STAFF EVALUATION OF THE EFFECT OF OVERTHICKNESS IN PIPE FITTINGS

I INTRODUCTION

Wrought steel butt welding fittings made according to the requirements of the ANSI B16.9 or ANSI B16.28 standards have been used for many years in piping systems, including nuclear power plants, and have generally given satisfactory service. It has recently become apparent to the staff that the actual wall thickness of elbows and tees made to these standards is considerably larger than the nominal wall thickness assumed by piping designers in their design analyses. The purpose of this report is to address the significance of overthickness in pipe fittings when used in safety-related piping systems and their effect on the calculational results of the piping design analyses.

II BACKGROUND

In May 1983, during a routine safety inspection of the Beaver Valley Power Station Unit 2 conducted by the NRC Region I staff, a potential concern was identified regarding the overthickness of elbows and tees in the emergency diesel generator exhaust piping system. The actual wall thickness and weight of elbows and tees used in the installation were about twice the nominal values used in the procurement specifications and design analyses.

Subsequently, NRR was requested to review and evaluate the significance of using overthickness pipe fittings in the safety-related systems at Beaver Valley-2 and to address the generic significance of this issue.

On July 27, 1983 the NRC staff (NRR and Region I) and its consultants from Oak Ridge National Laboratory met with representatives from Duquesne Light Company and Stone & Webster Engineering Corporation to discuss the applicant's response to the inspection finding. A summary of the meeting is discussed in Reference 1. At the conclusion of the meeting, the applicant proposed to provide a report to the staff addressing the influences of overthickness pipe fittings on the diesel generator exhaust system and the generic influences of these fittings on the NRC benchmark piping problems (Reference 2).

In a letter from E.J. Woolever (DLC) to R.W. Starostecki (USNRC) dated October 25, 1983, the applicant transmitted its final report to the staff addressing the issue of overthickness fittings. The staff has reviewed the October 25, 1983 report and has based our evaluation on the results presented in that report. Our evaluation is discussed in detail in Section V of this report.

Before addressing the significance of the overthickness pipe fitting, it would be beneficial to discuss some of the underlying factors which might have contributed to the as-manufactured condition of the overthickness fittings. We will briefly discuss the dimensional controls established by current standards and some common manufacturing practices that are used by several pipe fitting manufacturers.

III DIMENSIONAL CONTROLS

The ANSI B16.9 standard covers long radius elbows, tees, crosses, lap joint stub ends, caps, and reducers. ANSI B16.28 covers short radius elbows. Fittings made to these standards are usually accepted without additional requirements. Design requirements including the rules for the design and analysis of ASME Code* Class 1, 2, and 3 piping systems are contained in Subarticles NB/NC/ND-3600 of the ASME Code (Reference 3). The ASME Code accepts the use of B16.9 fittings and B16.28 short radius elbows provided the wall thickness of short radius elbows meet the additional requirements of NB-3642.2 for Class 1 piping systems. For Class 2 and 3 piping systems, the Code considers butt welding elbows to be suitable for use with pipe of the same nominal wall thickness and of the same material. Design analysis formulae, stress indices, stress intensification factors, and flexibility factors are based on the assumption that the dimensional characteristics of the fittings are within reasonably close tolerance to those specified in the ANSI standards. Neither of the standards, however, give complete and explicit control of all the dimensional

*The term "Code" refers to the ASME Boiler & Pressure Vessel Code, Section III.

characteristics that are important for an accurate design stress analysis. Thus, the piping designer does not have complete assurance that fittings purchased under the standards will be compatible with the method of analysis specified in NB/NC/ND-3600 of the ASME Code.

Prior to 1977, the dimensional controls contained in the butt welding fitting standards consisted of:

a) center-to-ends or overall length, with tolerance,
b) outside and inside diameters at the ends, with tolerance,
c) angularity tolerances for the end planes, and
d) minimum wall thickness requirements. (Ref. 4)

For design stress analysis purposes, an important dimensional characteristic not controlled was the maximum wall thickness (except at the ends by diameter control). Until 1977, none of the butt welding fittings standards contained an over-tolerance on wall thickness or weight. In the 1977 Edition of Manufacturing Standardization Society (MSS) standard practice SP-87 a requirement was added to control the actual thickness of pipe elbows and tees. The MSS-SP-87 standard in Chapter 8 states:

> 8.1.3 The actual thickness of the elbows may not exceed 1.25 times the nominal wall, except as follows:
>
> a) For short radius elbows, since the nominal wall must be increased by 20% to compensate for shape, the actual thickness of this elbow may not exceed 1.5 times the nominal wall.
> b) For elbows with a counterbore or other close tolerance internal machining, the thickness must be increased to provide material for these additional machining operations. For these elbows, thickness up to the next higher schedule than the nominal wall may be used. Where there is no next higher schedule the wall may not be thicker than 1.33 times the nominal wall. For short radius elbows,

the next higher schedule above the adjusted nominal wall may be used, or where there is no next higher schedule the wall may not be thicker than 1.33 times the adjusted nominal-wall.

