ENCLOSURE 1

QUAD-7-85-023
Revision 2

SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 AND 3

SNUBBER REDUCTION PROGRAM FOR NUCLEAR PIPING SYSTEMS

Prepared for

Nuclear Regulatory Commission

Prepared by

Southern California Edison Company

February 1986

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1.0 INTRODUCTION

Recent operating experience of nuclear power plants has highlighted reliability and maintenance problems associated with the use of snubbers on nuclear power plant piping systems (references 1, 2, and 3). Additionally, concerns have been expressed by knowledgeable industry personnel that piping systems may be overly designed with respect to seismic and other postulated plant design events (i.e., high energy line break), at the expense of optimum plant design for normal operating events. Over design of plant piping results in large numbers of unnecessary seismic supports (struts and snubbers), pipe whip restraints, and jet impingement barriers. Pipe supports, restraints, and barriers not needed to provide adequate design margins for seismic and other plant design events can restrict free thermal expansion of the pipe, hinder inservice inspection (ISI) of piping welds and components, and increase occupational radiation exposure (ORE) to plant personnel.

Recently completed testing at ANCO laboratories (reference 4) and by Teidoguchi (reference 5) have also demonstrated that piping systems can be subject to earthquake excitations at least three to five times larger than permitted by the ASME Code without failure of the piping. The ANCO testing also demonstrated that failure of a snubber or support in the Z-bend system tested did not result in loss of pressure retaining integrity of the piping. Historical data of fossil power plants and process plants subject to large earthquakes have not found failures of any major piping systems (references 6 and 7). In addition, examination of snubbers on the decay heat removal system at Three Mile Island Unit 2 found most to have failed as a result of a severe fluid dynamics transient. However, the piping system still retained its pressure retaining integrity (reference 8).

Other recently completed testing of typical nuclear piping systems has also demonstrated that snubbers may actually increase piping system response to the seismic event. This testing, sponsored by the Electric Power Research Institute (EPRI) at the University of California at Berkeley, concluded that "the influence of snubber connections on the dynamic response of the piping

appears to be unpredictable, although generally higher accelerations, forces in the connections and strains in the piping were introduced" (reference 9).

These concerns of piping over design for the seismic event have resulted in both industry and regulatory (reference 10) investigations into analytical methods, design criteria, and industry practices used for piping design, fabrication, and installation.

Southern California Edison Company (SCE) has been closely following these activities as principally conducted by the Nuclear Regulatory Commission (NRC), Pressure Vessel Research Committee (PVRC), American Society of Mechanical Engineers (ASME), and EPRI. Results of these activities to date have demonstrated that the seismic design of San Onofre Units 2 and 3 piping is excessively conservative and that many of the seismic supports (principally snubbers) are neither needed nor desirable to provide adequate design margins for the seismic events. Removal of these unnecessary seismic supports would result in piping systems of increased reliability, lower plant maintenance costs, and decreased occupational radiation exposure (ORE) to plant personnel.

Additionally, nuclear power plant operating experience, recent test data, and analytical advances in the mechanisms of High Energy Line Break (HELB) have demonstrated that the HELB design criteria of San Onofre 2 and 3 is also excessively conservative. Although SCE is not proposing to remove any pipe whip restraints or jet impingement barriers at this time, SCE is proposing modification to HELB criteria that will facilitate removal of unnecessary snubbers. However, SCE is reviewing information associated with the elimination of arbitrary intermediate pipe breaks (and associated pipe whip restraints) at the Catawba, Votgle, Byron, and Braidwood nuclear power plants and may apply for an associated criteria change at a future date.

Scope of the snubber reduction program is presented in Section 2.0. Design criteria for piping, pipe supports, and in-line components is presented in Section 3.0. Analytical methodology that will be utilized for the seismic event is presented in Section 4.0.

2.0 SCOPE

Scope of the snubber reduction program includes all safety related plant piping systems, snubbers on the Control Element Drive Mechanisms (CEDM), but exclusive of the nuclear steam supply system (NSSS) piping equal to or greater than 30 inches in diameter. Also excluded are snubbers used for seismic support of anchored equipment such as the reactor pressure vessel, steam generators, and reactor coolant pumps.

In the event that a later snubber reduction program is instituted for NSSS piping equal to or greater than 30 inches in diameter, or for anchored equipment, then a review will be performed to determine that snubber reductions performed under this program have not been invalidated.

3.0 DESIGN CRITERIA

Licensing commitments as provided in the San Onofre 2 and 3 Final Safety Analysis Report (updated FSAR) will be followed except as specifically noted below.

