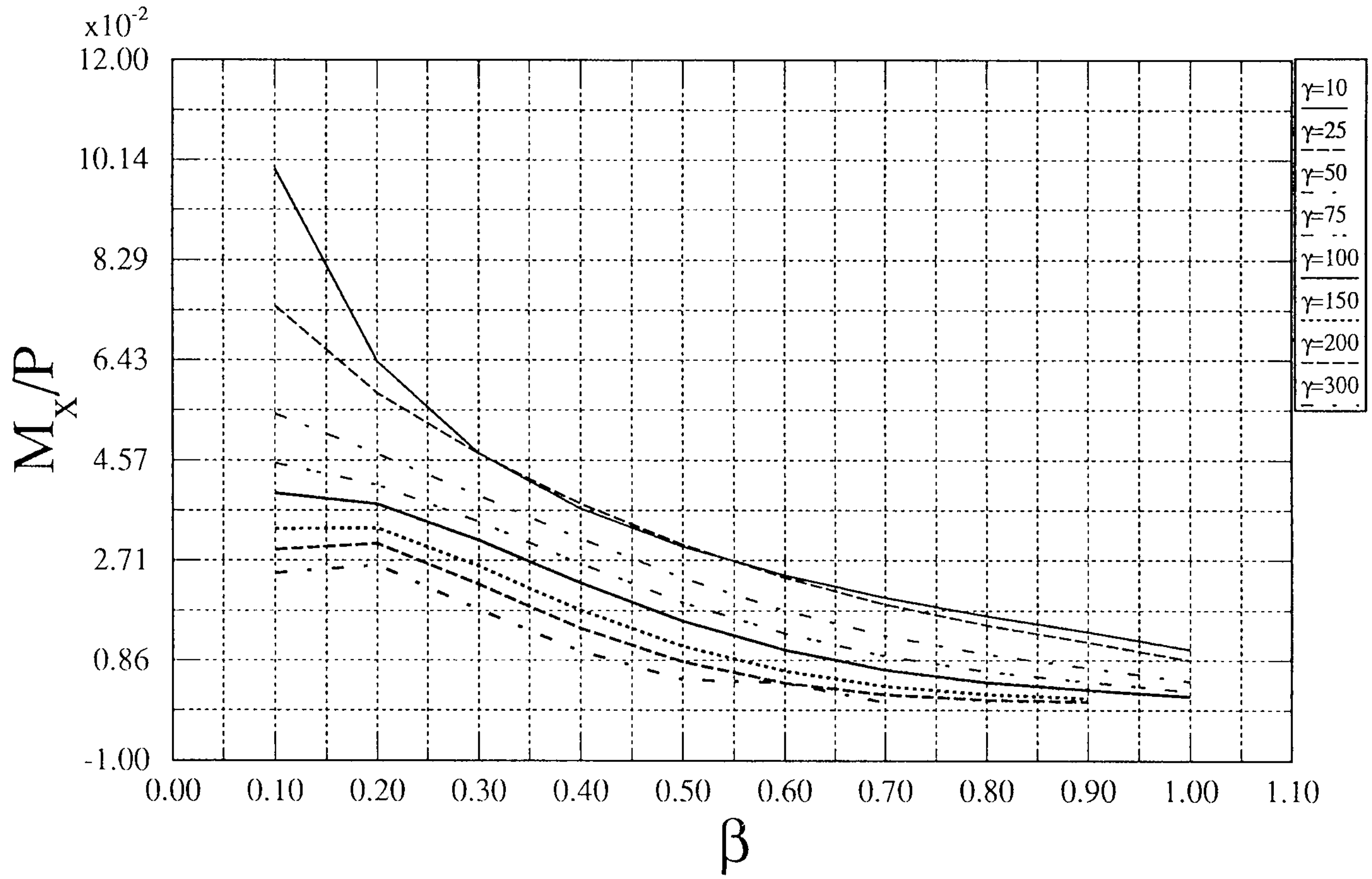


Figure 2P. Bending stress factor in longitudinal direction due to radial load, P, on the pipe at point A (BXPPA)

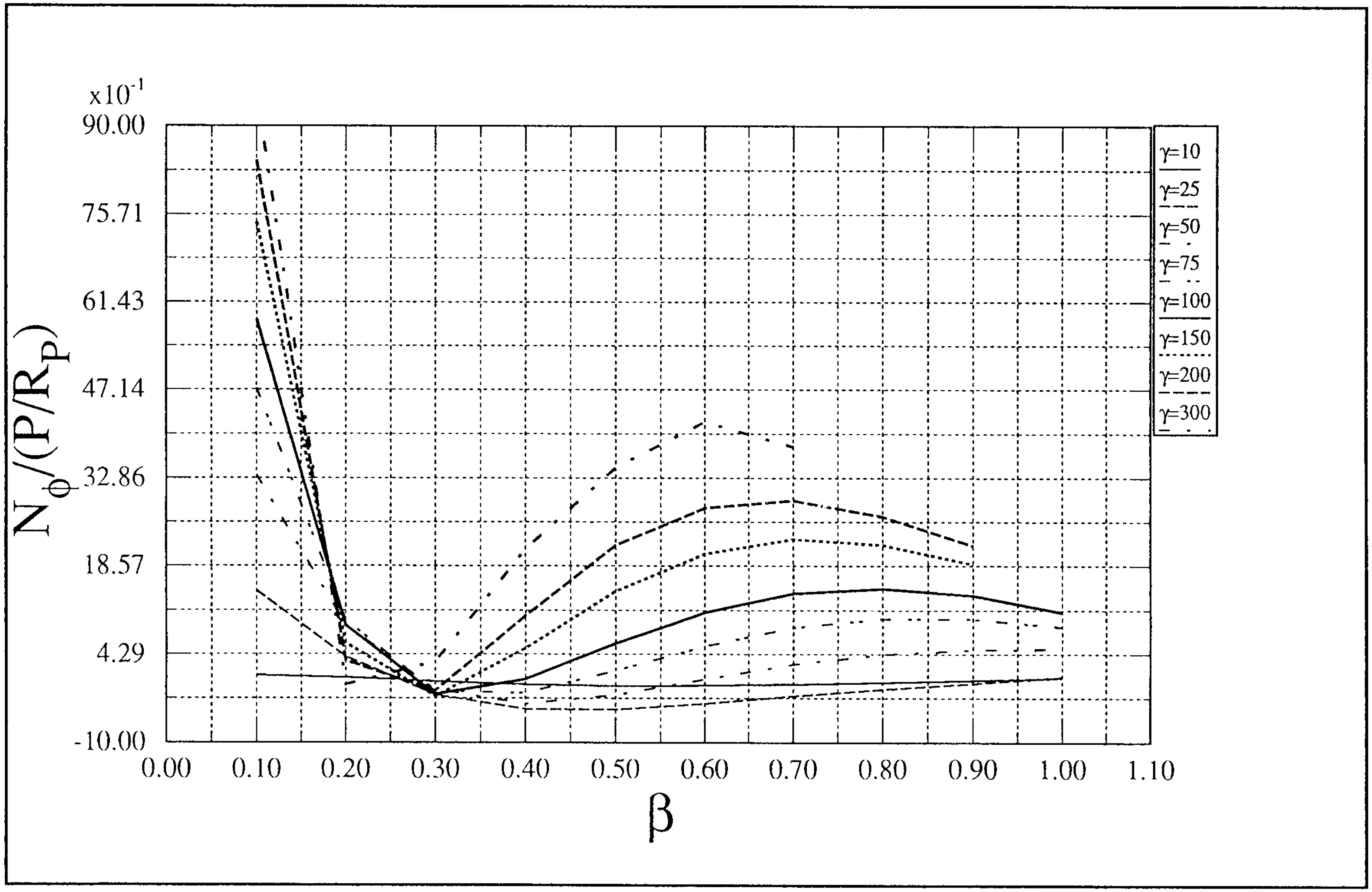


Figure 3P. Membrane stress factor in circumferential direction due to radial load, P, on the pipe at point A (MZPPA)

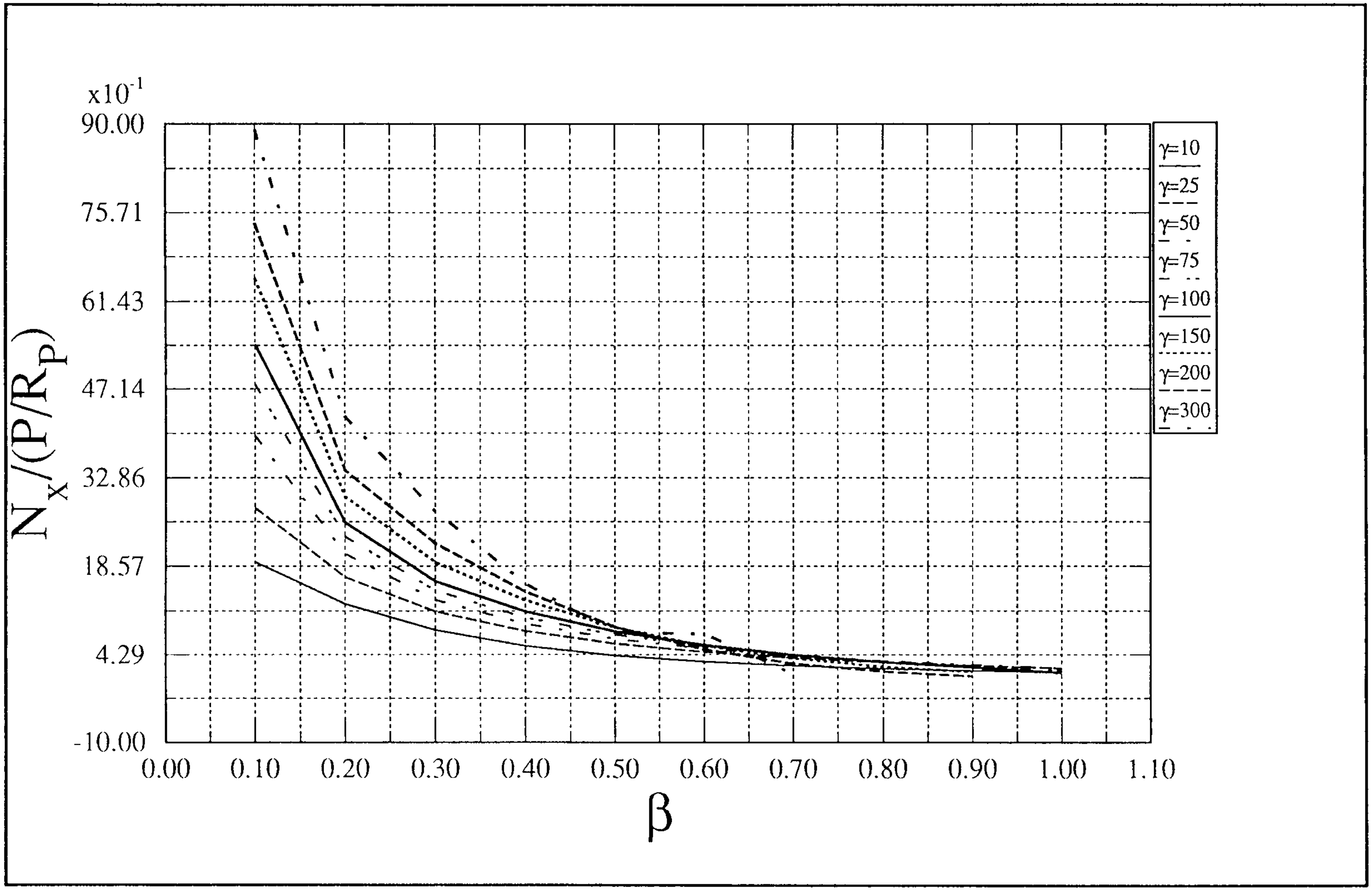


Figure 4P. Membrane stress factor in longitudinal direction due to radial load, P, on the pipe at point A (MXPPA)

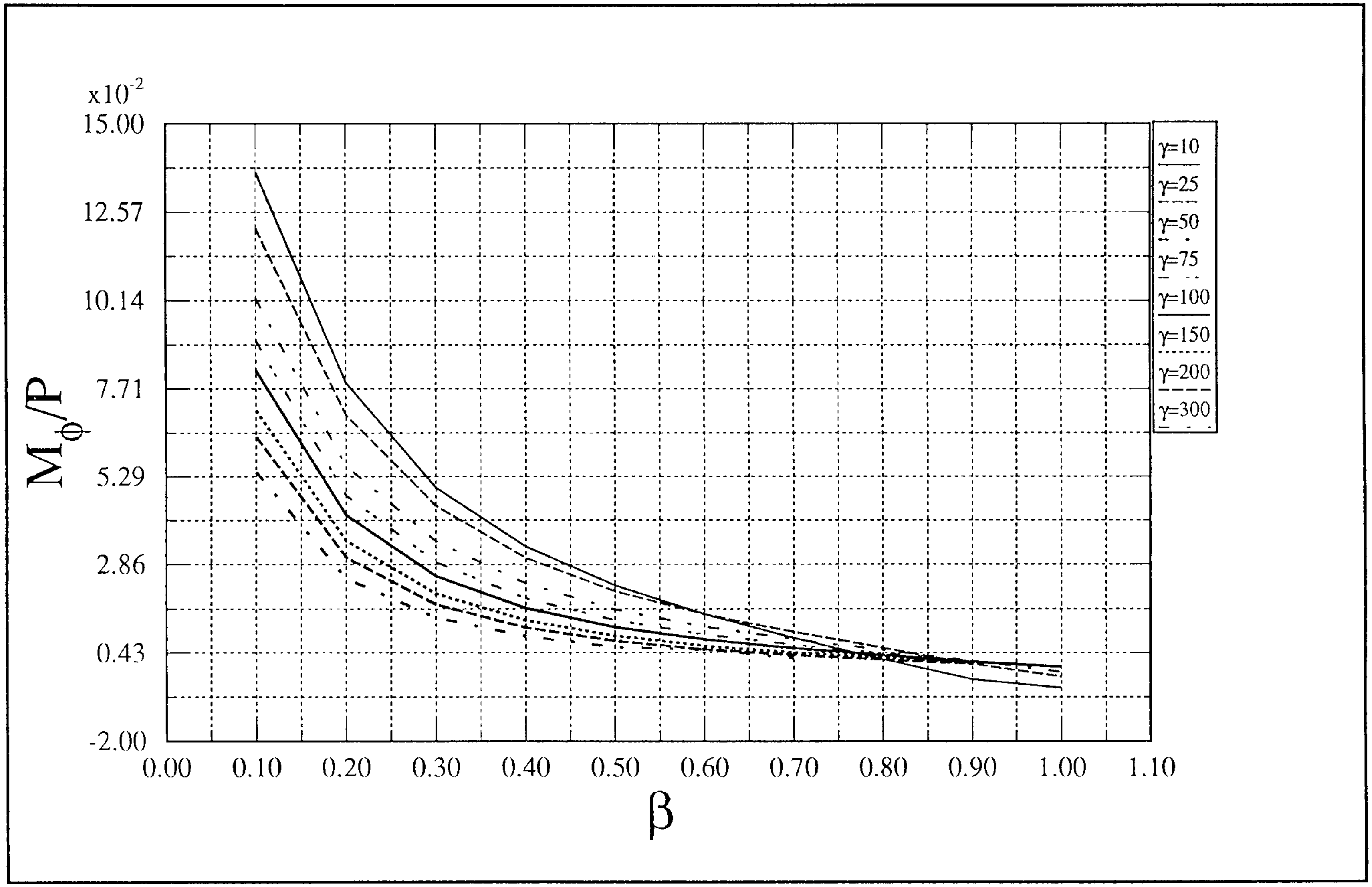


Figure 5P. Bending stress factor in circumferential direction due to radial load, P, on the pipe at point C (BZPPC)

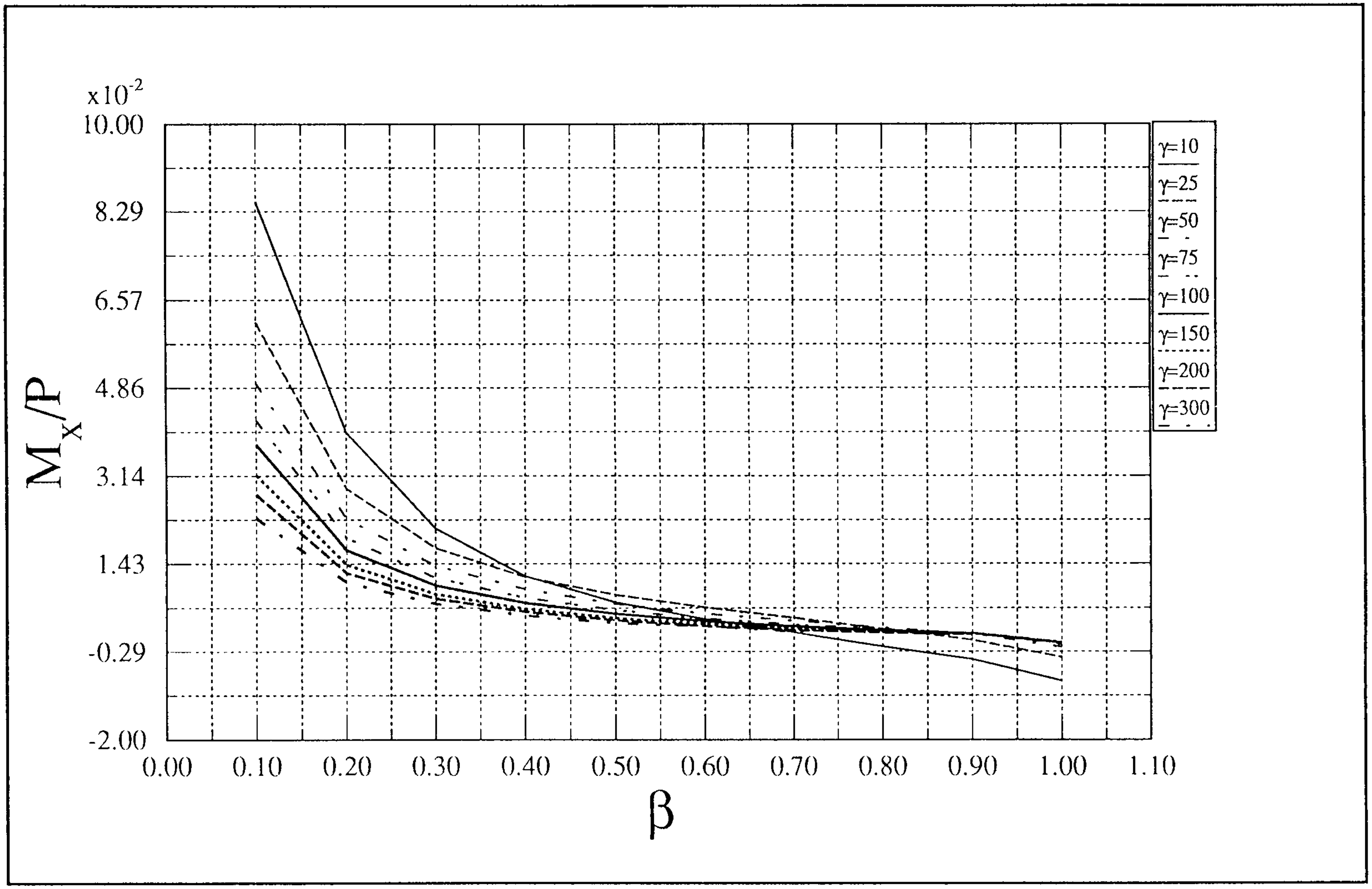


Figure 6P. Bending stress factor in longitudinal direction due to radial load, P, on the pipe at point C (BXPPC)