Furthermore, for tees the MSS-SP-87 standards states:

8.2.4 The actual thickness throughout the body except in the crotch may not exceed 2½ times the nominal wall thickness of the matching run pipe.

The MSS-SP-87 standard was subsequently adopted by the ASME Code in the Winter 1978 Addenda (issued December 31, 1978) in its reference to the MSS-SP-87 standard per Table NB-3132-1. However, prior to the MSS-SP-87 standard, there were no standards which controlled overthickness in pipe fittings.

As a result, a schedule 80 elbow taper-bored on the ends to schedule 40 dimensions could have fully met the fitting standards. However, from a piping system analysis standpoint, the wall thickness value which was used to calculate the flexibility factor (k), the stress index (C_2), and, the stress intensification factor (i) would have been incorrect. The significance of using nominal values versus actual dimensions is discussed in Section V of this report.

VI MANUFACTURING PRACTICES

Subsequent to the July 27, 1983 meeting with Duquesne Light Company and Stone & Webster (SWEC), the staff consultants surveyed several manufacturers of pipe fittings and briefly discussed our concern with overthickness of pipe elbows. The manufacturers were asked if they knew of any reasons why elbows for nuclear power plant piping would tend to be thicker than the nominal wall thickness. The following manufacturers were contacted (Reference 5).

1) Tube Turns
2) Taylor Forge
3) Crane

4) Ladish

5) Flowline

The answers provided were as follows:

(1) If elbows are ordered to be counterbored, it is common practice to use the next available heavier wall thickness to assure minimum wall. All except Taylor Forge cited this cause; Tube Turns had some maybe's.

(2) Depending upon the manufacturing practice, the wall thickness of elbows may be thin in the back region, thick in the crotch region. The starting material must be increased to compensate for the thinning. In elbows for nuclear power plants, the manufacturers are very aware of "quality control" and they may go heavier to make absolutely sure they will not have under-thickness. All except Tube Turns mentioned this.

(3) Raw material availability is an increasing problem. Let us suppose and elbow manufacturer wishes to start with a raw material that is 10% thicker than nominal. Let us suppose that nominal is 0.375" so the manufacturer wants to get pipe or plate with wall thickness of 1.1 x 0.375 = 0.412 in. Can the elbow manufacturer get that thickness in pipe or plate? Pipe and plate manufacturers, in streamling their operations, are becoming less willing to supply small quantities of "odd ball" wall thickness. Accordingly, the elbow manufacturer may be forced to use 0.500-in. wall pipe or plate. All five manufacturers mentioned this aspect.

(4) Buckling of large D/t elbows. Taylor Forge mentioned this although Ladish perhaps should have since it may be particularly relevant to the 38x0.375" nominal wall elbow at Beaver Valley-2. In making elbows with large D/t, it may be necessary to increase the wall thickness to prevent buckling (wrinkling) of the elbow.

From the informal discussions described above, the staff has found that:

(a) If elbows are ordered with a counterbore (ANSI B16.25 standard C-dimension), the chances are high that the wall thickness will be significantly (30% or more) greater than nominal.

(b) Elbows for nuclear power plants are a bit more likely to be over-thickness because of more concern about having under-thickness.

(d) Decrease in raw material availability of various sizes tends to lead toward increased elbow wall thickness. This applies to non-nuclear as well as nuclear piping.

Thus, it appears that in recent years pipe elbows have become progressively thicker. The staff took a few actual measurements of randomly selected pipe elbows and tees at the Beaver Valley-2 facility. The measurements were taken with a portable ultrasonic testing device (NORTEC NDT-131 Ultrascope). Attachment A to this report summarizes the wall thickness measurements obtained at Beaver Valley-2. The results appear to indicate that overthickness of elbows is prevalent throughout the Beaver Valley-2 facility and is likely to exist in most nuclear facilities today.