3.1 Piping

All non NSSS piping will continue to be analyzed to the 1974 edition, summer 1974 addenda, of the ASME Boiler and Pressure Vessel Code, Section III (reference 11). NSSS piping will continue to be analyzed to the 1971 edition of the ASME Section III Code. In special circumstances, later editions and addenda may be used provided that the new requirements are reconciled with the original design requirements as provided in Section XI of the ASME Code.

3.1.1 Design Allowables

All piping loads, load combinations, and allowable stresses identified in the San Onofre 2 and 3 updated FSAR (sections 3.9.3 and 3.9.4) will be complied with.

3.1.2 High Energy Line Break Criteria

Design criteria for selection of postulated locations of High Energy Line Break (HELB) is provided in Section 3.6.2 of the FSAR. This criteria is essentially that of Standard Review Plan 3.6.2 (reference 12a) and Regulatory Guide 1.46 (reference 13), and provides for the selection of HELB locations at terminal ends and at two or more intermediate locations of highest stress. Evolution of these criteria has been summarized in NUREG-1061 (reference 14b) which concludes that current nuclear power plants have too many pipe whip restraints and jet impingement barriers for the extremely low probability HELB event.

Revision 0 of Standard Review Plan 3.6.2, the current revision of Regulatory Guide 1.46, and the updated San Onofre 2 and 3 FSAR imply that each time the piping system is reanalyzed and the stress pattern changes, the intermediate locations of postulated HELB must be revised. Such revision can result in

the relocation of existing pipe whip restraints and jet impingement barriers, or the addition of new restraints and barriers. However, restraint and barrier modifications are not desirable from considerations of the extremely low probability of a HELB, ORE of plant personnel, further hinderance of ISI of the piping and components, hinderance of equipment maintenance, added potential to restrict free thermal expansion of the piping, and plant economics.

As discussed in reference 15, it was the intent of the NRC in issuing revision 1 to Standard Review Plan 3.6.2 that postulated arbitrary intermediate locations of HELB not be revised each time the pipe stress analysis is changed (as used herein arbitrary intermediate breaks are those postulated to provide a minimum of two breaks between anchors. An example are breaks of ASME Class 2 piping with equation 9 and 10 stress below 0.8 $(1.2\ S_h + S_A)$.

However, SCE proposes to maintain all existing postulated locations of HELB and not adding any new locations of HELB regardless of changes to the pipe stress pattern. This position is supported by the following:

1. The ANCO testing (reference 4) clearly demonstrated that piping systems have capacities to withstand excitations at least three to five times that equivalent to ASME Service Level D allowables without violating pressure retaining integrity. In addition, the testing demonstrated that at least some support failure could be withstood. Thus, exceeding arbitrary intermediate break stress criteria, but maintaining stresses below Code allowables, would not compromise piping integrity or capability to withstand the SSE.

2. The additional removal of snubbers that this position would provide will not change normal operating stresses. In addition, it eliminates the risk of inadvertent snubber lockup.

3. The removal of additional snubbers that this position would allow will result in increased space access for ISI of piping and components,

increased space access for equipment maintenance, and decreased ORE of plant personnel.

3.1.3 Pipe Displacements

All pipe displacements which exceed those provided by the original design analysis will be checked to ensure that no interference occurs with plant structures or other plant equipment.

3.2 Piping Supports

3.2.1 ASME Class 1, 2, and 3 Pipe Supports

Load combinations, applicable Code edition/addenda, and allowable stresses for NSSS and non NSSS pipe supports are provided in Sections 5.4 and 3.9 respectively of the San Onofre Units 2 and 3 updated FSAR. In special circumstances, later editions and addenda of the ASME Code may be used provided that the new requirements are reconciled with the original design requirements as provided in Section XI of the ASME Code.

The effects of both thermal anchor motion and seismic anchor motion will be considered as primary loads for evaluation of pipe supports and auxiliary steel.

3.2.2 ASME Welds

Weld allowables for ASME Class 1, 2, and 3 pipe supports will continue to be that provided by the applicable edition/addenda of Section III of the ASME Code.