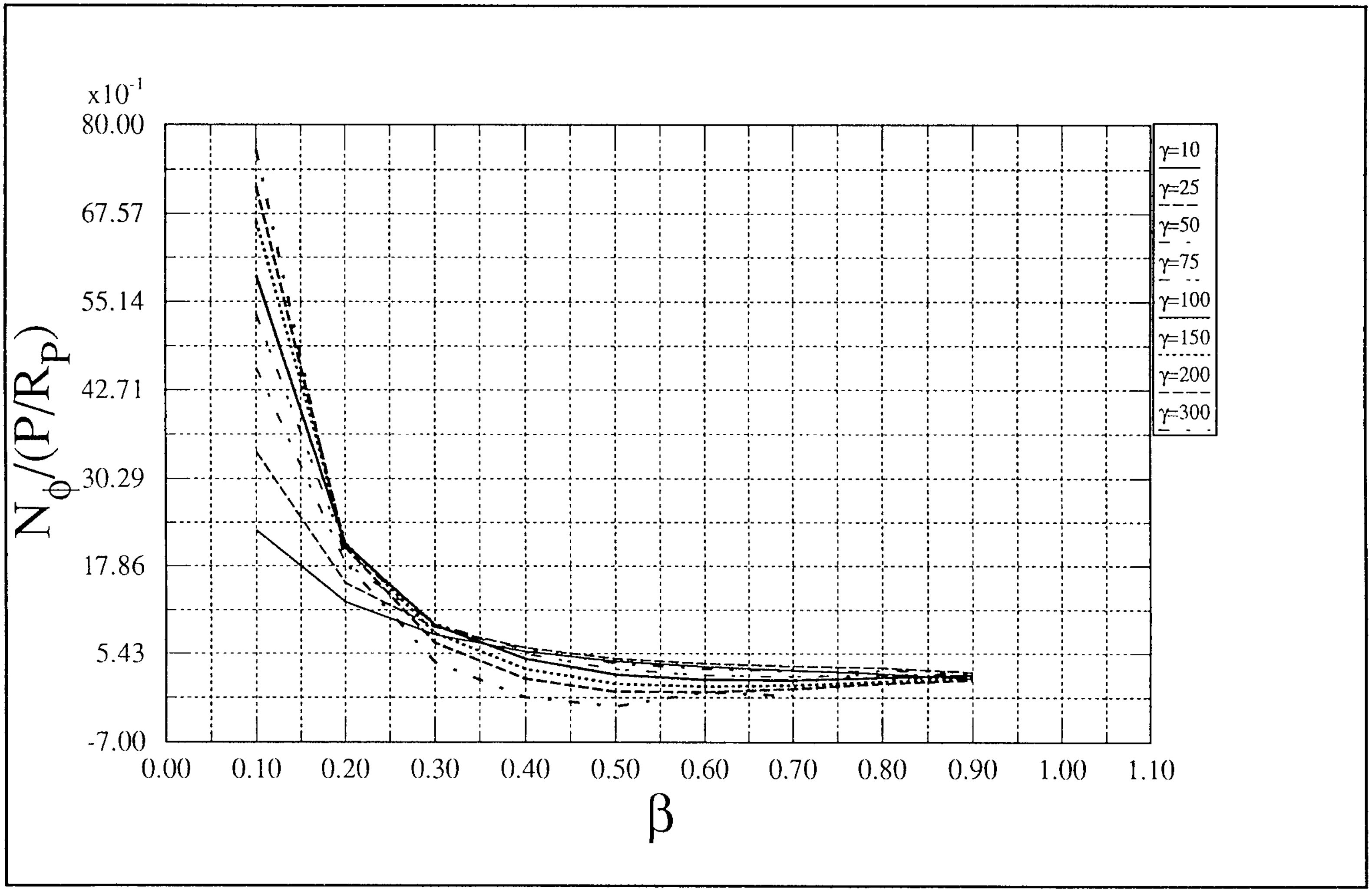


Figure 7P. Membrane stress factor in circumferential direction due to radial load, P, on the pipe at point C (MZPPC)

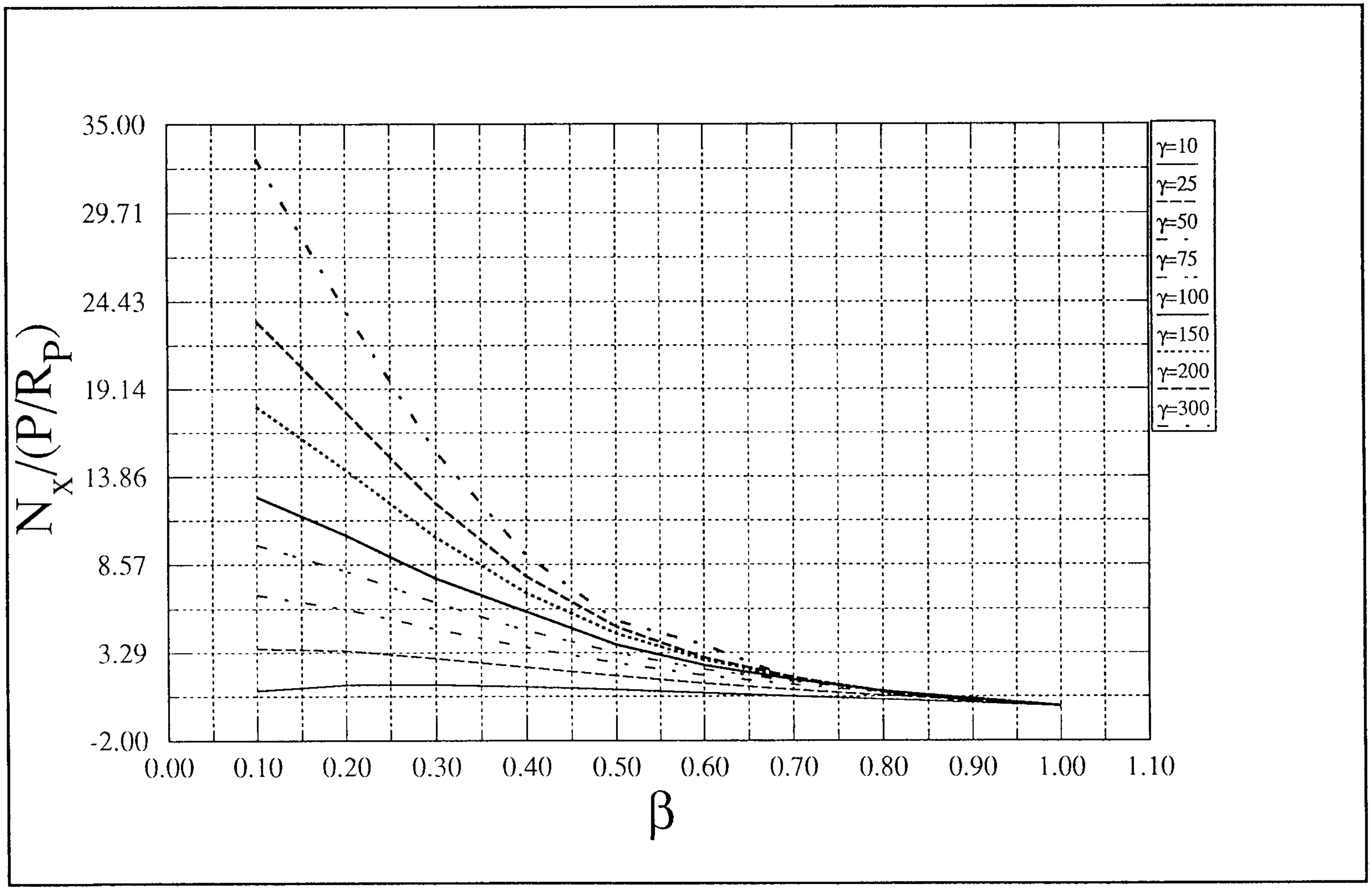


Figure 8P. Membrane stress factor in longitudinal direction due to radial load, P, on the pipe at point C (MXPPC)

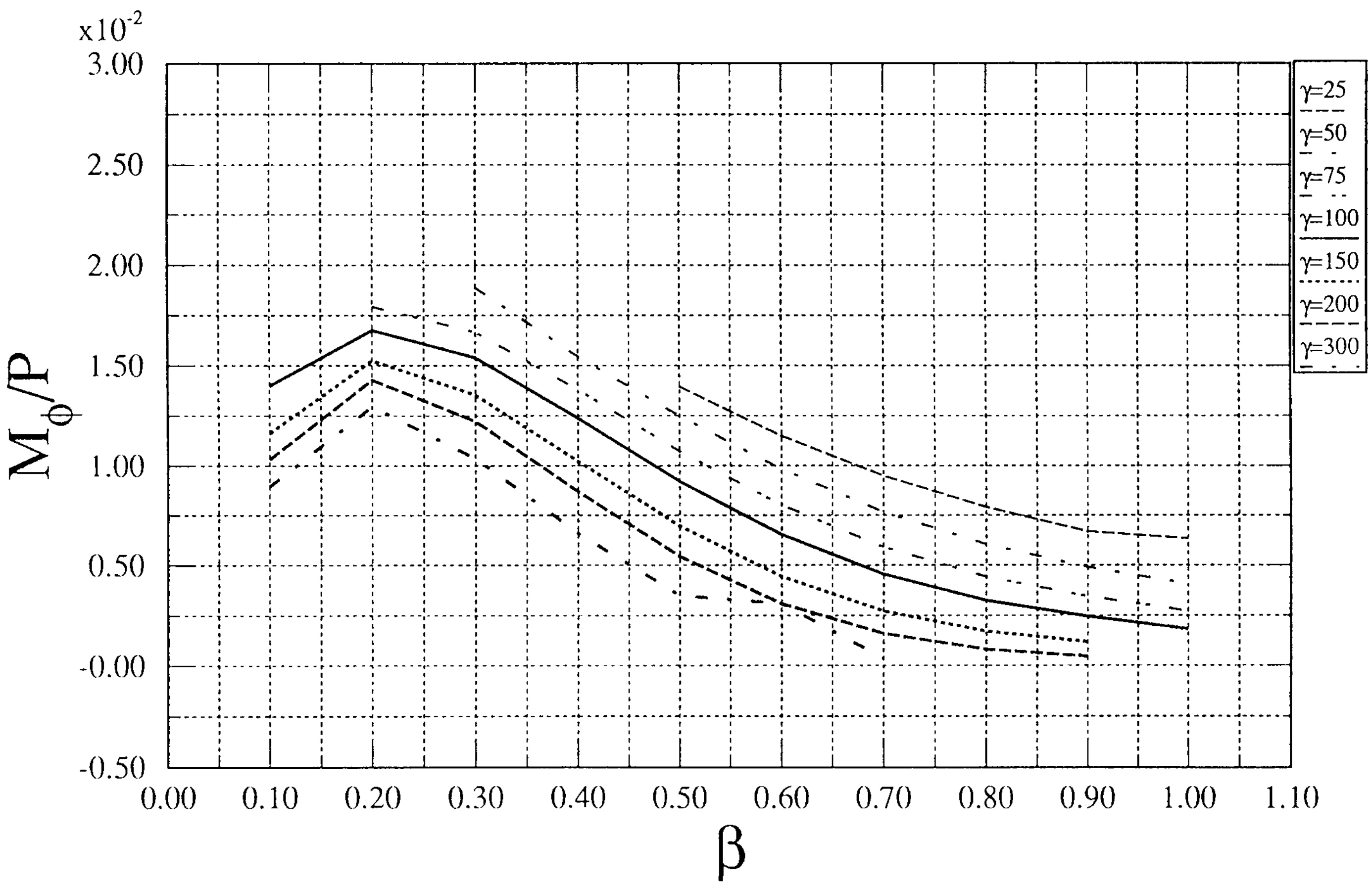


Figure 9P. Bending stress factor in circumferential direction due to radial load, P, on the nozzle at point A (BZPNA)

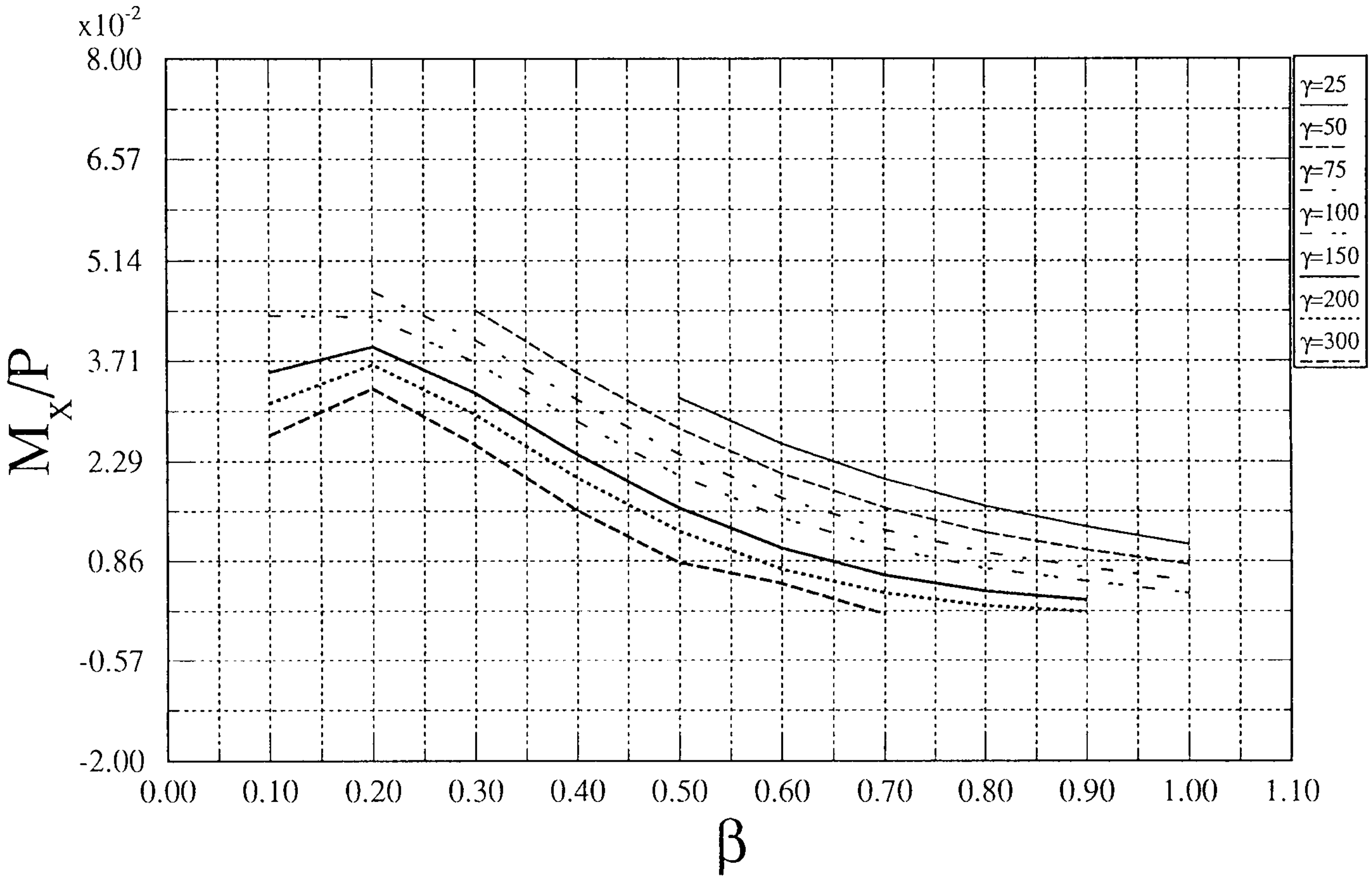


Figure 10P. Bending stress factor in longitudinal direction due to radial load, P, on the nozzle at point A (BYPNA)

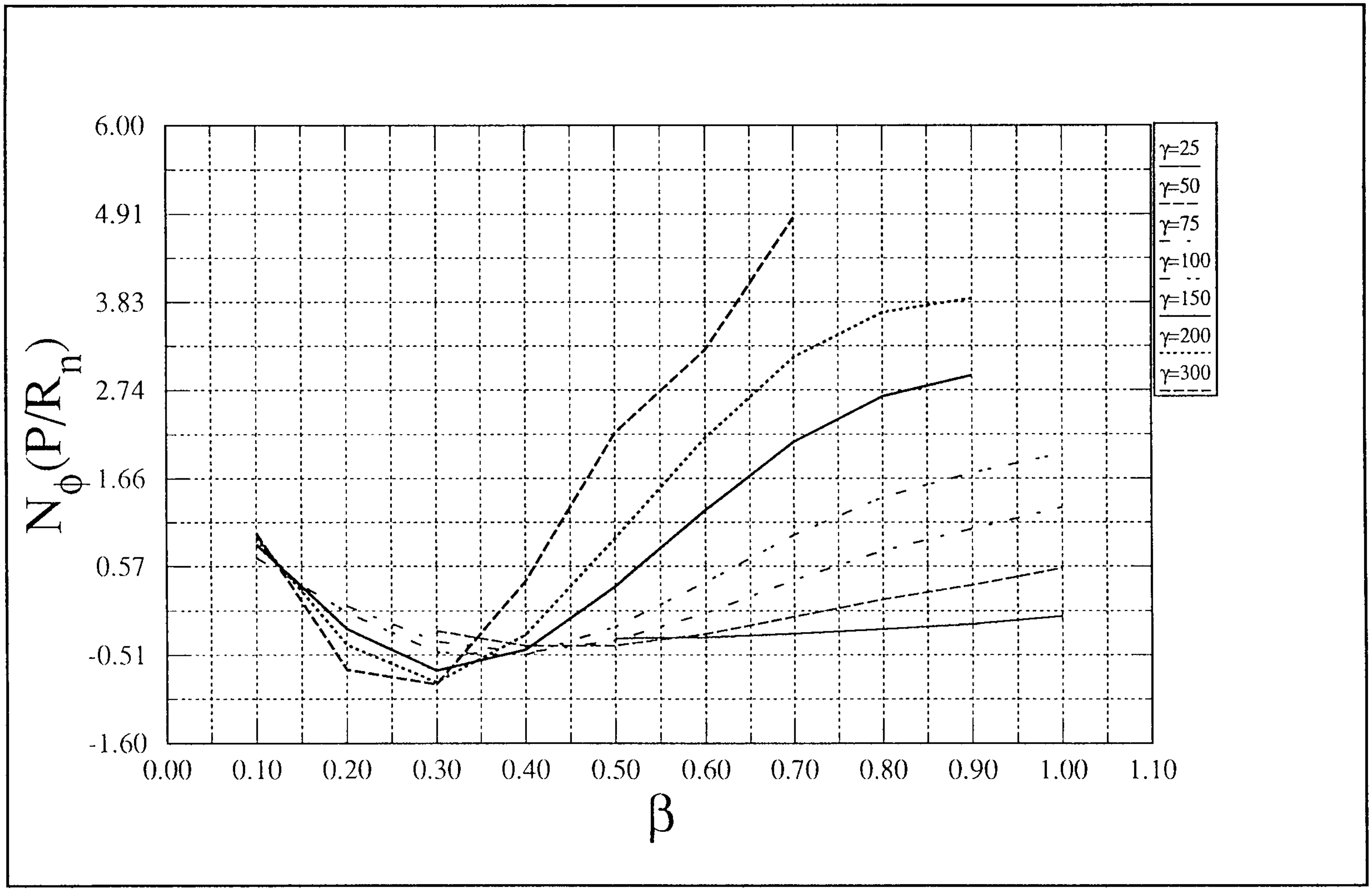


Figure 11P. Membrane stress factor in circumferential direction due to radial load, P, on the nozzle at point A (MZPNA)

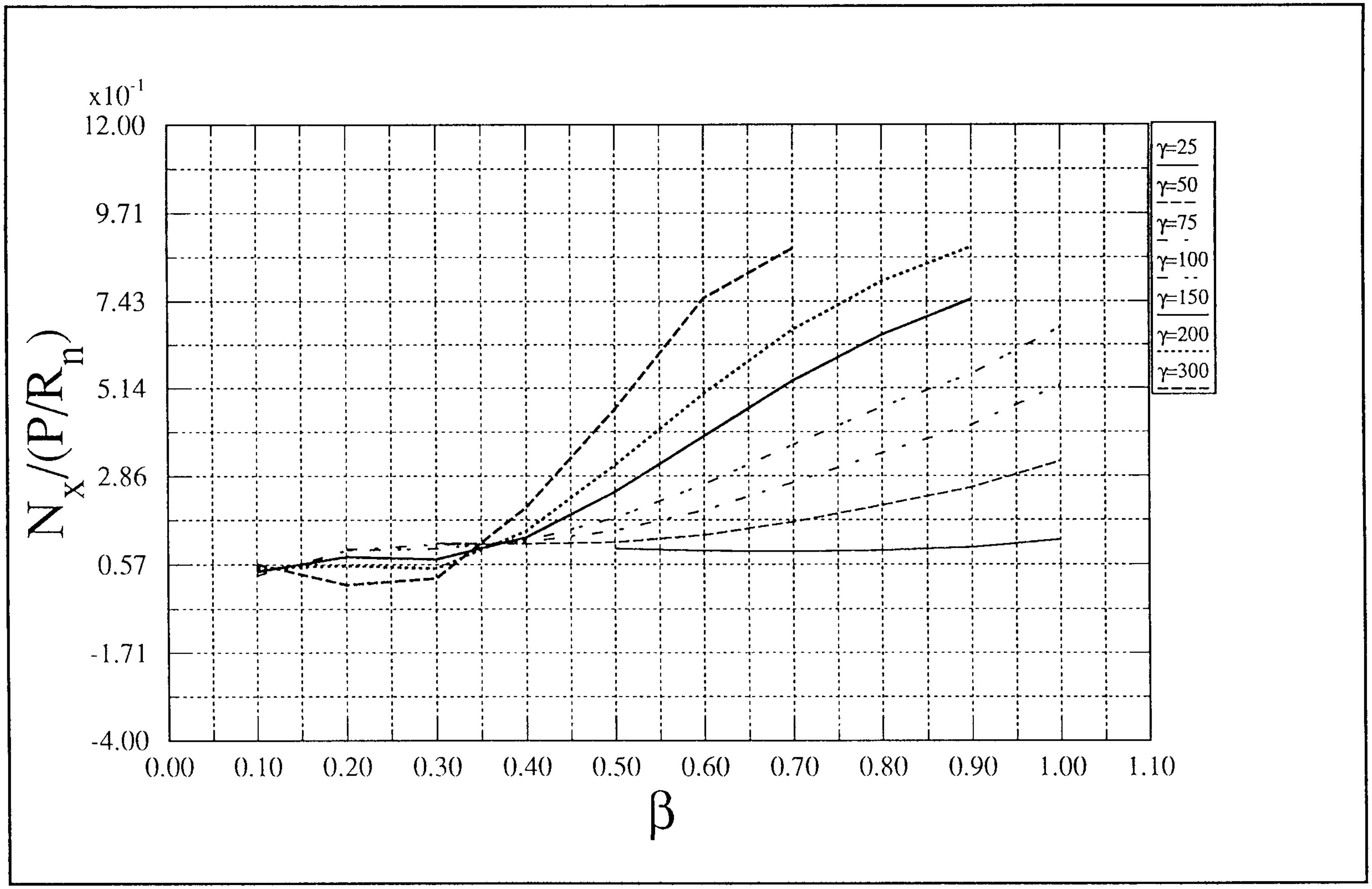


Figure 12P. Membrane stress factor in longitudinal direction due to radial load, P, on the nozzle at point A (MYPNA)

