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Analytical Considerations in the Code Qualification of Piping Systems (U)

by

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Analytical Considerations in the Code Qualification of Piping Systems

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ABSTRACT

The paper addresses several analytical topics in the design and qualification of piping systems which have a direct bearing on the prediction of stresses in the pipe and hence on the application of the equations of NB, NC and ND-3600 of the ASME Boiler and Pressure Vessel Code. For each of the analytical topics, the paper summarizes the current code requirements, if any, and the industry practice.

CHOICE OF ANALYTICAL TOPICS

In 1984 and again in 1990, several issues related to the analysis of piping systems were documented by the Pressure Vessel Research Council (PVRC) in WRC Bulletins 300 and 353 [1, 2]. More recently, within PVRC, a joint Section III and XI Review Committee provided further recommendations on the analysis and qualification of nuclear piping systems [3]. A Task Group on Analytical Methods was formed within the ASME Section III Working Group on Piping Design, to compile the topics addressed by the above PVRC reports and present, in each case, the industry practice and recommendations for improvements to Section III where appropriate. Members of the Task Group included Mesrs. T.M. Adams, K.C. Chang, G. Karshafdjian, J.E. Lucena, M.S. Sills, G.G. Thomas, E. Wais and G.A. Antaki.

Following is a summary of the topics researched by the Task Group. Several of these topics are under review by the Working Group on Piping Design to decide whether they warrant any changes to Section III.

CONTACT STRESS

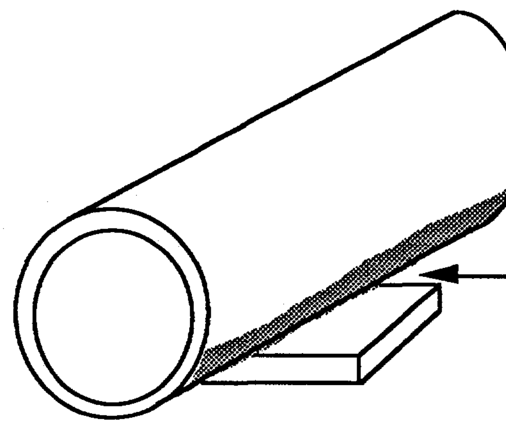

Figure 1. Local stresses at pipe - support interface

1) Source and Description of Topic

WRC-300 part III and WRC-353 Section 2.3.5 recognize that localized stresses are generated in the contact area between a pipe and a pipe support. Rules are needed to specify (a) when these stresses should be quantified and (b) how they should be evaluated.

WRC-353 Section 2.3.5 states that *"industry experience has shown that common forms of attachment, such as standard clamps and U-bolts and bearing on structural members, produce stresses in the pipe which are localized in the pipe wall and are secondary in nature, and hence can be neglected"*. The bulletin goes on however to say the *"in any case, the localized stresses must be evaluated and combined with other stresses or compared to a predefined allowable established for localized stress"*. The designer is cautioned to use loaddistributing features (such as cradles) when supporting Schedule 10 piping. WRC-300 Part III warns that *"High strength pipe clamp designs should be either avoided or carefully evaluated for their effect on local pipe wall stress".*

2) Current Code Position

Section III NB, NC and ND address the question of interaction between the pressure boundary and its attachments. The Code requires that *"the interaction effects of attachments on the pressure boundary, producing thermal gradients, localized bending stresses, stress concentrations or restraint of the pressure boundary shall be considered by the piping designer"* (NB.3651.3). Requirements for Class 2 (NC.3645) and Class 3 (ND.3645) are similar to Class 1 although the wording is somewhat different. The Code provides relief to the extent that *"standard clamps generally have a negligible effect on the pressure boundary"* [if thick-wall] (NB.3651.3).

Subsection 3200 classifies the stress due to a pipe attachment as secondary.

Section NB-3227.1 addresses bearing loads and states that *"the average bearing stress for resistance to crushing under the maximum load... shall be limited to Sy at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied [i.e. no risk of shear failure], a stress of 1.5Sy at temperature is permitted".*

The closest Subsection NF comes to addressing the contact load from the support onto the pipe is in NF-3412.4(d) where it states that *"design of functional [support] members such as interconnections ... shall consider the effect of internal pressure, thermal expansion and vibration loadings".*

Code Cases N-122, N-318, N-391 and N-392 address stresses generated on the pipe by integral welded attachments. The Code Cases provide equations for calculating stresses from the applied loads on the welded attachments, which are added to the code stress equations and compared to the code allowables.

3) Industry and Regulatory Position

The effect of pipe support loads on the pipe wall has been the subject of early studies in piping design. The Kellogg manual "Design of Piping Systems" (1955) suggests that *"when such local stresses are evaluated they should be treated in the category of secondary or localized stresses ... the allowable limit for such stresses when due to sustained loadings cannot reasonably be set at the limit for sustained primary stress S_h; instead it is recommended that a limit of 2Sh be used for design purposes".*

Today, there is no uniform commercial nuclear industry practice for the analysis of contact stresses in piping from non-welded (non-integral) supports. Most design applications did not explicitly analyze stresses induced in piping by localized contact loads. In some cases, mostly a later 1980's practice, pipe-to-support contact stresses are computed and added to the code stress equation.

