Pipe Stress Allowables for Operating Reactors

J.M. Eidinger, D.K. Leong
EDS Nuclear Inc., 220 Montgomery Street, San Francisco, California 94104, U.S.A.
M.C. Strait
*Commonwealth Edison, Station Nuclear Engineering Dept., Room 35 W., P.O. Box 767,
Chicago, Illinois 60690, U.S.A.*

During 1979, the NRC issued a series of bulletins which expressed concern on the seismic adequacy of piping systems in operating nuclear plants. Owners of these operating plants have had to reassess the original designs of the piping systems, and in many cases, make design upgrades to make the piping systems meet code requirements. In some cases, the magnitude of the design upgrades has been large enough to require four years for engineering and construction. During this interval, guidelines are required to justify continued plant operation.

This paper presents is a suggested 'operability' pipe stress allowable of 2Sy under faulted (SSE) short term conditions. This stress allowable is greater than ASME NC, ND or B31.1 stress allowables of 2.4Sh. The 2Sy value is developed recognizing plastic capacity of pipe elements, conservatisms in conventional elastic stress analysis assumptions, and flexible piping systems. In addition, this operability allowable is convenient as a practical engineering solution to efforts in a backfit piping analysis situation.

1.0 INTRODUCTION

In 1979, the NRC issued a series of inspection and enforcement bulletins (IEB 79-02, 79-07, 79-14), concerning the seismic adequacy of piping systems in operating nuclear plants. Owners of these operating plants have reassessed the original designs of the piping systems. In many cases, design upgrades are required to make the piping systems meet code requirements. For some plants, the magnitude of the design upgrades has required up to four years for engineering and construction. During this interval, and until piping systems are upgraded, to meet code requuirements, guidelines are required to justify continued plant operation.

This paper describes an engineering strategy employed in the re-analysis and design of piping systems at four nuclear plants, per IEB 79-14. The strategy minimizes dynamic piping analyses, minimizes undue conservatism and has met approval by the NRC. The strategy is based upon a SSE 'Operability Pipe Stress Allowable' of 2Sy. The steps of the engineering strategy are explained in section 2.0. Quantitative analyses used to derive the 2Sy stress allowable are discussed in section 3.0. A qualitative discussion of the 2Sy stress allowable is given in section 4.0.

2.0 ENGINEERING STRATEGY

The intent of NRC Bulletin IEB 79-14 was to verify that piping systems in operating nuclear plants would properly perform during earthquakes, as originally designed. This section of the report presents the basic engineering strategy used to respond to IEB 79-14 at four nuclear plants, namely the twin units at the Dresden and Quad Cities nuclear stations.

Step 1 Walkdown

A walkdown is performed for seismic-class piping. The nuclear plants under consideration had all piping originally designed to B31.1 (1967), with seismic-class piping extending to the second safety valve.

In the walkdown, notes are taken as to whether piping systems are routed as designed, and to whether supports are located as designed. If there are no discrepancies, then no further action is required for the piping system. If there are discrepancies, then the piping system is analyzed, so as to find out, what the stresses are in the as-built configuration.

Step 2 Stress Analysis By Hand Calculation

At this point, prior analyses used in the original design are reviewed, and if possible, applied to the current analysis situation. It is important to note that in older operating plants, only small percentages of piping systems were computer analyzed for dynamic loads. Very often, chart methods were employed. Thus, to deviate as little as possible away from the original design criteria, simplified hand calculation methods are used in order to analyse many piping systems.

This simplified method calculates peak pipe stresses as follows: first, find the highest 0.5% damping OBE floor spectra for the piping system; second, double this spectra for the SSE event (still using 0.5% damping, a conservative value); third, take 1.5 times the spectral peak of the floor spectra, and apply it as a uniform lateral load to the piping system; fifth, calculate pipe stresses by hand methods, using appropriate B31.1 stress indices; sixth, combine each horizontal and the vertical responses absolutely, and find the highest stress; seventh, compare this stress against the B31.1 stress allowable of 2.4Sh .

If the stress is below 2.4Sh, due to gravity plus pressure, plus SSE, the pipe is qualified. If the stress is over 2.4Sh, more rigorous analysis is performed.