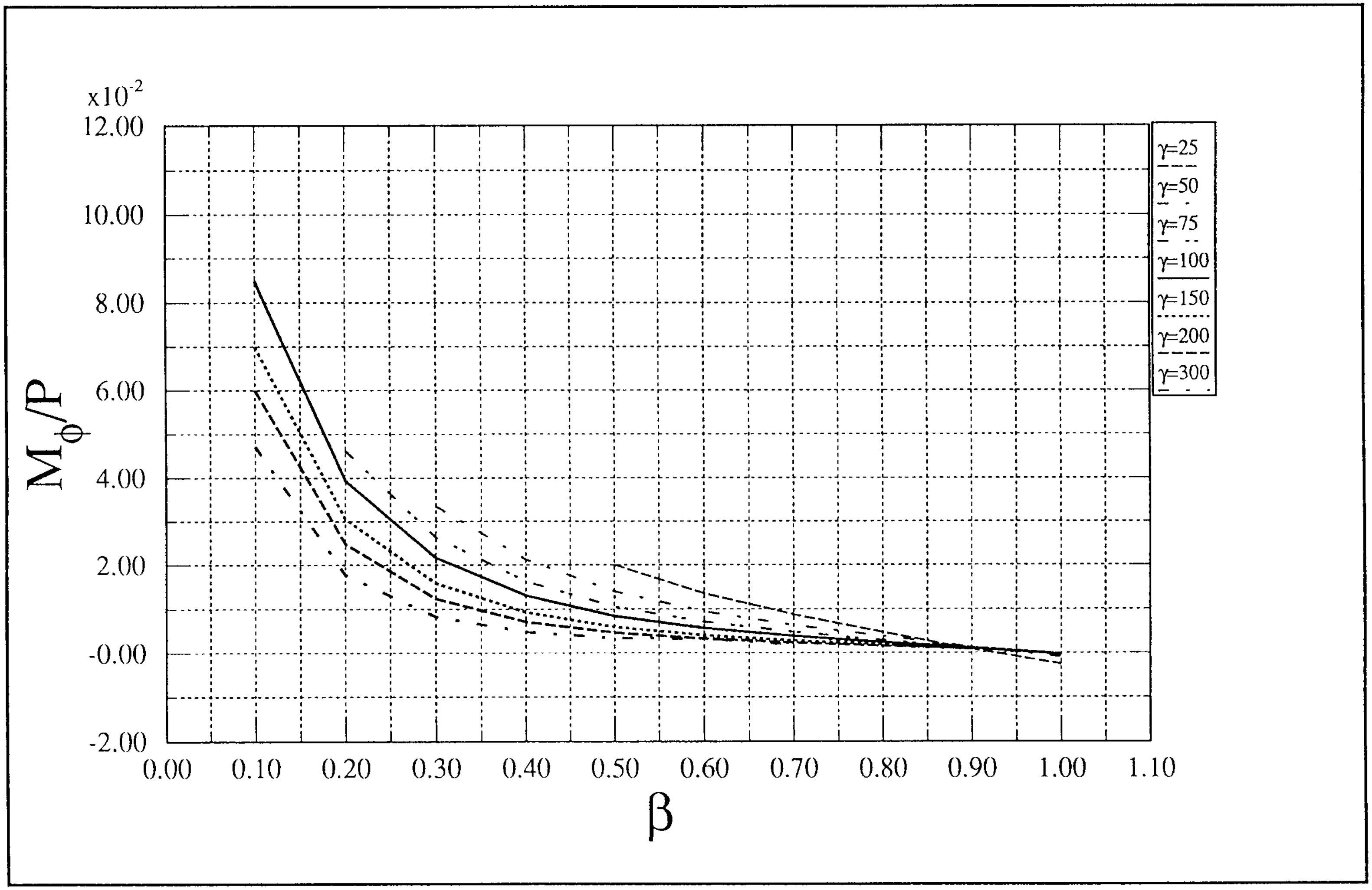


Figure 13P. Bending stress factor in circumferential direction due to radial load, P, on the nozzle at point C (BZPNC)

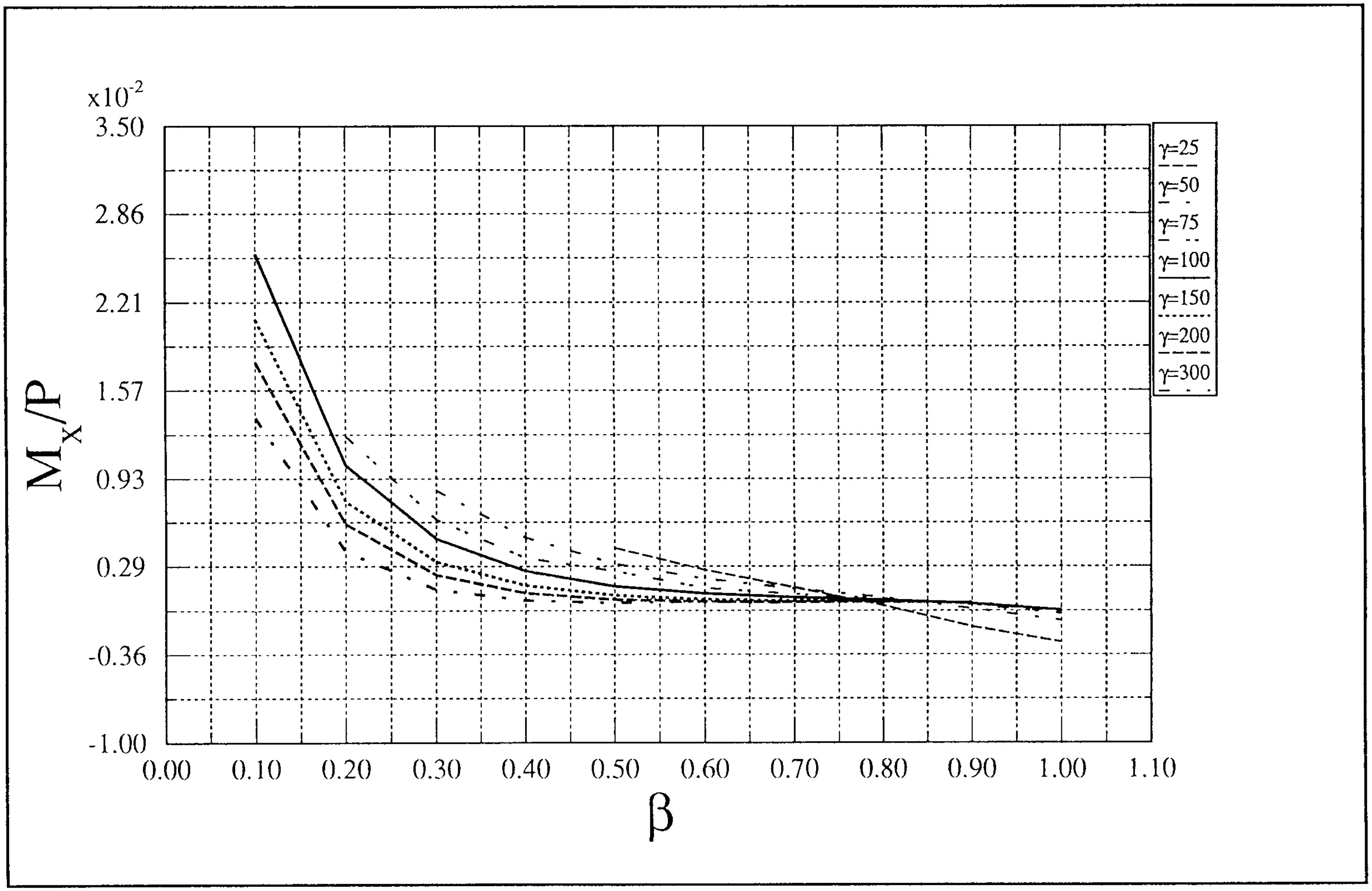


Figure 14P. Bending stress factor in longitudinal direction due to radial load, P, on the nozzle at point C (BYPNC)

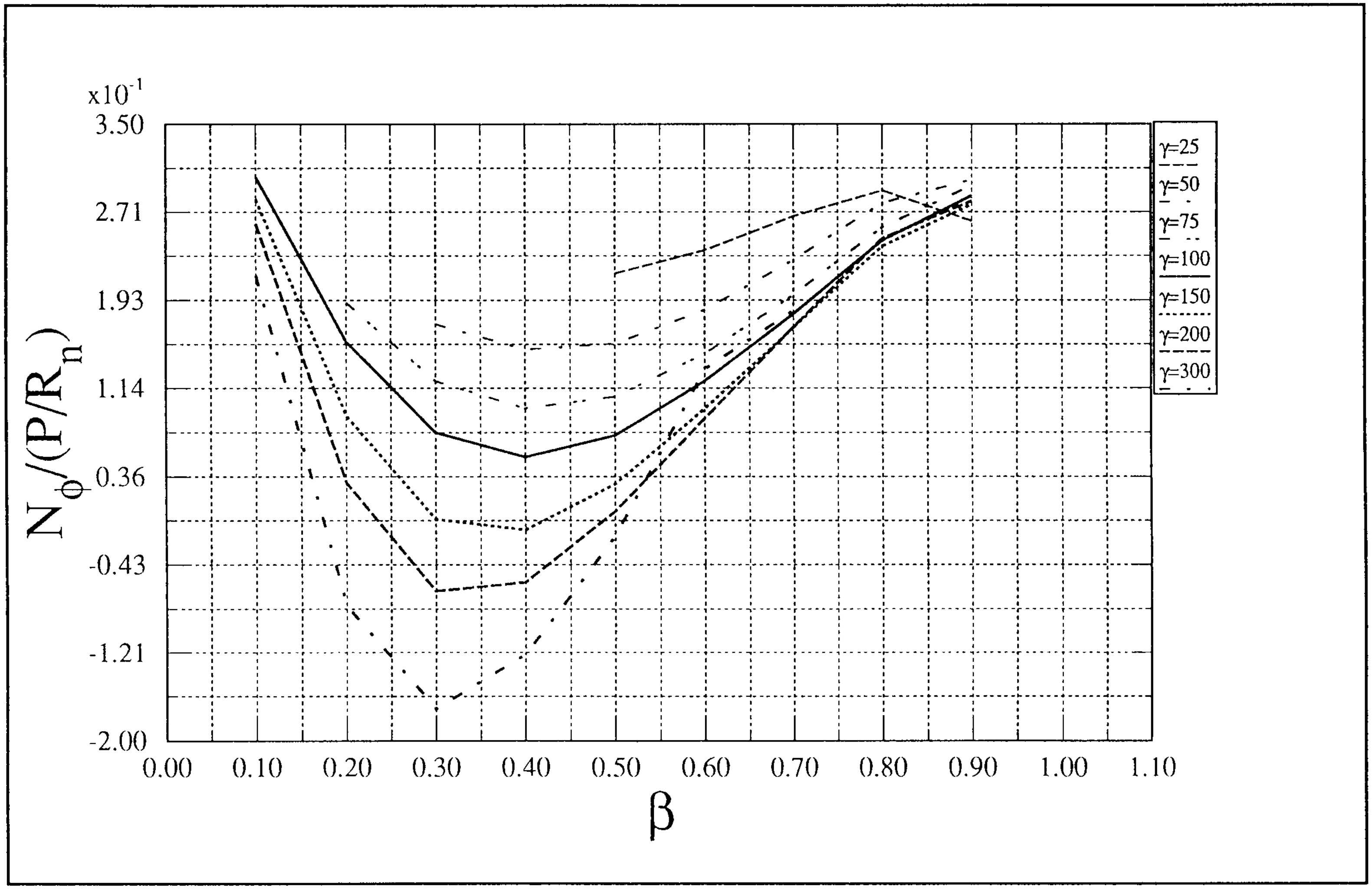


Figure 15P. Membrane stress factor in circumferential direction due to radial load, P, on the nozzle at point C (MZPNC)

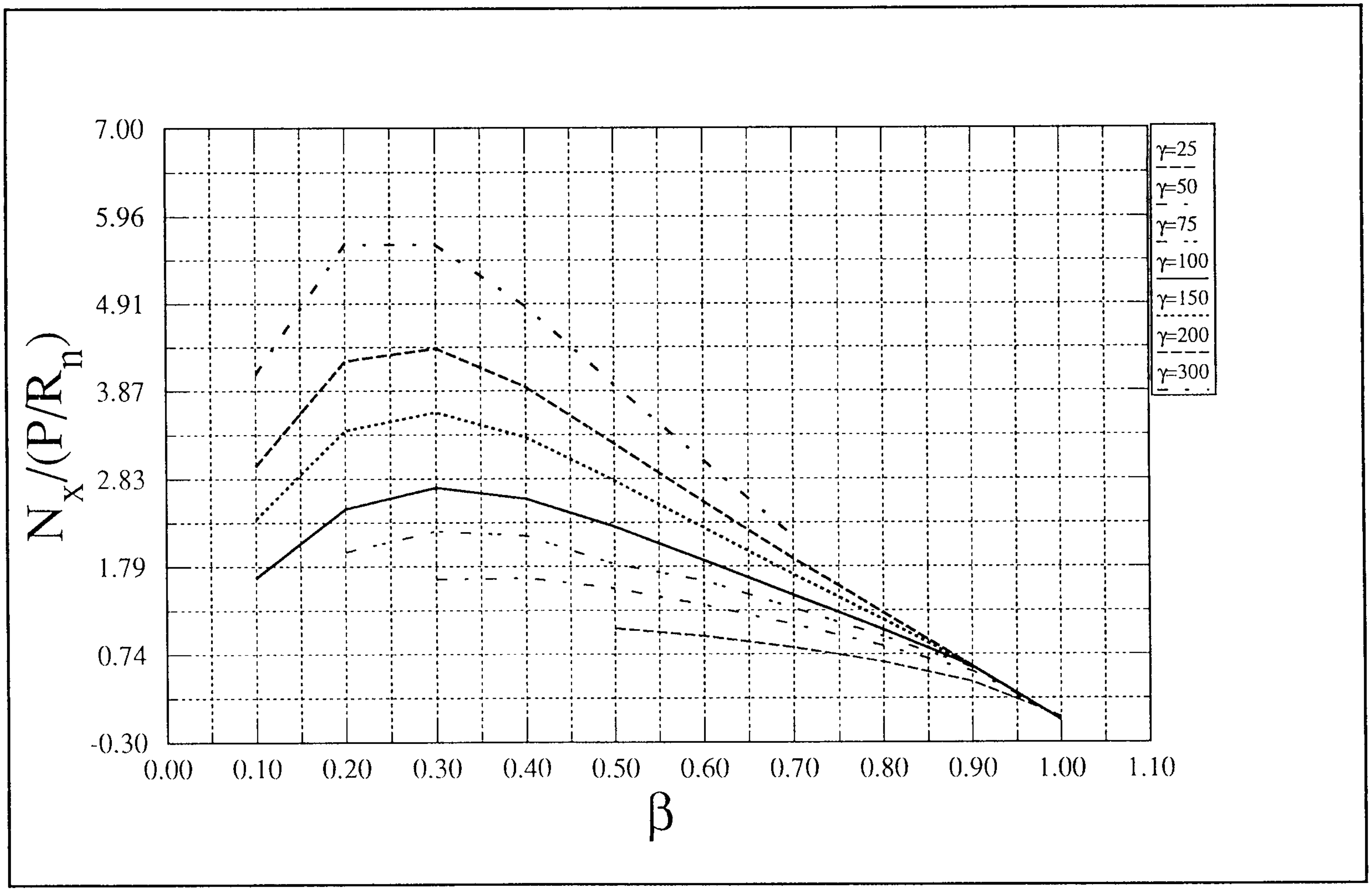


Figure 16P. Membrane stress factor in longitudinal direction due to radial load, P, on the nozzle at point C (MYPNC)

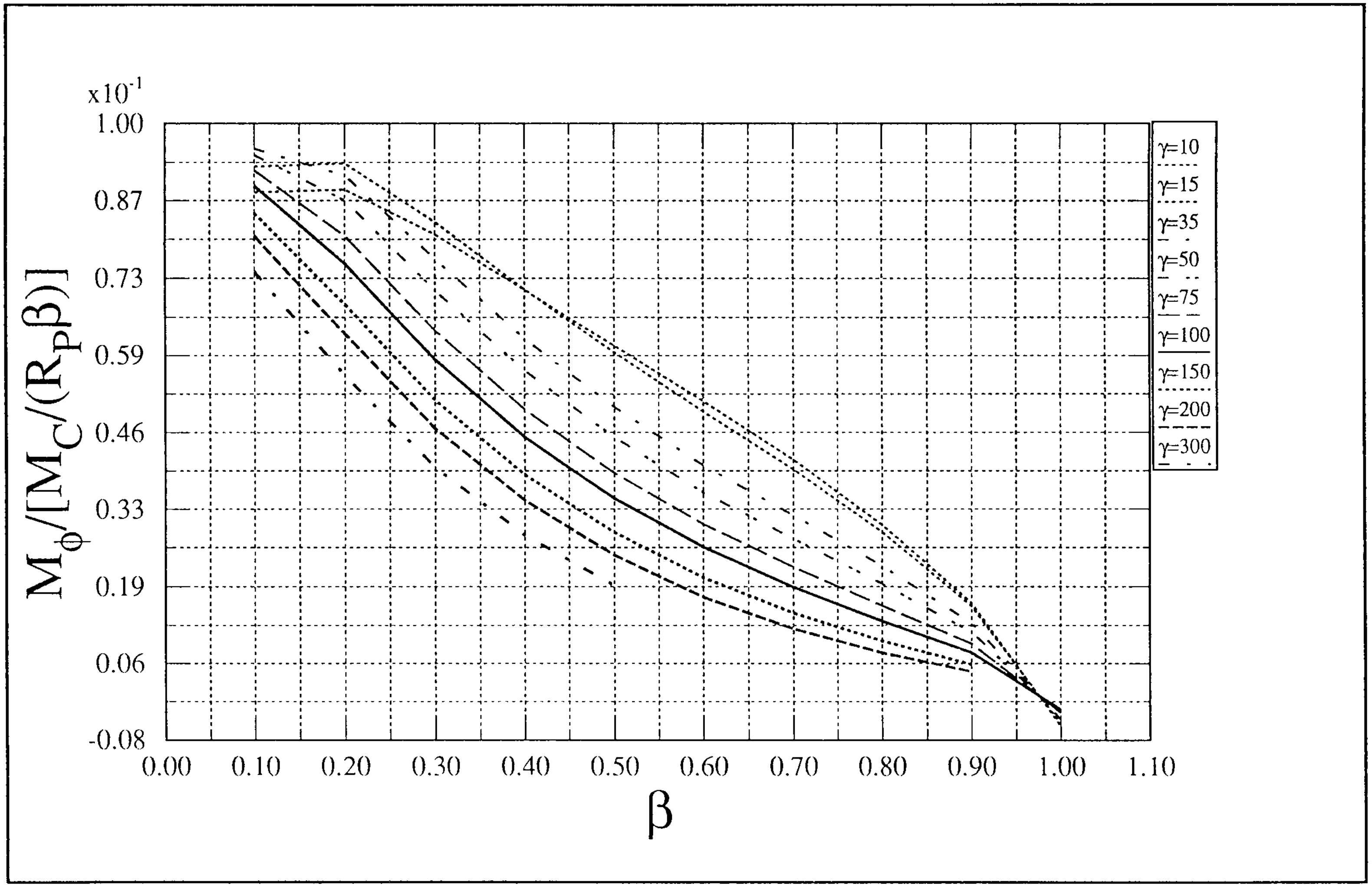


Figure 1Mc. Bending stress factor in circumferential direction due to circumferential bending moment, Mc, on the pipe at point C (BZMcPC)

