APPENDIX 3D

PROCEDURE FOR CALCULATING ELASTO-PLASTICALLY DESIGNED PIPE WHIP RESTRAINT LOADS BY ENERGY BALANCE METHOD

The information contained in this appendix was not revised, but has been extracted from the original FSAR and is provided for historical information.

A simplified mathematical model as shown on the next page can be used for elastic-plastic design of pipe whip restraints. An energy balance approach has been used to formulate the calculations for determining the plastic deformation in the restraints.

In applying the plastic deformation design for restraints, the regulatory guides require that either one of the following upper bound design limits for metallic ductile materials be met.

(a) 50% of the minimum ultimate uniform strain (the strain at the maximum stress of an engineering stress-strain curve based on actual material tests for the restraint), or

(b) 50% of the minimum percent elongation as specified in an applicable ASME, ASTM, etc. Code, specification, or standard when demonstrated to be less than 50% of the minimum ultimate uniform strain based on representative test results.

56

Simplified approach for designing elasto-plastic restraints

If the restraint is allowed to go into the plastic region, then the maximum restraint deflection, d_{max}, will consist of an elastic portion and a plastic portion as shown below. (Figure 1.0)

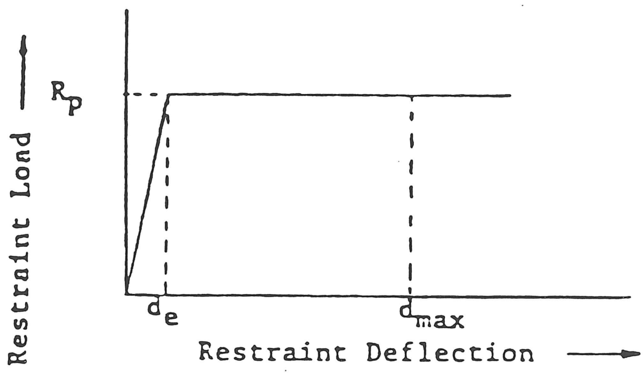


Figure 1.0 - Idealized Restraint Deflection Characteristics.

where, d_e = Restraint elastic deflection at yield stress

d_{max} = Maximum allowable restraint deflection

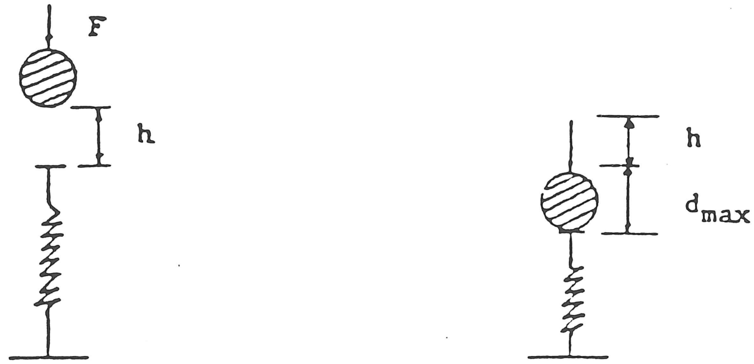
R_p = Maximum restraint resistance $R_p = k_e d_e$

k_e = Restraint elastic structural stiffness

If 'F' denotes the applied forcing Function (i.e., a blow down load in case of a pipe break) and 'h' denotes the gap between the piping and the restraint, an energy balance relation for this case gives, (see Figure 2.0).

$$F\ (h + d_{max}) = \frac{1}{2}\ R_p\ d_e + R_p\ (d_{max} - d_e)$$

$$= R_p\ (d_{max} - \frac{d_e}{2})$$



(a) Before Impact

(b) After Impact

Figure 2.0 Energy balance Analysis Model

Rearranging, $(R_p - F)\, d_{max} = \frac{1}{2}\,(2Fh + R_p d_e)$

Therefore, $$d_{max} = \frac{2Fh + R_p d_e}{2\,(R_p - F)} \quad \text{-- -- (1)}$$

The above formulation can be further simplified in 2Fh is much larger than $R_p d_c$.

Therefore, assuming, $R_p d_e << 2Fh$

Equation (1) gives, $$d_{max} = \frac{Fh}{(R_p - F)} \quad \text{--- (2)}$$

After determining d_{max}, either by equation (1) or equation (2) above (as applicable), the resulting strain in the member should be calculated and should be checked against the criteria give in page 1.

For uniaxial members, the strain ϵ is taken to be equal to $\frac{d_{max}}{L}$, where L is the original length of the restraint member.

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Pages 4 and 5

Deleted in Amendment 56

APPENDIX 3E

PROCEDURE FOR CALCULATING ELASTO-PLASTICALLY DESIGNED PIPE WHIP RESTRAINT LOADS BY EQUIVALENT STATIC ANALYSIS METHOD

The information contained in this appendix was not revised, but has been extracted from the original FSAR and is provided for historical information.

APPENDIX 3E

PROCEDURE FOR CALCULATING ELASTICALLY DESIGNED PIPE WHIP RESTRAINT LOADS

BY

EQUIVALENT STATIC ANALYSIS METHOD

PREPARED BY: F. Jan 11/29/77
F. JAN
MECHANICAL ANALYSIS GROUP

REVIEWED BY: R. F. Perry 11/29/77
R. F. PERRY
MECHANICAL ANALYSIS GROUP

APPROVED BY: G. Rigamonti
G. RIGAMONTI, ACTING MANAGER
MECHANICAL ANALYSIS GROUP

In order to evaluate the response of an elastically designed pipe whip restraint to a pipe break load by using the equivalent static analysis approach, the dynamic load factor associated with the applicable forcing function and the clearance (gap) between the pipe and the restraint has to be determined.

A simplified mathematical model as shown on the next page, can be used to determine the dynamic load factor. Since the pipe size effects are already being reflected in the magnitude of the pipe break load, the pipe size alone is not considered again as a model parameter. The dynamic load factor (DLF) thus determined is used to calculate the restraint load (R) as follows:

$$R = (\alpha PA) \times DLF$$

where:

$$\alpha = \begin{cases} 1.26 \text{ for steam-saturated water} \\ 2.0 \text{ for subcooled non-flashing water} \end{cases}$$

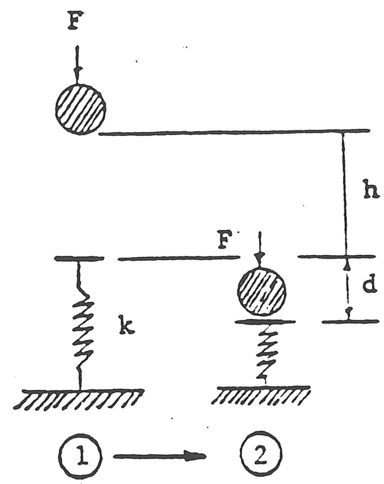
[Ref. U.S. NRC Standard Review Plan, 3.6.2 (III) (2) (c) (4)]

P = Operating Pressure

A = Pipe Break Area

A series of parametric curves for determining the restraint loads for steam-saturated water or steam-water mixtures only are given in Pages 3 - 14.

A SIMPLE MODEL FOR COMPUTING DYNAMIC LOAD FACTOR



$$d_{st} = \frac{F}{k} \qquad (1)$$

$$F(h + d) = 1/2\ kd^2 \qquad (2)$$

From (1) $k = \dfrac{F}{d_{st}}$ (3)

By substituting (3) into (2), we have

$$F(h + d) = 1/2\left(\frac{F}{d_{st}}\right) d^2$$

$$d^2 - 2\ d_{st}\ d - 2\ d_{st}\ h = 0$$

Or,

$$\left(\frac{d}{d_{st}}\right)^2 - 2\left(\frac{d}{d_{st}}\right) - 2\left(\frac{h}{d_{st}}\right) = 0$$

$$DLF = \frac{d}{d_{st}} = 1 + \left[1 + \frac{2h}{d_{st}}\right]^{\frac{1}{2}} = 1 + \left[1 + \frac{2hk}{F}\right]^{\frac{1}{2}}$$

Where,

F = Applied Load = (Pipe Rupture Load)

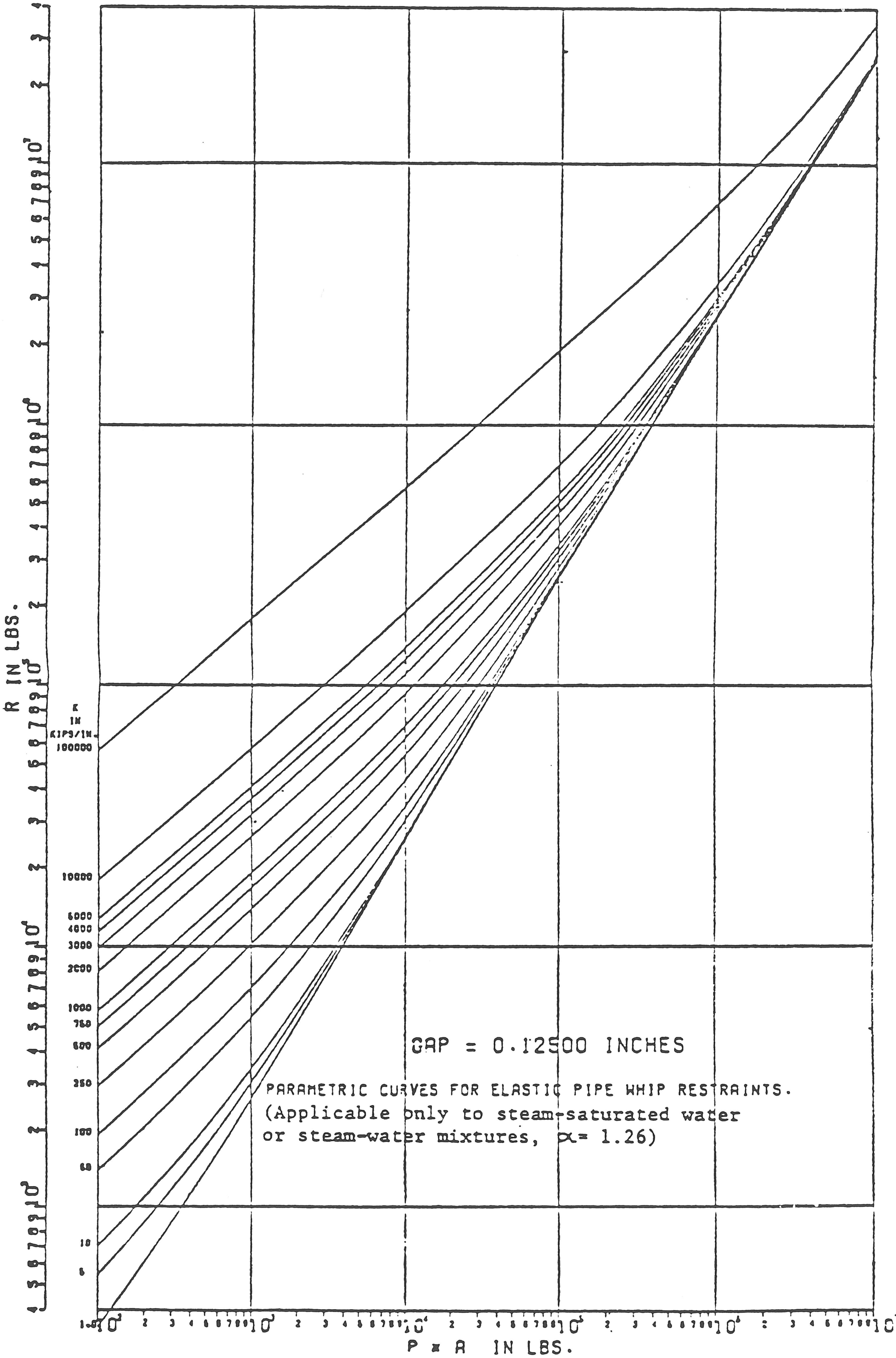
d_{st} = Restraint deflection for statically applied F