Where contact stresses are calculated, they typically cover:

(a) line load from a longitudinal contact between the pipe and the flat surface of a support member.

(b) circumferential loads from a circular line load between the pipe and a circular stiff clamp, strap or collar plate.

Each of the loads is, in turn, comprised of four contributions:

(a) preload (such as tight fit or torque)
(b) internal pressure (constrained radial expansion of pipe wall)
(c) thermal expansion (constrained radial expansion and, for Class 1, thermal discontinuity). Note that in non-nuclear plants, the effects of thermal radial expansion are at times accounted for by construction rules, such as leaving the pipe clamp sufficiently loose to allow for a gap around the pipe.
(d) support reactor loads.

The pipe stress due to contact load, when calculated, is typically based on solutions such as "Formulas for Stress and Strain" by R.J. Roark and W.C. Yound or WRC Bulletin 198..

The Roark formula for contact stresses is adopted by the American Water Works Association (AWWA) "Guide for Design and Installation" (Manual M11). The AWWA manual states that "the ability of steel pipe to resist saddle load has sometimes been greatly underestimated by designers' and, consistently with Roark, recommends an allowable of 2Sy for the maximum localized stress at the saddle.

Surveys of earthquake damage to piping systems (EPRI research project RP-2635-1) does not indicate failure from contact stress effects.

The NRC has issued Information Notice 83-80 "Use of Specialized Stiff Pipe Clamps" to warn that *"piping designers who are accustomed to neglecting these localized [pipe-to-support contact] stresses because of the low magnitude stresses associated with conventional pipe clamps might incorrectly assume that such stresses can be neglected with these new [stiff] clamps".*

In conclusion, the industry practice varies from no explicit analysis (in most cases) to analysis based on stress formulas (mostly in the late 1980's). There is no evidence through tests or operational experience that contact stresses are a credible source of pipe failure.

DESIGN - BY - RULE FOR SMALL BORE PIPING SYSTEMS

1) <u>Source and Description of Topic</u>

WRC-300 Part III Section 4.7 recommends *"rather than to continue to insist on complex analytical solutions, it may be more beneficial to take our experience and develop detailed design by rule requirements that control geometry for envelopes of conditions".*

WRC-300 Part II, recommendations 4.15 and 4.16 state:

"4.15 The piping codes should be revised to require a simple analysis related to the expected mode of failure coupled with specified standard design and fabrication details," and

"4.16 Experience and judgment must be relied on as much as complicated analytical solutions."

Recommendation F-05(3) of the **PVRC Committee on Review of ASME** Nuclear Codes and Standards (1988-1991) states *"Bounding spectra with applicable limitations as developed by NCIG-EPRI should be permitted as the basis for layout and design of supports for all small bore piping (D_o = or < 2 1/2 inches)".*

2) Current Code Position

The Code provides rules for evaluation of stresses resulting from Design and Service Loads. However, the definition of these loads is the responsibility of the Owner and certificate holder, through the Design Specification.

The Code does require a stress analysis in NB-3625: *"Stress Analysis :*

"A Stress analysis shall be prepared in sufficient detail to show that each of the stress limitations of NB-3640 and NB-3650 is satisfied when the piping is subjected to the loadings required to be considered by this Sub-article."

Appendix N, Section N-1100, states *"... a dynamic system analysis is required to show how seismic loading is transmitted...".*

In NB-3672.6, the Code allows for some qualification per comparison:

"NB-3672.6 Method Of Analysis. All systems shall be analyzed for adequate flexibility by a rigorous structural analysis unless they can be judged technically adequate by an engineering comparison with previously analyzed systems."

3) Industry and Regulatory Position

The original piping Codes (B31 Series) were based on rules for proper layout and detailing of piping systems. The rules evolved to focus on analysis for operating loads (thermal expansion stress evaluation introduced by Markl in the 1950's) and, later, analysis for accident loads. The practice since the early-1970's and through the 1980's has been to qualify nuclear safety related piping by analysis. For small bore piping (2" and smaller) various "cook books" were developed over time, which were based on limiting span lengths and layouts to certain pre-analyzed configurations.

Recognizing the excessive costs and the limited value added of wholesale analysis, the nuclear industry, through EPRI, has developed rules for the seismic evaluation of small bore piping systems.

Recently (1990) EPRI and NCIG have issued a *"Procedure For Seismic Evaluation and Design of Small Bore Piping (NCIG-14)"* EPRI NP-6628, which provides criteria to design against realistic seismic failure modes. The criteria are based on the investigation of earthquake experience and test data. NP 6628 does not change current use of code rules for the evaluation of seismic anchor movements and non seismic loads, but does not require including seismic inertia stress in the qualification process.