The hand calculation method described above is obviously very conservative. Examples of this conservatism are the 0.5% SSE damping value, and the 1.5 times peak spectral acceleration.

Perhaps less obvious is the conservatism induced in the 'class-break' problem. This class-break problem deserves further discussion.

In older nuclear plants, 'seismic-class' or 'safety-class' piping systems were generally stress analyzed, in some fashion, and then lateral supports were added to the pipe system. However, often times these lateral supports were included only up to the second safety valve on 'seismic-class' piping systems. Upon re-analysis, we recognize that piping runs on the 'non-seismic-class' side of the valve can impart significant response to the 'seismic-class' piping.

In practice, it is common to have 'seismic-class' piping systems with runs of 20 feet, followed by 'non-seismic-class' piping systems with runs of over 200 feet. The 200 foot run is supported only by dead-weight hangers. Thus, the above hand calculation methodology often gives highly conservative stresses on the safety class piping in 'class-break' systems.

Step 3 Stress Analysis By Response Spectrum Method

For pipe systems with stresses exceeding 2.4Sh from Step 2, a response spectrum analysis is performed. At this point a 2% damping SSE spectrum is used. Although this value is higher than that specified in the original design basis (0.5% for OBE), this 2% value is well documented, and appropriate when used in conjunction with the more rigorous response spectrum analysis methodology.

For 'seismic-class' piping systems with long unsupported 'non-seismic-class' piping runs, our experience shows that the response spectrum analysis method often gives peak pipe stresses 5 to 8 times lower than the stresses as predicted by the hand calculation method.

From the response spectrum analysis, peak stresses are compared against 2.4Sh. If lower, then no action is required. If greater, but up to the 'operability stress allowable' of 2.0Sy, then design modifications will be made. The modifications are scheduled so as to meet regular outages.

It has been our experience that only rarely will a pipe system have stresses exceeding 2.0Sy. However, if such a situation arises, there may be concern as to whether the plant is outside a safe condition. Under this rare situation, quick action is taken to install 'operability supports', thus bringing the pipe stress down to below the 2Sy limit.

3.0 DERIVATION OF 2.0Sy OPERABILITY PIPE STRESS ALLOWABLE

It is recognized that the ANSI B31.1 pipe stress allowables have inherent conservatisms. There are ongoing efforts in industry such as by EPRI to quantify these conservatisms and possibly revise relevant code allowables. These efforts are comprehensive, and factors such as ductility, fatigue and materials are being considered. However, for purposes of responding to IEB 79-14, we quickly required an easy-to-use 'operability stress allowable'. This stress allowable should recognize the inherent conservatisms in piping system design. Also, this stress allowable would need to be acceptable to the NRC as justification for continued short-term operation of the nuclear plant, when piping systems were found to have stresses over 2.4Sh due to the SSE event.

The operability stress allowable is 2Sy, at the material's temperature. The following paragraphs describe two quantitative analyses which support the derivation of this value.

Analysis 1 - Elastic vs. Yielding Piping.

A portion of a complex piping system is modelled using SUPERPIPE for elastic analyses and ANSYS for nonlinear analyses. The system is shown in Figure 1. The system is analysed for three dimensional time history motions. Independent time history motions are simultaneously input to the piping system. Modal damping is 2% (SUPERPIPE) and alpha-beta damping is set to 2% at 0.2Hz and 33Hz (ANSYS).

In the nonlinear analysis, failure would first occur at elbow elements. To ensure correct behaviour of the ANSYS model, we correlated the ANSYS elbow element against experimental test data, by Greenstreet (1). This correlation was done for a 6" schedule 80 pipe. Results are shown in Figure 2. As the piping system used in the analysis had 3" schedule 40 elbows, the above correlation model was rerun with this smaller section. Results are shown in Figure 3.

The key results from the dynamic elastic and nonlinear analyses are shown in Figure 4. The elastic analysis shows several excursions past the yield moment for the piping system. The nonlinear analysis, as expected, predicts lower moments. The moments for the highest stressed elements are shown in Table I. At these moments, strains in the elbow elements reach about 1%. These strains can be tolerated by the elbows with less than 1% flow restriction (2, 3, 4). Thus, the pipe system remains functional, even with elbow yielding.