d = Maximum restraint deflection

h = Gap size

k = Restraint stiffness

DLF = Dynamic load factor


R IN LBS.
K IN KIPS/IN.
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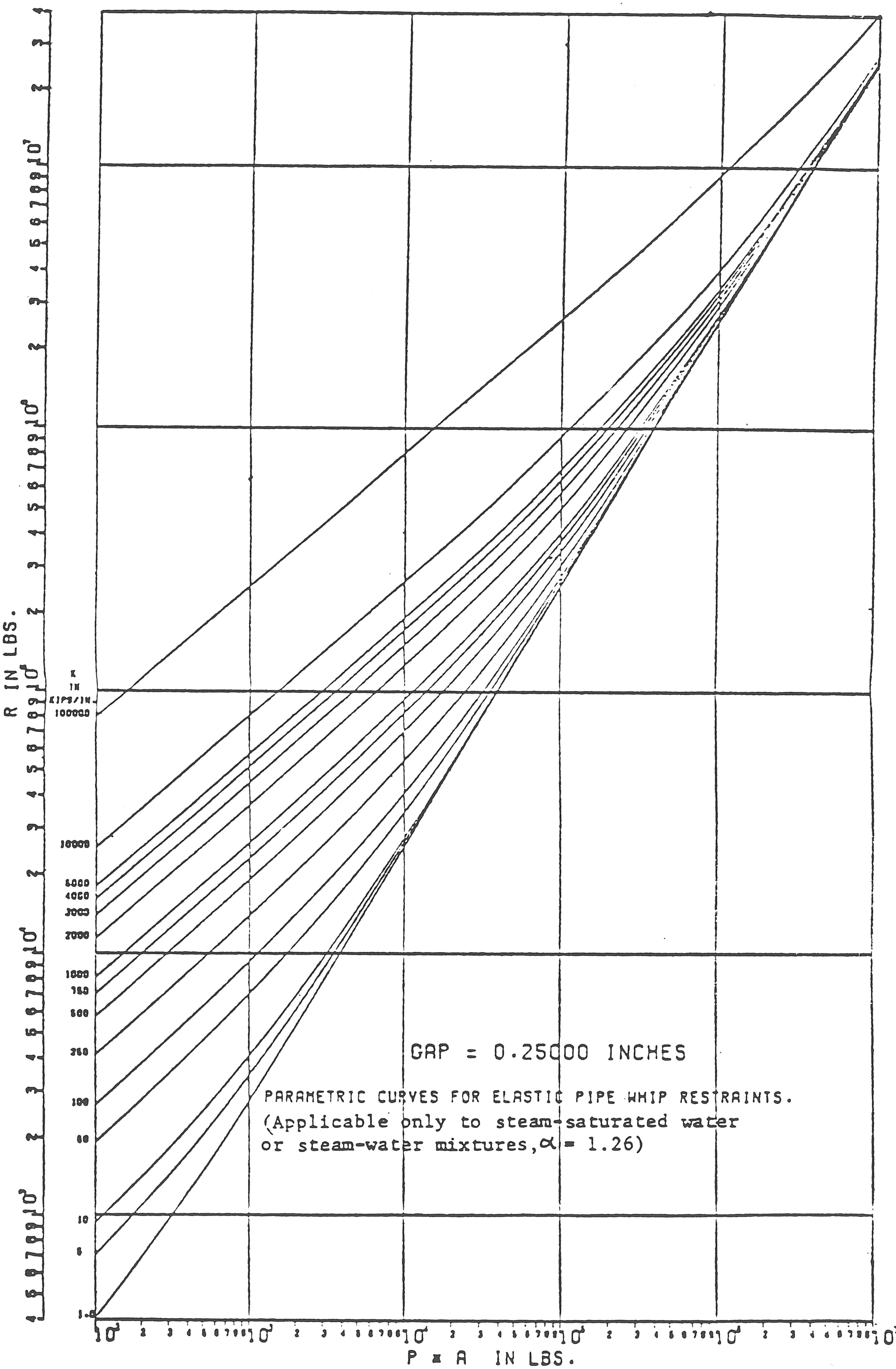
10000
6000
4000
3000
2000
1000
750
500
250
100
50
10
5
P x A IN LBS.
GAP = 0.12500 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α= 1.26)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K IN KIPS/IN.
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1.0
P = A IN LBS.
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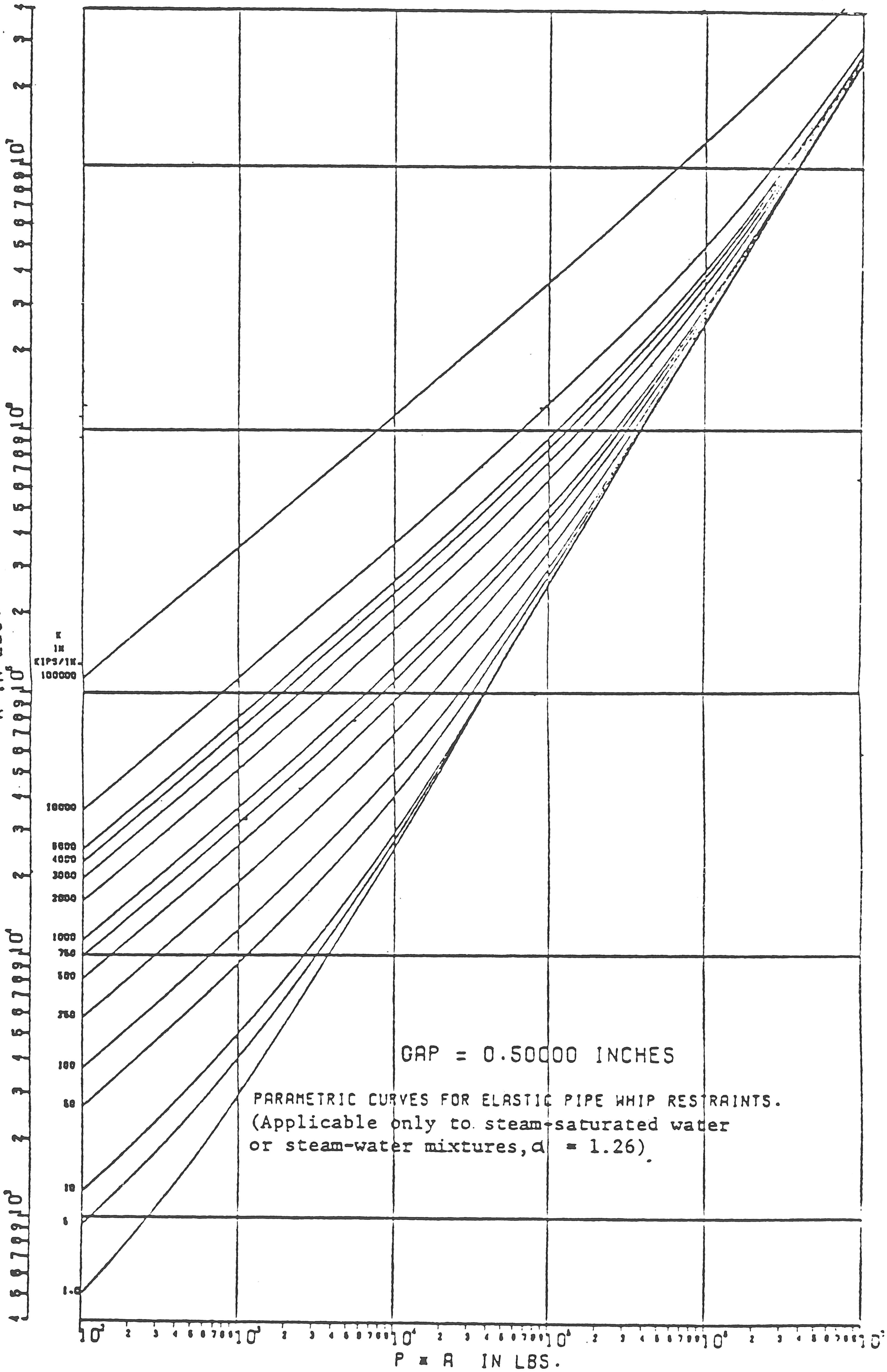