V SIGNIFICANCE OF OVERSIZED PIPE FITTINGS

The applicant for the Beaver Valley-2 facility has provided the staff with a report entitled, "Structural Review of Piping Analysis Including Effect on Heavy Elbows," dated October 1983 (Reference 6). The report presents the many conservatisms inherent in the analysis of piping systems. The report also presents the results of a generic study performed on four sample piping models. The conclusion of the report is that the data presented in the study "provides a sufficient basis to conclude that the current design methods, which use SSE ARS having 1 percent of critical equipment damping and nominal standard weight fittings, will yield conservative pipe stress results and conservative pipe support loads."

The staff has reviewed the applicant's report and has found that the report contains a considerable amount of detailed results comparing the loads and stresses for three different cases; 1) standard fittings, 2) heavy fittings, and 3) extra heavy fittings.

The "standard fittings" models used the nominal wall thickness of elbows and tees that would normally be used in piping design analyses. The "heavy fittings" models used a value for the fittings equal to twice the nominal wall thickness. The "extra-heavy" fittings" used a value for the fittings equal to three times the nominal wall thickness. The staff believes that the models for "heavy fittings" (2 x nominal wall thickness) are likely to be bounding for the fittings installed in the Beaver Valley-2 facility.

The applicant's report contains the results for

1) pipe stresses,
2) anchor loads, and
3) support loads.

The results include the loads resulting from thermal, weight, and seismic loadings. However, the staff finds the report to be inadequate because the results have not been appropriately evaluated by the applicant (neither quantitatively nor qualitatively). The report draws its conclusions based on the many conservative assumptions used in piping dynamic analysis. However, the report does not explicitly address the significance of the tabulated results. Furthermore, the conservatisms used in static (weight and thermal) analysis methods are not sufficiently discussed.

Consequently, the staff has interpreted the "raw data" provided in the applicant's report. Using the tabulated values provided in the report (Figures 7.9 through 7.38 of Reference 6), the staff has calculated the average increase or decrease in piping stresses, anchor loads, and restraint loads that could result from using oversized fittings. The evaluation was performed for thermal, weight, and seismic loadings. The results are summarized in Attachment B to this report.

The average load change was calculated as follows: (e.g. for "heavy fittings")

$$\text{load change} = \frac{\text{heavy fittings value} - \text{standard fittings value}}{\text{standard fittings value}}$$

Thus, a positive load change indicates that the heavy fitting results in a load increase. A negative load change indicates that the heavy fitting results in a load decrease. The load change is defined as the "percent change divided by 100." The load change was calculated for all the node points provided in the applicant's report tables. The "average load change" was calculated as follows and is simply the arithmetical mean of the load changes:

$$\text{Average Load change} = \frac{\Sigma x}{n}$$

where n = total number of node data points provided for the particular evaluation

x = load change for a specific node point

A detailed evaluation of each of the selected components and their loadings is discussed in the following sections with regards to the significance of using oversized fittings. We will discuss only the effect of "heavy" fittings.

Pipe Stresses (Thermal)

The effect of "heavy" elbows and tees on piping system stresses subjected to thermal loadings tend to decrease such stresses in the fittings when the piping system is modelled with oversized fittings. The average decrease was 35%. The decrease can be attributed to the larger moment of inertia of the elbow and tee cross-sectional area due to the increased thickness.

For straight pipe and anchors, the thermal stresses increased significantly. For straight pipe, the average stress increase was 43% whereas, for piping connected to anchors, the average thermal stress increased 40%. For the straight pipe the individual stress change values were either very high or very low which resulted in a large standard deviation value of 0.63. This would indicate that the effect of the oversized fittings on straight pipe is a function of the piping system configuration.

Pipe Stresses (Weight)

For elbow and tees, the pipe stresses due to the weight loading tend to decrease approximately 33%. The load change was very similar to the thermal load change (35%) and is also likely to be attributed to the increased moment of inertia.

For straight pipe and anchors, there was a small increase in the pipe stresses. Individual load changes were either very large or very small which resulted in a large standard deviation value of 0.32. However, the actual stress magnitude was generally found to be a small value when the percent stress increase was large (i.e. a 50 psi stress increasing to a 100 psi stress would be shown as a 100% increase although the 50 and 100 psi values are relatively low stresses).

The staff concludes that the effect of the increased weight of the oversized fittings could be significant when an equipment nozzle, to which the piping is attached, has a very low allowable value. Otherwise, the effect is considered minimal.