This analysis demonstrates that there is conservatism in elastically-calculated bending moments, when these moments predict stresses over yield. This conservatism is shown to be in the range of 20% - 40%.

Analysis 2 - Elastic vs. Yielding Pipe Supports

A piping system is modelled using SUPERPIPE for elastic analyses and ADINA for nonlinear analyses. The system is shown in Figure 5. All piping remains elastic in both analyses. In the nonlinear analyses, supports can yield, as also shown in Figure 5. Three dimensional time history analyses are performed, as described previously. Figure 6 shows the comparison of time history responses of the two analyses. Table II shows the linear versus nonlinear support loads. Table III shows the reduction in pipe stress, caused by the yielding and energy dissipation by the supports.

This analysis demonstrates that there is conservatism in pipe stresses, when overloaded supports are modelled as elastic elements. This conservatism is shown to be in the range of 30% - 60%.

4.0 JUSTIFICATION OF 2.0Sy OPERABILITY STRESS ALLOWABLE

The above two analyses independently indicate that elastic dynamic analysis methods can considerably over estimate pipe stresses, when the pipe system actually undergoes yielding. These effects are due to energy absorption in the pipe material and energy absorption in the pipe supports.

In addition to the above factors, we should consider other aspects when justifying the 2.0Sy operability stress allowable. These aspects include the following: first, the weakest piping element, the elbow, has collapse loads 50% higher when pressurized than when not. In the above analyses, we have considered the unpressurized strength of the elbow, but also added in stress for the existing pressure; second, we have used only code minimum allowables for material properties and dimensions; third, we have ignored any beneficial effects of high strain rate increases to material properties; fourth, and perhaps most important, we have used this pipe stress allowable only for interim plant operation purposes. At the completion of design modifications, all piping systems are upgraded to meet the B31.1 code.

5.0 CONCLUSION

Presented in this report is a practical methodology for addressing the redesign of piping systems in operating plants. This methodology utilizes a 'pipe stress operability allowable' of 2.0Sy. This methodology provides a basis to justify continued plant operation until modifications are made to bring pipe stresses within original code stress allowables. This methodology has been successfully implemented for four operating nuclear plants.

6.0 REFERENCES

1. Greenstreet W.L., 'Experimental Study of Plastic Responses of Pipe Elbows,' ORNL/NUREG 24, February 1978.

2. Evaluation of the Functional Capability of ASME Section III Class 1, 2 and 3 Piping Components, Mark I Containment Program Task 3.1.5.4, Sargent and Lundy Engineers Report Sl-3670, September 21, 1978.

3. Gross, Nicol, 'Experiments on Short-Radius Pipe Bends,' Proceedings Institution Of Mechanical Engineers, (B), Vol. 1B, 1952 - 1953, p465.

4. Ellyin, Fernand, 'An experimental Study of Elasto-Plastic Response of Branch-Pipe Tee Connections Subjected to Internal Pressure, External Couples and Combined Loadings,' Welding Research Council Bulletin 230, September 1977.

TABLE I. Nonlinear Piping Analysis Results - Pipe Moments

Element	Elastic Analysis SUPERPIPE	Nonlinear Analysis ANSYS
Straight Pipe	111.9 K-in (64.9Ksi)	71.6 K-in
Elbow Pipe	53.8 K-in (60.0Ksi)	42.6 K-in

TABLE II. Nonlinear Piping Results - Support Loads

	Elastic Analysis SUPERPIPE	Nonlinear Analysis ADINA		
Support	Load - lbs	Load-lbs	Displacement - Inch	Strain
H13	14.6	16.0	-	elastic
H14	12.7	7.2	0.71	1.3%
H18	41.3	10.0	2.22	1.9%
H19	18.2	9.2	0.36	1.5%
H20	20.3	23.1	-	elastic

TABLE III. Nonlinear Piping Analysis Results - Pipe Stresses

Element	Elastic Analysis SUPERPIPE (Percent of Allowable)	Nonlinear Analysis ADINA (Percent of Allowable
Elbow Pipe	62%	38%