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)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K IN KIPS/IN.
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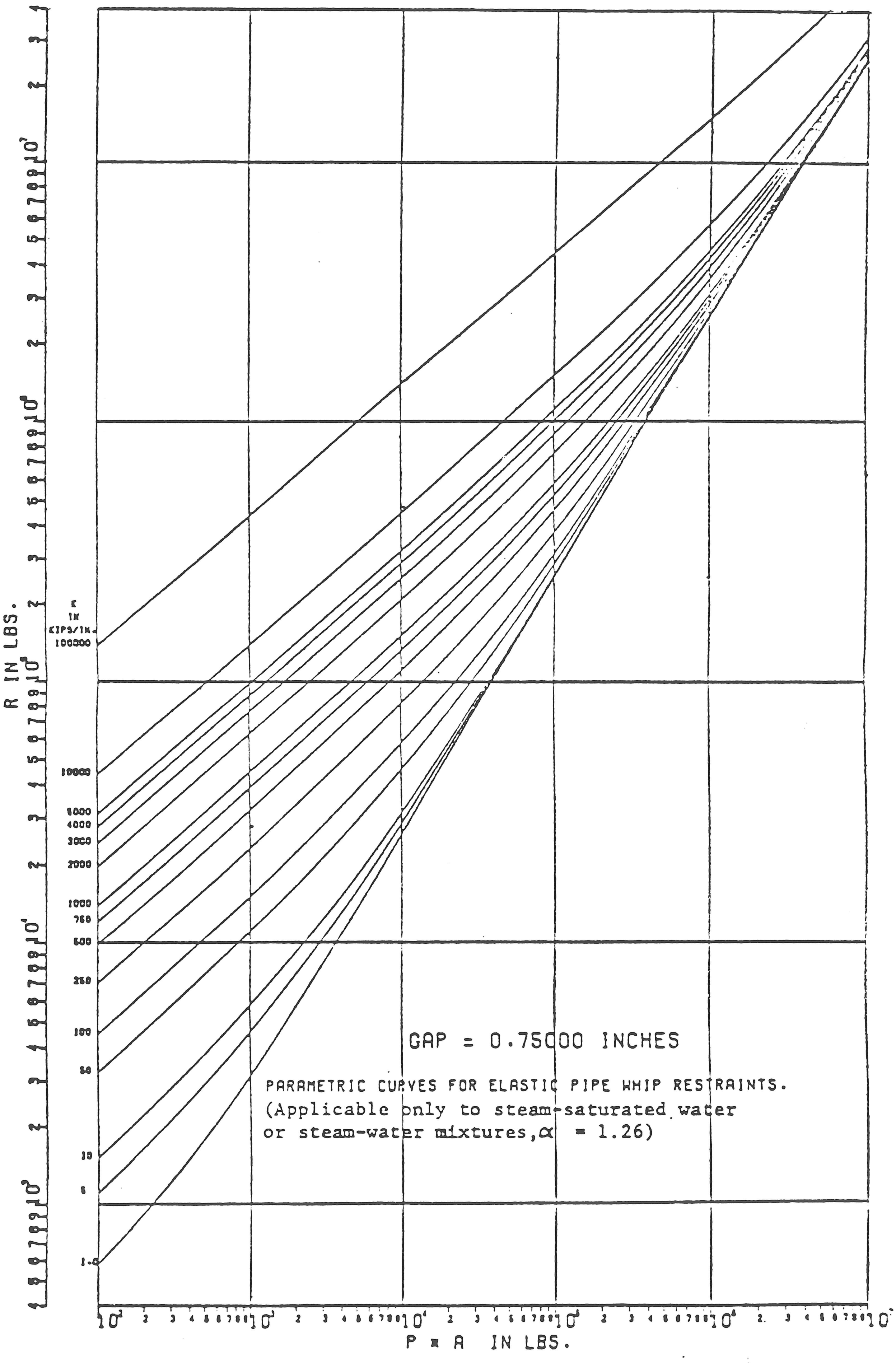
1.0
GAP = 0.50000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water or steam-water mixtures, α = 1.26)
P x A IN LBS.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K IN KIPS/IN.
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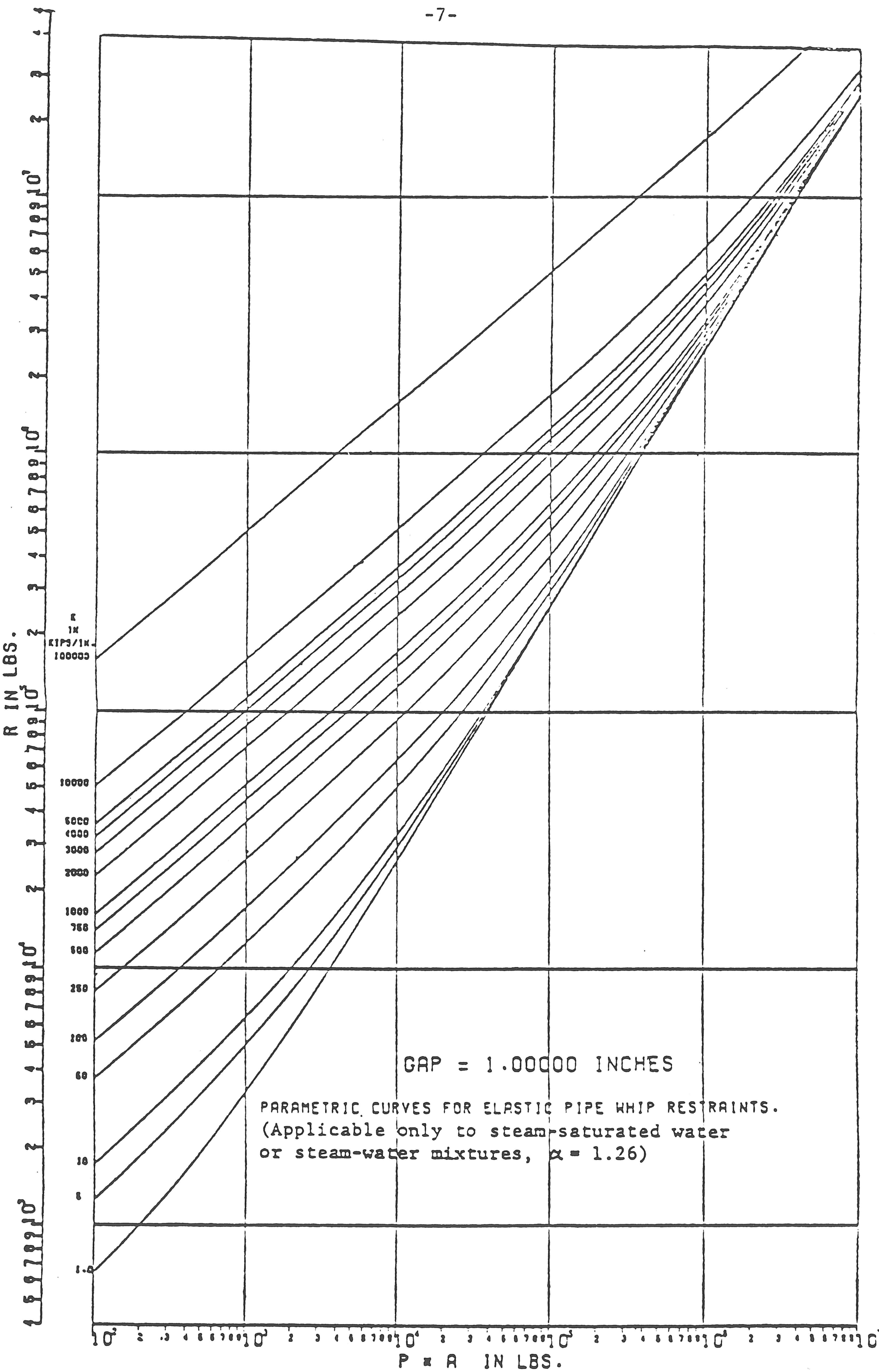
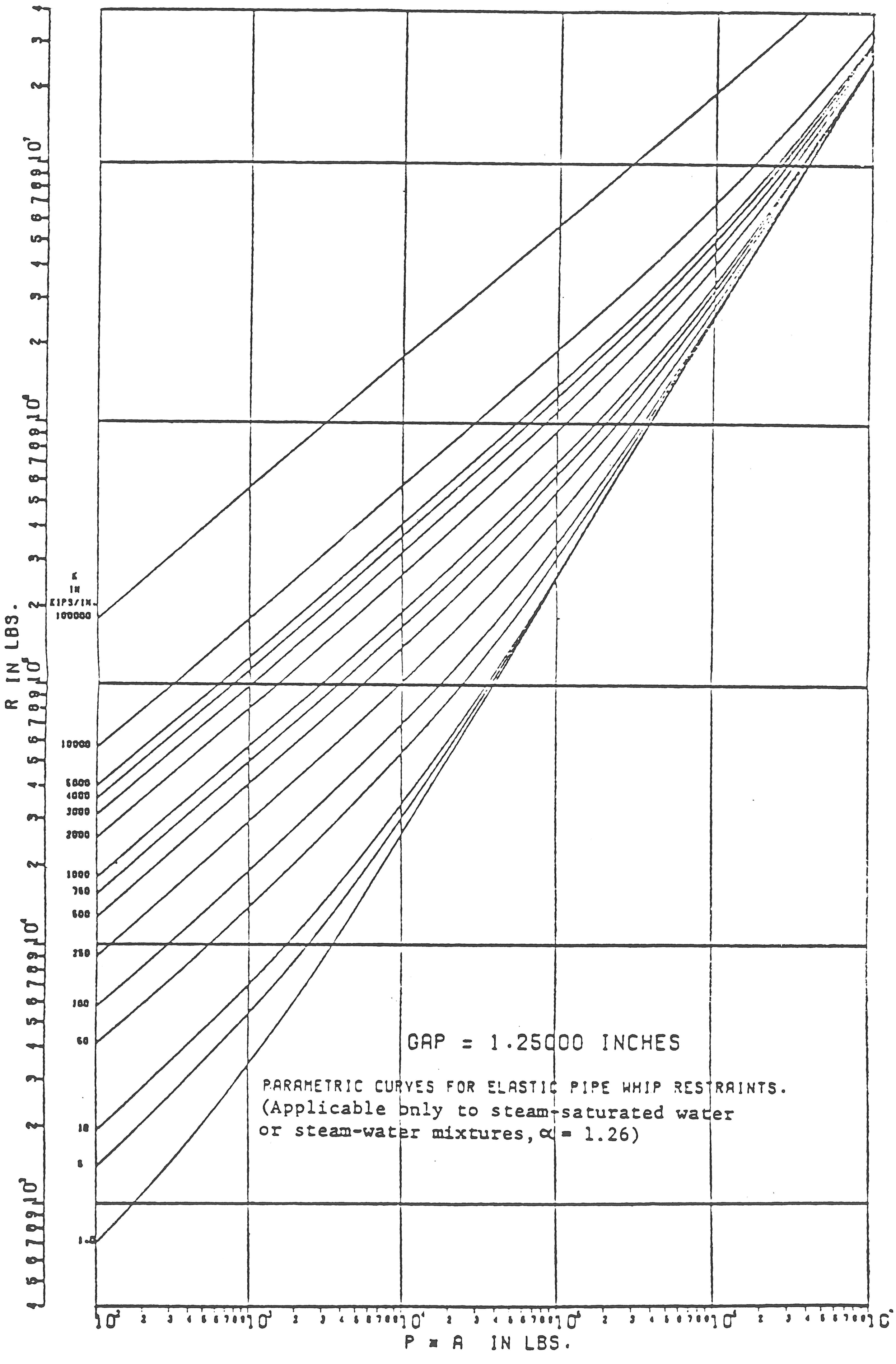
1.0
GAP = 0.75000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)
P x A IN LBS.



PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water or steam-water mixtures, $\alpha = 1.26$)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K IN KIPS/IN.
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750
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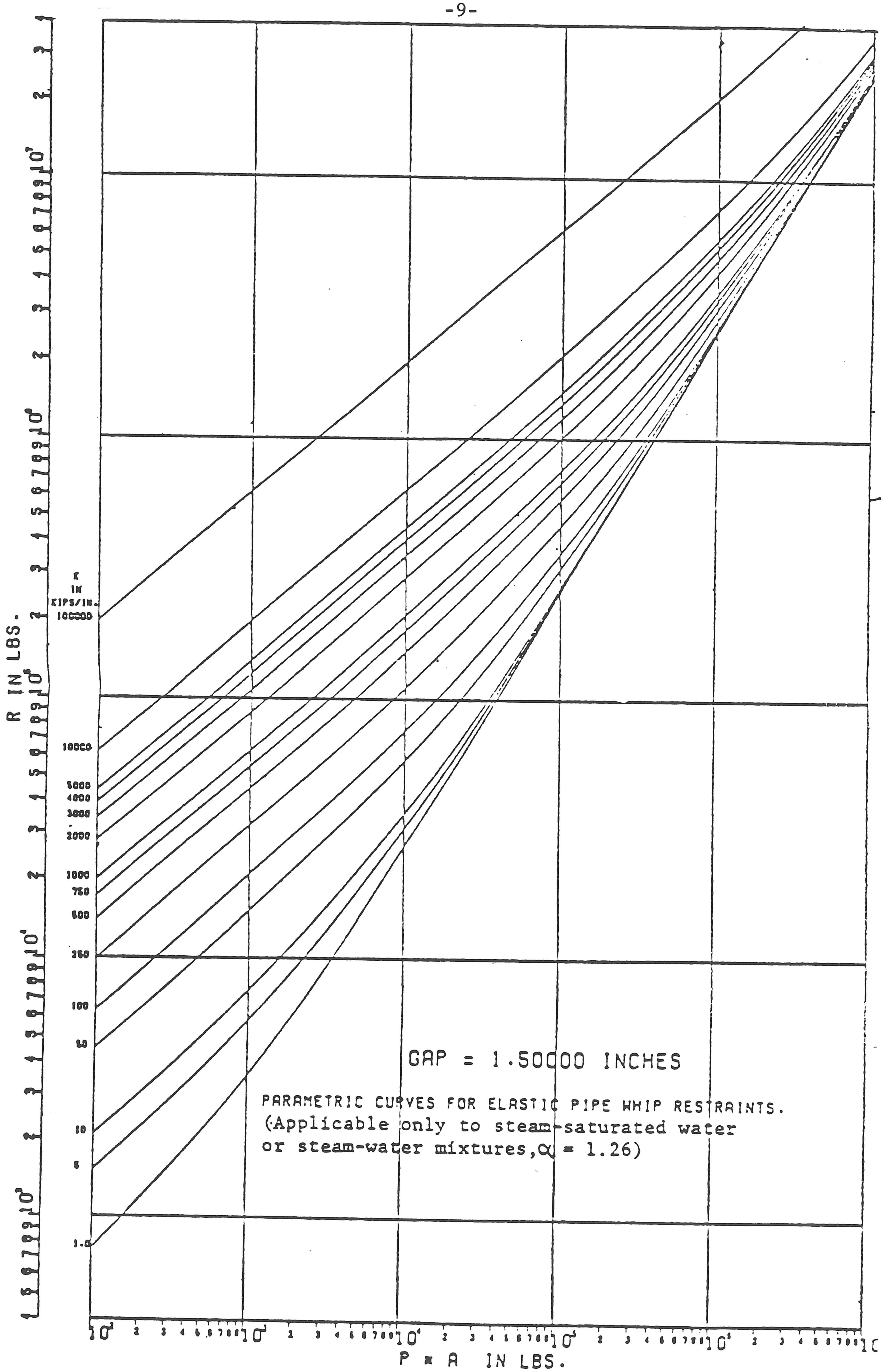
100
50
10
5
1.5
GAP = 1.25000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)
P = A IN LBS.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K IN KIPS/IN.
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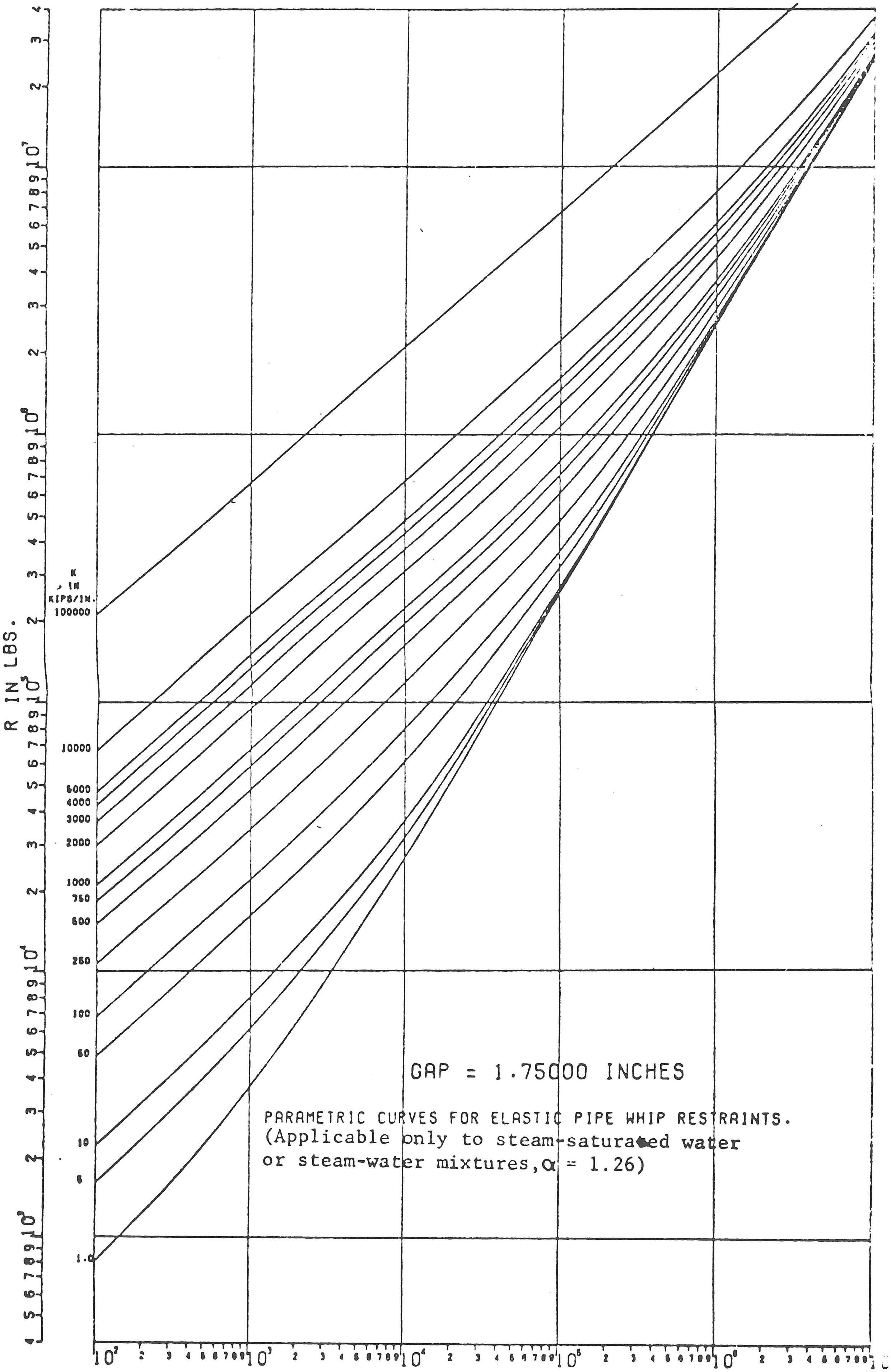
1.0
GAP = 1.50000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)
P = A IN LBS.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P = A IN LBS.
K, IN KIPS/IN.
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10
5
1.0
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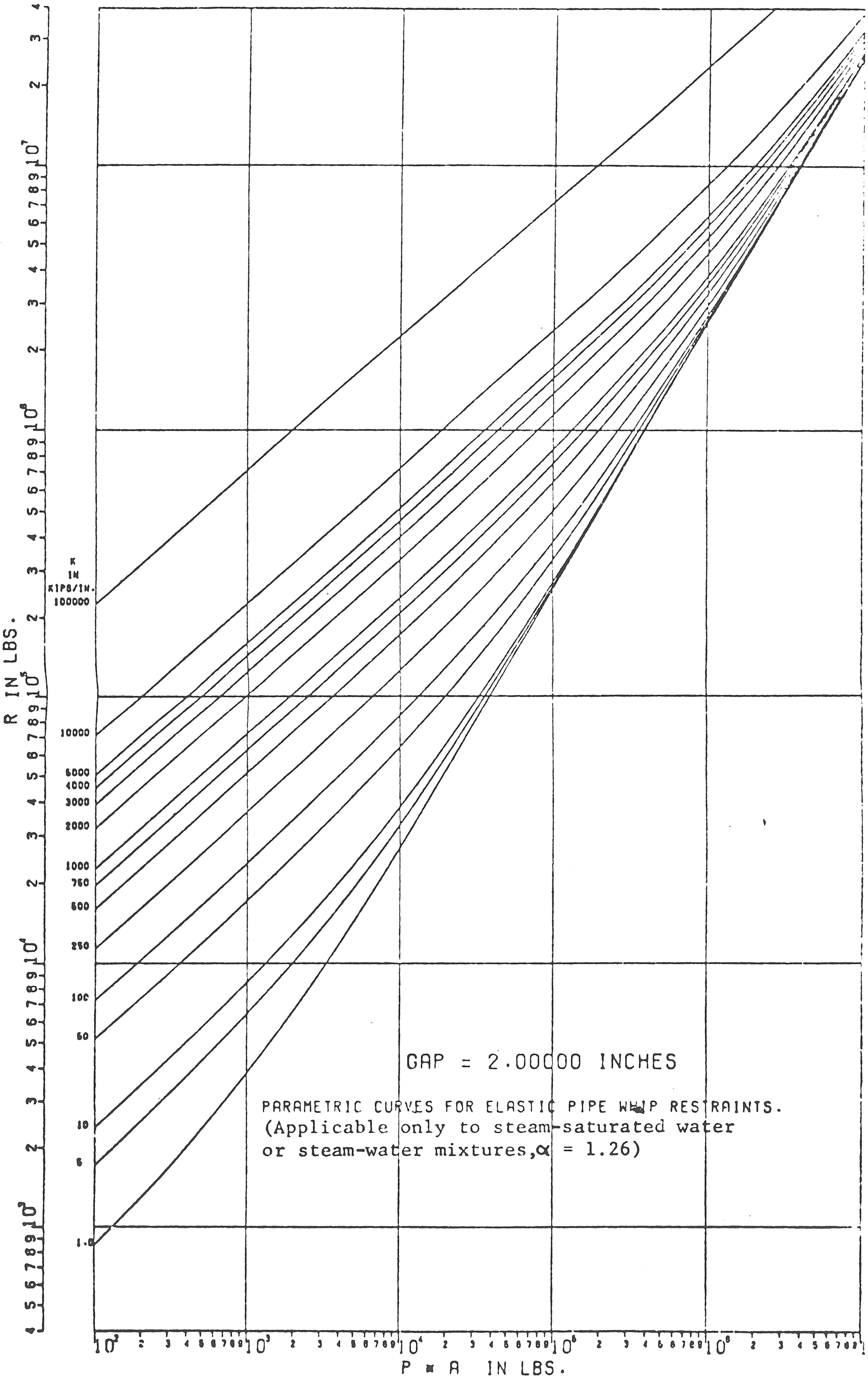
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)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K IN KIPS/IN.
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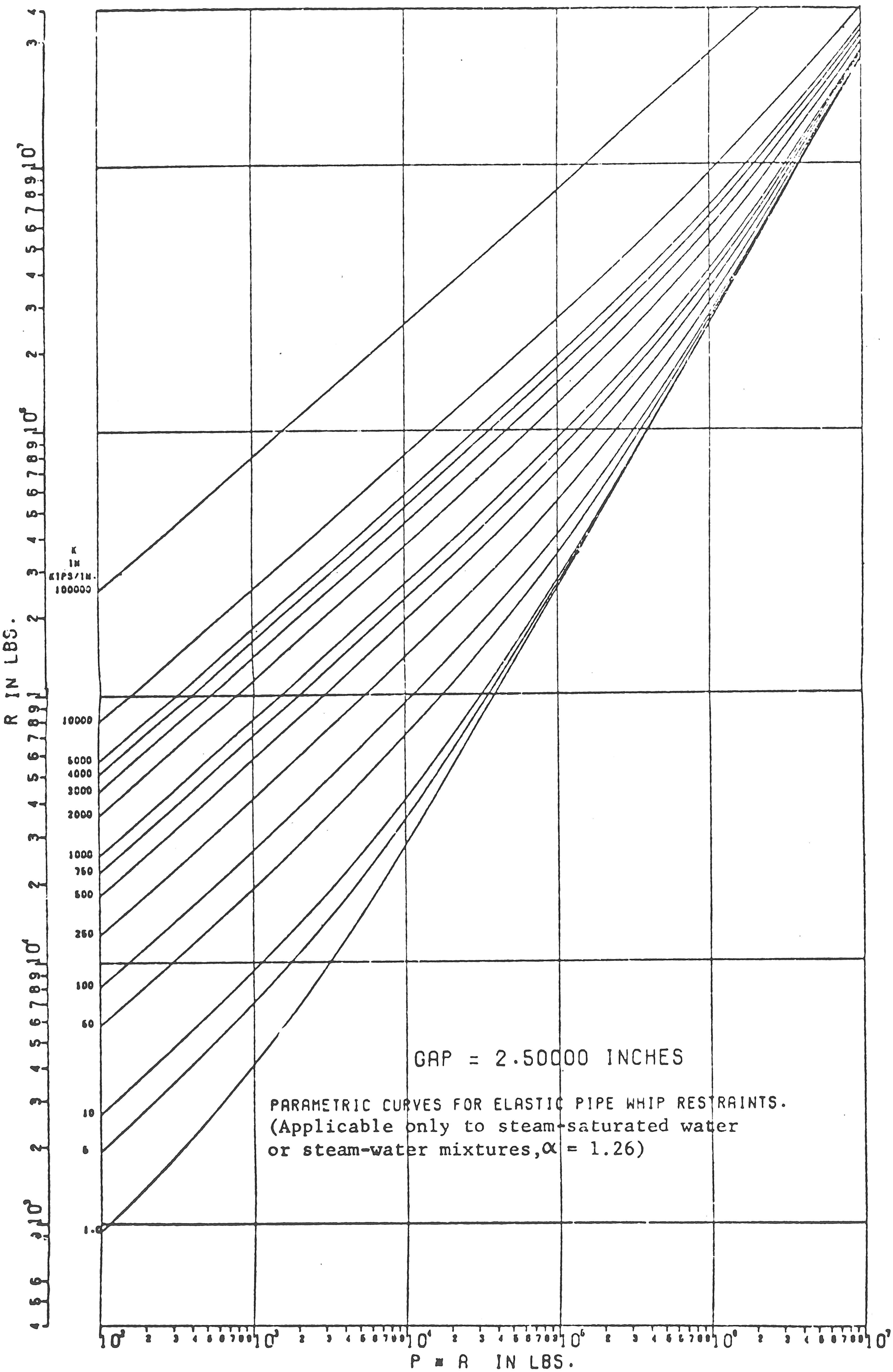
3000
2000
1000
750
500
250
100
50
10
5
1.0
GAP = 2.00000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)
P * A IN LBS.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K IN KIPS/IN.
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100
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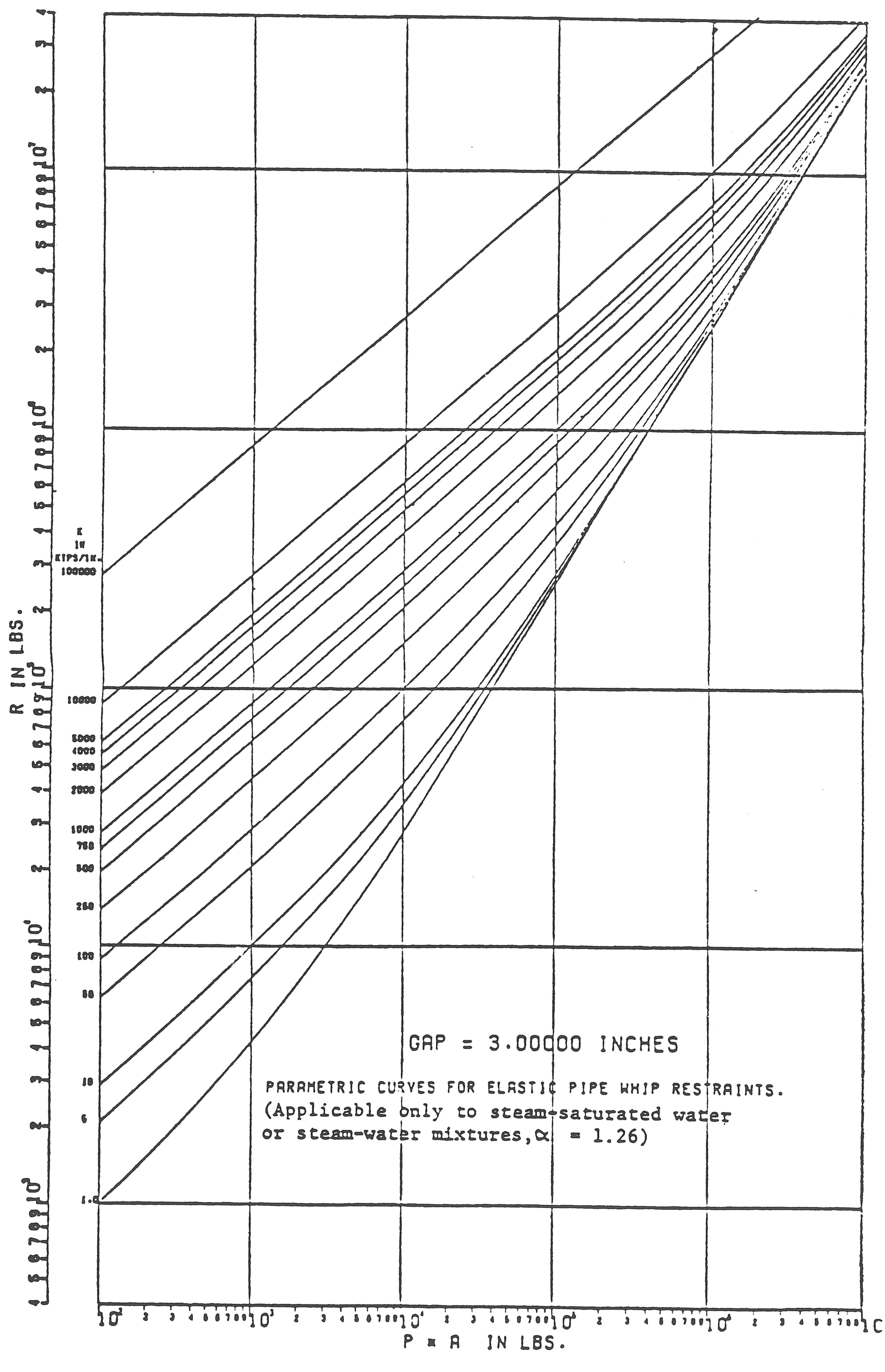
5
1.0
GAP = 2.50000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)
P * A IN LBS.


