AN ECONOMICAL PROCEDURE FOR SMALL PIPE SUPPORT DESIGN

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SUMMARY

It is costly and time consuming to perform detailed static and dynamic analyses by computer programs for all piping systems in nuclear power plants. The purpose of this paper is to present an economical procedure (to determine support spacings and support design loads for ASME Section III Class 2 and 3 piping systems with small diameters) which does not require the use of computer programs, but still gives results which satisfy the ASME code requirements conservatively.

The procedure consists of choosing the support locations such that both the maximum weight and seismic span requirements and the minimum thermal span requirements are satisfied and then determining the support design loads for the chosen configuration. These span requirements and design loads are given in a set of tables and figures prepared as follows:

(1) A table (for each building) of maximum weight and seismic support span length and support load as functions of pipe size and schedule - Based on the "Modified Spectrum Method" of dynamic analysis and implemented by Bechtel computer program ME602. Maximum stresses of 0.6 S_h and 0.1 S_h are the criteria for maximum seismic spans and maximum dead weight spans respectively.

(2) A curve showing the normalized equivalent span length ($\ell/(L+S)$) for a bend as a function of the ratio of leg lengths (S/L) - Based on the equivalence of the fundamental natural frequency of a straight pipe of length ℓ and that of a 90° bend with short leg length S and long leg length L under corresponding end conditions.

(3) A table of span reduction ratio L_2/L_1 due to a concentrated weight as a function of L_1/a and W/wa - Based on the equivalence of the static and dynamic maximum bending moments in a uniform pipe of unit weight w and length L_1 and those in a uniform pipe of unit weight w and length L_2 with a concentrated weight W located at distance a from one of the supports.

(4) A set of curves for the thermal expansion coefficient as a function of temperature for various pipe materials.

(5) A table of minimum flexible length as a function of thermal growth and pipe size and of thermal support load as a function of the actual flexible length and pipe size and schedule - Based on the "Guided Cantilever Method" of flexibility analysis. The maximum stress of 0.67 S_A is the criterion for the minimum flexible lengths. This leaves 0.33 S_A to accommodate stresses due to seismic anchor movements.

(6) A table of maximum anchor moments as functions of pipe size and schedule - Based on the conservative assumption that the adjacent piping carries its full allowable stresses due to dead weight, seismic (SSE, taken as twice the OBE loading), thermal and seismic anchor movement loading simultaneously.

The specific types of tables and figures which, once prepared, enable small pipe support designs with great timesaving and costsaving are believed to be new and significant for the nuclear power industry.

1. Introduction

With several tables and figures properly prepared for a specific nuclear power plant the determination of support spacings and support design loads for small piping systems (say, 2" nominal pipe size and smaller) can be achieved by a simple procedure without using any digital computer program. This paper describes this procedure and presents the analytical bases of preparing these tables and figures such that the satisfaction of ASME Section III requirements for Class 2 and 3 piping [1] can be assured. Example tables and figures for a typical nuclear power plant are given.

2. Procedure for Locating the Supports

Pipe supports are located such that both the maximum weight and seismic span requirements and the minimum thermal span requirements are satisfied. The maximum allowable vertical support spans (for dead weight and "operating basis earthquake" (OBE)) and the maximum allowable horizontal support spans (for OBE) are given for each building in a table such as Table I. At bends the total bend length must be shorter than the allowable straight span by a factor given in Figure 1. Whenever a concentrated weight is present the allowable span must be reduced by a ratio given in Table II.

The minimum flexible length L_m required to absorb a thermal expansion Δ (which is obtained as the product of pipe length and the expansion coefficient given in Figure 2 plus the thermal anchor motion, if any) can be calculated from the data in a table such as Table III. When the thermal expansion Δ is to be absorbed by more than one flexible legs perpendicular to it (say, n legs of length L_1, L_2 ... L_n) it should be distributed into n portions δ_i (to be absorbed by L_i) according to the formula

$$\delta_i = \Delta L_i^3 \Big/ \sum_{j=1}^{n} L_j^3, \quad (i = 1,2,\ldots n) \tag{1}$$

3. Determination of Pipe Support Loads

When the pipeline has been supported to meet the flexibility and weight and seismic span criteria of Section 2 the support loads can be determined by using one of the two methods:

3.1 Component Load Method

The total design load for each support is the summation of the dead weight (for vertical supports only), the "safe shutdown earthquake" (SSE) seismic load, the thermal load and the appropriate loads due to concentrated masses (including masses of pipe sections parallel to the supports). The design moments at an anchor can be read off from Table III.