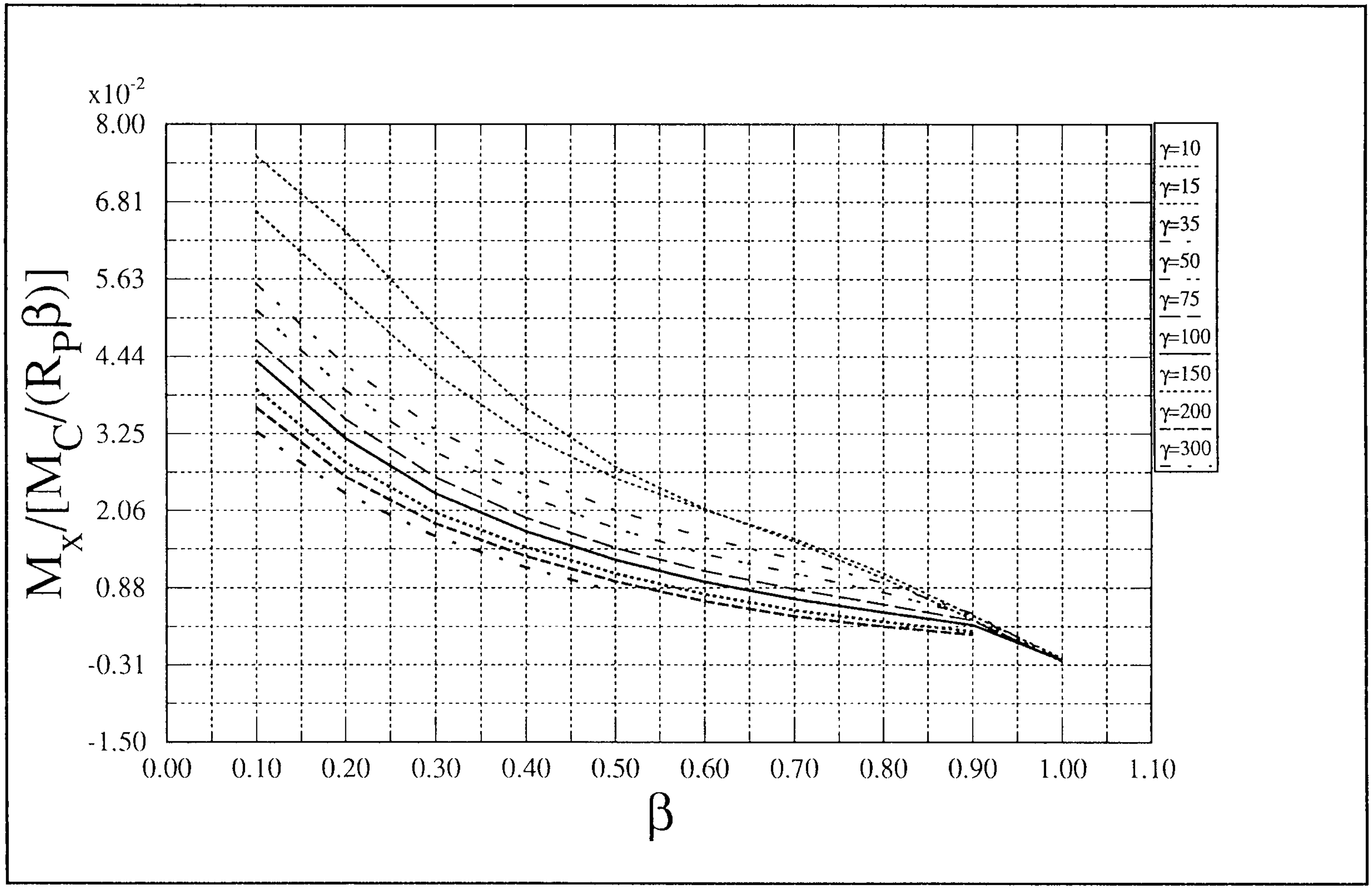


Figure 2Mc. Bending stress factor in longitudinal direction due to circumferential bending moment, Mc, on the pipe at point C (BXMcPC)

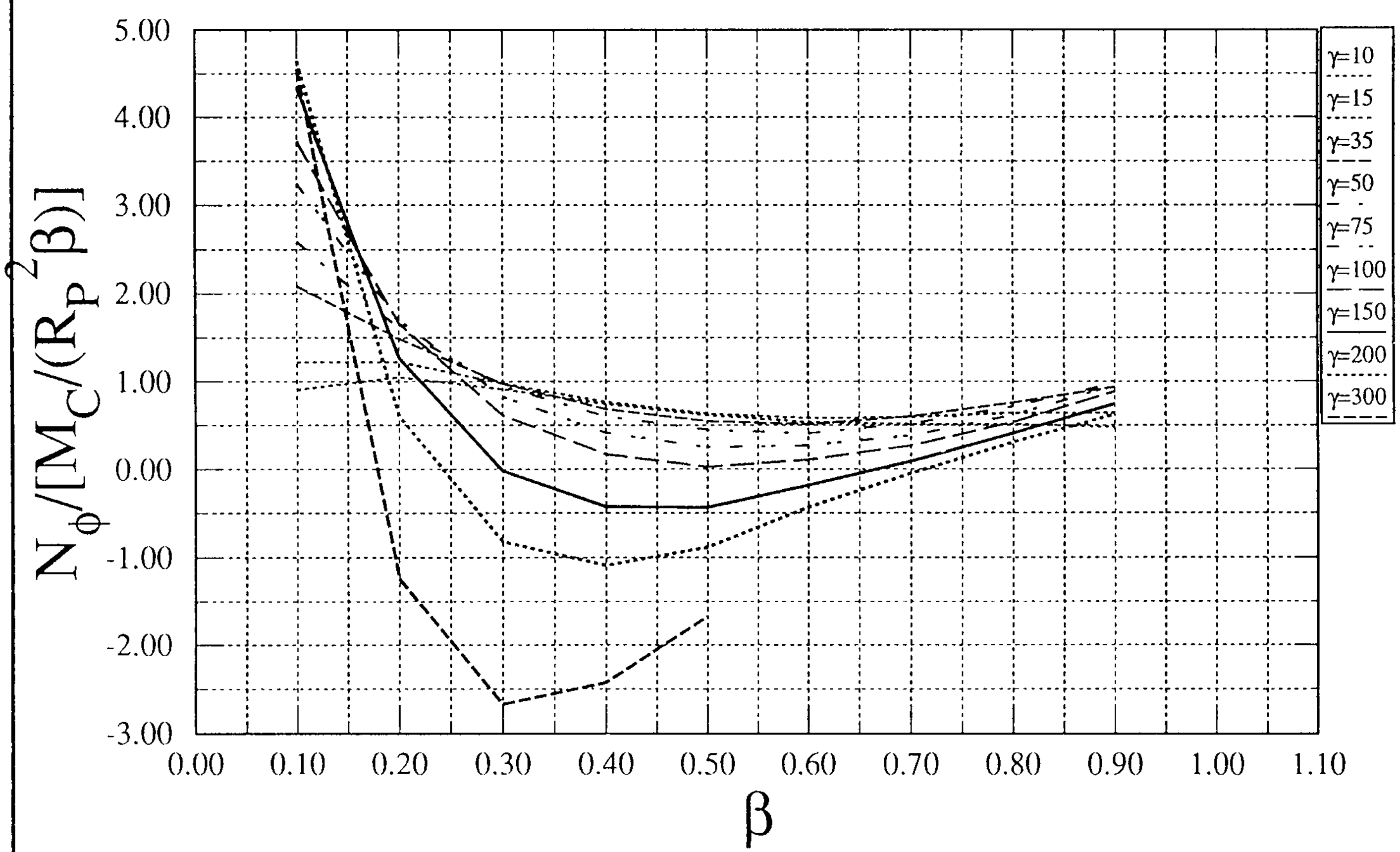


Figure 3Mc. Membrane stress factor in circumferential direction due to circumferential bending moment, Mc, on the pipe at point C (MZMcPC)

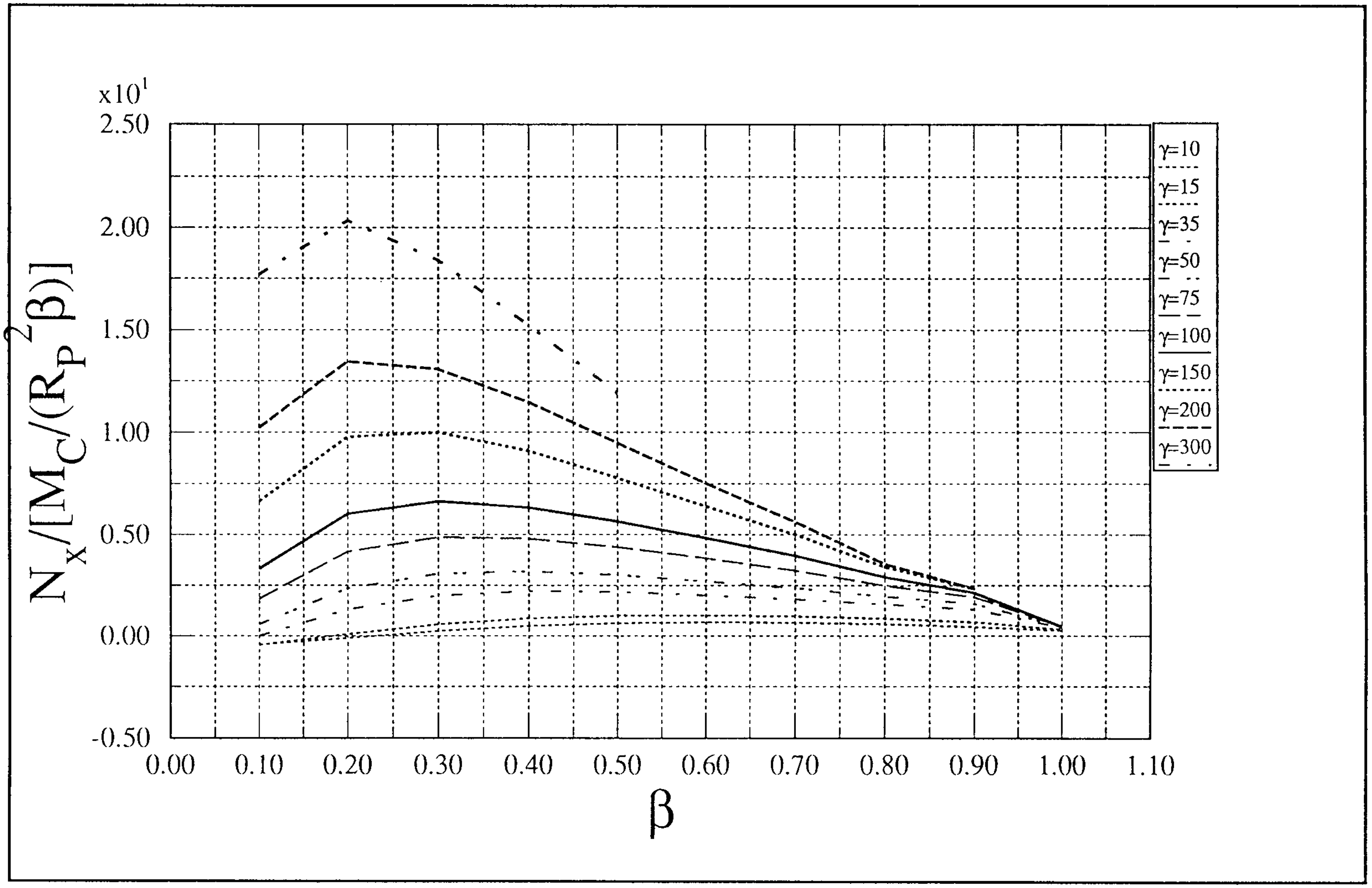


Figure 4Mc. Membrane stress factor in longitudinal direction due to circumferential bending moment, Mc, on the pipe at point C (MXMcPC)

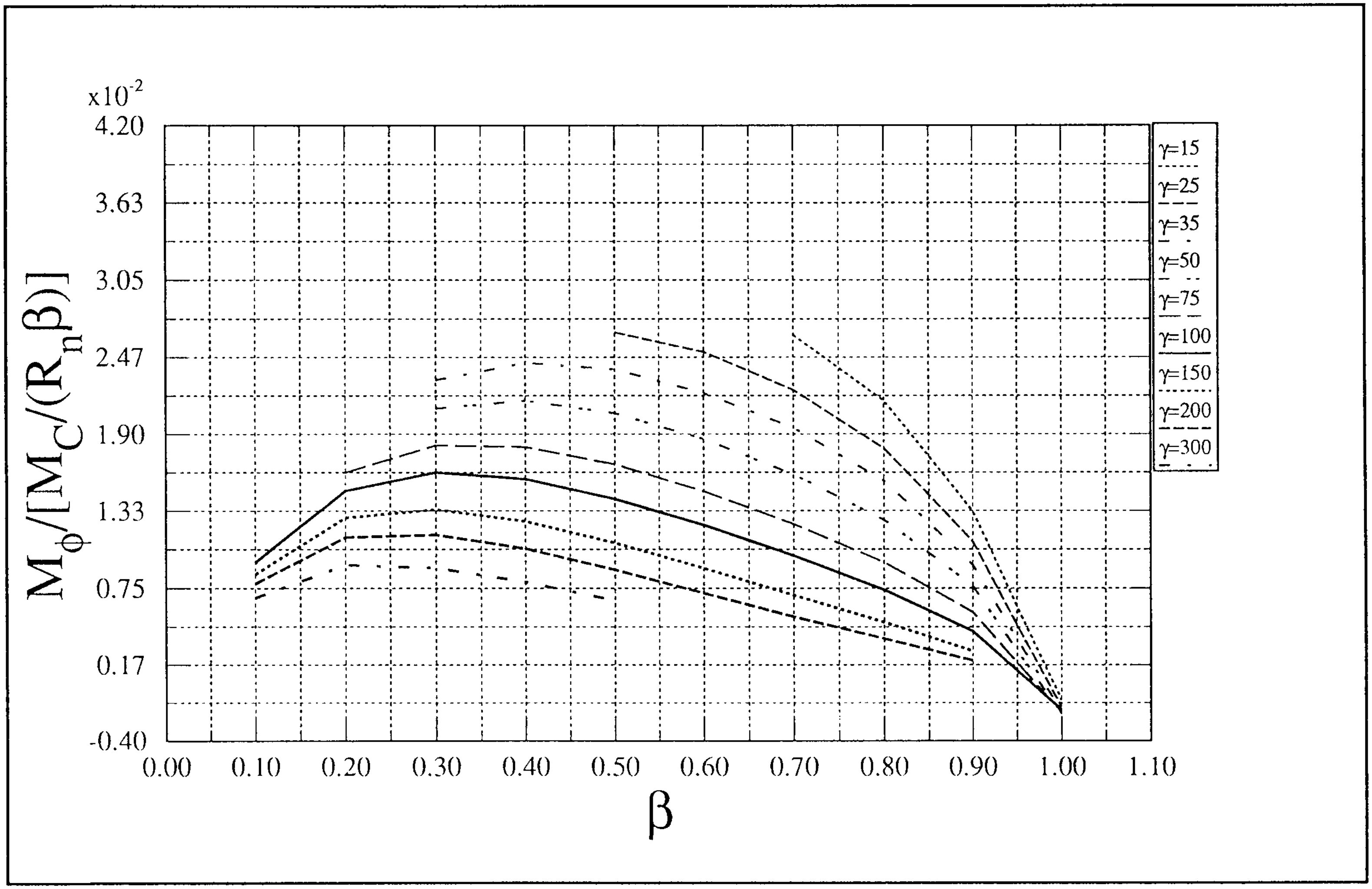


Figure 5Mc. Bending stress factor in circumferential direction due to circumferential bending moment, Mc, on the nozzle at point C (BZMcNC)

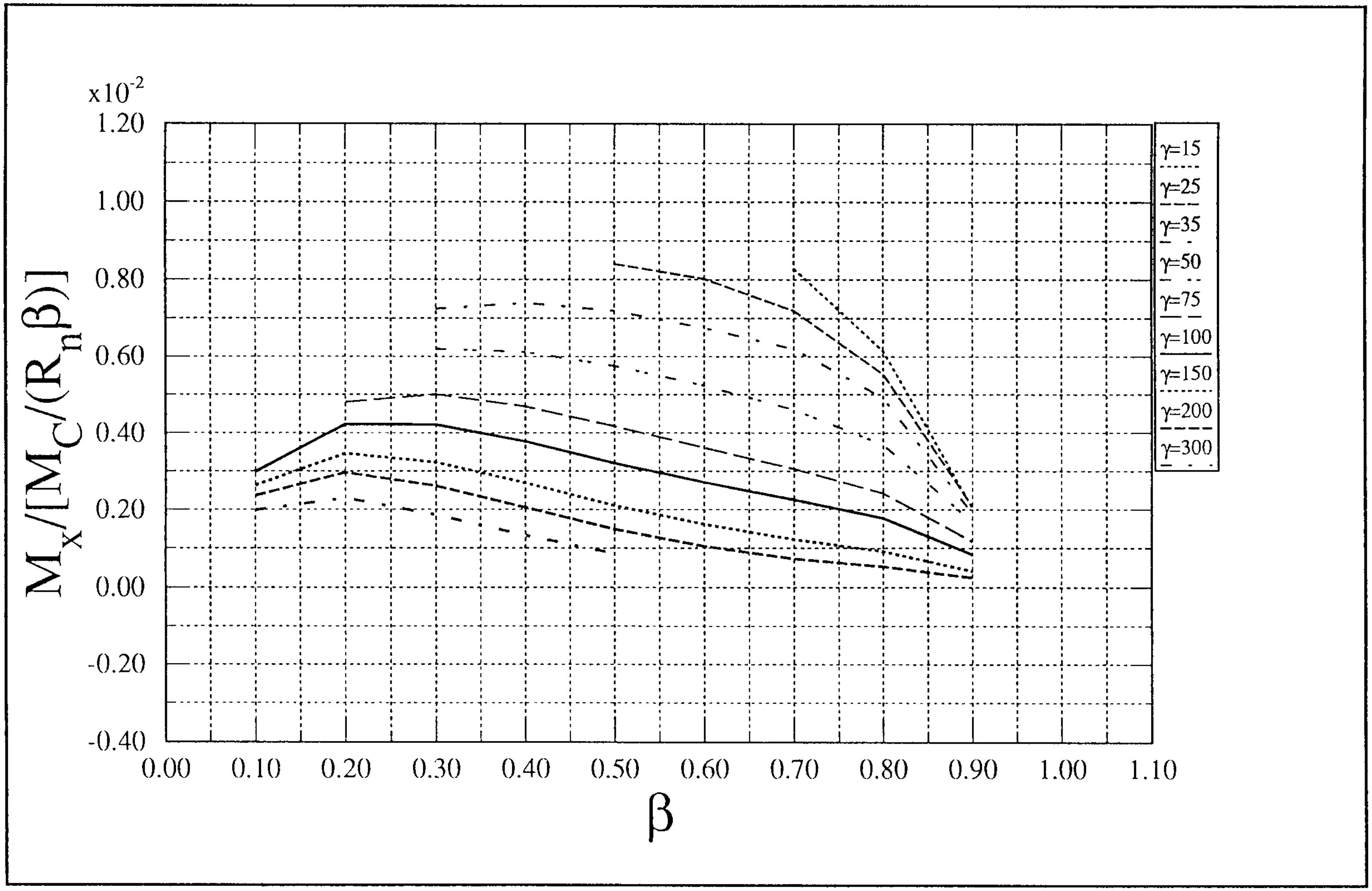


Figure 6Mc. Bending stress factor in longitudinal direction due to circumferential bending moment, Mc, on the nozzle at point C (BYMcNC)

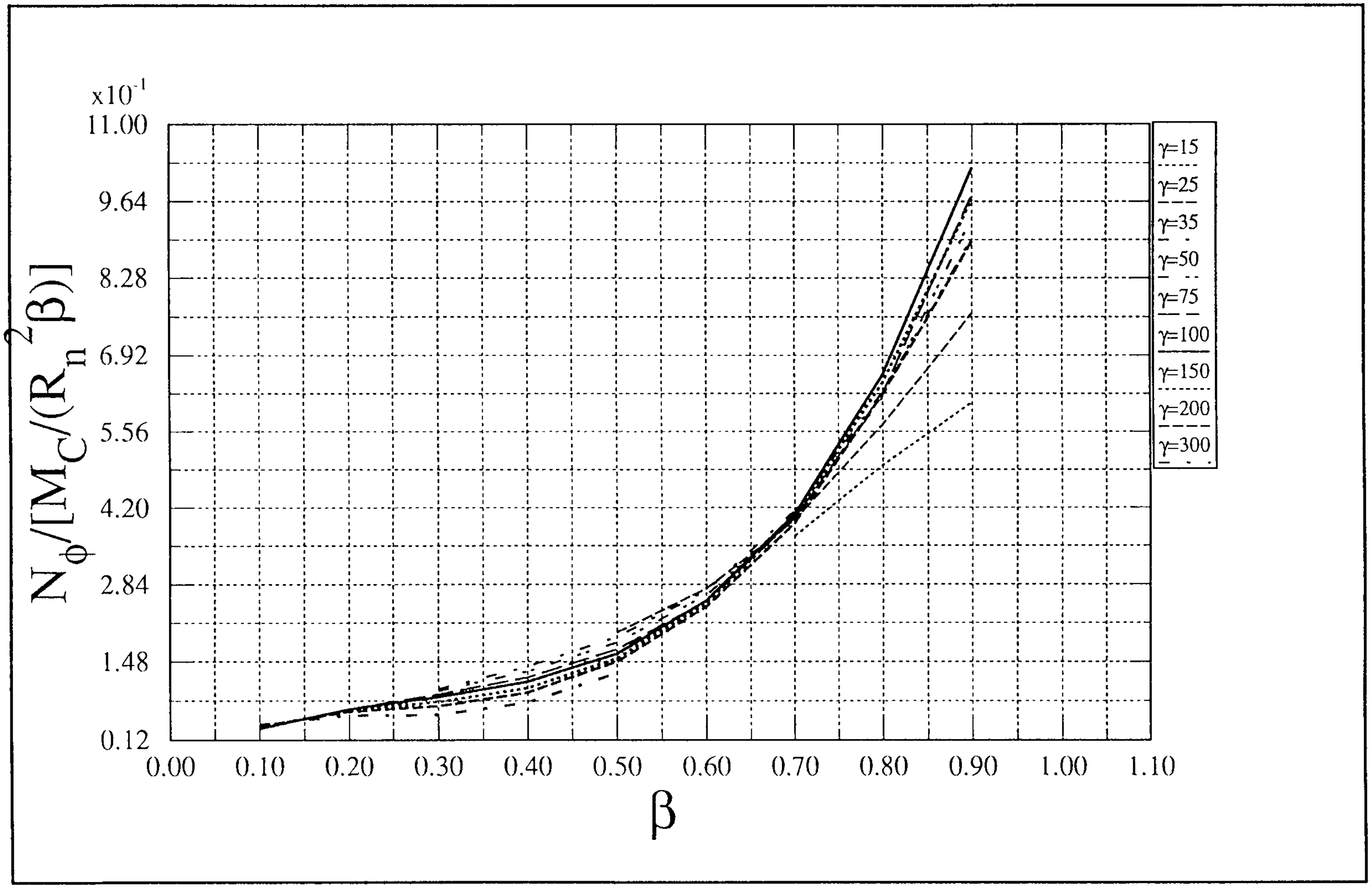


Figure 7Mc. Membrane stress factor in circumferential direction due to circumferential bending moment, Mc, on the nozzle at point C (MZMcNC)