NUMARC submitted NP-6628/NCIG-14 for NRC review, and TVA requested approval of use of NP 6628 for Bellefonte completion. The NRC responded with a request for additional information. EPRI developed a response to the NRC request consistent with recent work done by the SGD Special Task Group and work done for the Advanced Reactor Corporation First of a Kind Engineering activity related to ASME piping. This response was provided to the NRC in October 1993 with a request from NUMARC for an estimate of review cost to complete the effort.

In Generic Letter 81-14, the NRC had endorsed the use of an experience based approach including *"walkdown by personnel experienced in the analysis, design and evaluation"* to identify flagrant weaknesses in the seismic adequacy of auxiliary feedwater systems. The Generic Letter stated *"Given the time frame...no explicit analyses are requested to* *demonstrate system qualification unless deemed necessary by you".*

SUPPORT STIFFNESS RULE

1) Source and Description of Topic

WRC-353 Section 2.3.2 provides several rules for the treatment of the effects of support stiffness on a piping system. The Bulletin does not make a recommendation on whether to introduce this topic into the ASME Code.

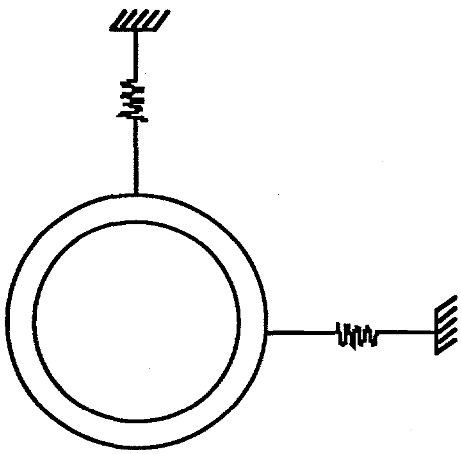

Figure 2. Supports are modeled as spring stiffnesses

2) Current Code Position

Section III NB, NC and ND do not address modeling details, such as support stiffness to be used in determining stresses for comparison against the limits in 3600. NF 3122 states that *"deformation limits for the supported piping or component shall be stipulated in the Design Specifications, if required".*

3) Industry and Regulatory Position

Among U.S. nuclear plants, a variety of piping supports/restraint stiffness criteria have been used. They have included designing pipe support restraint to a minimum stiffness or a minimum frequency of either 20HZ or 33HZ, modeling the actual stiffness (mostly in Class 1 applications), or using a deflection criterion ranging from 1/32" to 1/8".

EPRI Research Project 2967-2 developed seismic restraint stiffness criteria as part of a study on support modeling, based on numerous papers, studies, laboratory tests and reviews of actual earthquakes.

The recommendations of the EPRI project for ductile piping systems (with no brittle joints and with stable restraints) is that the total maximum restraint deformation, under maximum dynamic loads, not exceed a small nominal predetermined value. This value could be less than 5% of the average piping system dynamic response displacement or a fraction of an inch such as 1/8" or 1/4" total displacement. The Research Project is also recommending the use of minimum design loads based on the average loads for a subsystem or a fixed value based on pipe size.

SUPPORT GAPS

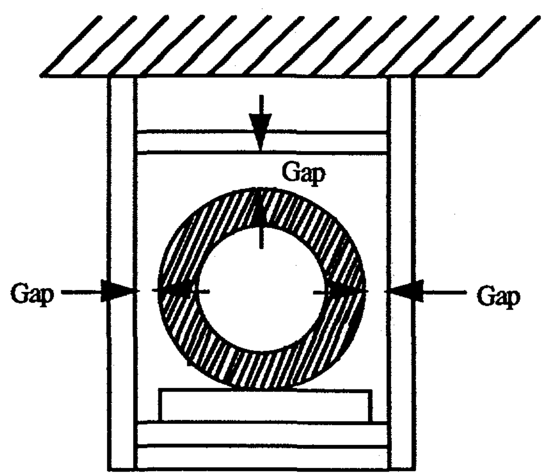

Figure 3. Small gaps can exist around the pipe in the restrainted direction

1) Source and Description of Topic

WRC 353, Section 2.3.3 provides guidelines for the treatment of pipe-to-support gaps (clearances). The Bulletin does not make a recommendation on whether to introduce this topic into the ASME Code.

2) Current Code Position

Section III NB, NC and ND do not address modeling details, such as gaps between pipe and restraint to be considered in determining the stresses for comparison against the limits of 3650. In various places, NF 3000 requires the pipe support to provide for movement of the piping or component.

3) Industry and Regulatory Position

A thorough discussion of pipe support gaps is provided in WRC-353. Gaps are used to allow unrestrained movements of piping in the non-load directions while being sufficiently small to be negligible in the loaded direction. The industry practice for the analysis of piping with small gaps (usually 1/16" per side or 1/8" total clearance) is to ignore the pipe support gaps where they are small.

The recent EPRI Research Project 2967-2 identified several studies of the effects of support gaps. In almost all cases, when a non-linear analysis was performed considering small gaps, the restraint loads and pipe stresses were enveloped by the linear analysis methods. Small support gaps (including snubber clearances) acquire more importance in the vicinity of equipment nozzles which are particularly sensitive to small load redistributions.