The dead weight loads for vertical supports are given in Table I. The SSE seismic loads are taken as two times the OBE loads given in Table I. The thermal design load R can be calculated from the data in Table III. Alternatively more conservative values of maximum thermal loads can be read off from Table I. The design loads R_m due to concentrated masses can be evaluated (with ZPA and MRA data given in Table I) as follows and distributed according to the simple beam formula to the adjacent supports:

(a) For dead weights in vertical direction

$$R_m = \text{(concentrated mass) (gravitational acceleration g)} \tag{2}$$

(b) For axial seismic loads (horizontal or vertical)

$$R_m = 2 \text{ (concentrated mass) ("zero period acceleration" ZPA)} \tag{3}$$

(c) For laterial seismic loads (horizontal or vertical)

$$R_m = 2 \text{ (concentrated mass) ("maximum response acceleration" MRA)} \tag{4}$$

3.2 Design Load Method

For this method conservative estimates of the total design loads have been tabulated in Table I for "Type A" and "Type B" supports and in Table III for intermediate and terminal anchors. "Type A" supports are those needed to resist thermal expansions such as supports adjacent to elbows or to anchors with thermal motions. All other supports are called "Type B." Simply read off the design load for each support from Table I or Table III.

4. Analytical Bases for Preparation of the Tables and Figures

4.1 Maximum Support Spans

Maximum support spans given in tables such as Table I are determined by considering both seismic and dead weight effects. The maximum dead weight spans are taken from Table 121.1.4 of ANSI B31.1 code [2] (which is based on a maximum stress of 0.1 S_h where S_h = ASME primary allowable stress for pipe material at the maximum operating temperature). For any pipe size not listed in the code the span is determined by computing the length of a simply supported beam such that the maximum stress due to its own weight (including water and 2" insulation) is equal to 0.1 S_h and then rounding off the length to the nearest whole footage.

The maximum seismic spans are determined by the "Modified Spectrum Method" of dynamic analysis [3] in which the spectrum curve for a particular building elevation is modified so that the flexible side of the peak of the curve remains constant at the peak spectral acceleration for decreasing frequencies (so that the analysis is simplified and the results are conservative). The numerical computation to implement this method is performed by using the Bechtel computer program ME602 [4]. For each building in the plant the SRSS (square root of the sum of squares) of two horizontal OBE modified response spectra (with 1% damping at the highest elevation) and the corresponding vertical OBE modified response spectrum is applied to a simply supported pipe. The program calculates the maximum stresses in the pipe for a number of pipe spans until the desired span is reached in which the maximum stress is just below 0.6 S_h and the fundamental frequency is not less than 5 cps. The stress intensification factor needed in this calculation is conservatively taken as 2.10 for socket-welded pipes (see [1], Fig. NC-3673.2(b)-1).

4.2 Equivalent Span Length for Bends

The curve given in Figure 1 is based on the equivalence of the fundamental natural frequency of a straight pipe of length ℓ and that of a 90° bend of short leg S and long leg L with corresponding end conditions (both ends fixed, both ends pinned, short leg pinned and long leg fixed, or short leg fixed and long leg pinned). Its development is fully documented in [5].

4.3 Span Reduction Ratio Due to a Concentrated Weight

The L_2/L_1 data given in Table II are based on the equivalence of the static and dynamic maximum bending moments in a simply supported uniform pipe of length L_1 and those in a simply supported uniform pipe of length L_2 with a concentrated weight located at distance a from one of the supports. The development of this table is fully documented in [6].