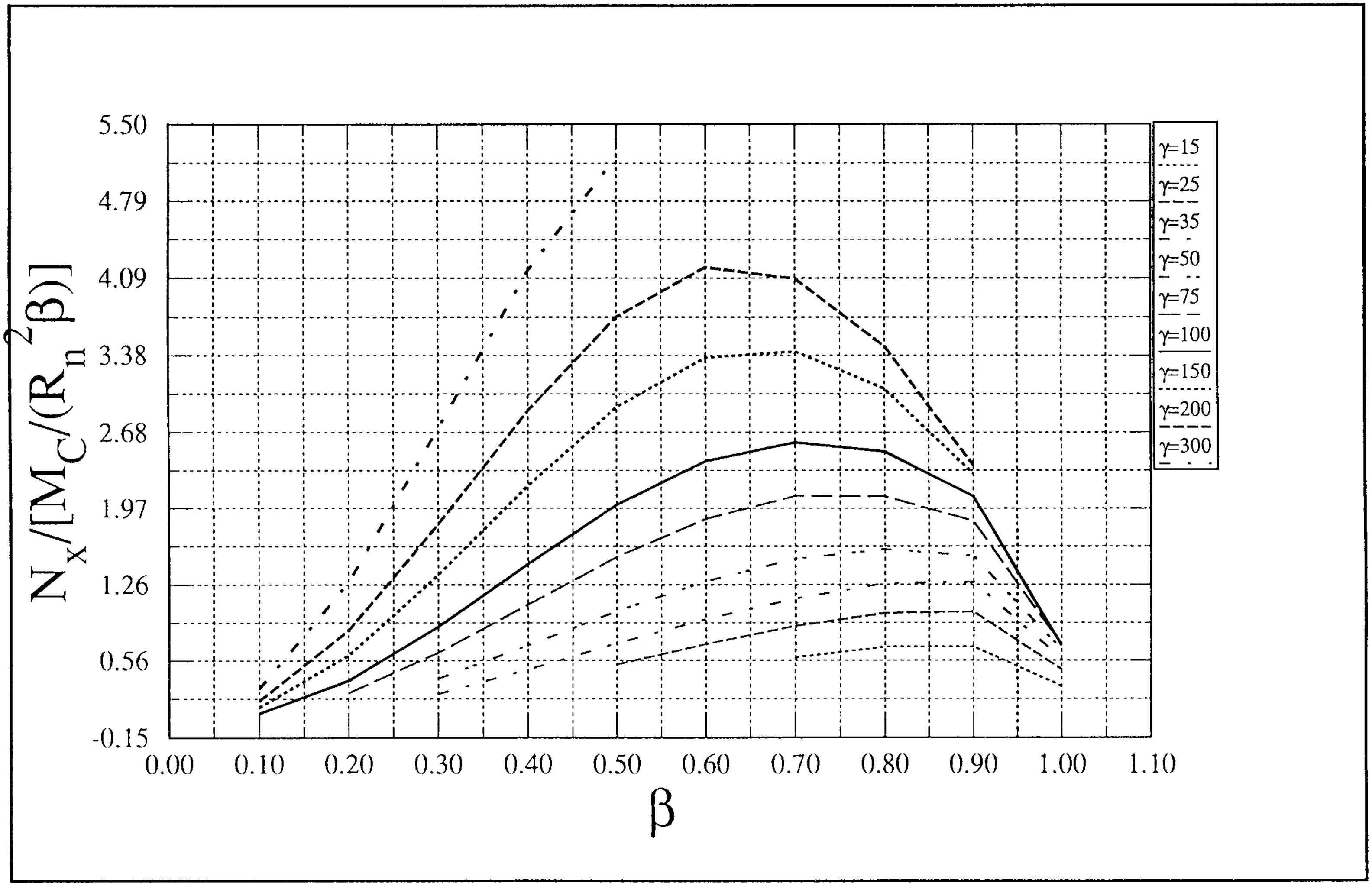


Figure 8Mc. Membrane stress factor in longitudinal direction due to circumferential bending moment, Mc, on the nozzle at point C (MYMcNC)

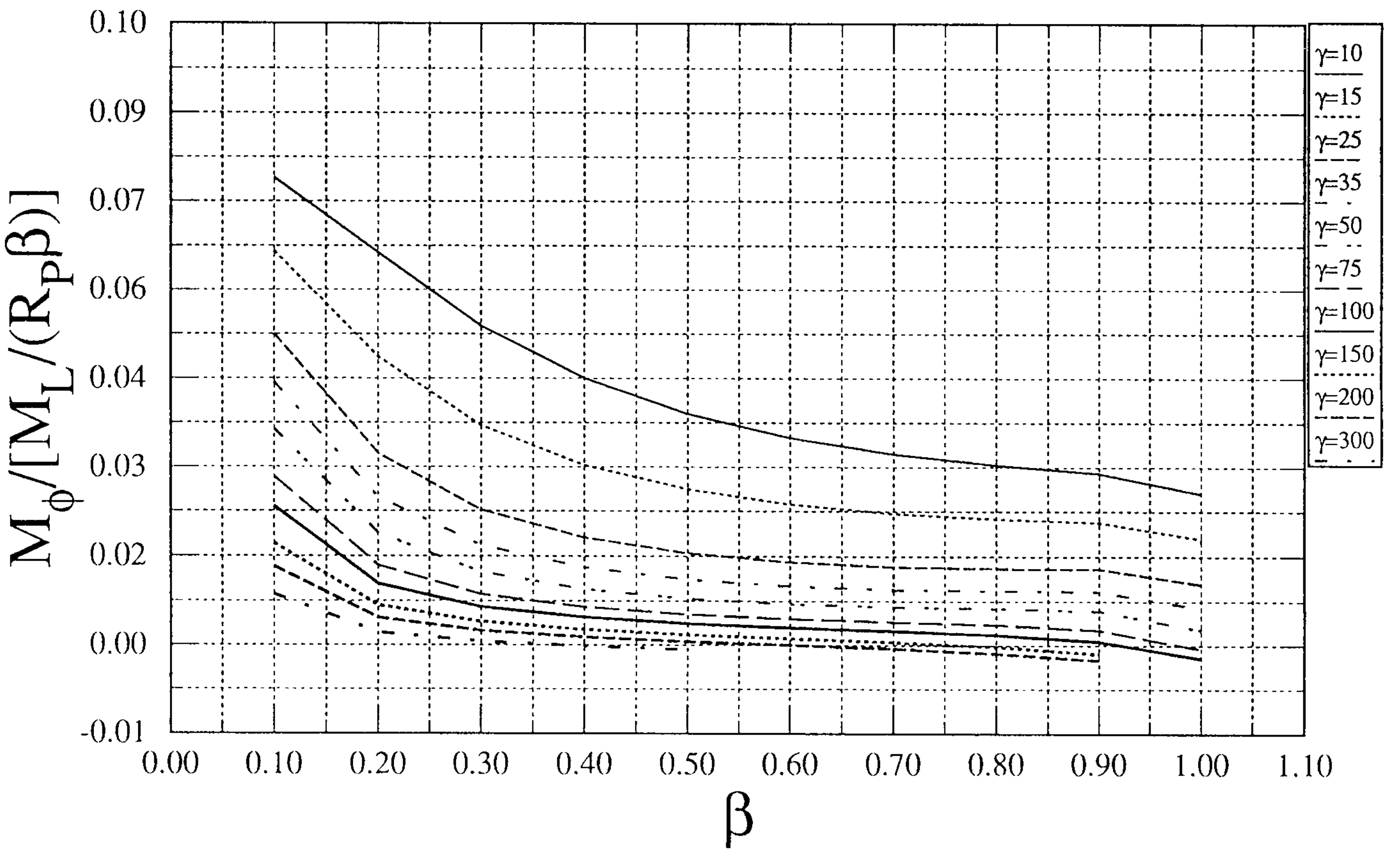


Figure 1M_L. Bending stress factor in circumferential direction due to longitudinal bending moment, M_L, on the pipe at point A (BZM_LPA)

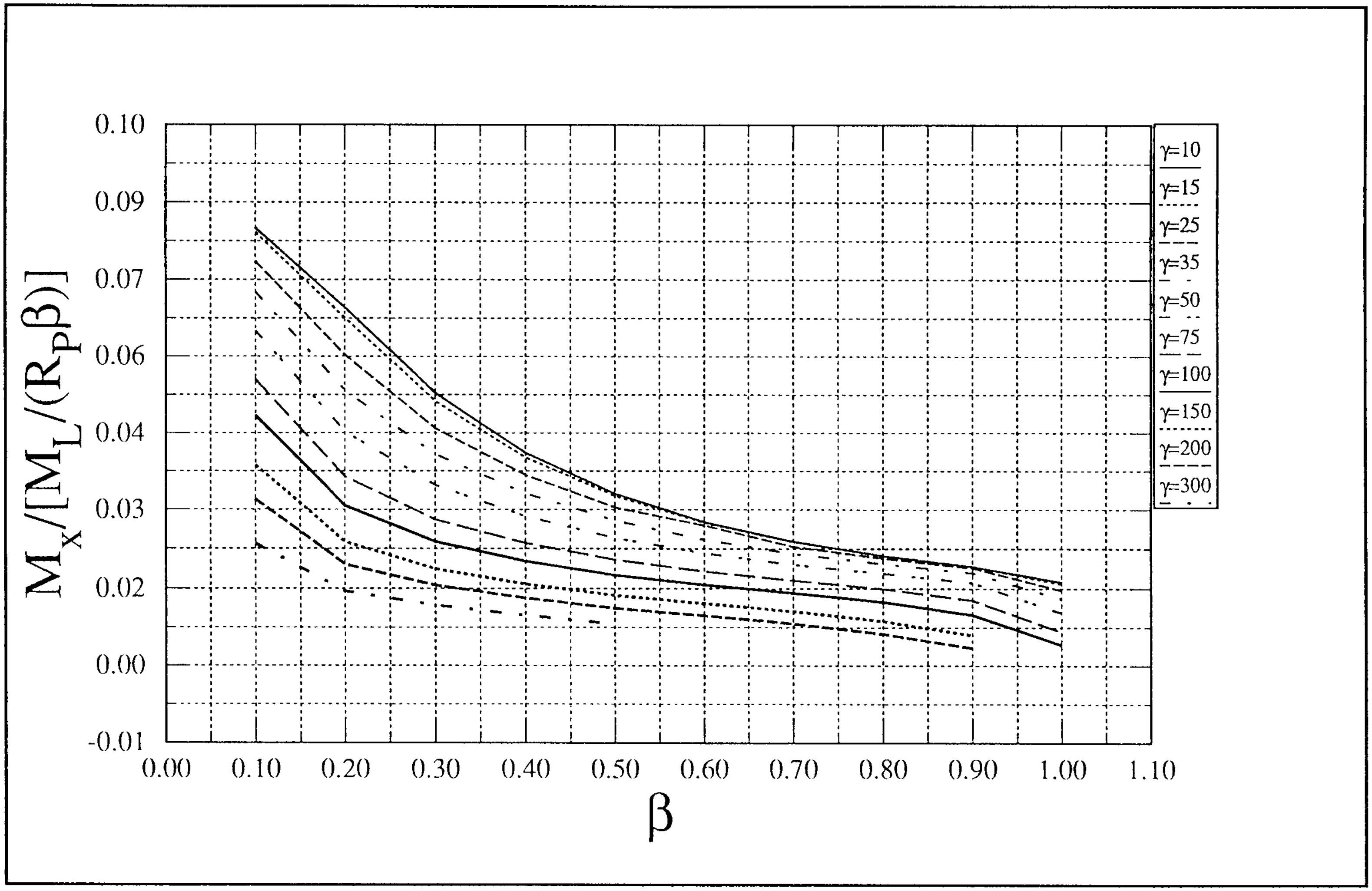


Figure $2M_L$. Bending stress factor in longitudinal direction due to longitudinal bending moment, M_L, on the pipe at point A (BXM_LPA)

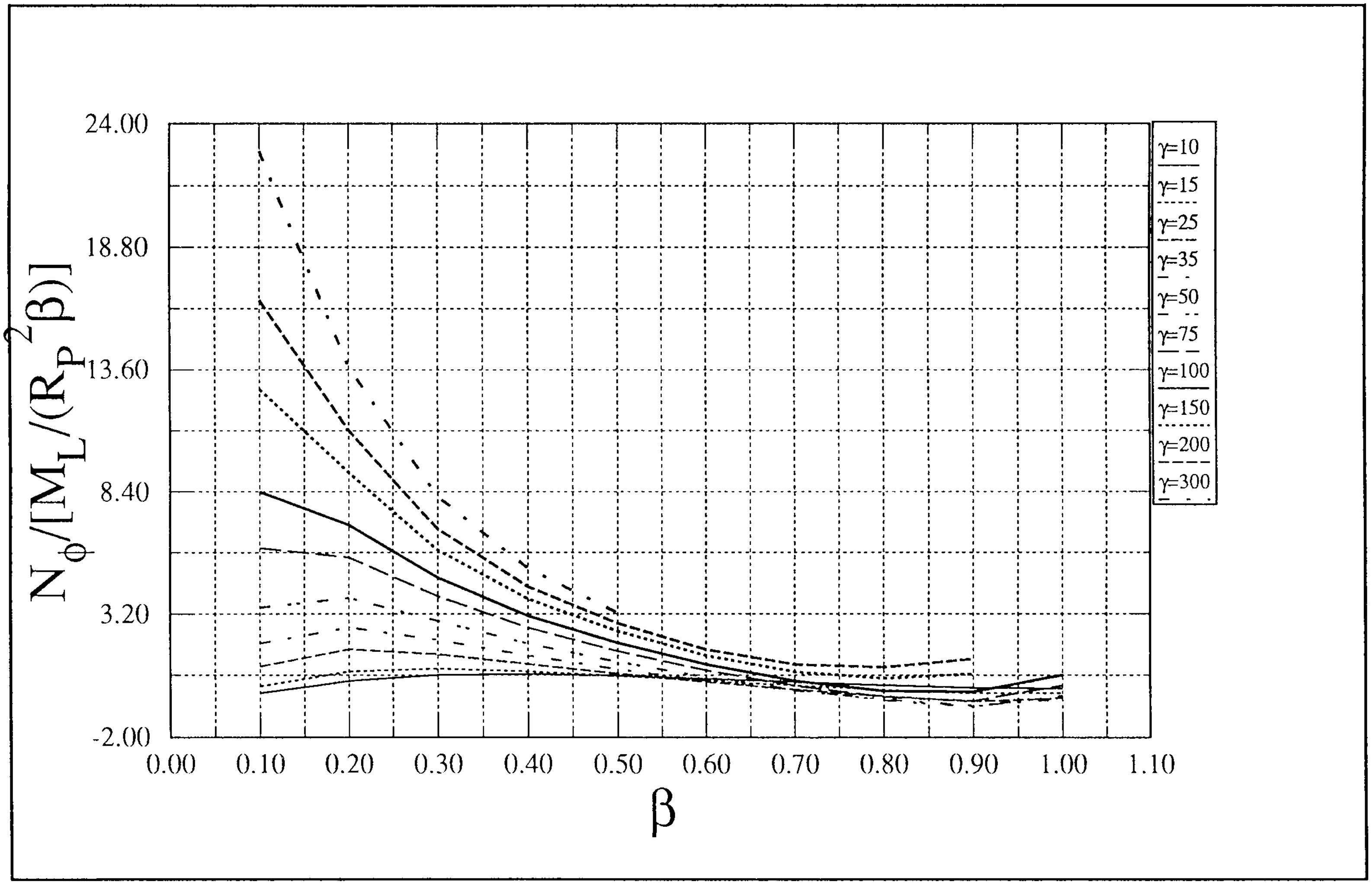


Figure 3M_L. Membrane stress factor in circumferential direction due to longitudinal bending moment, M_L, on the pipe at point A (MZM_LPA)

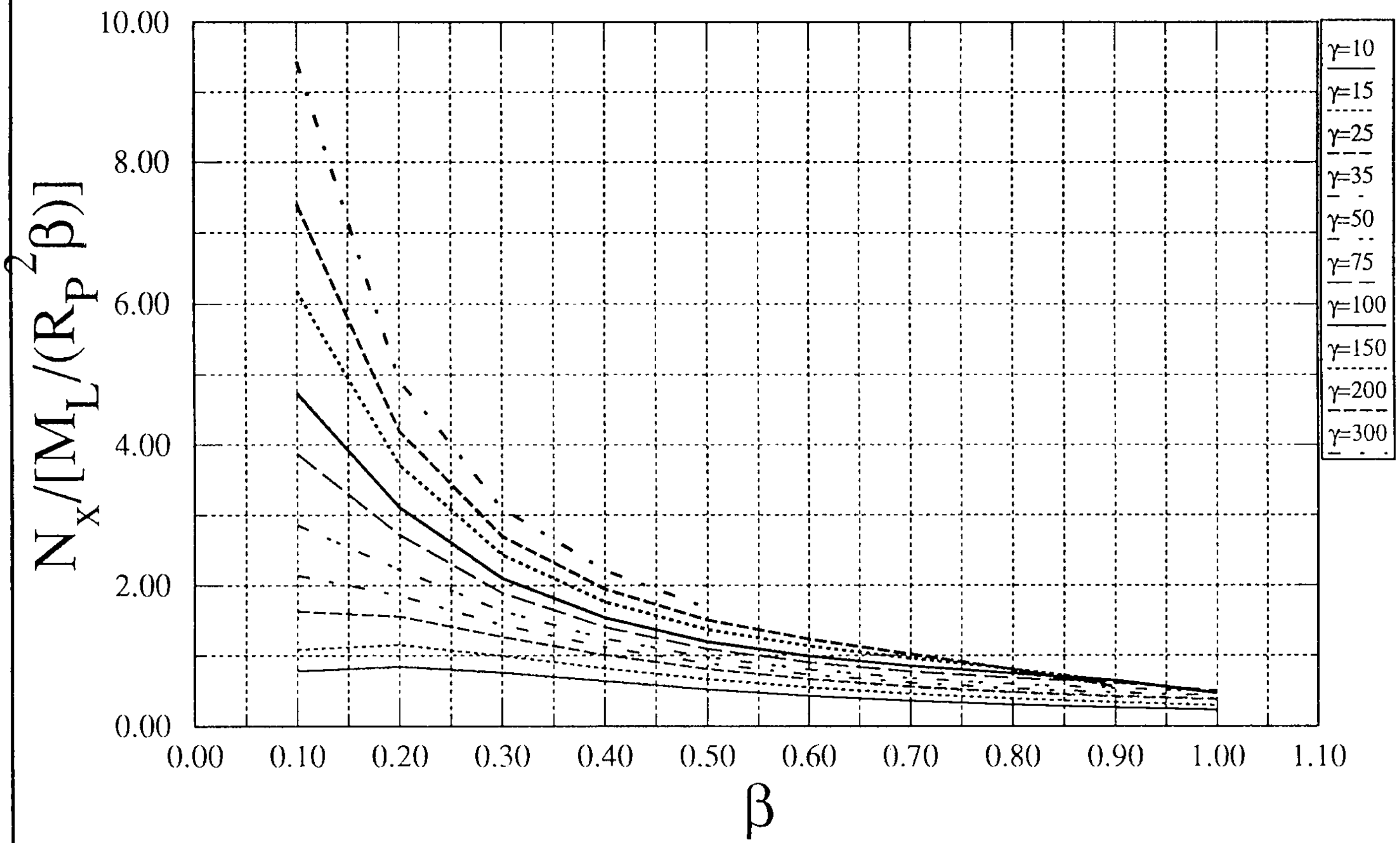


Figure 4M_L. Membrane stress factor in longitudinal direction due to longitudinal bending moment, M_L, on the pipe at point A (MXM_LPA)