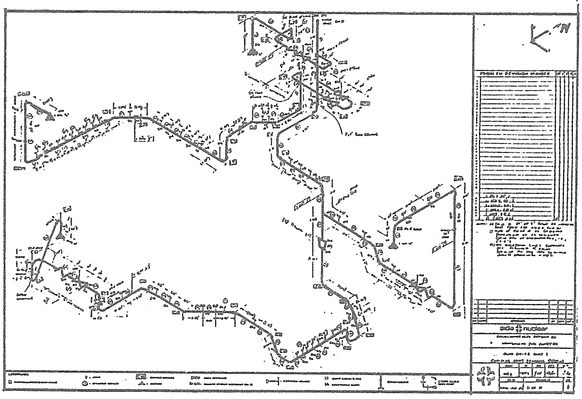


Figure 1 - Piping System for Analysis 1.

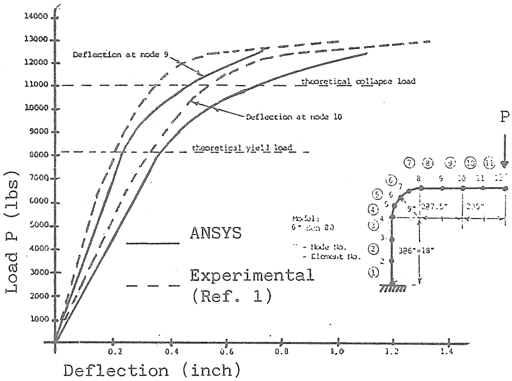
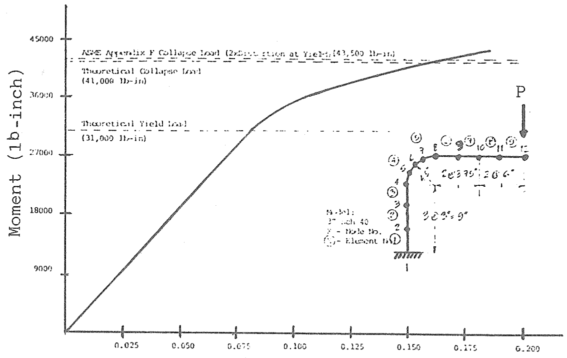
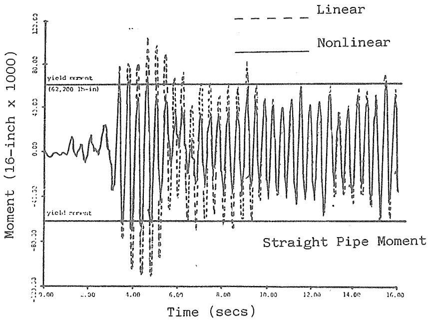


Figure 2. Elbow Correlation Study

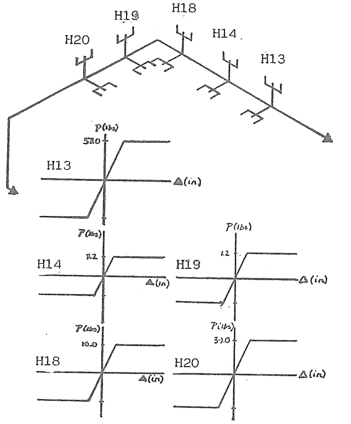


Deflection (inch) at Point 9
Figure 3 - Elbow Capacity In Piping System



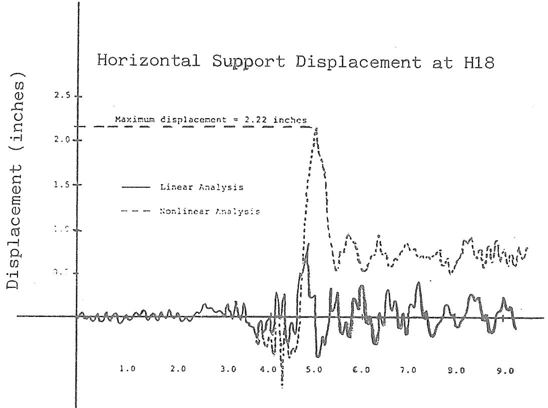
Time (secs)

Figure 4 Linear Versus Nonlinear Dynamic Response



Nonlinear Support Load-Deflection Curves

Figure 5. Piping System for Analysis 2.



Time (secs)

Figure 6 Linear Versus Nonlinear Dynamic Response