3.2.3 Auxiliary Steel

For auxiliary steel, whose design loads are determined to be greater than current design loads, the load combinations and allowable stresses will be provided by Standard Review Plan 3.8.4 (reference 12b) as limited by the following:

1. The allowable limit for compression members during emergency and faulted condition loads will be 1.33S.

2. For angle members, the maximum bending stress during normal and upset condition events will be limited to F_b*, where

$$F_b = \left[0.55 - 0.10 \frac{F_{ob}}{F_y}\right] F_{ob} \quad \text{for } F_{ob} \leq F_y$$

$$F_b = \left[0.95 - 0.50\sqrt{\frac{F_y}{F_{ob}}}\right] F_y \quad \text{for } F_{ob} > F_y$$

where

F_{ob} = elastic buckling stress

$$= \frac{\Pi E}{2\sqrt{2.6}} \frac{t}{L}$$

t = member thickness

L = unsupported length

For normal and upset events, F_b shall be limited as follows:

$b/t < 65/\sqrt{F_y}$	$F_b = 0.66\ F_y$
$65/\sqrt{F_y} < b/t \leq 76/\sqrt{F_y}$	$F_b = 0.60\ F_y$
$b/t > 76/\sqrt{F_y}$	$F_b = 0.60 Q_s\ F_y$

where: b = width of angle leg

Q_s is per Appendix C of AISC (reference 26).

For emergency and faulted events F_b shall be limited to 0.95 F_y.

3. For auxiliary steel subject to eccentric load application, uniform torsional stress, warping shear stress, and warping normal stress will be determined and included for comparison with appropriate allowables.

*For normal and upset events these limits are based on the Australian code for angle sections (reference 23) which has been endorsed by AISC (reference 24). The 0.66 F_y allowable for compact angles (for normal and upset events) is also part of the Australian code and endorsed by AISC (reference 24). For emergency and faulted events the 0.95 F_y limitation provides approximately a 1.9 factor of safety against plastification (reference 25).

3.3 Mechanical Equipment

Load combinations, allowable stresses, and applicable Code versions identified in Sections 3.9 and 5.4 of the updated San Onofre 2 and 3 FSAR will be met for mechanical equipment. This includes vessels, pumps, heat exchangers, tanks, valves, and containment penetrations.

4.0 METHODOLOGY

Methodology that will be utilized by SCE in performing the snubber reduction program will include one or more of the following:

4.1 Response Spectra Method

Piping response to the inertia portions of the seismic input may be determined by either the uniform method or the Independent Support Motion (ISM) method. ISM is also referred to as multiple support motion or multiple input response spectra analysis in the literature. Acceptable analytical techniques include those defined in Appendix N of the 1983 edition of ASME Section III.

For the ISM method, each pipe support will be identified with a group experiencing a common response spectra and common seismic anchor movement (pseudo static component of the seismic response) according to its attachment point to the structural (building) model.

For the uniform method, the response spectra of all applicable pipe supports will be enveloped to determine the response spectra to be utilized for the entire piping subsystem. Each piping support will also be identified with the applicable seismic anchor movement.

4.1.1 Closely Spaced Frequencies

As demonstrated and recommended in NUREG/CR-3811 (reference 16) modal and directional responses will be combined by the square root of sum of the squares (SRSS) method without considering closely spaced frequencies. This is consistent with the design practices of non-NSSS San Onofre 2 and 3 piping (FSAR Section 3.7B.5). For NSSS piping, in the original design, closely spaced modes were combined by the absolute sum method as described in FSAR section 3.7.3.7.

As an alternate to the SRSS method, the Complete Quadratic Combination procedure defined in reference 17 may be used.

4.1.2 Sequence of Combinations

As demonstrated and recommended in NUREG/CR-3811 (reference 16), any sequence can be selected for combining modal and spacial components.

4.1.3 Combination of Group Responses for Independent Support Motion (Inertia Contribution)

For the ISM method, responses from each of the pipe support groups will be combined by the absolute sum method.*

4.1.4 Combination of Group Responses (Anchor Motion Contribution)

Per the recommendations of reference 16, pseudo static movement of each pipe support group will be combined by the absolute combination procedure to determine the seismic anchor movement response, as is the current design practice of San Onofre Units 2 and 3.

4.1.5 Combination of Directional Components

Results from each direction of earthquake (X, Y, and Z directions) will be combined by the SRSS method to determine total seismic response. This is consistent with the current design practices of San Onofre Units 2 and 3 piping (FSAR section 3.7B.5).

4.1.6 Combination of Inertia and Anchor Motion Contributions

Seismic design loads on pipe supports and reaction loads on in-line components will be determined using a SRSS combination of inertia and anchor motion contributions. This procedure is in accordance with the recommendations of the Brookhaven study.

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* Pending completion of the current Brookhaven study on ISM utilizing PVRC damping (follow on work to reference 16), SCE may apply to combine responses from each of the pipe support groups by the SRSS method.