R IN LBS.
P = A IN LBS.
K IN KIPS/IN.
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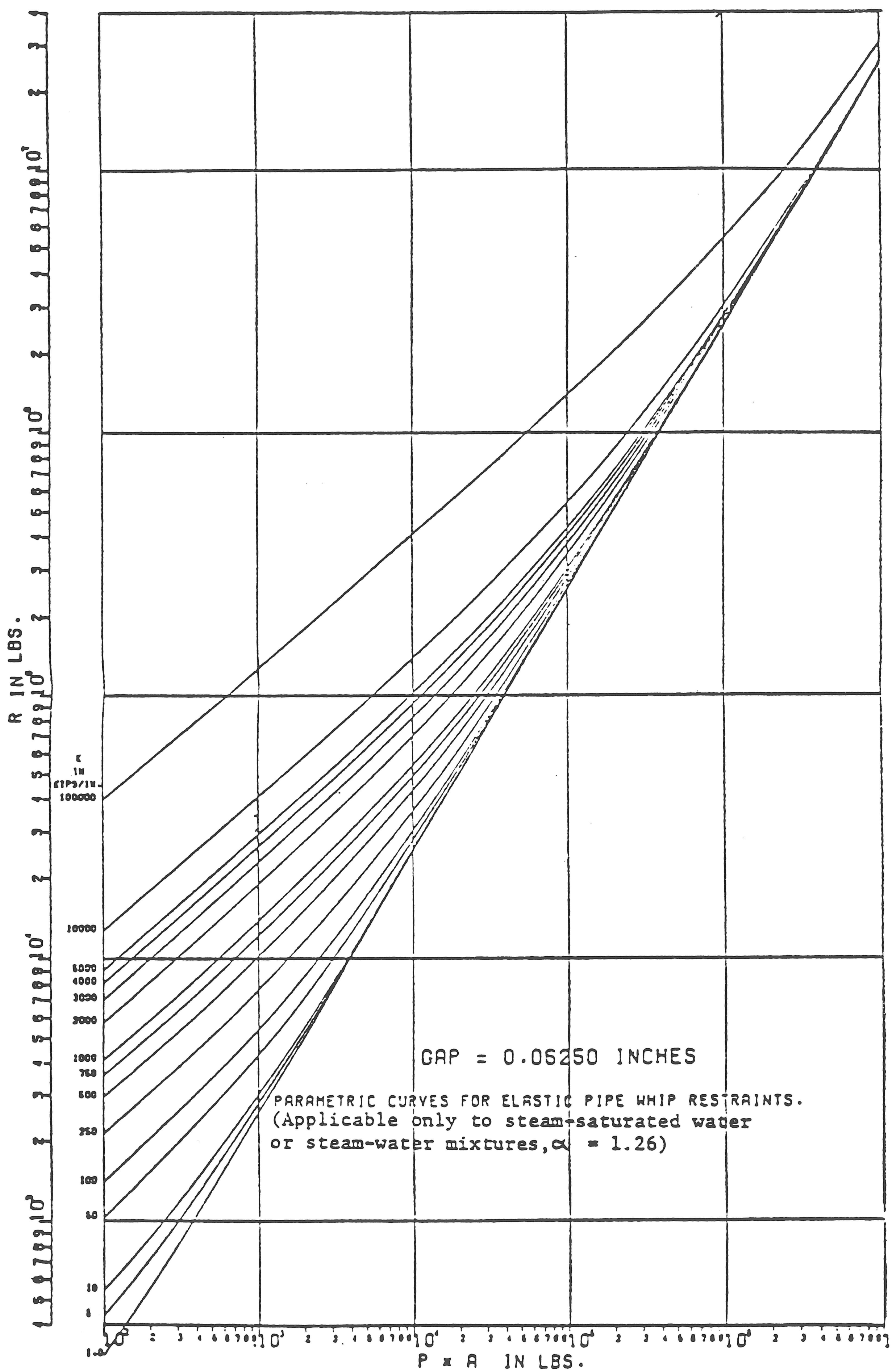
3000
2000
1000
750
500
250
100
50
10
5
1.0
GAP = 3.00000 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)