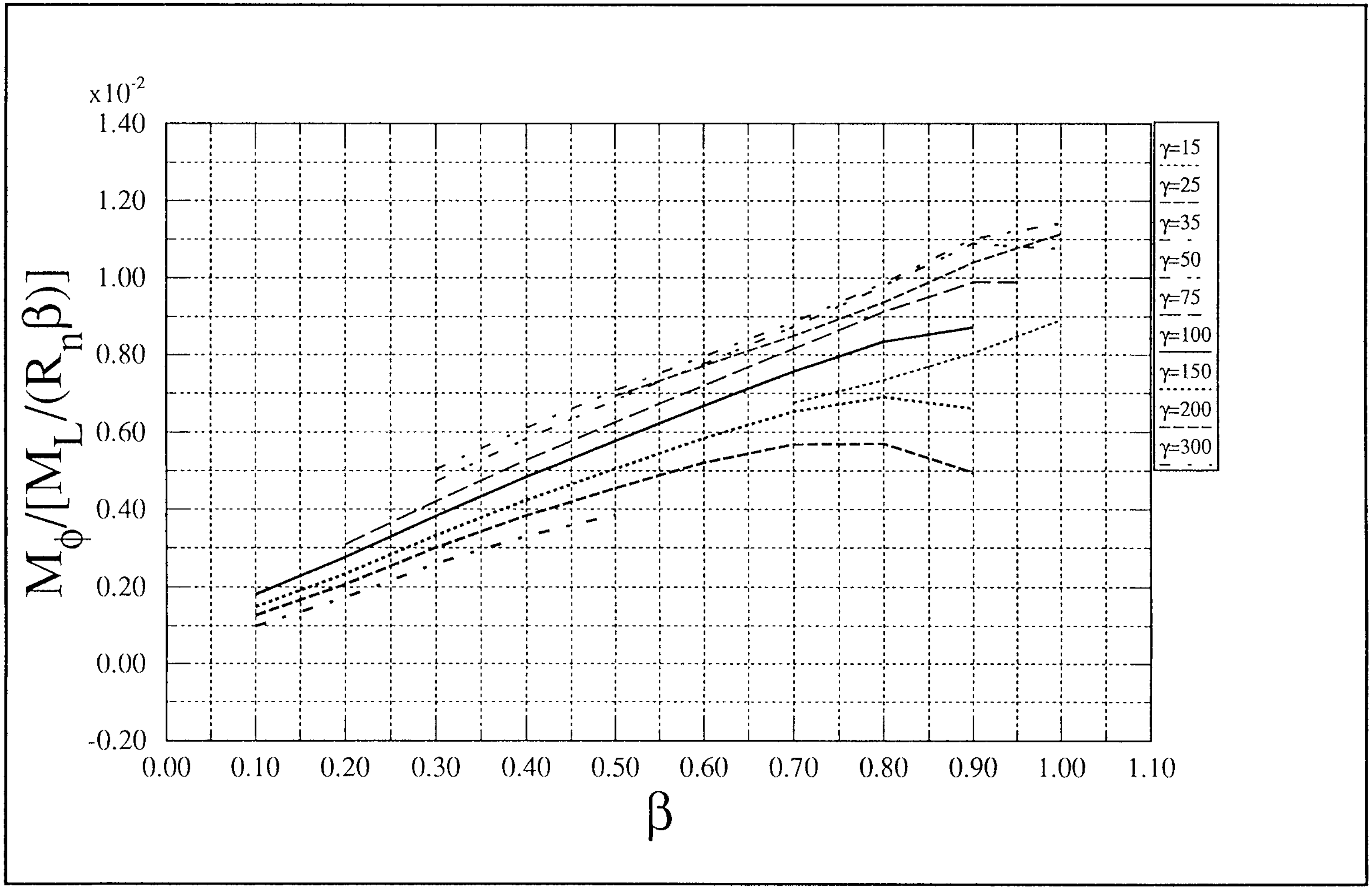


Figure $5M_L$. Bending stress factor in circumferential direction due to longitudinal bending moment, M_L, on the nozzle at point A (BZM_LNA)

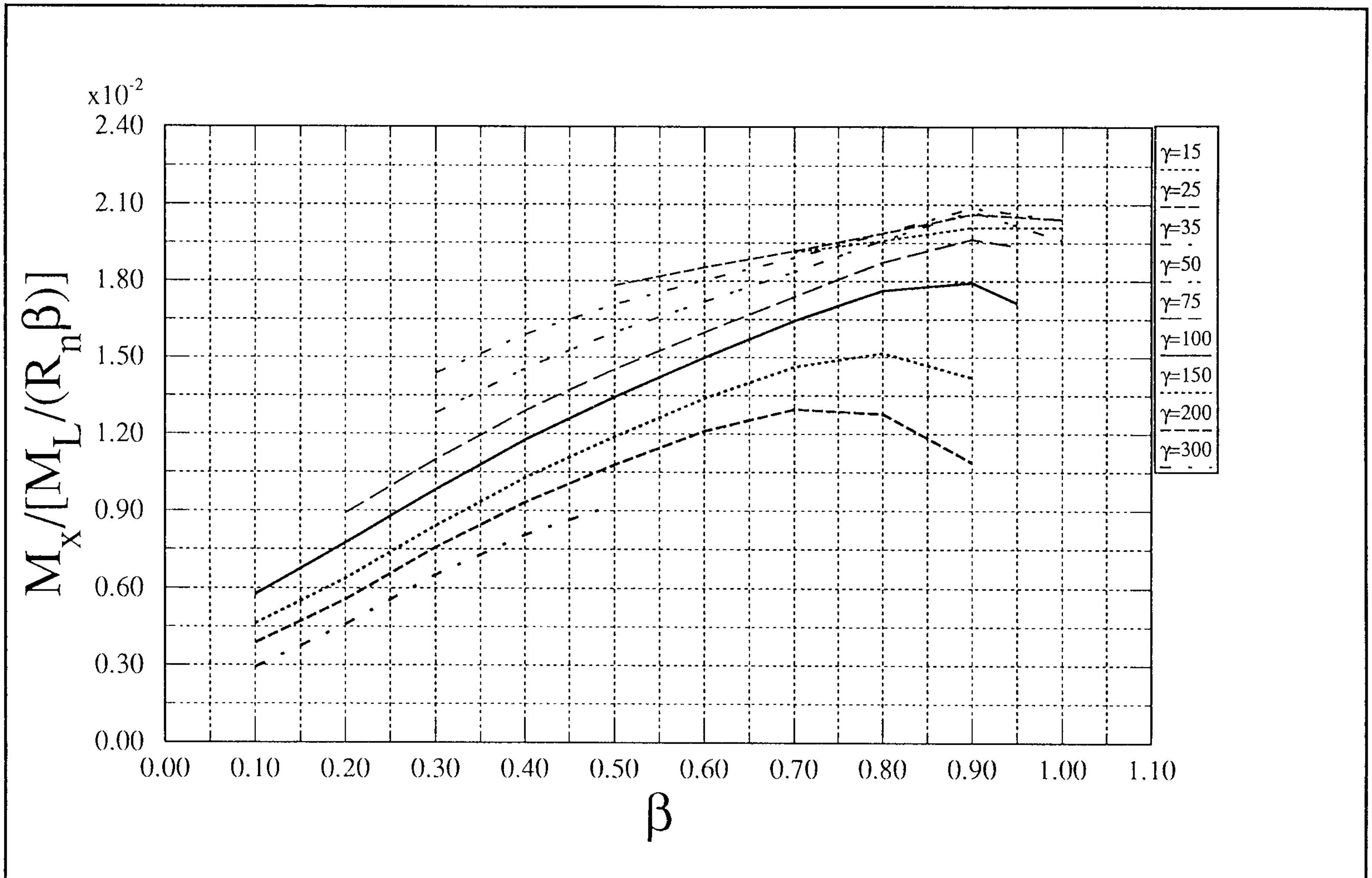


Figure $6M_L$. Bending stress factor in longitudinal direction due to longitudinal bending moment, M_L, on the nozzle at point A (BYM_LNA)

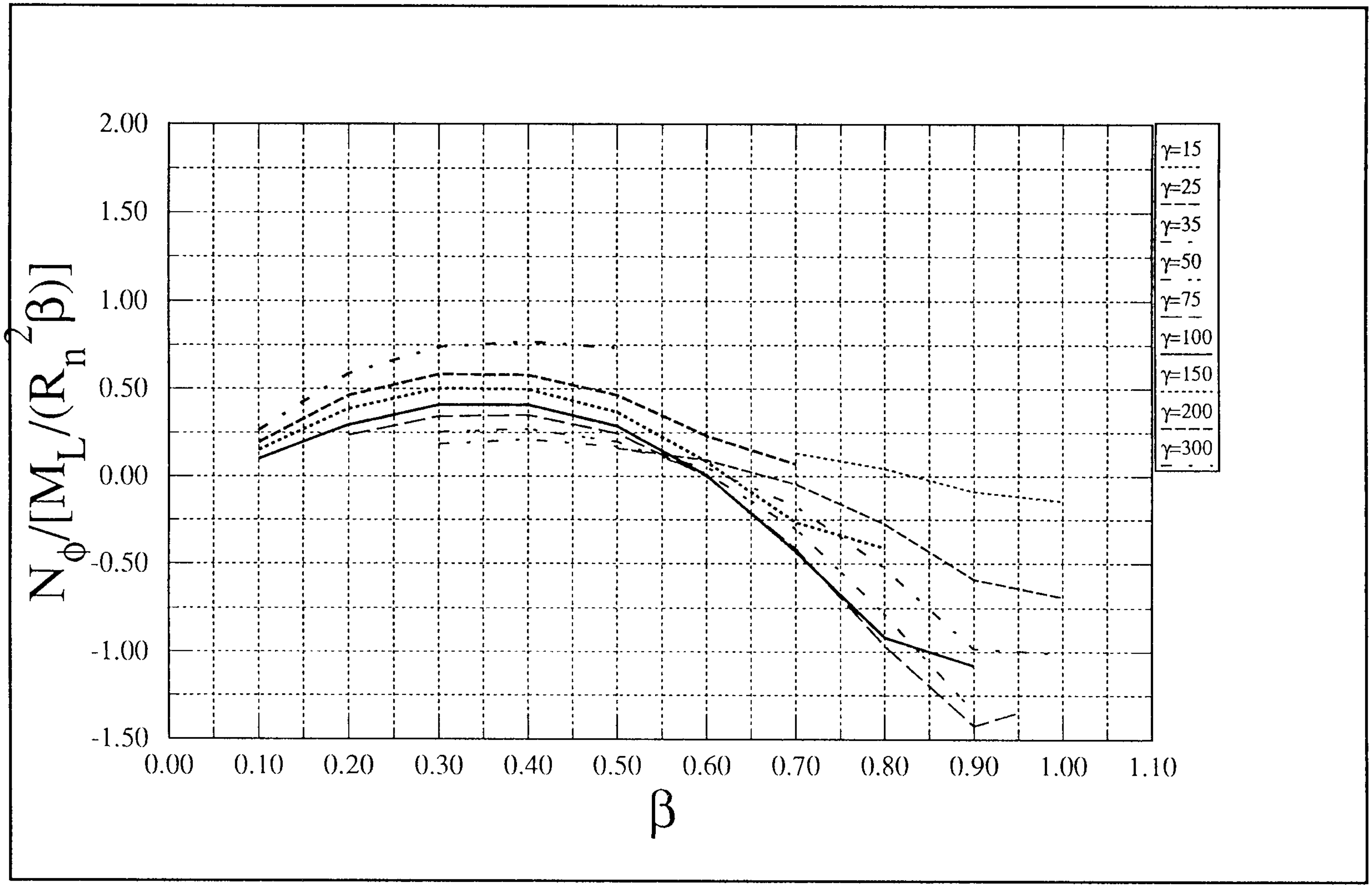


Figure 7M_L. Membrane stress factor in circumferential direction due to longitudinal bending moment, M_L, on the nozzle at point A (MZM_LNA)

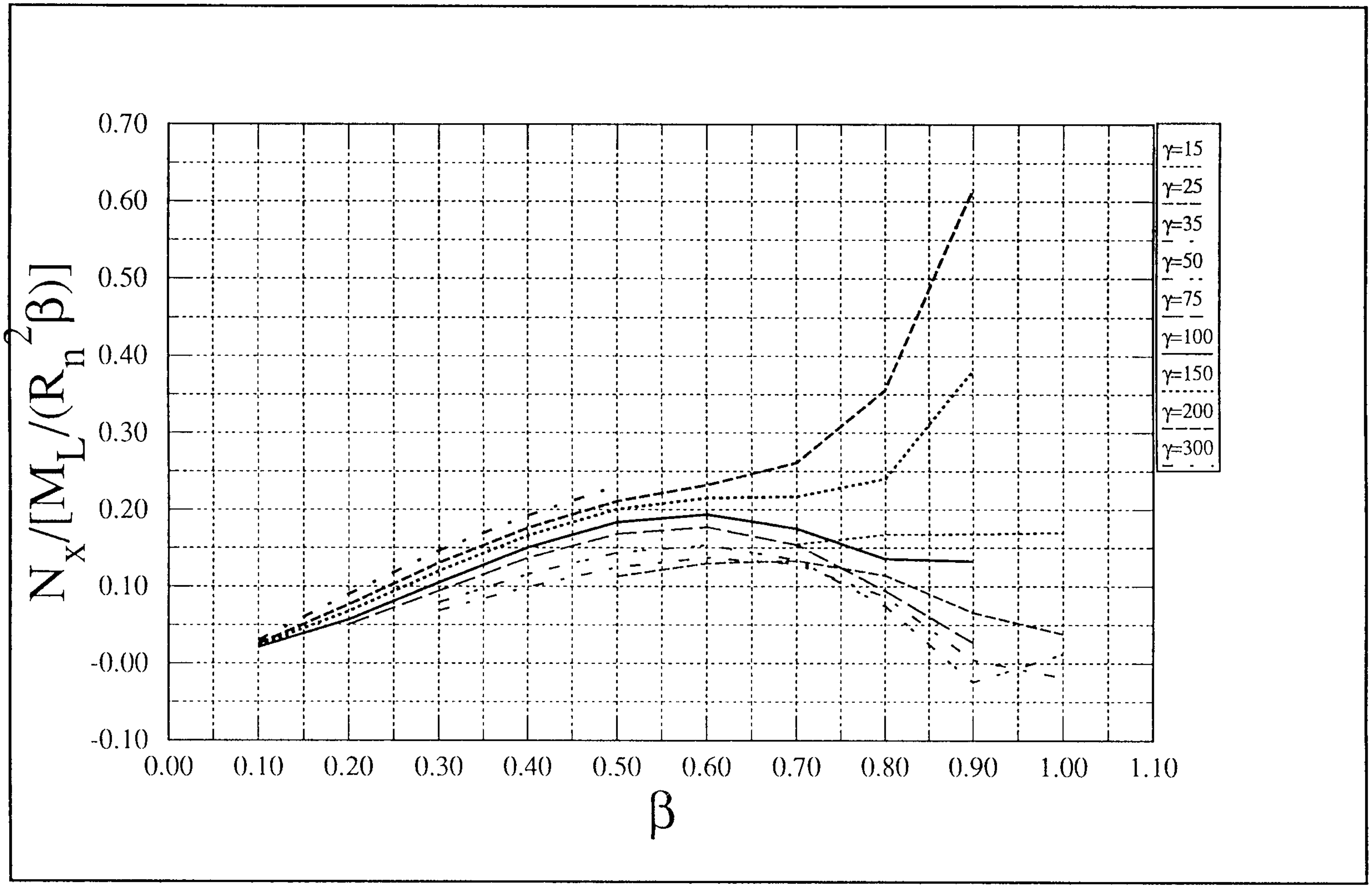


Figure $8M_L$. Membrane stress factor in longitudinal direction due to longitudinal bending moment, M_L, on the nozzle at point A (MYM_LNA)

APPENDIX B. ANSYS INPUT PROGRAMS

1. ANSYS PROGRAM FOR RADIAL LOAD P (BETA = 0.1-0.5)

```
/PREP7
KAN,0
/TITLE  BETA=0.1  GAMMA=25   T=t=0.2
/COM RADIAL LOADING CIRCUMFERENTIAL DIRECTION
/COM BETA=0.1  GAMMA=25    T=t=0.2
/SHOW
*SET,PRSS,0
*SET,PLBS,-1000
*SET,BETA,0.1
*SET,GAMA,25
*SET,THNP,0.2
*SET,THNT,0.2
*SET,PLB1,PLBS*0.0052083
*SET,PLB2,PLB1*2
*SET,RPIP,THNP*GAMA
*SET,RTRU,BETA*RPIP
*SET,LENT,RPIP*0.1
*SET,LORT,RPIP*4
*SET,ANG,ACOS(BETA)
*SET,THED,(ANG-0.5236)*57.296
*SET,MIDD,(THED-90)/2
*SET,RPME,RPIP+LENT
*SET,MMEE,(2.10-ANG)
*SET,MECE,MMEE*RPIP
ET,1,63,,,,,,1
EX,1,30E6
NUXY,1,0.3
ET,2,63,,,,,2
EX,2,30E6
```

```
NUXY,2,0.3
R,1,THNP
R,2,THNT
N,1 $,2,1 $,3,,,1
CS,11,1,1,3,2
/VIEW,,1,1,1
CSYS,11
K,1,RTRU,90,RPME
K,2,RTRU,,RPME
K,3,RTRU,90,1
K,4,RTRU,,RPIP
KMOVE,3,11,RTRU,90,999,1,RPIP,999,0
KMOVE,4,11,RTRU,0,RPIP,1,RPIP,90,RTRU
L,1,3,4,0.3
L,2,4,4,0.3
K,5,RTRU,45,RPME
K,6,RTRU,45,1
KMOVE,6,11,RTRU,45,999,1,RPIP,999,999
L,1,5,12
L,5,2,12
L,4,6,12
L,6,3,12
L,5,6,4,0.3
TYPE,1
REAL,2
A,1,5,6,3
A,5,2,4,6
AMESH,ALL
CSYS,1
K,7,RPIP,90,MECE
K,8,RPIP,THED,MECE
K,9,RPIP,THED
```

```
K,10,RPIP,-90,
K,11,RPIP,-90,MECE
K,12,RPIP,-90,LORT
K,13,RPIP,THED,LORT
K,14,RPIP,90,LORT
K,15,RPIP,MIDD
K,16,RPIP,MIDD,MECE
K,17,RPIP,MIDD,LORT
L,3,9,12,1.5
L,6,8,12,1.5
L,4,7,12,1.5
REAL,1
TYPE,1
L,8,9,12
L,7,8,12
A,3,6,8,9
A,6,4,7,8
TYPE,1
L,8,16,6
L,16,15,12
L,15,9,6
L,16,11,6
L,11,10,12
L,10,15,6
A,9,8,16,15
A,15,16,11,10
L,7,14,16
L,14,13,12
L,13,8,16
A,8,7,14,13
L,13,17,6
L,17,16,16
```

```
A,8,13,17,16
L,17,12,6
L,12,11,16
A,16,17,12,11
AMESH,ALL
CSYS,0
SYMBC,0,1,0,0.005
SYMBC,0,3,0,0.005
MERGE,0.001
NALL
EALL
F,6,FY,PLB2,,16,1
F,70,FY,PLB2,,80,1
F,4,FY,PLB1
F,69,FY,PLB1
F,5,FY,PLB2
NSEL,Z,LORT
D,ALL,ALL
NALL
EALL
/VIEW,,1,1,1
KNUM,1
KPLOT
/VIEW,,1,1,1
WFRONT
WSTART,ALL
WAVES
APLOT,ALL
/PBC,FORCE,1
/PBC,TDIS,1
/PBC,RDIS,1
/PBC,PRES,1
```

```
NPLOT
EPLOT
ITER,1,1,1
AFWRITE,,1
FINISH
/EXEC
/INPUT,27
FINISH
/POST1
/OUTPUT,35
/TITLE CASE-1 1/4 MODEL PIPE-NOZZLE RADIAL FORCE
/COM RADIAL FORCE
/COM BETA=0.1  GAMMA=25    t=T=0.2
/AUTO
STORE,STRES,DISP
/NOPR
/NOLIST
STRESS,SXCT,63,9
STRESS,SYCT,63,10
STRESS,SXYT,63,11
STRESS,SXCM,63,13
STRESS,SYCM,63,14
STRESS,SXYM,63,15
STRESS,MXC,63,6
STRESS,MYC,63,7
STRESS,MXYC,63,8
STRESS,NXIT,63,21
STRESS,NYIT,63,22
STRESS,NXIM,63,37
STRESS,NYIM,63,38
STRESS,PXCT,63,129
STRESS,PYCT,63,130
```

```
STRESS,PZCT,63,131
STRESS,PSIT,63,132
STRESS,SGET,63,133
STRESS,PXCM,63,134
STRESS,PYCM,63,135
STRESS,PZCM,63,136
STRESS,PSIM,63,137
STRESS,SGEM,63,138
STRESS,PSST,63,151
STRESS,PSSB,63,152
SET
NSEL,NODE,81
ENODE
NASEL,NODE,21
ENODE
PRELEM
PRSTRS,SXCT,SYCT,SXCM,SYCM
NELEM
NASEL,NODE,22,32,1
NASEL,NODE,81,95,1
NASEL,NODE,17
ENODE
NSORT,SY,,,6
NUSORT
ESORT,SYCT,,,20
NUSORT
NSORT,DISP,,,10
AVPRIN
NALL
EALL
/VIEW,,1,1,1
PLNSTR,SIGE,SZ
```

```
PLNSTR,SIGE,SX
PLNSTR,SX
PLNSTR,SY
SET,1,1
SAVE
FINISH
```