Pipe Stresses (Seismic)

For seismic loadings, the staff reviewed only the results where a flat amplified reponse spectrum (ARS) was used. The BVPS-2 ARS results were not evaluated because the steep slopes of the ARS peaks would tend to cause large differences in the results. Thus, if the staff had used the BVPS-2 ARS, the staff would not have been able to determine whether the increase or decrease in the load change were caused by the modal frequency shift on or off the spectrum peaks or were caused by the difference in the oversized fittings. By using the results from a flat ARS, the load changes can be attributed only to the use of oversized fittings.

The seismic results indicate that for all piping stresses, the effect of oversized fittings is not significant and will decrease in elbows and tees. The small increase in straight pipe stresses is likely attributed to the small increase in the weight of the oversized fittings. However, the staff does not believe the small increase is significant.

Anchor Loads (Thermal)

The most significant impact of oversized fittings was found in its effect on anchor loads. The effect on anchor loads is important because the equipment nozzles to which the piping is attached tend to be the limiting component with respect to stress (i.e. the equipment nozzles tend to reach their allowable values prior to the piping reaching its allowable value). The staff found that the average thermal expansion load on the anchors tends to increase 40 to 50%. This large increase is attributed primarily to the increased stiffness (or conversely, a decreased flexibility) in the pipe elbows. The staff considers the effect to be significant.

Anchor Loads (Weight)

For anchor loads, the increase in the force due to the added weight of oversized fittings was found to be insignificant. The moment load was found to increase very slightly. As in the piping stress at anchors described above, the moment load percent increase was either very large or very small. However, when the percent increase was found to be very large, the actual magnitude of the moment load was found to be a small value. Thus, the overall effect of the increased weight on anchors is not significant unless the anchor (equipment nozzle) allowable load value is very low.

Anchor Loads (Seismic)

The effect of oversized fitting for seismic loads on anchors was found to be insignificant. The average load increased approximately 10%. The increase is likely to be attributed to the increase in elbow mass.

Restraint Loads (Thermal)

The thermal expansion loads on the piping supports tend to increase significantly with oversize fittings. The average load increased 36%. However, the individual load increases ranged from 8% to 82%. This indicates that the restraint loads are impacted significantly but is dependent on the piping system configuration. The results appear to be similar to the effect of oversized fittings on the stress in straight pipe.

Restraint Loads (Weight)

The staff found that the effect of the increased weight of oversized fittings is insignificant for the pipe support loads. The average load increase was found to be 3%.

Restraint Loads (Seismic)

The effect of oversized fittings on the seismic support loads was found to be insignificant. Using the results for "flat ARS" the staff found an average load increase of 4%.

VI CONCLUSIONS AND REQUIRED ACTIONS

The staff has reviewed and evaluated the results of the analyses performed by the applicant which was provided to the staff in its October 25, 1983 letter. The staff recognizes that many conservative assumptions are used in dynamic piping analysis methods. However, based on our review of the analysis results, the staff has found that the effect of oversized fittings on seismic loadings is insignificant. Thus, the staff does not believe that there is a safety concern with respect to the effect of oversized fittings on seismic loadings.

For thermal expansion loadings, the static analysis methods do not employ large uncertainties typically found in seismic analysis methods. The values used to calculate thermal expansion are reasonably accurate (±10%) and the analysis is relatively straight-forward (Reference 7). However, the staff recognizes that the modelling of anchors (equipment nozzles) with an infinite stiffness value is conservative. For those cases where equipment nozzle loads are near their allowable value, the applicant should verify with the vendor that the potential increase in thermal loads will not result in an unacceptable overloading of the equipment nozzle.

Action:

> The staff requires that the applicant address the impact of thermal expansion loads on the equipment nozzles and provide the basis for assuring that any significant increase will not impair the ability of the equipment to perform its safety-related function.

For restraints and piping other than tees and elbows, the staff believes that the effect of secondary (self-limiting) stresses due to restraint of thermal expansion can be shown to be acceptable because of local yielding or redistribution of stresses

Action:

> The staff requires that the applicant address the impact of the effect of "heavy" fittings on thermal expansion stresses for restraints and piping other than tees and elbows.

Therefore, based on an acceptable resolution of the above identified concerns, the staff believes that the issue regarding the use of oversized pipe fittings can be acceptably resolved.

REFERENCES

1) Memorandum from D. Terao to R. Bosnak dated August 18, 1983.

2) NUREG/CR-1677, "Piping Benchmark Problems," (Volume 1) dated August 1980.

3) ASME Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components," 1977 Edition.

4) Rodabaugh, E.C., Moore, S.E., and Robinson, J.N., "Dimensional Control of Buttwelding Pipe Fittings for Nuclear Power Plant Class 1 Piping Systems," ORNL/Sub/2913-5, Oak Ridge National Laboratory, December 1976.