R IN LBS.
K IN KIPS/IN.
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10000
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4000
3000
2000
1000
750
500
250
100
50
10
5
1.0
GAP = 0.06250 INCHES
PARAMETRIC CURVES FOR ELASTIC PIPE WHIP RESTRAINTS.
(Applicable only to steam-saturated water
or steam-water mixtures, α = 1.26)
P x A IN LBS.

APPENDIX 3F

VERIFICATION OF COMPUTER PROGRAMS USED FOR STRUCTURAL ANALYSIS AND DESIGN

The information contained in this appendix was not revised, but has been extracted from the original FSAR and is provided for historical information.

APPENDIX 3F

VERIFICATION OF COMPUTER PROGRAMS USED FOR STRUCTURAL ANALYSIS AND DESIGN

Computer programs used for structural analysis and design have been verified according to the criteria described in the US NRC Standard Review Plan 3.8.1, Section II-4(e).

(a) The following computer programs are recognized in the public domain, and have had sufficient history to justify their applicability and validity without further demonstration:

	Hardware	Source
STARDYNE	CDC	CDC(1)
MARC-CDC	CDC	CDC(1)
STRU-PAK	CDC	CDC(1)
System Professional	CDC	CDC(1)
ANSYS	CDC	CDC(1)
STRUDL	UCCEL	PSDI(2)
UEMENU	UCCEL	UCCEL(3)

(1) CDC - Control Data Corporation
P. O. Box O, HQWOSH
Minneapolis, Minnesota 55440

(2) PSDI - Programs for Structural Design, Inc.
14 Story Street
Cambridge, Massachusetts 02138

(3) UCCEL - UCCEL Corporation
P. O. Box 84028
Dallas, Texas 75284

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(b) The following computer programs have been verified by solving test problems with a similar and independently-written and recognized program in the public domain:

SAG058 (Response Spectra)

A summary of comparison results is shown in Table 3F-1.

AX2 (Axisymmetric Shell Program)

A verification manual comparing AX2 with results obtained from either ANSYS or BOSOR4 (Lockhead Missile and Space Company - Palo Alto, CA) can be obtained from Pittsburgh - Des Moines Corporation, 3400 Grand Avenue, Neville Island, Pittsburgh, PA 15225 54

(c) The following computer programs have been verified by comparison with analytical results published in technical literature:

SAG001 (WILSON 1)
SAG010 (WILSON 2, DYN)

Summaries of comparison results are shown in Tables 3F-2 and 3F-3, respectively.

(d) The following computer programs have been verified by comparison with hand calculations for test problems which are representative of the type used in actual analyses:

SAG008 (TAPAS)
SAG017 (FOUREXP)
SAG024 (MMIC)
SAG025 (SECTION)
PM-910 (LESCAL)
*PM-906 (STRAP) 54

A summary of comparison results is shown in Tables 3F-4 through 3F-8.

(e) The following computer programs are verified by inspection of the graphical output data.

SAG054 (Response Envelope)

A typical verification example is presented in Table 3F-9.

* Documentation of STRAP is available in the Final Safety Analysis Report for the Carolina Power and Light Co., Brunswick 1 & 2, US NRC Docket Nos. 50-324 and 50-325. 54

TABLE 3F-1

SAG058 (RESPONSE SPECTRA)

SAG058(1) is verified against STARDYNE, sub-routine DYNRE5. The input T/H is of 22 second duration, with a time interval of 0.01 seconds and a maximum acceleration of 1.0g.

Frequency (Hz)	Spectral Acceleration (g)			
	0.5% Damping		2% Damping	
	SAG058	DYNRE5	SAG058	DYNRE5
0.33	0.91	0.98	0.79	0.83
1.00	2.68	2.67	2.03	2.03
2.00	8.23	8.23	4.33	4.32
3.03	6.04	6.02	4.31	4.32
4.00	5.20	5.18	4.40	4.37
5.00	5.25	5.21	3.95	3.94
6.25	7.51	7.42	4.47	4.38
7.14	5.33	5.25	3.94	3.90
8.33	4.87	4.80	3.69	3.68
9.09	7.09	6.93	4.96	4.81
10.00	5.00	4.97	3.37	3.35
20.00	2.61	2.60	1.77	1.77
33.33	1.22	1.22	1.13	1.14

(1) SAG058 is an in-house computer program run on the Control Data Corporation CYBER-175 and is used as a post-processor to the STARDYNE program.