SUPPORT WEIGHT

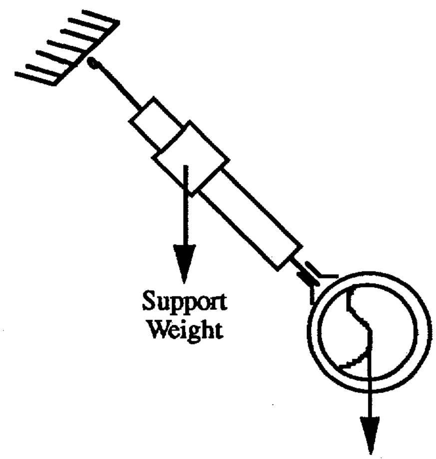

Figure 4. In certain cases part of the support weight is carried by the pipe.

1) Source and Description of Topic

WRC 353, Section 2.3.4 provides rules for judging the significance of support mass on a piping system. The Bulletin does not make a recommendation on whether to introduce this topic into the ASME Code.

2) Current Code Position

Section III NB, NC and ND 3623 states that *"piping systems shall provide for the effects of live and dead weights"* and defines dead weight as *"the weight of the piping, insulation, and other loads permanently imposed upon the piping"*.

3) Industry and Regulatory Position

The industry practice is to generally neglect the weight of the support mass in considering piping stresses. Normally, if proportionally sized support components are used, the ratio of the support mass to the piping mass is sufficiently low to justify neglecting the effects of the support component. However, when disproportionally sized components are used, results have shown the mass of the support components can have an effect on the piping stresses and should be factored into the piping analysis. EPRI Research Project 2967-2 identified isolated cases where support component mass was factored into the piping analysis, particularly for certain types of configurations and primarily on small bore pipes.

PIPE BRANCH AND RUN DECOUPLING TECHNIQUES

1) Source and Description of Topic

WRC-300 Part III recommends the *"use [of] a moment of inertia ratio of 25 to 1 for analysis decoupling of small branch lines from major runs"* further clarifications and exceptions are provided in Section 2.2.2 of the Bulletin.

The Bulletin does not make a recommendation on whether to introduce this topic into the ASME Code.

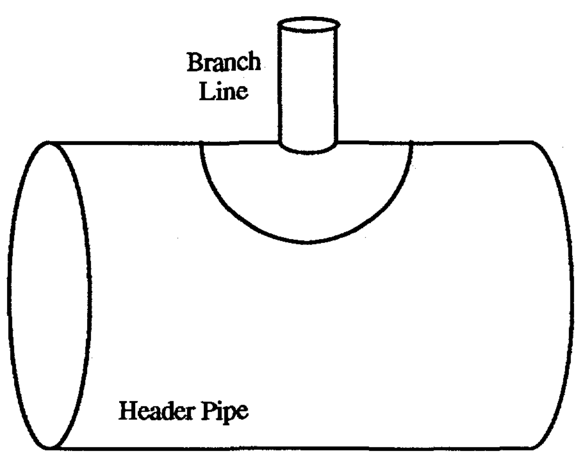

Figure 5. Certain branch lines are decoupled from the header system analytical model.

2) Current Code Position

Section III NB, NC and ND address the question of intersections in piping. For class 1 piping, NB-3683.1 requires that branch and run moments be combined to calculate the total stress at a branch connection. For Class 2 and 3 piping, the branch and run moments are calculated separately, each with its own stress intensification factor. There is no explicit Code Criteria on how to decouple branch lines from run piping to accomplish this.

Application Subsections: NB-3643, NC-3643 and ND-3643.

3) Industry and Regulatory Position

There is no uniform commercial nuclear industry practice for pipe branch and run decoupling techniques. In dynamic and flexibility analysis, a piping run is typically used as an anchor point for a branch line, if it meets certain criteria. Criteria usually include that the ratio of run to branch diameter, moment of inertia or section modulus should exceed a specified ratio. Decoupling criteria for moment of inertia typically ranged from 10:1 to 25:1 and 4:1 for diameter. A moment in inertia ratio of 25:1 was used in the industry recommendation of WRC Bulletin 300, with the additional recommendation that lower values should be considered where applicable.

An analysis of a branch pipe that meets these criteria typically use the connection to the run pipe as a rigid anchor. The practice has been not to develop run pipe amplified response spectra at the decoupling point, but rather to apply anchor motions and to envelope run pipe support attachment points response spectra. This approach gets to be less accurate as the run pipe is more flexible.

Run pipe SIF's were typically not included in the original piping analyses in the late 1960's and early 1970's for most branch connection locations. This is because the Code did not provide formulas for calculation of SIF's except for the connections. The SIF's for branch connection point, and for the run pipe at the branch connection point in the run pipe analysis (when applicable).

Vent or drain lines are seldom included in the model of the run pipe as they meet the requirements for decoupling as described in the preceding paragraphs.