4.4 Minimum Flexible Length and Thermal Support Load

The L_m and R data given in a table such as Table III are based on the "Guided Cantilever Method" of flexibility analysis (see [7], p.97). When two fixed ends of a pipe (of length ℓ, moment of inertia I and Young's modulus E) are displaced a distance Δ from each other normal to the pipe axis the maximum moment and the reaction force are given by (see, for example, [8], p.456).

$$M = \frac{6EI\Delta}{\ell^2} \quad , \qquad R = \frac{12EI\Delta}{\ell^3} = \frac{2M}{\ell} \tag{5}$$

If another displacement (normal to the pipe axis) takes place in a direction normal to the first displacement and if a stress intensification factor i is taken into account, the maximum resultant stress in the pipe with section modulus Z is

$$\sigma = \frac{\sqrt{2}i}{Z} \left(\frac{6EI\Delta}{\ell^2}\right) \tag{6}$$

Therefore for a given maximum allowable stress σ_{max} the minimum required flexible length is

$$\ell_m = \left[\frac{\sqrt{2}i}{Z} \left(\frac{6EI\Delta}{\sigma_{max}}\right)\right]^{1/2} \tag{7}$$

When the relations (L_m is the minimum flexible length in ft. and D_o is the outside diameter of the pipe in inches)

$$\ell_m = 12\ L_m \quad , \qquad \frac{I}{Z} = \frac{I}{I/(D_o/2)} = \frac{D_o}{2} \tag{8}$$

are used we have the formula for data in Table III

$$\frac{L_m}{\Delta^{1/2}} = \left(\frac{\sqrt{2}iED_o}{48\ \sigma_{max}}\right)^{1/2} \tag{9}$$

In preparing Table III σ_{max} has been taken as 0.67 S_A where S_A = ASME allowable stress range for secondary stresses.

If the actual flexible length is ℓ_a in. or L_a ft. the actual reaction force will be

$$R = \frac{12EI\Delta}{\ell_a^{\ 3}} = \frac{EI\Delta}{144\ L_a^{\ 3}} \tag{10}$$

Expressing Δ in terms of L_m obtained in eq. (9) we have

$$\frac{RL_a^{\ 3}}{L_m^{\ 2}} = \frac{\sqrt{2}\ Z\ \sigma_{max}}{12\ i} \tag{11}$$

which is given in Table III.

4.5 Component Loads and Design Loads

The dead weight component loads in Table I are the product of the pipe running weight in Table III and the corresponding maximum spans for vertical supports. The OBE component loads in Table I are results of decomposition into horizontal and vertical components of the resultant reaction forces in the ME602 computer outputs. The maximum thermal component loads in Table I are computed values of R from Table III for the case of $L_m = L_a$ = 2 ft. This is the condition of the most severe thermal loading assumed in Table I.

The "Type A Support" design loads in Table I are sums of the 2(OBE) and maximum thermal component loads for the horizontal supports and are sums of the dead weight, 2(OBE) and maximum thermal component loads for the vertical supports and then rounded off to the nearest 10 pounds. The "Type B Support" design loads in Table I are similarly computed except half of each maximum thermal component load is taken instead of the maximum thermal component load. The conservative assumption for estimating the maximum thermal loads and the inclusion of half of the maximum thermal loads for "Type B Supports" are intended to compensate for a reasonable amount of support loads due to concentrated masses when the "Design Load Method" is used. However, spans containing very heavy components are better analyzed by the "Component Load Method."

In order to account for additional support loads due to concentrated masses by the "Component Load Method" it is necessary to use the ZPA and MRA data in Table I. ZPA data are taken from the building OBE acceleration spectra (horizontal and vertical) as the response accelerations corresponding to the "rigid range" periods and 1% damping. ME602 computer outputs print out the response accelerations (horizontal and vertical) of each pipe span corresponding to its natural frequency. The MRA data in Table I are the maximum values of these response accelerations among all the pipe spans covered in each table.

4.6 Maximum Anchor Loads

The force loading in Table III is taken as the maximum "Type A Support" loads (vertical and horizontal) among all the buildings in tables such as Table I for an intermediate anchor and half of this maximum for a terminal anchor. The moment loading in Table III is based on the assumption that the adjacent piping is carrying its full allowable stresses due to dead weight, SSE seismic and thermal and seismic anchor movement loading simultaneously. Thus the maximum possible total component moment at each terminal anchor is

$$M_x = M_y = M_z = [0.1\ S_h + 2(0.6\ S_h) + 0.67\ S_A + 0.33\ S_A]\ Z/\sqrt{3} \tag{12}$$

and at each intermediate anchor (consider both upstream and downstream of the anchor) is

$$M_x = M_y = M_z = 2\ [2(0.6\ S_h) + 0.67\ S_A]\ Z/\sqrt{3} \tag{13}$$

(dead weight moments being cancelled out between the upstream and downstream sides and seismic anchor motions being non-existent).