TABLE 3F-2

SAG001 (WILSON 1)

The following is a comparison of the results from SAG001 with results obtained from published technical literature. SAG001 runs on the Honeywell 66/60 system with the GCOS operating system.

Sample Problem No. 1

Analysis of a thick-walled cylinder subjected to an internal pressure.

Reference - Gallagher, R. H., Finite Element Analysis, Figure 11.5, pg. 317, Prentice-Hall, Inc., 1975.

Comparison of the theoretical solution with the WILSON 1 solution is shown on Figure 3F-1 for the radial stress and the hoop stress.

Sample Problem No. 2

Analysis of a cylindrical shell, fixed at both ends and subjected to an internal pressure.

Reference - Timoshenko, S., Woinowsky- Krieger, S., Theory of Plates and Shells, Second Edition, pg. 475, McGraw-Hill, 1959.

Comparison of the theoretical solution with the WILSON 1 solution is shown on Figures 3F-2 and 3F-3 for the radial shear and meridional moment, respectively.

TABLE 3F-3

SAG010 (WILSON 2, DYN)

The original version of SAG010, "Dynamic Stress Analysis of Axisymmetric Structures Under Arbitrary Loading," written by Ghosh and Wilson was revised by UE&C in September, 1975. The program is distributed in the public domain by the Earthquake Engineering Research Center, University of California, Berkeley, California. The program has been verified against a series of problems whose results are published in technical literature. Documentation of this verification is contained in the report EERC 69-10 which can be obtained from the Earthquake Engineering Research Center. SAG010 is run on the Honeywell 66/60 System.

TABLE 3F-4

SAG008 (TAPAS)

The following is a comparison of the results from SAG008, which computes the temperature distribution through plane and axisymmetric solids, with hand calculations. The sample results are for the temperature distribution through the thickness of a hemispherical concrete dome which is 42 inches thick and subject to 120°F inside and (-)10°F outside.

Element No.	SAG008[1] (°F)	Hand Calculation (°F @ Mid Pt. of Elem.)
724	110.38	110.7143
848	88.89	89.048
972	65.33	65.833
1096	42.12	42.619
1220	19.26	19.405
1344	(-)1.04	(-)0.7143

SAG008 runs on the Honeywell 66/60 system

References:

(1) Wilson, E. L., Nickell, R. E., "Application of the Finite Element," Journal of Nuclear Engineering and Design, 4, 1966.

TABLE 3F-5

SAG017 (FOUREXP)

The following is a verification of SAG017 with hand calculations for an arbitrary loading distribution which is an even function and can be expanded using a cosine Fourier Series. The periodic function is, $f(\theta) = \begin{cases} -\theta & -\pi \leq \theta < 0 \\ \theta & 0 < \theta \leq \pi \end{cases}$

Comparison of Fourier Coefficients:

n	SAG017[1]	Hand Calculations[2]
0	1.5699	1.5708
1	-1.2739	-1.2732
2	-0.0019	0
3	-0.1421	-0.1415
4	-0.0019	0
5	-0.0516	-0.0509
6	-0.0020	0
7	-0.0266	-0.0260
8	-0.0021	0
9	-0.0164	-0.0157
10	-0.0022	0
11	-0.0112	-0.0105
12	-0.0023	0
13	-0.0082	-0.0075
14	-0.0025	0
15	-0.0063	-0.0057
16	-0.0028	0
17	-0.0051	-0.0044
18	-0.0031	0
19	-0.0042	-0.0035
20	-0.0036	0

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SAG017 runs on the Honeywell 66/60 system.

References:

(1) The Fourier coefficients are computed for a digitized function by a recursive technique described in Mathematical Methods for Digital Computers, by Rolsten and Wilf, John Wiley and Sons, New York, 1960, Chapter 24. The solution technique is from subroutine FORIT in the IBM Scientific Subroutine package. The program is run on the Honeywell 66/60 system.

(2) Wylie, C. R., Advanced Engineering Mathematics, 4th Ed., McGraw-Hill, 1975.

TABLE 3F-6

SAG024 (MMIC)

The following is a comparison of the results of hand calculations with SAG024 for the weight of a typcial lumped mass point in a dynamic model of a shear building.

Parameter	SAG024[1]	Hand Calculation
X_{CM} (X-Coordinate of the Center of Mass) - ft.	26.19	26.19
Y_{CM} (Y-Coordinate of the Center of Mass) - ft.	0.08	0.08
W_T (Total Weight of Mass Point) - Kips	1444	1444
I_{MX} (Rotary Weight Moment of Inertia about X-Axis) $K\text{-}ft^2$	162,323	162,320
I_{MY} (Rotary Weight Moment of Inertia about Y-Axis) $K\text{-}ft^2$	379,552	379,550
I_{MZ} (Rotary Weight Moment of Inertia about Z-Axis) $K\text{-}ft^2$	470,152	470,150

SAG024 runs on the Honeywell 66/60 system.

Reference:

(1) Bear, F. P. and Johnston, R. E., Jr., Vector Mechanics for Engineers: Static and Dynamics, McGraw-Hill, 1962, pps. 343-347.

TABLE 3F-7

SAG025 (SECTION)

The following is a comparison of the results of hand calculations with SAG025 for a system of resisting structural elements between floors in a typcial shear building.

	SAG025	Hand Calculations
X_{CR} (X-Coordinate of Center of Rigidity) - ft.	26.3	26.257
Y_{CR} (Y-Coordinate of Center of Rigidity) - ft.	0.0	0.0
A_T (Area) - ft	466.0	466.0
S_{FX} (Shear Shape Factor about X-Axis)	.456	0.456
S_{FY} (Shear Shape Factor about Y-Axis)	.555	0.555
I_{XX} (Moment of Inertia about X-Axis) - ft.	11,100	11,079
I_{YY} (Moment of Inertia about Y-Axis) - ft.	44,000	43,957
J (Torsional Constant) - ft.	117,000	117,470

SAG025 runs on the Honeywell 66/60 system.

TABLE 3F-8
(Sheet 1 of 2)

PM-910 (LESCAL)

The following is a comparison of the results from the LESCAL computer program with hand calculations. LESCAL calculates the stresses and strains in rebars and/or concrete in accordance with the criteria set forth in Subarticle CC-3511.1 of ASME Section III, Division II. The section is concrete reinforced with horizontal, vertical and/or diagonal rebars, subjected to axial force and moment on a vertical and horizontal face and in-plane shear. When inplane shear forces are included, a solution is obtained by solving Duchon's equations[1]. 56

Load Condition	Parameter	LESCAL (Ksi)	Hand Calculations
$D + P_a + E_s$	f_m outside	29.39	29.46
Applied @ c.g. of	f_h outside	23.08	23.05
Concrete Section	$f_{seis.}$ (3)	52.26	52.35
	$f_{seis.}$ (4)	0.21	0.21
	f_m inside	26.67	26.75
	f_h inside	23.82	23.77
$D+1.25P_a+1.25E_o$	f_m outside	-2.22	-2.99
Applied @ c.g. of	f_n outside	-0.41	-0.16
Concrete Section	$f_{seis.}$ (3)	9.70	9.47
	$f_{seis.}$ (4)	-12.34	-12.63
	f_m inside	38.37	39.34
	f_h inside	1.98	2.12
$D + P_a + E_s$	f_m outside	37.70	37.70
Applied @ c.g.	f_h outside	25.08	25.07
of Rebar	$f_{seis.}$ (3)	57.41	57.41
	$f_{seis.}$ (4)	5.37	5.37
	f_m inside	12.74	12.73
	f_h inside	19.01	19.01

56 56 56

TABLE 3F-8
(Sheet 2 of 2)

Load Condition	Parameter	LESCAL (Ksi)	Hand Calculations
$D+1.25P_a+1.25E_o$	f_m outside	-2.01	-1.77
Applied @ c.g.	f_h outside	7.33	7.82
of Rebar	$f_{seis.}$ (3)	16.07	16.08
	$f_{seis.}$ (4)	-10.76	-10.02
	f_m inside	40.94	40.64
	f_h inside	9.54	10.06

56

LESCAL runs on the Honeywell 66/60 system.

Notes (3) and (4) indicate directions of seismic rebars.

56

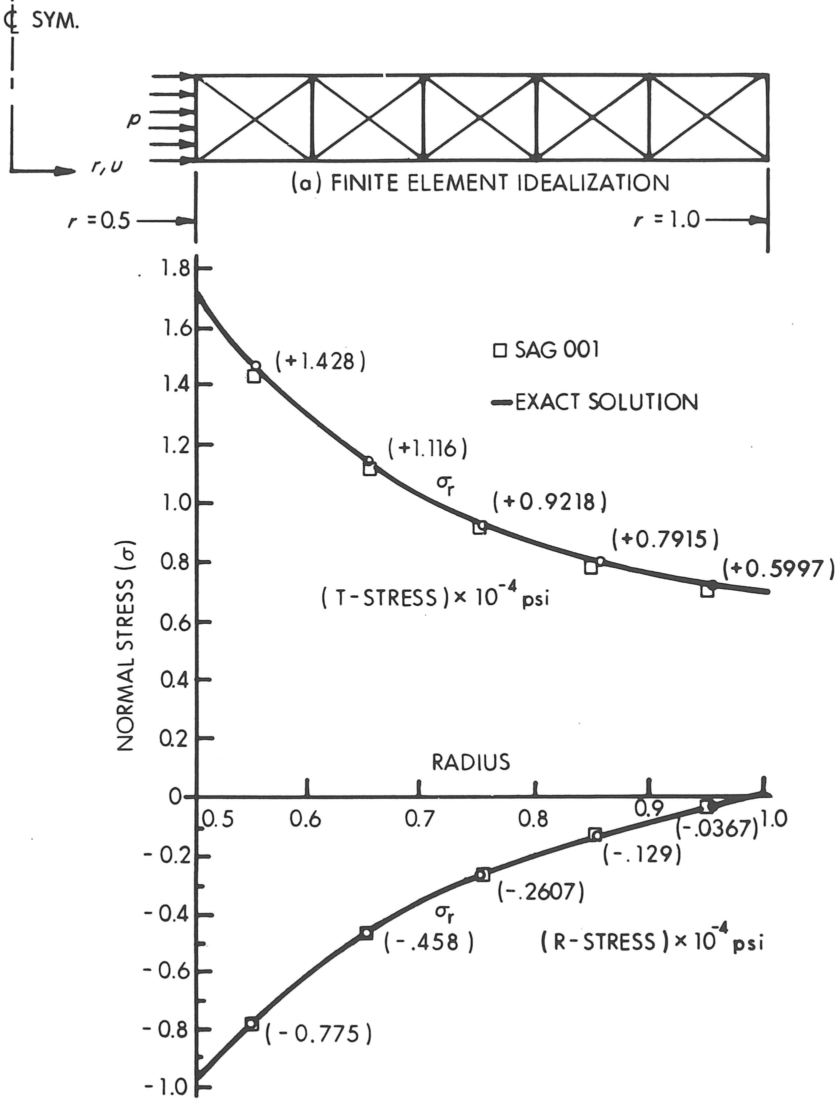
References:

(1) Duchon, N. B., "Analysis of Reinforced Concrete Membrane Subject to Tension and Shear," ACI Journal, September 1972, pp. 578-583.