In a 1980 memorandum, the NRC Mechanical Engineering Branch accepted a moment of inertia ratio of 7:1 for a specific plant application. A broader decoupling criterion is provided in Section 3.7.2 of the Standard Review Plan.

DESIGN TEMPERATURE FOR SMALL BORE PIPING

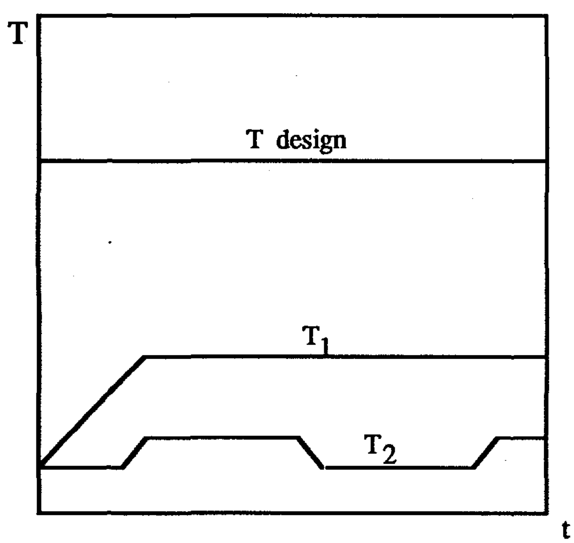

Figure 6. The Design Temperature may be set significantly higher than actual system operating temperatures.

1) <u>Source and Description of Topic</u>

WRC Bulletin 300 Part III Section 2.2.6 advises that *"using the system design temperature in place of the operating temperature for thermal flexibility analyses should be avoided........The design specification should reflect the appropriate temperature for analysis".* The Bulletin recommends considering temperature decay in stagnant lines; and limiting thermal expansion analysis to normal and upset operating modes. A similar warning is provided in Section 3.3, which states *"A common mistake leading to increasingly conservative nozzle loads is to use the system design temperature rather than actual operating temperatures when analyzing piping".*

2) <u>Current Code Position</u>

ASME Code Section III addresses design loadings in NCA-2142.1. The design temperature is defined as follows:

"Design temperature shall not be less than the expected maximum mean metal temperature through the thickness of the part considered for which Level A service limits are specified".

The Level A service limits are *"those set of limits which must be satisfied for all Level A service loading identified in the Design Specification to which the component or support may be subjected in the performance of its specified service function".*

From the above definitions, it is clear that design temperature is the maximum metal temperature which is expected to occur during normal plant operations.

3) Industry and Regulatory Position

The design process requires the identification of all operating conditions by system engineers. The design temperature is then defined, typically by the equipment vendor, as a temperature higher than all the operating temperatures, regardless of their service levels. For large bore and ASME Class 1 systems, this process may not be overly conservative. However, for small bore Class 2, 3 and non-nuclear safety piping, whose design does not require design specification, this process leads to unnecessary conservatism in both high thermal expansion stresses and low allowable stress intensities.

The use of unnecessarily large design temperatures for small bore piping systems can also lead to the addition of expansion loops, with the corresponding increase in congestion, material procurement, construction, support structures and risk of leaks at pipe joints.

Advancement in nuclear piping design proved that the old design process does not necessarily lead to a safer system. Thermal sleeve failures at branch nozzles with reinforcement are typical examples.

In conclusion, the industry design practice tends to select conservatively high design temperature which in turn penalize system design with no obvious benefits. This penalty is especially severe for small bore piping.

DEFINITION OF "COLD" PIPING

1) Source and Description of Topic

The term *"Cold"* piping refers to piping that operates at low temperature and as a consequence, the stresses associated with the thermal expansion are relatively small and not required to be explicitly calculated. The source of the topic is two fold:

(a) recommendation F-05 (4) of the **PVRC Committee on Review of ASME Nuclear Codes and Standards** (1988-1991(which states: *"Thermal Stress analysis (flexibility analysis) of piping systems is not required only [SIC] for ASME Class 2 and 3 where T_o = or < 150 ^{0}F and D_o = or < 6 inches."*

(b) an upcoming PVRC Position Paper that proposes a temperature of 150^{0}F as a boundary between cold and hot piping.

2) Current Code Position

Section III NB, NC, ND do not address the definition of cold piping. The Code requirements for evaluation of thermal expansion are as follows:

"The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction and from the effects of expansion joints" NC,ND-3624.1.

"The design of the complete piping system shall be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads". NC/ND-3651 (a).

"....piping systems subject to thermal expansion or contraction... shall be designed in accordance with the requirements for the evaluation and analysis of flexibility and stress specified in this paragraph". NC/ND-3672.1 (a).

"All systems shall be analyzed for adequate flexibility by a structural analysis unless they can be judged technically adequate by an engineering comparison with

previously analyzed systems." NC/ND-3673.1

Subsection NB has similar requirements NB-3624.1, 3672 (a), 3672.7.