5. Satisfaction of ASME Stress Limits

Since the tables and figures have been prepared such that the maximum stresses due to dead weight, OBE and thermal expansion are 0.1 S_h, 0.6 S_h and 0.67 S_A respectively eq. (9) of ASME Section III [1] Subsection NC-3652 for primary stresses is satisfied whenever the maximum stress due to the internal pressure does not exceed 0.5 S_h, and eq. (10) in the same ASME subsection for secondary stresses is satisfied whenever the maximum stress due to the OBE seismic anchor movements does not exceed 0.33 S_A. These stress values due to internal pressure and seismic anchor movements are in practice rarely exceeded for small diameter piping systems.

6. Conclusion

An economical procedure for small pipe support design has been presented which is simple to apply and which gives conservative results.

7. Acknowledgement

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References

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Table I

MAXIMUM SUPPORT SPAN AND DESIGN LOAD

Plant Area	Nominal Pipe Size (in.)	Pipe Schedule	Horizontal Support					Vertical Support					
			Maximum Span (ft)	Component Load (lb)		Design Load (lb)		Maximum Span (ft)	Component Load (lb)			Design Load (lb)	
				OBE	Maximum Thermal	Type A Support	Type B Support		Dead Weight	OBE	Maximum Thermal	Type A Support	Type B Support
Auxiliary	1/2	40	5.75	13	17	40	30	4.00	10	9	17	50	40
Building		80	6.00	16	20	50	40	4.00	11	10	20	50	40
		160	6.25	20	22	60	50	4.00	12	10	22	50	40
	3/4	40	7.00	22	30	80	60	5.00	15	14	30	70	60
		80	7.25	29	36	90	70	5.00	16	15	36	80	60
		160	7.50	33	43	110	80	5.00	18	17	43	100	70
	1	40	8.25	35	56	130	100	7.00	27	31	56	150	120
		80	8.75	47	68	160	120	7.00	30	32	68	160	130
		160	8.75	51	80	200	160	7.00	34	35	80	180	140
ZPA_H=0.45g	1-1/2	40	10.50	71	137	280	210	9.00	51	65	137	320	250
ZPA_V=0.38g		80	11.00	91	174	370	280	9.00	58	69	174	370	280
MRA_H=1.67g		160	11.25	111	214	440	330	9.00	68	76	214	430	330
MRA_V=1.43g	2	40	12.00	110	236	460	340	10.00	74	90	236	490	370
		80	12.50	139	308	590	440	10.00	86	95	308	580	430
		160	13.00	190	412	800	590	10.00	107	112	412	750	540

Notes: 1. "Type A" supports are those needed to resist thermal expansions such as supports adjacent to elbows or to anchors with thermal motions. All other supports are called "Type B."

2. ZPA = zero period acceleration. MRA = maximum response acceleration. Subscripts H and V indicate horizontal and vertical directions, respectively. See the text for proper usage of these data.

Table II

SPAN REDUCTION RATIO L_2/L_1 DUE TO A CONCENTRATED WEIGHT

W/wL_1	L_1/a 20	15	10	8	6	4	3	2.5	2
0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.100	0.990	0.986	0.980	0.974	0.965	0.947	0.928	0.912	
0.200	0.980	0.973	0.958	0.947	0.928	0.887	0.842	0.820	
0.225									
0.300	0.969	0.958	0.936	0.918	0.887	0.816	0.750		
0.400	0.958	0.943	0.912	0.887	0.842	0.726	0.677		
0.417							0.667		
0.500	0.947	0.928	0.887	0.854	0.789	0.640			
0.600	0.936	0.912	0.861	0.816	0.723	0.573			
0.700	0.924	0.896	0.832	0.774	0.634	0.521			
0.750						0.500			
0.800	0.912	0.879	0.800	0.724	0.551				
0.900	0.900	0.861	0.765	0.658	0.485				
1.000	0.887	0.842	0.724	0.566	0.434				
1.200	0.861	0.800	0.600	0.427	0.364				
1.333					0.333				
1.400	0.832	0.752	0.439	0.344					
1.600	0.800	0.692	0.340	0.293					
1.800	0.765	0.600	0.281	0.260					
1.875				0.250					
2.000	0.724	0.433	0.243						
2.200	0.673	0.324	0.218						
2.400	0.600	0.258	0.200						
2.600	0.440	0.217							
2.800	0.321	0.189							
3.000	0.250	0.177							
3.200	0.206	0.156							
3.400	0.176	0.145							
3.600	0.156	0.136							
3.683		0.133							
3.800	0.141								
4.000	0.130								
4.200	0.121								
4.400	0.114								
4.600	0.108								
4.800	0.103								
4.950	0.100								