2. ANSYS PROGRAM FOR RADIAL LOAD P (BETA = 0.6-1.0)

```
/PREP7
KAN,0
/TITLE  Beta=0.6   Gamma=25   T=t=0.2
/COM RADIAL LOADING CIRCUMFERENTIAL DIRECTION
/SHOW
*SET,PRSS,0
*SET,PLBS,-1000
*SET,BETA,0.6
*SET,GAMA,25
*SET,THNP,0.2
*SET,THNT,0.2
*SET,PLB1,PLBS*0.0052083
*SET,PLB2,PLB1*2
*SET,RPIP,THNP*GAMA
*SET,RTRU,BETA*RPIP
*SET,LENT,RPIP*0.1
*SET,LORT,RPIP*4
*SET,ANG,ACOS(BETA)
*SET,THED,(ANG-0.5236)*57.296
*SET,MIDD,(THED-90)/2
*SET,RPME,RPIP+LENT
*SET,MMEE,(2.10-ANG)
*SET,MECE,MMEE*RPIP
```

```
ET,1,63,,,,,,,1
EX,1,30E6
NUXY,1,0.3
ET,2,63,,,,,2
EX,2,30E6
NUXY,2,0.3
R,1,THNP
R,2,THNT
N,1 $,2,1 $,3,,,1
CS,11,1,1,3,2
NDELE,1,3,1
/WIND,1,-1,-0.5,-1,-0.5
/VIEW,,1,1,1
/WIND,4,-0.5,1,-0.5,1
/FOCUS,4,5,5,5
/VIEW,4,4,4,3
/TYPE,4,3
/DIST,4,1*BETA
CSYS,11
K,1,RTRU,90,RPME
K,2,RTRU,,RPME
K,3,RTRU,90,1
K,4,RTRU,,RPIP
KMOVE,3,11,RTRU,90,999,1,RPIP,999,0
KMOVE,4,11,RTRU,0,RPIP,1,RPIP,90,RTRU
L,1,3,4,0.3
L,2,4,4,0.3
K,5,RTRU,45,RPME
K,6,RTRU,45,1
KMOVE,6,11,RTRU,45,999,1,RPIP,999,999
L,1,5,12
L,5,2,12
```

```
L,4,6,12
L,6,3,12
L,5,6,4,0.3
TYPE,1
REAL,2
A,1,5,6,3
A,5,2,4,6
AMESH,ALL
CSYS,1
K,7,RPIP,90,MECE
K,8,RPIP,30,MECE
K,9,RPIP,THED
K,10,RPIP,-90,
K,11,RPIP,-90,MECE
K,12,RPIP,-90,LORT
K,13,RPIP,30,LORT
K,14,RPIP,90,LORT
K,15,RPIP,MIDD
K,16,RPIP,-30,MECE
K,17,RPIP,-30,LORT
L,3,9,12,1.5
L,6,8,12,1.5
L,4,7,12,1.5
REAL,1
TYPE,1
L,8,9,12
L,7,8,12
A,3,6,8,9
A,6,4,7,8
TYPE,1
L,8,16,6
L,16,15,12
```

```
L,15,9,6
L,16,11,6
L,11,10,12
L,10,15,6
A,9,8,16,15
A,15,16,11,10
L,7,14,16
L,14,13,12
L,13,8,16
A,8,7,14,13
L,13,17,6
L,17,16,16
A,8,13,17,16
L,17,12,6
L,12,11,16
A,16,17,12,11
AMESH,ALL
CSYS,0
SYMBC,0,1,0,0.005
SYMBC,0,3,0,0.005
MERGE,0.001
NALL
EALL
F,6,FY,PLB2,,16,1
F,70,FY,PLB2,,80,1
F,4,FY,PLB1
F,69,FY,PLB1
F,5,FY,PLB2
NSEL,Z,LORT
D,ALL,ALL
NALL
EALL
```

```
/VIEW,,1,1,1
KNUM,1
KPLOT
/VIEW,,1,1,1
WFRONT
WSTART,ALL
WAVES
APLOT,ALL
/PNUM,NODE,1  $NPLOT,ALL
/PNUM,ELEM,1  $EPLOT,ALL
/PNUM,AREA,1  $APLOT,ALL
/PBC,FORCE,1
/PBC,TDIS,1
/PBC,RDIS,1
/PBC,PRES,1
NPLOT
EPLOT
ITER,1,1,1
AFWRITE,,1
FINISH
/EXEC
/INPUT,27
FINISH
/POST1
/OUTPUT,35
/TITLE CASE-1 1/4 MODEL PIPE-NOZZLE RADIAL FORCE
/COM RADIAL FORCE
/COM BETA=0.6    GAMMA=25    t=T=0.2
/AUTO
STORE,STRES,DISP
/NOPR
/NOLIST
```

```
STRESS,SXCT,63,9
STRESS,SYCT,63,10
STRESS,SXYT,63,11
STRESS,SXCM,63,13
STRESS,SYCM,63,14
STRESS,SXYM,63,15
STRESS,MXC,63,6
STRESS,MYC,63,7
STRESS,MXYC,63,8
STRESS,NXIT,63,21
STRESS,NYIT,63,22
STRESS,NXIM,63,37
STRESS,NYIM,63,38
STRESS,PXCT,63,129
STRESS,PYCT,63,130
STRESS,PZCT,63,131
STRESS,PSIT,63,132
STRESS,SGET,63,133
STRESS,PXCM,63,134
STRESS,PYCM,63,135
STRESS,PZCM,63,136
STRESS,PSIM,63,137
STRESS,SGEM,63,138
STRESS,PSST,63,151
STRESS,PSSB,63,152
SET
NSEL,NODE,81
ENODE
NASEL,NODE,21
ENODE
PRELEM
PRSTRS,SXCT,SYCT,SXCM,SYCM
```

```
NELEM
NASEL,NODE,22,32,1
NASEL,NODE,81,95,1
NASEL,NODE,17
ENODE
NSORT,SY,,,6
NUSORT
ESORT,SYCT,,,20
NUSORT
NSORT,DISP,,,10
AVPRIN
NALL
EALL
/VIEW,,1,1,1
PLNSTR,SIGE,SZ
PLNSTR,SIGE,SX
PLNSTR,SX
PLNSTR,SY
SET,1,1
SAVE
FINISH
```

3. ANSYS PROGRAM FOR CIRCUMFERENTIAL MOMENT M_C (BETA = 0.1-0.5)

```
/PREP7
KAN,0
/TITLE BETA=0.1  GAMMA=75   T=t=0.2
/COM  MOMENT LOADING CIRCUMFERENTIAL DIRECTION
/COM BETA=0.1  GAMMA=75, t=0.2 T=0.2
/SHOW
*SET,PRSS,0
*SET,PLBS,-1000
```

```
*SET,PLBS,-1000
*SET,BETA,0.1
*SET,GAMA,75
*SET,THNP,0.2
*SET,THNT,0.2
*SET,PLB1,PLBS*0.0052083
*SET,PLB2,PLB1*2
*SET,RPIP,THNP*GAMA
*SET,RTRU,BETA*RPIP
*SET,LENT,RPIP*0.1
*SET,LORT,RPIP*4
*SET,ANG,ACOS(BETA)
*SET,THED,(ANG-0.5236)*57.296
*SET,MIDD,(THED-90)/2
*SET,RPME,RPIP+LENT
*SET,MMEE,(2.10-ANG)
*SET,MECE,MMEE*RPIP
ET,1,63,,,,,,,1
EX,1,30E6
NUXY,1,0.3
ET,2,63,,,,,2
EX,2,30E6
NUXY,2,0.3
R,1,THNP
R,2,THNT
N,1 $,2,1 $,3,,,1
CS,11,1,1,3,2
NDELE,1,3,1
/WIND,1,-1,-.5,-1,-.5
/VIEW,,1,1,1
/WIND,4,-.5,1,-.5,1
/FOCUS,4,7,7,7
```

```
/VIEW,4,4,4,3
/TYPE,4,3
/DIST,4,10
CSYS,11
K,1,RTRU,90,RPME
K,2,RTRU,,RPME
K,3,RTRU,90,1
K,4,RTRU,,RPIP
KMOVE,3,11,RTRU,90,999,1,RPIP,999,0
KMOVE,4,11,RTRU,0,RPIP,1,RPIP,90,RTRU
L,1,3,4,0.3
L,2,4,4,0.3
K,5,RTRU,45,RPME
K,6,RTRU,45,1
KMOVE,6,11,RTRU,45,999,1,RPIP,999,999
L,1,5,12
L,5,2,12
L,4,6,12
L,6,3,12
L,5,6,4,0.3
TYPE,1
REAL,2
A,1,5,6,3
A,5,2,4,6
AMESH,ALL
CSYS,1
K,7,RPIP,90,MECE
K,8,RPIP,THED,MECE
K,9,RPIP,THED
K,10,RPIP,-90,
K,11,RPIP,-90,MECE
K,12,RPIP,-90,LORT
```

```
K,13,RPIP,THED,LORT
K,14,RPIP,90,LORT
K,15,RPIP,MIDD
K,16,RPIP,MIDD,MECE
K,17,RPIP,MIDD,LORT
L,3,9,12,1.5
L,6,8,12,1.5
L,4,7,12,1.5
REAL,1
TYPE,1
L,8,9,12
L,7,8,12
A,3,6,8,9
A,6,4,7,8
TYPE,1
L,8,16,6
L,16,15,12
L,15,9,6
L,16,11,6
L,11,10,12
L,10,15,6
A,9,8,16,15
A,15,16,11,10
L,7,14,16
L,14,13,12
L,13,8,16
A,8,7,14,13
L,13,17,6
L,17,16,16
A,8,13,17,16
L,17,12,6
L,12,11,16
```

```
A,16,17,12,11
AMESH,ALL
CSYS,0
ASYMBC,0,1,0,0.005
SYMBC,0,3,0,0.005
MERGE,0.001
NALL
EALL
*SET,RY,PLBS/(48*RTRU)
*SET,M1,RY*0.5
*SET,M2,RY*0.997859
*SET,M3,RY*0.991445
*SET,M4,RY*0.98079
*SET,M5,RY*0.965926
*SET,M6,RY*0.94693
*SET,M7,RY*0.92388
*SET,M8,RY*0.896873
*SET,M9,RY*0.86603
*SET,M10,RY*0.83147
*SET,M11,RY*0.79335
*SET,M12,RY*0.75184
*SET,M13,RY*0.70711
*SET,M14,RY*0.659346
*SET,M15,RY*0.608761
*SET,M16,RY*0.55557
*SET,M17,RY*0.5
*SET,M18,RY*0.442289
*SET,M19,RY*0.390731
*SET,M20,RY*0.3214395
*SET,M21,RY*0.258819
*SET,M22,RY*0.19509
*SET,M23,RY*0.13053
```

```
*SET,M24,RY*0.065403
NALL
EALL
F,80,FY,M24
F,79,FY,M23
F,78,FY,M22
F,77,FY,M21
F,76,FY,M20
F,75,FY,M19
F,74,FY,M18
F,73,FY,M17
F,72,FY,M16
F,71,FY,M15
F,70,FY,M14
F,5,FY,M13
F,16,FY,M12
F,15,FY,M11
F,14,FY,M10
F,13,FY,M9
F,12,FY,M8
F,11,FY,M7
F,10,FY,M6
F,9,FY,M5
F,8,FY,M4
F,7,FY,M3
F,6,FY,M2
F,4,FY,M1
NSEL,Z,LORT
D,ALL,ALL
NALL
EALL
/VIEW,,1,1,1
```

```
KNUM,1
KPLOT
/VIEW,,1,1,1
WFRONT
WSTART,ALL
WAVES
APLOT,ALL
/PNUM,NODE,1  $NPLOT,ALL
/PNUM,ELEM,1  $EPLOT,ALL
/PNUM,AREA,1  $APLOT,ALL
/PBC,FORCE,1
/PBC,TDIS,1
/PBC,RDIS,1
/PBC,PRES,1
NPLOT
EPLOT
ITER,1,1,1
AFWRITE
FINISH
/EXEC
/INPUT,27
FINISH
/POST1
/OUTPUT,36
/TITLE CASE-2 1/4 MODEL MOMENT LOAD IN CIRCUMFERENTIAL DIREC-
TION
/COM MOMENT IN CIRCUMFERENTIAL DIRECTION
/COM BETA=0.1   GAMMA=75   t=0.2 T=0.2
/AUTO
STORE,STRES,DISP
/NOPR
/NOLIST
```

```
STRESS,SXCT,63,9
STRESS,SYCT,63,10
STRESS,SXYT,63,11
STRESS,SXCM,63,13
STRESS,SYCM,63,14
STRESS,SXYM,63,15
STRESS,MXC,63,6
STRESS,MYC,63,7
STRESS,MXYC,63,8
STRESS,NXIT,63,21
STRESS,NYIT,63,22
STRESS,NXIM,63,37
STRESS,NYIM,63,38
STRESS,PXCT,63,129
STRESS,PYCT,63,130
STRESS,PZCT,63,131
STRESS,PSIT,63,132
STRESS,SGET,63,133
STRESS,PXCM,63,134
STRESS,PYCM,63,135
STRESS,PZCM,63,136
STRESS,PSIM,63,137
STRESS,SGEM,63,138
STRESS,PSST,63,151
STRESS,PSSB,63,152
SET
NSEL,NODE,81
ENODE
NASEL,NODE,21
ENODE
PRELEM
PRSTRS,SXCT,SYCT,SXCM,SYCM
```

```
NASEL,NODE,22,32,1
NASEL,NODE,81,95,1
NASEL,NODE,17
ENODE
NSORT,SY,,,6
NUSORT
ESORT,SYCT,,,20
NUSORT
NSORT,DISP,,,10
AVPRIN
NALL
EALL
/VIEW,,1,1,1
PLNSTR,SIGE,SZ
PLNSTR,SIGE,SX
PLNSTR,SX
PLNSTR,SY
SET,1,1
SAVE
FINISH
```

3. ANSYS PROGRAM FOR CIRCUMFERENTIAL MOMENT M_C (BETA = 0.6-1.0)

```
/PREP7
KAN,0
/TITLE BETA=0.6   GAMMA=75  T=t=0.2
/COM  MOMENT LOADING CIRCUMFERENTIAL DIRECTION
/COM BETA=0.6    GAMMA=75  t=0.2 T=0.2
/SHOW
*SET,PRSS,0
*SET,PLBS,-1000
*SET,BETA,0.6
```

```
*SET,PLBS,-1000
*SET,BETA,0.6
*SET,GAMA,75
*SET,THNP,0.2
*SET,THNT,0.2
*SET,PLB1,PLBS*0.0052083
*SET,PLB2,PLB1*2
*SET,RPIP,THNP*GAMA
*SET,RTRU,BETA*RPIP
*SET,LENT,RPIP*0.1
*SET,LORT,RPIP*4
*SET,ANG,ACOS(BETA)
*SET,THED,(ANG-0.5236)*57.296
*SET,MIDD,(THED-90)/2
*SET,RPME,RPIP+LENT
*SET,MMEE,(2.10-ANG)
*SET,MECE,MMEE*RPIP
ET,1,63,,,,,,1
EX,1,30E6
NUXY,1,0.3
ET,2,63,,,,,2
EX,2,30E6
NUXY,2,0.3
R,1,THNP
R,2,THNT
N,1 $,2,1 $,3,,,1
CS,11,1,1,3,2
NDELE,1,3,1
/WIND,1,-1,-.5,-1,-.5
/VIEW,,1,1,1
/WIND,4,-.5,1,-.5,1
/FOCUS,4,7,7,7
```

```
/VIEW,4,4,4,3
/TYPE,4,3
/DIST,4,10
CSYS,11
K,1,RTRU,90,RPME
K,2,RTRU,,RPME
K,3,RTRU,90,1
K,4,RTRU,,RPIP
KMOVE,3,11,RTRU,90,999,1,RPIP,999,0
KMOVE,4,11,RTRU,0,RPIP,1,RPIP,90,RTRU
L,1,3,4,0.3
L,2,4,4,0.3
K,5,RTRU,45,RPME
K,6,RTRU,45,1
KMOVE,6,11,RTRU,45,999,1,RPIP,999,999
L,1,5,12
L,5,2,12
L,4,6,12
L,6,3,12
L,5,6,4,0.3
TYPE,1
REAL,2
A,1,5,6,3
A,5,2,4,6
AMESH,ALL
CSYS,1
K,7,RPIP,90,MECE
K,8,RPIP,30,MECE
K,9,RPIP,THED
K,10,RPIP,-90,
K,11,RPIP,-90,MECE
K,12,RPIP,-90,LORT
```

```
K,13,RPIP,30,LORT
K,14,RPIP,90,LORT
K,15,RPIP,MIDD
K,16,RPIP,-30,MECE
K,17,RPIP,-30,LORT
L,3,9,12,1.5
L,6,8,12,1.5
L,4,7,12,1.5
REAL,1
TYPE,1
L,8,9,12
L,7,8,12
A,3,6,8,9
A,6,4,7,8
TYPE,1
L,8,16,6
L,16,15,12
L,15,9,6
L,16,11,6
L,11,10,12
L,10,15,6
A,9,8,16,15
A,15,16,11,10
L,7,14,16
L,14,13,12
L,13,8,16
A,8,7,14,13
L,13,17,6
L,17,16,16
A,8,13,17,16
L,17,12,6
L,12,11,16
```

```
A,16,17,12,11
AMESH,ALL
CSYS,0
ASYMBC,0,1,0,0.005
SYMBC,0,3,0,0.005
MERGE,0.001
NALL
EALL
*SET,RY,PLBS/(48*RTRU)
*SET,M1,RY*0.5
*SET,M2,RY*0.997859
*SET,M3,RY*0.991445
*SET,M4,RY*0.98079
*SET,M5,RY*0.965926
*SET,M6,RY*0.94693
*SET,M7,RY*0.92388
*SET,M8,RY*0.896873
*SET,M9,RY*0.86603
*SET,M10,RY*0.83147
*SET,M11,RY*0.79335
*SET,M12,RY*0.75184
*SET,M13,RY*0.70711
*SET,M14,RY*0.659346
*SET,M15,RY*0.608761
*SET,M16,RY*0.55557
*SET,M17,RY*0.5
*SET,M18,RY*0.442289
*SET,M19,RY*0.390731
*SET,M20,RY*0.3214395
*SET,M21,RY*0.258819
*SET,M22,RY*0.19509
*SET,M23,RY*0.13053
```

```
*SET,M24,RY*0.065403
NALL
EALL
F,80,FY,M24
F,79,FY,M23
F,78,FY,M22
F,77,FY,M21
F,76,FY,M20
F,75,FY,M19
F,74,FY,M18
F,73,FY,M17
F,72,FY,M16
F,71,FY,M15
F,70,FY,M14
F,5,FY,M13
F,16,FY,M12
F,15,FY,M11
F,14,FY,M10
F,13,FY,M9
F,12,FY,M8
F,11,FY,M7
F,10,FY,M6
F,9,FY,M5
F,8,FY,M4
F,7,FY,M3
F,6,FY,M2
F,4,FY,M1
NSEL,Z,LORT
D,ALL,ALL
NALL
EALL
/VIEW,,1,1,1
```

```
KNUM,1
KPLOT
/VIEW,,1,1,1
WFRONT
WSTART,ALL
WAVES
APLOT,ALL
/PNUM,NODE,1  $NPLOT,ALL
/PNUM,ELEM,1  $EPLOT,ALL
/PNUM,AREA,1  $APLOT,ALL
/PBC,FORCE,1
/PBC,TDIS,1
/PBC,RDIS,1
/PBC,PRES,1
NPLOT
EPLOT
ITER,1,1,1
AFWRITE
FINISH
/EXEC
/INPUT,27
FINISH
/POST1
/OUTPUT,36
/TITLE CASE-2 1/4 MODEL MOMENT LOAD IN CIRCUMFERENTIAL DIREC-
TION
/COM MOMENT IN CIRCUMFERENTIAL DIRECTION
/COM BETA=0.6   GAMMA=75   t=0.2 T=0.2
/AUTO
STORE,STRES,DISP
/NOPR
/NOLIST
```

```
STRESS,SXCT,63,9
STRESS,SYCT,63,10
STRESS,SXYT,63,11
STRESS,SXCM,63,13
STRESS,SYCM,63,14
STRESS,SXYM,63,15
STRESS,MXC,63,6
STRESS,MYC,63,7
STRESS,MXYC,63,8
STRESS,NXIT,63,21
STRESS,NYIT,63,22
STRESS,NXIM,63,37
STRESS,NYIM,63,38
STRESS,PXCT,63,129
STRESS,PYCT,63,130
STRESS,PZCT,63,131
STRESS,PSIT,63,132
STRESS,SGET,63,133
STRESS,PXCM,63,134
STRESS,PYCM,63,135
STRESS,PZCM,63,136
STRESS,PSIM,63,137
STRESS,SGEM,63,138
STRESS,PSST,63,151
STRESS,PSSB,63,152
SET
NSEL,NODE,81
ENODE
NASEL,NODE,21
ENODE
PRELEM
PRSTRS,SXCT,SYCT,SXCM,SYCM
```

```
NELEM
NASEL,NODE,22,32,1
NASEL,NODE,81,95,1
NASEL,NODE,17
ENODE
NSORT,SY,,,6
NUSORT
ESORT,SYCT,,,20
NUSORT
NSORT,DISP,,,10
AVPRIN
NALL
EALL
/VIEW,,1,1,1
PLNSTR,SIGE,SZ
PLNSTR,SIGE,SX
PLNSTR,SX
PLNSTR,SY
SET,1,1
SAVE
FINISH
```