In summary, the Code requires a thermal expansion analysis except when an engineering comparison with previously analyzed systems indicates that the system is technically adequate.

3) Industry and Regulatory Position

There have been several attempts in the piping industry to develop simplified rules to screen those piping systems that require a detailed flexibility analysis. The only one rule that is part of a code appeared in the 1955 edition of the Piping Code (ASA B31.1) and can still be found in the current editions of the ASME B31 codes. This rule is not based on a temperature threshold, but on a formula that relates various parameters such as, pipe size, movements to be absorbed, developed length and minimum length between piping anchors. This formula tries to quantify the relative flexibility of the piping system in a simplified manner. There are however so many cautions that the rule becomes practically useless.

Current industry practice in fossil and co-generation plants is to analyze piping systems with a temperature at or above 250^{0}F.

WRC Bulletin #300 refers to cold piping in the chapter related to the piping restraint selection criteria indicating that "For piping systems where the analyst has determined that thermal expansion stresses, loads and deflections are minimal, rod or frame type restraints in lieu of snubbers should be specified".

The draft version of the upcoming *"PVRC Position Paper-Piping Analysis Techniques"* proposes the following criterion: *"The definition of "cold" versus "hot" piping as a dividing line between piping that is analyzed for thermal expansion and that which is not, is important. A reasonable criterion establishes piping containing fluids at 150^{0}F or greater as "hot" and therefore requiring expansion analysis."*

EPRI Report NP-5184M *"Snubber Reduction Program"* in page 1-2, when dealing with snubber reduction techniques for cold piping systems, states: "...Those systems that are essentially cold (<200^{0}F)..."

We are not aware of a regulatory position on the definition of *"cold"* piping. Many nuclear power plants have used and justified the absence of detailed thermal expansion analysis for piping systems below a certain operating temperature. For example, a 1980 NRC Mechanical Engineering Branch memo for a plant specific application accepts *"Thermal expansion stress analyses...not to be performed when the design temperature is less than 150^{0}F"* as a reasonable and conservative engineering practice that has been widely adopted throughout the industry. It should be noted that the NRC's definition of *"high energy piping system"* is partially based on a simple temperature criteria. Piping systems with an operating temperature above 200^{0}F are defined as high energy.

None of the above criteria takes into account the differences in the piping material coefficient of thermal expansion. If one establishes a criteria for defining cold piping based on the rate of thermal expansion (product of alpha x delta T) and sets a limiting value at say, 0.0008 in/in, then the limiting temperature for cold piping would be 195^{0}F $\approx$ 200^{0}F for carbon steel piping and 155°F ≈ 150°F for stainless steels. This appears to be a more reasonable criteria.

NOZZLE FLEXIBILITY

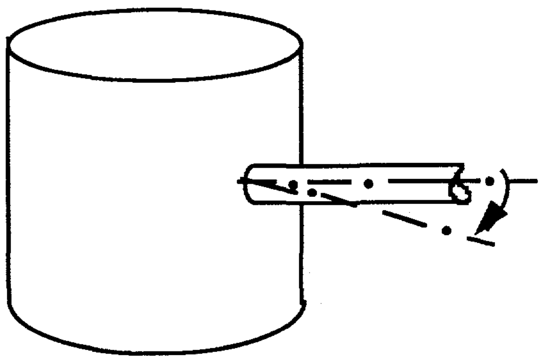

Figure 7. Equipment nozzles and shells have flexibilities which can reduce pipe reaction loads.

1) Source and Description of Topic

WRC - 300 Part III recommendation 3.5 states that *"the flexibility analysis of equipment nozzles and foundation supports should be considered in the analysis".* Recommendation 3.8 states that *"A coupled piping analysis, including nozzle flexibility and foundation support flexibility, can reduce calculated nozzle loads".* The Bulletin does not make a recommendation on whether to introduce this topic into the ASME Code.

2) Current Code Position

Section III of the Code does not address nozzle flexibility in piping system analysis.

3) Industry and Regulatory Position

Terminations of piping systems quite often consist of nozzles in pressure vessels and tanks or nozzles of rotating equipment such as pumps or steam turbines in branch connections to run pipe. The specified allowable loads on nozzles are often so low that they require additional restraints on the piping. Also, quite often the nozzles are modeled as rigid anchors in the piping system analysis.

The combination of using low allowable nozzle loads and ignoring nozzle flexibility may lead to additional restraint which by a more rational approach, could be shown to be unnecessary. these additional restraints may reduce the reliability of the piping system and will add to its cost.

Typically, the nozzle on a plate or shell is more flexible than the attached pipe. Use of the correct flexibility in static, thermal and dynamic analyses will frequently reduce predicted nozzle loads by a significant amount. Flexibility can be computed using equations from plate and shell theory, with proper considerations of stiffening members and internals. WRC Bulletin 297 provides data from which the nozzle flexibility can be obtained.

WRC Bulletin 300, published in 1984, recommend that flexibility of the nozzle should be included in the piping model.