TABLE 3F-9

SAG054 (RESPONSE ENVELOPE)

SAG054 is a post-processing program for STARDYNE which is used in seismic analysis The program spreads the peaks of the amplified response spectra created by SAG058 (See Table 3F-1) by a predetermined amount and tabulates the ordinates and abscissas of the resulting curve. Verification of this program is accomplished by visual inspection of the graphical output to insure that the raw data has, in fact, been enveloped. SAG054 runs on the CDC CYBER-175 svstem.

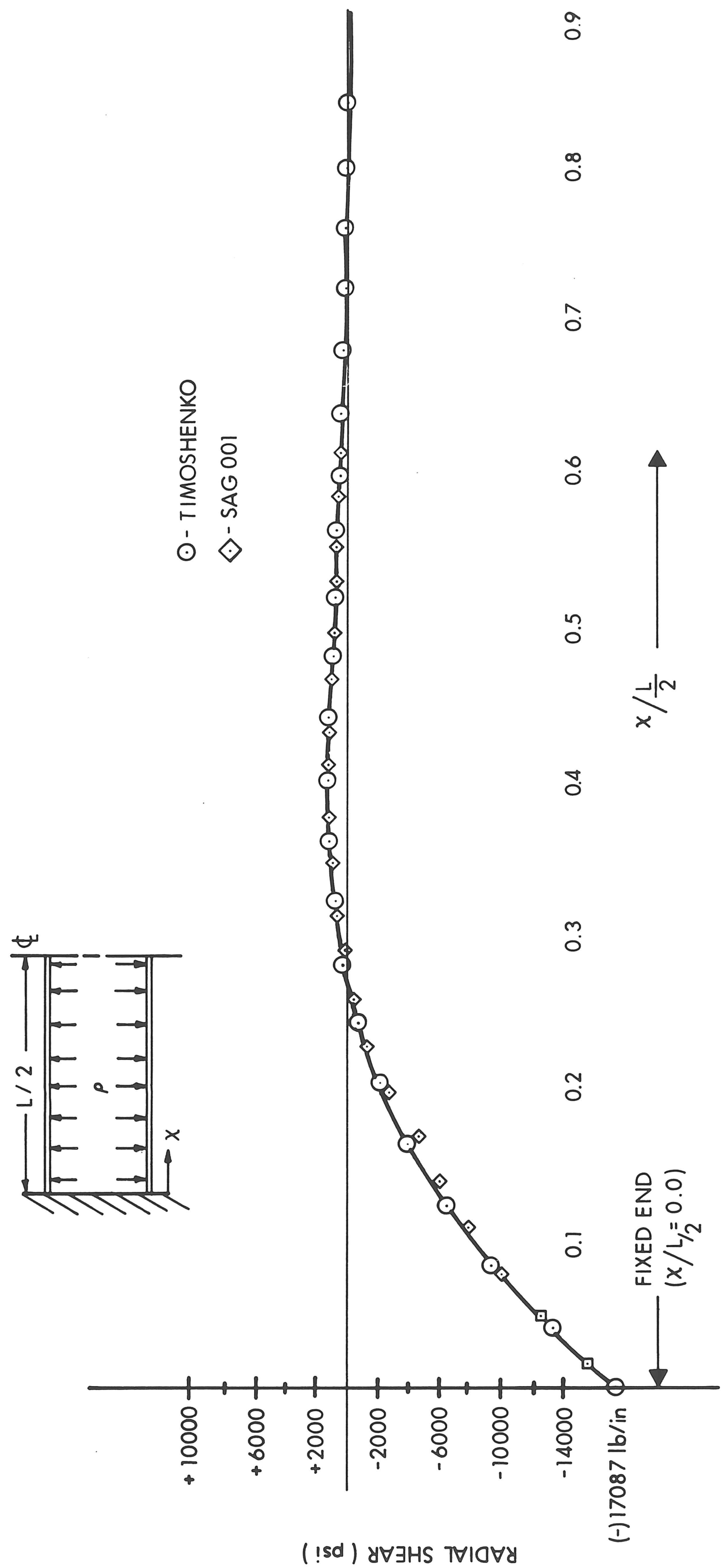


(b) CALCULATED STRESSES

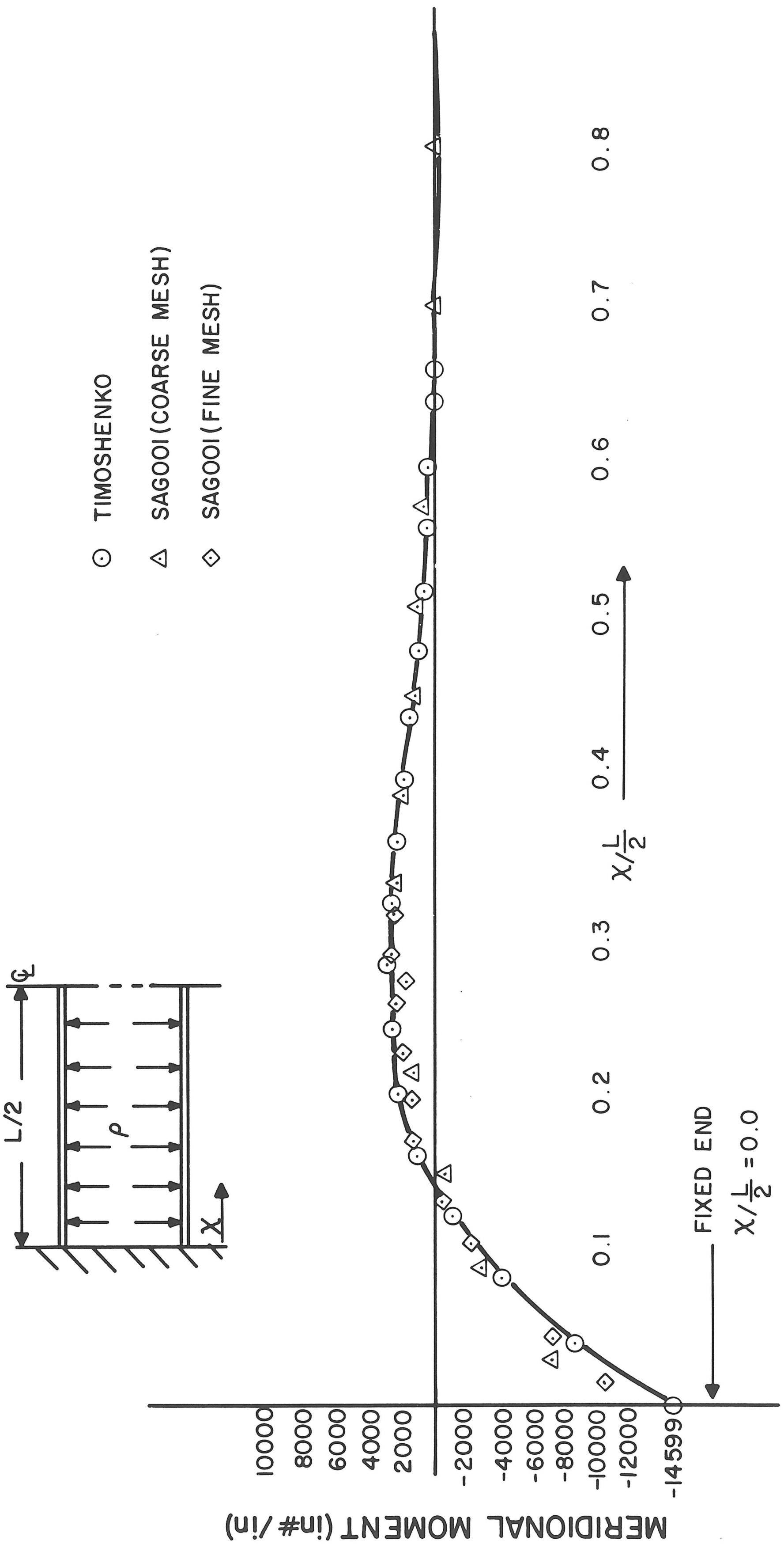
ANALYSIS OF THICK-WALLED CYLINDER UNDER INTERNAL PRESSURE

REFERENCE: GALLAGHER, R.H., FINITE ELEMENT ANALYSIS, PRENTICE-HALL, INC. 1975. FIGURE 11.5, PG.317

PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE SEABROOK STATION - UNITS 1 & 2 FINAL SAFETY ANALYSIS REPORT	SAG001 SAMPLE PROBLEM NO.1
	FIGURE 3F-1



PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE SEABROOK STATION - UNITS 1 & 2 FINAL SAFETY ANALYSIS REPORT	SAG001 SAMPLE PROBLEM NO.2 RADIAL SHEAR
	FIGURE 3F-2



PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE SEABROOK STATION - UNITS 1 & 2 FINAL SAFETY ANALYSIS REPORT	SAGOO1 SAMPLE PROBLEM NO. 2 MERIDIONAL MOMENT
	FIGURE 3.F-3