5. ANSYS PROGRAM FOR LONGITUDINAL MOMENT M_L (BETA = 0.1-0.5)

```
/PREP7
KAN,0
/TITLE BETA=0.1  GAMMA=75  T=t=0.2
/COM  MOMENT LOADING LONGITUDINAL DIRECTION
/COM BETA=0.1  GAMMA=75, t=0.2 T=0.2
/SHOW
*SET,PRSS,0
*SET,PLBS,-1000
```

```
*SET,BETA,0.1
*SET,GAMA,75
*SET,THNP,0.2
*SET,THNT,0.2
*SET,PLB1,PLBS*0.0052083
*SET,PLB2,PLB1*2
*SET,RPIP,THNP*GAMA
*SET,RTRU,BETA*RPIP
*SET,LENT,RPIP*0.1
*SET,LORT,RPIP*4
*SET,ANG,ACOS(BETA)
*SET,THED,(ANG-0.5236)*57.296
*SET,MIDD,(THED-90)/2
*SET,RPME,RPIP+LENT
*SET,MMEE,(2.10-ANG)
*SET,MECE,MMEE*RPIP
ET,1,63,,,,,,,1
EX,1,30E6
NUXY,1,0.3
ET,2,63,,,,,2
EX,2,30E6
NUXY,2,0.3
R,1,THNP
R,2,THNT
N,1 $,2,1 $,3,,,1
CS,11,1,1,3,2
NDELE,1,3,1
/WIND,1,-1,-.5,-1,-.5
/VIEW,,1,1,1
/WIND,4,-.5,1,-.5,1
/FOCUS,4,7,7,7
/VIEW,4,4,4,3
```

```
/TYPE,4,3
/DIST,4,10
CSYS,11
K,1,RTRU,90,RPME
K,2,RTRU,,RPME
K,3,RTRU,90,1
K,4,RTRU,,RPIP
KMOVE,3,11,RTRU,90,999,1,RPIP,999,0
KMOVE,4,11,RTRU,0,RPIP,1,RPIP,90,RTRU
L,1,3,4,0.3
L,2,4,4,0.3
K,5,RTRU,45,RPME
K,6,RTRU,45,1
KMOVE,6,11,RTRU,45,999,1,RPIP,999,999
L,1,5,12
L,5,2,12
L,4,6,12
L,6,3,12
L,5,6,4,0.3
TYPE,1
REAL,2
A,1,5,6,3
A,5,2,4,6
AMESH,ALL
CSYS,1
K,7,RPIP,90,MECE
K,8,RPIP,THED,MECE
K,9,RPIP,THED
K,10,RPIP,-90,
K,11,RPIP,-90,MECE
K,12,RPIP,-90,LORT
K,13,RPIP,THED,LORT
```

```
K,14,RPIP,90,LORT
K,15,RPIP,MIDD
K,16,RPIP,MIDD,MECE
K,17,RPIP,MIDD,LORT
L,3,9,12,1.5
L,6,8,12,1.5
L,4,7,12,1.5
REAL,1
TYPE,1
L,8,9,12
L,7,8,12
A,3,6,8,9
A,6,4,7,8
TYPE,1
L,8,16,6
L,16,15,12
L,15,9,6
L,16,11,6
L,11,10,12
L,10,15,6
A,9,8,16,15
A,15,16,11,10
L,7,14,16
L,14,13,12
L,13,8,16
A,8,7,14,13
L,13,17,6
L,17,16,16
A,8,13,17,16
L,17,12,6
L,12,11,16
A,16,17,12,11
```

```
AMESH,ALL
CSYS,0
SYMBC,0,1,0,0.005
ASYMBC,0,3,0,0.005
MERGE,0.001
NALL
EALL
*SET,RY,PLBS/(48*RTRU)
*SET,M1,RY*0.5
*SET,M2,RY*0.997859
*SET,M3,RY*0.991445
*SET,M4,RY*0.98079
*SET,M5,RY*0.965926
*SET,M6,RY*0.94693
*SET,M7,RY*0.92388
*SET,M8,RY*0.896873
*SET,M9,RY*0.86603
*SET,M10,RY*0.83147
*SET,M11,RY*0.79335
*SET,M12,RY*0.75184
*SET,M13,RY*0.70711
*SET,M14,RY*0.659346
*SET,M15,RY*0.608761
*SET,M16,RY*0.55557
*SET,M17,RY*0.5
*SET,M18,RY*0.442289
*SET,M19,RY*0.390731
*SET,M20,RY*0.3214395
*SET,M21,RY*0.258819
*SET,M22,RY*0.19509
*SET,M23,RY*0.13053
*SET,M24,RY*0.065403
```

```
NALL
EALL
F,69,FY,M1
F,80,FY,M2
F,79,FY,M3
F,78,FY,M4
F,77,FY,M5
F,76,FY,M6
F,75,FY,M7
F,74,FY,M8
F,73,FY,M9
F,72,FY,M10
F,71,FY,M11
F,70,FY,M12
F,5,FY,M13
F,16,FY,M14
F,15,FY,M15
F,14,FY,M16
F,13,FY,M17
F,12,FY,M18
F,11,FY,M19
F,10,FY,M20
F,9,FY,M21
F,8,FY,M22
F,7,FY,M23
F,6,FY,M24
NSEL,Z,LORT
D,ALL,ALL
NALL
EALL
/VIEW,,1,1,1
KNUM,1
```

```
KPLOT
/VIEW,,1,1,1
WFRONT
WSTART,ALL
WAVES
APLOT,ALL
/PNUM,NODE,1  $NPLOT,ALL
/PNUM,ELEM,1  $EPLOT,ALL
/PNUM,AREA,1  $APLOT,ALL
/PBC,FORCE,1
/PBC,TDIS,1
/PBC,RDIS,1
/PBC,PRES,1
NPLOT
EPLOT
ITER,1,1,1
AFWRITE
FINISH
/EXEC
/INPUT,27
FINISH
/POST1
/OUTPUT,36
/TITLE CASE-2 1/4 MODEL MOMENT LOAD IN LONGITUDINAL DIREC-
TION
/COM MOMENT IN LONGITUDINAL DIRECTION
/COM BETA=0.1 GAMMA=75 t=0.2 T=0.2
/AUTO
STORE,STRES,DISP
/NOPR
/NOLIST
STRESS,SXCT,63,9
```

```
STRESS,SYCT,63,10
STRESS,SXYT,63,11
STRESS,SXCM,63,13
STRESS,SYCM,63,14
STRESS,SXYM,63,15
STRESS,MXC,63,6
STRESS,MYC,63,7
STRESS,MXYC,63,8
STRESS,NXIT,63,21
STRESS,NYIT,63,22
STRESS,NXIM,63,37
STRESS,NYIM,63,38
STRESS,PXCT,63,129
STRESS,PYCT,63,130
STRESS,PZCT,63,131
STRESS,PSIT,63,132
STRESS,SGET,63,133
STRESS,PXCM,63,134
STRESS,PYCM,63,135
STRESS,PZCM,63,136
STRESS,PSIM,63,137
STRESS,SGEM,63,138
STRESS,PSST,63,151
STRESS,PSSB,63,152
SET
NSEL,NODE,81
ENODE
NASEL,NODE,21
ENODE
PRELEM
PRSTRS,SXCT,SYCT,SXCM,SYCM
NELEM
```

```
NASEL,NODE,22,32,1
NASEL,NODE,81,95,1
NASEL,NODE,17
ENODE
NSORT,SY,,,6
NUSORT
ESORT,SYCT,,,20
NUSORT
NSORT,DISP,,,10
AVPRIN
NALL
EALL
/VIEW,,1,1,1
PLNSTR,SIGE,SZ
PLNSTR,SIGE,SX
PLNSTR,SX
PLNSTR,SY
SET,1,1
SAVE
FINISH
```

6. ANSYS PROGRAM FOR LONGITUDINAL MOMENT (BETA = 0.6-1.0)

```
/PREP7
KAN,0
/TITLE BETA=0.6  GAMMA=75  T=t=0.2
/COM  MOMENT LOADING LONGITUDINAL DIRECTION
/SHOW
*SET,PRSS,0
*SET,PLBS,-1000
*SET,BETA,0.6
*SET,GAMA,75
```

```
*SET,THNP,0.2
*SET,THNT,0.2
*SET,PLB1,PLBS*0.0052083
*SET,PLB2,PLB1*2
*SET,RPIP,THNP*GAMA
*SET,RTRU,BETA*RPIP
*SET,LENT,RPIP*0.1
*SET,LORT,RPIP*4
*SET,ANG,ACOS(BETA)
*SET,THED,(ANG-0.5236)*57.296
*SET,MIDD,(THED-90)/2
*SET,RPME,RPIP+LENT
*SET,MMEE,(2.10-ANG)
*SET,MECE,MMEE*RPIP
ET,1,63,,,,,,,1
EX,1,30E6
NUXY,1,0.3
ET,2,63,,,,,2
EX,2,30E6
NUXY,2,0.3
R,1,THNP
R,2,THNT
N,1 $,2,1 $,3,,,1
CS,11,1,1,3,2
NDELE,1,3,1
/WIND,1,-1,-.5,-1,-.5
/VIEW,,1,1,1
/WIND,4,-.5,1,-.5,1
/FOCUS,4,7,7,7
/VIEW,4,4,4,3
/TYPE,4,3
/DIST,4,10
```

```
CSYS,11
K,1,RTRU,90,RPME
K,2,RTRU,,RPME
K,3,RTRU,90,1
K,4,RTRU,,RPIP
KMOVE,3,11,RTRU,90,999,1,RPIP,999,0
KMOVE,4,11,RTRU,0,RPIP,1,RPIP,90,RTRU
L,1,3,4,0.3
L,2,4,4,0.3
K,5,RTRU,45,RPME
K,6,RTRU,45,1
KMOVE,6,11,RTRU,45,999,1,RPIP,999,999
L,1,5,12
L,5,2,12
L,4,6,12
L,6,3,12
L,5,6,4,0.3
TYPE,1
REAL,2
A,1,5,6,3
A,5,2,4,6
AMESH,ALL
CSYS,1
K,7,RPIP,90,MECE
K,8,RPIP,30,MECE
K,9,RPIP,THED
K,10,RPIP,-90,
K,11,RPIP,-90,MECE
K,12,RPIP,-90,LORT
K,13,RPIP,30,LORT
K,14,RPIP,90,LORT
K,15,RPIP,MIDD
```

```
K,16,RPIP,-30,MECE
K,17,RPIP,-30,LORT
L,3,9,12,1.5
L,6,8,12,1.5
L,4,7,12,1.5
REAL,1
TYPE,1
L,8,9,12
L,7,8,12
A,3,6,8,9
A,6,4,7,8
TYPE,1
L,8,16,6
L,16,15,12
L,15,9,6
L,16,11,6
L,11,10,12
L,10,15,6
A,9,8,16,15
A,15,16,11,10
L,7,14,16
L,14,13,12
L,13,8,16
A,8,7,14,13
L,13,17,6
L,17,16,16
A,8,13,17,16
L,17,12,6
L,12,11,16
A,16,17,12,11
AMESH,ALL
CSYS,0
```

```
SYMBC,0,1,0,0.005
ASYMBC,0,3,0,0.005
MERGE,0.001
NALL
EALL
*SET,RY,PLBS/(48*RTRU)
*SET,M1,RY*0.5
*SET,M2,RY*0.997859
*SET,M3,RY*0.991445
*SET,M4,RY*0.98079
*SET,M5,RY*0.965926
*SET,M6,RY*0.94693
*SET,M7,RY*0.92388
*SET,M8,RY*0.896873
*SET,M9,RY*0.86603
*SET,M10,RY*0.83147
*SET,M11,RY*0.79335
*SET,M12,RY*0.75184
*SET,M13,RY*0.70711
*SET,M14,RY*0.659346
*SET,M15,RY*0.608761
*SET,M16,RY*0.55557
*SET,M17,RY*0.5
*SET,M18,RY*0.442289
*SET,M19,RY*0.390731
*SET,M20,RY*0.3214395
*SET,M21,RY*0.258819
*SET,M22,RY*0.19509
*SET,M23,RY*0.13053
*SET,M24,RY*0.065403
NALL
EALL
```

```
F,69,FY,M1
F,80,FY,M2
F,79,FY,M3
F,78,FY,M4
F,77,FY,M5
F,76,FY,M6
F,75,FY,M7
F,74,FY,M8
F,73,FY,M9
F,72,FY,M10
F,71,FY,M11
F,70,FY,M12
F,5,FY,M13
F,16,FY,M14
F,15,FY,M15
F,14,FY,M16
F,13,FY,M17
F,12,FY,M18
F,11,FY,M19
F,10,FY,M20
F,9,FY,M21
F,8,FY,M22
F,7,FY,M23
F,6,FY,M24
NSEL,Z,LORT
D,ALL,ALL
NALL
EALL
/VIEW,,1,1,1
KNUM,1
KPLOT
/VIEW,,1,1,1
```

```
WFRONT
WSTART,ALL
WAVES
APLOT,ALL
/PNUM,NODE,1 $NPLOT,ALL
/PNUM,ELEM,1 $EPLOT,ALL
/PNUM,AREA,1 $APLOT,ALL
/PBC,FORCE,1
/PBC,TDIS,1
/PBC,RDIS,1
/PBC,PRES,1
NPLOT
EPLOT
ITER,1,1,1
AFWRITE
FINISH
/EXEC
/INPUT,27
FINISH
/POST1
/OUTPUT,36
/TITLE CASE-2 1/4 MODEL MOMENT LOAD IN LONGITUDINAL DIREC-
TION
/COM MOMENT IN LONGITUDINAL DIRECTION
/COM BETA=0.6 GAMMA=75 t=0.2 T=0.2
/AUTO
STORE,STRES,DISP
/NOPR
/NOLIST
STRESS,SXCT,63,9
STRESS,SYCT,63,10
STRESS,SXYT,63,11
```

```
STRESS,SXCM,63,13
STRESS,SYCM,63,14
STRESS,SXYM,63,15
STRESS,MXC,63,6
STRESS,MYC,63,7
STRESS,MXYC,63,8
STRESS,NXIT,63,21
STRESS,NYIT,63,22
STRESS,NXIM,63,37
STRESS,NYIM,63,38
STRESS,PXCT,63,129
STRESS,PYCT,63,130
STRESS,PZCT,63,131
STRESS,PSIT,63,132
STRESS,SGET,63,133
STRESS,PXCM,63,134
STRESS,PYCM,63,135
STRESS,PZCM,63,136
STRESS,PSIM,63,137
STRESS,SGEM,63,138
STRESS,PSST,63,151
STRESS,PSSB,63,152
SET
NSEL,NODE,81
ENODE
NASEL,NODE,21
ENODE
PRELEM
PRSTRS,SXCT,SYCT,SXCM,SYCM
NELEM
NASEL,NODE,22,32,1
NASEL,NODE,81,95,1
```

```
NASEL,NODE,17
ENODE
NSORT,SY,,,6
NUSORT
ESORT,SYCT,,,20
NUSORT
NSORT,DISP,,,10
AVPRIN
NALL
EALL
/VIEW,,1,1,1
PLNSTR,SIGE,SZ
PLNSTR,SIGE,SX
PLNSTR,SX
PLNSTR,SY
SET,1,1
SAVE
FINISH
```

APPENDIX C. PROGRAMS FOR CALCULATION OF STRESS

1. C PROGRAM FOR CALCULATION OF STRESS ON THE PIPE DUE TO THE RADIAL LOAD P

```
#include<stdio.h>
#include<math.h>
#include<stdlib.h>
/* Calculation of the stresses cofficients for bending(S1,S2) & Membrane(S3,S4) on
the pipe..*/
main()
{
FILE *handle;
double    gama,beta,thnz,thnp,P,Rm,A,B,    SXCT,SYCT,SXCM,SYCM,Mx,Mf,-
S1,S2,S3,S4;
{
scanf("%lf %lf %lf %lf %lf %lf",&gama,&beta,&SXCT,&SYCT,&SXCM,&SYCM);
handle=fopen("r50","a");
P=-1000;
thnp=0.2;
thnz=0.2;
Rm=gama*thnp;
A=P/(Rm*thnp);
B=6*P/(thnp*thnp);
Mx=SXCT-SXCM;
Mf=SYCT-SYCM;
S1=Mx/B;
S2=Mf/B;
S3=SYCM/A;
S4=SXCM/A;
 printf("%s %s %s %s %s %s %s %s %s %s %s\n", "beta"," S1"," S2"," S3"," S4","
```

```
gama"," SXCT"," SYCT"," SXCM"," SYCM"," Pipe-radial_force,");
  printf("%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.3f %8.3f %8.3f %8.3f\n",be-
ta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);
 fprintf(handle,"%s %s %s %s %s %s %s %s %s %s %s\n", "beta"," S1"," S2","
S3"," S4"," gama"," SXCT"," SYCT"," SXCM"," SYCM"," Pipe-radial_force,");
fprintf(handle,"%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.3f %8.3f %8.3f
%8.3f\n",beta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);
}
fclose(handle);
}
```

2. C PROGRAM FOR CALCULATION OF STRESS ON TEH NOZZLE DUE TO THE RADIAL LOAD P

```
#include<stdio.h>
#include<math.h>
#include<stdlib.h>
/*.Calculation of the stresses cofficients for bending(S1,S2) & Membrane(S3,S4) on
the nozzle..*/
main()
{
FILE *handle;
double                                    gama,beta,thnz,thnp,P,Rm,A,B,SX-
CT,SYCT,SXCM,SYCM,Mx,Mf,S1,S2,S3,S4;
{
scanf("%lf %lf %lf %lf %lf %lf",&gama,&beta,&SXCT,&SYCT,&SXCM,&SYCM);
handle=fopen("r300","a");
P=-1000;
thnp=0.2;
thnz=0.2;
Rm=gama*thnp;
A=P/(Rm*beta*thnz);
B=6*P/(thnz*thnz);
```

```
Mx=SXCT-SXCM;
Mf=SYCT-SYCM;
S1=Mx/B;
S2=Mf/B;
S3=SYCM/A;
S4=SXCM/A;
printf("%s %s %s %s %s %s %s %s %s %s %s\n", "beta","S1","S2","S3","S4",
"gama","SXCT","SYCT","SXCM","SYCM","Nozzle-radial_force,");
printf("%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.3f %8.3f %8.3f %8.3f\n",be-
ta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);
fprintf(handle,"%s %s %s %s %s %s %s %s %s %s
%s\n","beta","S1","S2","S3","S4","gama","SXCT","SYCT","SXCM","SYCM","
Nozzle-radial_force,");
fprintf(handle,"%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.3f %8.3f %8.3f
%8.3f\n",beta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);

}
fclose(handle);
}
```

3. C PROGRAM FOR CALCULATION OF STRESS ON THE PIPE DUE TO THE BENDING MOMENT LOAD

```
#include<stdio.h>
#include<math.h>
#include<stdlib.h>
/*.Calculation of the stresses cofficients for bending(S1,S2) & Membrane(S3,S4)
due to an external moment (on the pipe..*/
main()
{
FILE *handle;
double gama,beta,thnz,thnp,Mc,Rm,A,B, SXCT,SYCT,SXCM,SYCM,Mx,Mf,-
S1,S2,S3,S4;
```

```
{
scanf("%lf %lf %lf %lf %lf %lf",&gama,&beta,&SXCT,&SYCT,&SXCM,&SYCM);
handle=fopen("r50","a");
Mc=-1000;
thnp=0.2;
thnz=0.2;
Rm=gama*thnp;
A=Mc/(Rm*Rm*thnp*beta);
B=6*Mc/(Rm*thnp*thnp*beta);
Mx=SXCT-SXCM;
Mf=SYCT-SYCM;
S1=Mx/B;
S2=Mf/B;
S3=SYCM/A;
S4=SXCM/A;
 printf("%s %s %s %s %s %s %s %s %s %s %s\n", "beta"," S1"," S2"," S3"," S4","
gama"," SXCT"," SYCT"," SXCM"," SYCM"," Pipe-moment,");
  printf("%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.6f %8.6f %8.6f %8.6f\n",be-
ta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);
 fprintf(handle,"%s %s %s %s %s %s %s %s %s %s %s\n", "beta"," S1"," S2","
S3"," S4"," gama"," SXCT"," SYCT"," SXCM"," SYCM"," Pipe-moment,");
   fprintf(handle,"%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.6f %8.6f %8.6f
%8.6f\n",beta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);

}
fclose(handle);
}
```

4. C PROGRAM FOR CALCULATION OF STRESS ON THE NOZZLE DUE TO THE BENDING MOMENT LOAD

```
#include<stdio.h>
#include<math.h>
```

```
#include<stdlib.h>
/*.Calculation of the stresses cofficients for bending(S1,S2) & Membrane(S3,S4)
due to an external moment on the nozzle..*/
main()
{
FILE *handle;
double gama,beta,thnz,thnp,Mc,Rm,A,B,SX-
CT,SYCT,SXCM,SYCM,Mx,Mf,S1,S2,S3,S4;
{
scanf("%lf %lf %lf %lf %lf %lf",&gama,&beta,&SXCT,&SYCT,&SXCM,&SYCM);
handle=fopen("r30","a");
Mc=-1000;
thnp=0.2;
thnz=0.2;
Rm=gama*thnp;
A=Mc/(Rm*Rm*beta*beta*beta*thnz);
B=6*Mc/(Rm*beta*beta*thnz*thnz);
Mx=SXCT-SXCM;
Mf=SYCT-SYCM;
S1=Mx/B;
S2=Mf/B;
S3=SYCM/A;
S4=SXCM/A;
  printf("%s %s %s %s %s %s %s %s %s %s %s\n", "beta","S1","S2","S3","S4",
"gama","SXCT","SYCT","SXCM","SYCM","Nozzle-moment,");
  printf("%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.6f %8.6f %8.6f %8.6f\n",be-
ta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);
      fprintf(handle,"%s %s %s %s %s %s %s %s %s %s
%s\n","beta","S1","S2","S3","S4","gama","SXCT","SYCT","SXCM","SYCM","
Nozzle-moment,");
   fprintf(handle,"%3.2f %8.6f %8.6f %8.6f %8.6f %3.2f %8.6f %8.6f %8.6f
%8.6f\n",beta,S1,S2,S3,S4,gama,SXCT,SYCT,SXCM,SYCM);
```

```
}
fclose(handle);
}
```

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