NUREG-1061, published in 1985, recognizes that the design of piping branch connections and tank and vessel nozzles do not generally take credit for nozzle flexibility, resulting in higher calculated stresses. Improving nozzle design procedures could help reduce the number of seismic restraints required in current piping design.

NUREG-1061 report made the following recommendations with regard to nozzle loads and flexibility:

1) Request that WGPD revise the Code sections addressing pipe system flexibility calculation to

also consider tank and vessel nozzle flexibility.

2) Revise Standard Review Plan 3.9.2 to consider nozzle flexibility in piping analysis.

3) Develop improved design guidance on nozzle stress limits and flexibilities.

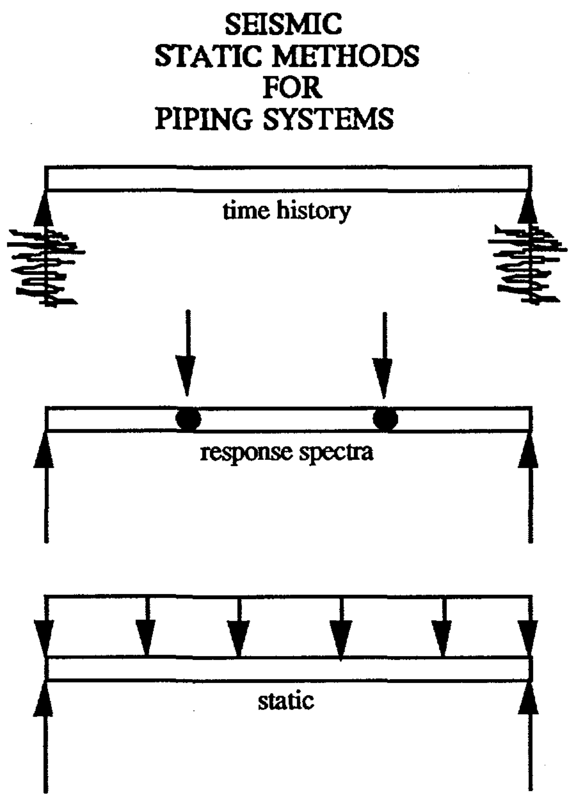

Figure 8. Applied loadings for various analytical methods.

1) SOURCE AND DESCRIPTION OF TOPIC

PVRC recommendation F-05 "Section III Analysis Requirements for Piping" proposes that "ASME Section III Code rules should be modified to include the following: (1) The use of rigorous dynamic seismic analysis methods (response spectra, time history) for piping systems is not always required. (2) Simplified static load procedures (e.g., Code Case N-468), which on the average give higher or the same results as dynamic analysis, should be permitted for large bore class 2 and 3 piping".

2) CURRENT CODE POSITION

Appendix N. Article N-100 "Dynamic Analysis Methods" currently states: "In order to determine the specific seismic designs for each component, dynamic system analysis is required to show how seismic loadings if transmitted form the defined ground motions to all parts of the buildings, structures, equipment and components". The common interpretation of the requirement is that floor spectra will be developed by dynamic analysis of the building structures. However, this requirement may be interpreted textually to mean that a dynamic analysis is required for "equipment and components" and therefore for piping systems.

3) INDUSTRY AND REGULATORY POSITION

While lateral load design for earthquake resistant buildings was introduced into practice in the 1930's, the concept of lateral load design for piping systems has been introduce much more recently (.20g static design of nuclear plant piping in the 1960;s) and published in the early 1970's (J.D. Stevenson, 1973; J.M. Gwinn and N.A. Coldstein, 1974; T.R. Simonson and G. Kost, 1976). At the time, it was judged that rigorous dynamic analysis was not required for the "tens of thousands of feet of conduits consisting of smaller diameter piping, tubing, electrical conduit raceways and ductwork which serve a safety function and therefore require a determination of seismic design adequacy" (J.D. Stevenson and W.S. LaPay, 1975). It was estimated that a coefficient of 0.67 to 1.50 could be applied to the input response acceleration to determine the lateral load. A coefficient of 1.20 was later proposed (C.W. Lin and T.C. Esselman, 1982).

The NRC Standard Review Plan (SRP) adopted the equivalent static load method with a factor of 1.5 applied to the peak floor acceleration if "the system can be realistically represented by a simple model" (SRP 3.9.2-7, July 1981). The "simple model" condition does not make the SRP 1.5 factor necessarily applicable to piping systems.

Currently, the California Uniform Building Code specifies lateral load provisions for "non-structural components supported by structures", including "plumbing" and "machinery and associated piping" as $F_p = ZIC_pW_p$, where Z is a seismic zone factor, the importance factor I is 1.5 for hazardous contents and C_p is 2x0.75 = 1.5 for flexible (f<17 hz) systems.