5) Letter from E.C. Rodabaugh to S.E. Moore (ORNL) dated August 10, 1983.

6) Letter from E.J. Woolever (DLC) to R.W. Starostecki dated October 25, 1983 with attachments.

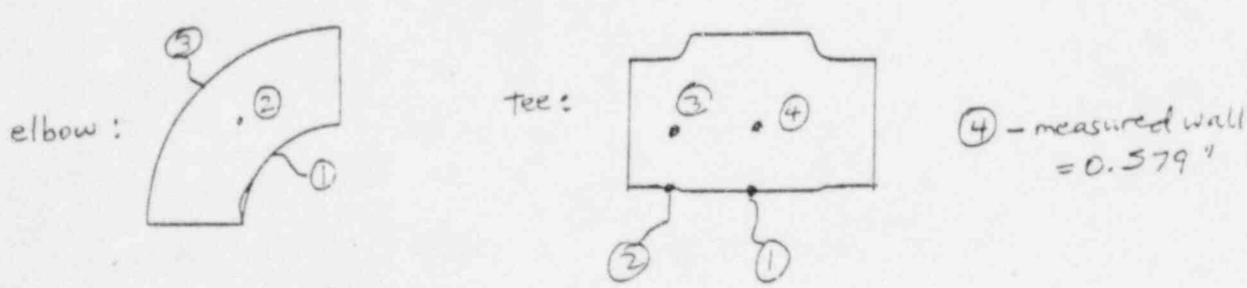
7) Rodabaugh, E.C., "Sources of Uncertainty in the Calculation of Loads on Supports of Piping Systems," (DRAFT) (Work funded by the USNRC).

ATTACHMENT A

WALL THICKNESS MEASUREMENTS
BEAVER VALLEY-2, JULY 27, 1983

Component	Manu-facturer	Mat-erial	NPS	Nom. Wall, n.	Measured Wall[a], in. 1	2	3	t_{avg}/t_{nom} (a)
90° El	Ladish	C	6	0.280	0.501	0.453	0.422	1.64
90° El	B & W	C	6	0.280	0.565	0.530	0.437	1.82
90° El	Flowline	S	6	0.718	0.881	0.720	0.711	1.07
90° El,S.R.	Flowline	S	6	0.718	0.884	0.785	0.695	1.10
90° El	Ladish	C	16	0.843	1.136	1.150	1.043	1.32
90° E'	Ladish	C ?	4	0.337	0.503	0.484	0.444	1.42
90° El	Flowline	S	12	0.375	0.639	0.585	0.512	1.54
90° El	Flowline	S	10	0.365	0.568	0.499	0.437	1.37
Tee	Flowline	S	12	0.375	0.467	0.514	0.596	1.44
Tee[b]	———	S	14	0.438		1.120		2.56
90° El[b]	———	S	14	0.438	0.607	0.496	0.485	1.18

(a)



(b) Dimensions previously measured and obtained from Glen Walton, Sen. Res. Insp. (NRC), Beaver Valley-2.

ATTACHMENT 6

COMPARATIVE RESULTS FOR OVERSIZED FITTINGS

System Component	Trend	Average Load Change (% ÷ 100)	
Pipe Stresses			
Thermal		Heavy	X-Heavy
elbows/tees	decrease	-0.35	-0.50
straight	large increase (1)	0.43	0.75
anchors (pipe)	large increase	0.40	0.55
Weight			
elbows/tees	decrease	-0.33	-0.44
straight	small increase (2)	0.33	0.56
anchors	small increase (2)	0.53	0.89
Seismic (flat ARS)			
elbows/tees	decrease	-0.62	-0.75
straight	small increase	0.16	0.27
anchors	insignificant	-0.002	0.06
Anchor Loads			
Thermal			
Force	large increase	0.50	0.70
Moment	large increase	0.42	0.56
Weight			
Force	insignificant (3)	0.04	0.09
Moment	small increase (2)	0.38	0.53
Seismic (flat ARS)			
Force	insignificant	0.10	0.18
Moment	insignificant	0.08	0.17
Restraint Loads			
Thermal	large increase	0.36	0.51
Weight	insignificant	0.03	0.06
Seismic (flat ARS)	insignificant	0.04	0.06

Notes:

(1) Individual values are typically either very large or very small.

(2) Individual % change values are typically very large or very small, however, the actual stress (or moment) is usually a small value when the % is large.

(3) One data point was not consistent with other results and is neglected.