w = Pipe weight per unit length
W = concentrated weight
L_1 = maximum allowable pipe span
L_2 = maximum allowable span for pipe with concentrated weight

(Note) "a" is measured from the end closer to "W." ($L_2 > 2a$.) The last entries in the columns represent data for $L_2 = 2a$.

Table III

PIPE RUNNING WEIGHT, FLEXIBLE LENGTH AND MAXIMUM ANCHOR LOADS

Nominal Pipe Size (in.)	Pipe Schedule	Pipe Running Weight* (lb/ft)	Flexible Length** $\frac{L_m}{\Delta^{1/2}}$ (ft-in.$^{-1/2}$)	$\frac{RL_a^3}{L_m^2}$ (ft-lb)	Maximum Anchor Loads: Intermediate Anchor $F_x=F_y=F_z$ (lb)	Intermediate Anchor $M_x=M_y=M_z$ (ft-lb)	Terminal Anchor $F_x=F_y=F_z$ (lb)	Terminal Anchor $M_x=M_y=M_z$ (ft-lb)
1/2	40	2.470	9.7967	34	70	130	40	80
	80	2.677	9.7967	40	70	150	40	100
	160	2.866	9.7967	44	80	170	40	110
3/4	40	2.960	10.9531	59	100	230	50	140
	80	3.259	10.9531	72	120	270	60	180
	160	3.664	10.9531	85	130	320	70	210
1	40	3.791	12.2576	112	210	420	110	270
	80	4.221	12.2576	135	270	510	140	330
	160	4.808	12.2576	160	290	610	150	390
1-1/2	40	5.644	14.7339	274	430	1040	220	660
	80	6.442	14.7339	347	540	1310	270	840
	160	7.514	14.7339	428	710	1620	360	1030
2	40	7.401	16.4730	472	680	1780	340	1140
	80	8.597	16.4730	615	970	2320	490	1480
	160	10.712	16.4730	824	1140	3110	570	1980

NOTES: L_m = minimum flexible length (ft)

L_a = actual flexible length (ft)

Δ = thermal growth (in.)

R = thermal design load (lb)

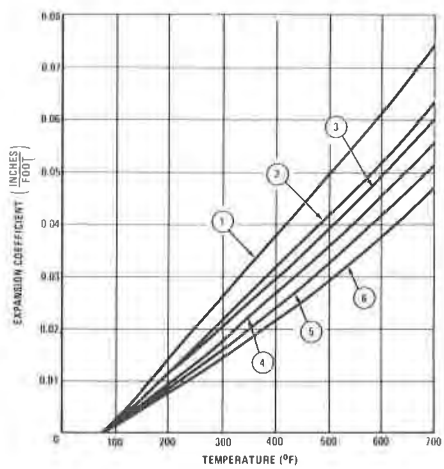
*The pipe running weight includes the weight of pipe, weight of water and weight of 2" insulation.

**In this calculation the stress intensification factor has been conservatively taken as 2.10 for socket-welded pipes.

Figure 1
EQUIVALENT SPAN LENGTH FOR BEND

L = LENGTH OF LONG LEG OF BEND
S = LENGTH OF SHORT LEG OF BEND
ℓ = LENGTH OF EQUIVALENT STRAIGHT RUN

Figure 2
EXPANSION COEFFICIENT FOR STEEL



MATERIALS

1 – AUSTENITIC STAINLESS STEEL
2 – 25% CR. – 20% NI.
3 – NICKEL-CHROME-IRON
4 – CARBON STEEL
5 – 5 TO 9% CHROMIUM STEEL
6 – 12% TO 17% CHROMIUM STEEL