A similar form of static load factor was introduce in the IAEA "Earthquake Resistant Design of Nuclear Facilities with Limited Radioactive Inventory" (1985) and has been pursued by the ASME Working Group on Dynamic Analysis since 1986. the later effort resulted in ASME Code Case N-468 "Alternate Method of Earthquake Description for Class 2 and 3 Piping at Low Seismicity Sites Section III, Division 1" now expired. In its latest form, (as presented in 4-468), the load coefficient is developed by a statistical process based on comparative static and dynamic (response spectra) analysis of representative piping configurations. A review of the methods in N-468 by concluded that "it is not ready for incorporation into Appendix N" (attachment 10 to 9/14/92 WGPD meeting minutes). A revised proposal is being reviewed by the Special Working Group on Dynamic Analysis. The revised proposal includes static coefficients of .50, .75 or 1.0 depending on applied to the peak of the floor response spectra. Further documentation of the method is being developed through the PVRC Subcommittee on Dynamic Stress Criteria.

Recently, the Seismic Qualification Utilities Group (SQUG) established that a 1.0 equivalent static coefficient was to be used for determining seismic inertial equipment loads. The 1.0 coefficient for equipment anchorage is based on closed form solutions documented in EPRI NP-5228 Volume 1 "Development of Anchorage Guidelines", Appendix D. Piping systems are not addressed by the SQUG.

NON-LINEAR DESIGN OF DUCTILE PIPING

1) Source and Description of Topic

Recommendation F-05 (5) of the PVRC Committee on Review of ASME Nuclear Codes and Standards (1988 - 1991) states *"Limited non-linear behavior of ductile piping and other mechanical systems should be permitted for seismic design".*

2) Current Code Position

Appendix N, N-1222.2 provides acceptable numerical methods to analyze nonlinear problems, including:

(1) material non-linearities (plasticity);
(2) geometric non-linearities (large displacement);
(3) combination of material and geometric non-linearities (impact and friction)".

Appendix F provides for the inelastic analysis of vessels, pumps, valves, piping and core support structures subject to level D loadings. The Appendix F, *"Inelastic analysis"* is defined as a class of methods which includes *"limit analysis"* (elasticperfectly plastic model) and *"plastic analysis"* (strain hardening model). Appendix F also allows for the use of collapse load methods (unstable hinge mechanisms).

For piping, Appendix F, F-1430 permits as an alternative to either elastic or plastic analysis to apply the pipe stress equations of NB-3652 limited to the lesser of 2SM or 2Sy. In this context, the increased allowable is viewed as a simplified alternative (a substitute) for plastic analysis. The allowables are specified in NX-3655.

3) Industry and Regulatory Position

In the late 1960's Newmark and Hall proposed that for *"small excursions into the inelastic range"* the seismic response spectrum be decreased by the ductility factor (mu) as follows:
1/(mu) below approximately 2 hz;
$1/\sqrt{2(mu)-1}$ between 2 hz and 8 hz; and no decrease beyond about 33 hz. The ductility factor (mu) was defined as the ratio of the maximum allowable displacement of a structure to its elastic displacement. They suggested that equipment and components that can deform *"inelastically to a moderate extent"* be allowed a ductility factor of 2 to 3. The method later evolved into the *"inelastic response spectrum approach."* This and other analytical methods for estimating the non-linear response of piping systems are discussed in the recent WRC Bulletin 379 *"Alternative method for seismic Analysis of Piping Systems"*.

In a 1976 commentary on the newly developed faulted stress limits for class 2 and 3 components (76-PVP-61), Branch and Gascoyne recognized that faulted condition limits were selected on the basis of *"ultimate tensile strength, rather than yield"*, allowing therefore yielding. The faulted stress allowable being the minimum of (0.5 S_u or 1.25 Sy) for general primary membrane stress and the minimum of (0.6 S_u or 1.6 Sy) when primary bending is included.

The non-linear behavior of ductile piping has been correlated to the ASME III faulted stress allowables by Rodabaugh and Moore (NUREG/CR-0261) and more recently by Rodabaugh and Terao (NUREG-1367).

In the Standard Review Plan (NUREG-0800, 3.7.2-5 Rev. 2) the NRC states *"The SRP criteria generally deal with linear elastic analysis coupled with allowable stresses near elastic limits of the structures. However, for certain special cases (e.g., evaluation of as-built structures), the staff has accepted the concept of limited inelastic/nonlinear behavior when appropriate. The actual analysis, incorporating inelastic/nonlinear considerations, is reviewed on a case-by-case basis"*.

The NRC Piping Review Committee concluded in 1985 (NUREG-1061) that *"since SSE is a low-probability event, it is appropriate to accept some inelastic behavior in the design of piping systems in order to fully use their capability to absorb and dissipate energy. Pseudo linear-elastic estimation methods should be developed and procedures designed to account for inelastic response"*.

REFERENCES

1 Welding Research Council Bulletin 300 "Technical Position on Industry Practice", December 1984.

2 Welding Research Council Bulletin 353 "Position Paper on Nuclear Plant Pipe Supports", May 1990.

3 Welding Research Council Bulletin 370 "Recommendations Proposed by the PVRC Committee on Review of ASME Nuclear Codes and Standards", February 1992.