For evaluation of pipe stress, the seismic inertia contribution will continue to be classified as a primary load and seismic anchor motion will continue to be classified as a secondary load. This is consistent with the current design basis of San Onofre 2 and 3 piping.

4.2 Time History Method

As an alternate to the response spectra method defined in Section 4.2, piping system response may be determined by the time history method. Inertia and anchor motion contributions will be combined by the SRSS method, as discussed in Section 4.1.6.

4.3 Damping

Seismic analysis using the uniform response spectra method will be based on the damping curve developed by the PVRC in WRC Bulletin 300 (reference 18) and accepted by ASME for nuclear piping as Code Case N-411 (reference 19). This damping will be used in its entirety for all applicable analysis and not be mixed with that provided in Table 3.7-22 of the FSAR.

For piping frequencies in the range of 10 Hz to 20 Hz, a linear interpolation of 2% and 5% response spectra is considered an acceptable approximation of the response spectra which would be generated by utilizing the PVRC frequency variable damping.

For time history analysis or response spectra analysis using the ISM method, damping values provided in Table 3.7-22 of the San Onofre 2 and 3 FSAR will be used. These are identical to those recommended in Regulatory Guide 1.61 (reference 20).

4.4 Peak Shifting

To account for uncertainties in the natural frequencies of the piping system, either the peak broadening procedures of reference 21 or the peak shifting procedures of references 18 and 22 may be used. For the case of peak shifting, shifting will be performed about a minimum of two peaks of the response spectra.

5.0 REFERENCES

1. U.S. Nuclear Regulatory Commission, IE Bulletin 81-1, "Surveillance of Mechanical Snubbers", January 27, 1981.

2. U.S. Nuclear Regulatory Commission, IE Information Notice 84-67, "Recent Snubber Inservice Testing with High Failure Rates", August 17, 1984.

3. U. S. Nuclear Regulatory Commission, IE Information Notice 84-73, "Downrating of Self-Aligning Ball Bushings Used in Snubbers", September 14, 1984.

4. Electric Power Research Institute, NP-3746, "Dynamic Response of Pressurized Z-Bend Piping Systems Tested Beyond Elastic Limits and With Support Failures", December 1984.

5. H. Teidoguchi, "Experimental Study on Limit Design for Nuclear Power Plant Facilities During Earthquakes, 1973", JPNRSR-5 (USERDA Technical Information Center); Part 2.2, "Vibration Tests of the Distribution Piping Systems".

6. R. L. Cloud, "Seismic Performance of Piping in Past Earthquakes", presented at the Specialty Conference on Civil Engineering and Nuclear Power, Knoxville, Tenn. 1980.

7. Lawrence Livermore Laboratory, NUREG/CR-1665, "Equipment Response at the El Centro Steam Plant During the October 15, 1979 Imperial Valley Earthquake", October 1980.

8. Pentek Inc., EPRI Project NP-3593, "Examination of TMI-2 Snubbers: Phase 2", July 1984.

9. University of California at Berkeley, EPRI Project RP-364-8, "The Results of an Experimental Program on the Seismic Response of Multiply Supported Piping Systems", Final Report, February 1984.

10. U.S. Nuclear Regulatory Commission, memorandum from H. Denton and R. Minogue to W. Dircks, "Proposal for Reviewing NRC Requirements for Nuclear Power Plant Piping", July 13, 1983.

11. American Society of Mechanical Engineers, "Section III-Nuclear Power Plant Components", 1974 Edition including Addenda through Summer, 1974.

12. U.S. Nuclear Regulatory Commission, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", July 1981.
    a. Standard Review Plan 3.6.2, "Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping".
    b. Standard Review Plan 3.8.4, "Other Seismic Category 1 Structures", Revision 1, July 1981.

13. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.46, "Protection Against Pipe Whip Inside Containment", May 1973.

14. U.S. Nuclear Regulatory Commission, NUREG-1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee".
    a. Volume 2, "Evaluation of Seismic Designs - A Review of Seismic Design Requirements for Nuclear Power Plant Piping", April 1985.
    b. Volume 3, "Evaluation of Potential for Pipe Breaks", November 1984.
    c. Volume 4, "Evaluation of Other Dynamic Loads and Load Combinations", December 1984.
    d. Volume 5, "Summary - Piping Review Committee Conclusions and Recommendations", April 1985.

15. U.S. Nuclear Regulatory Commission, "Catawba Nuclear Station Unit 2, Safety Evaluation for the Elimination of Arbitrary Intermediate Pipe Breaks", Docket No. 50-414, March 1984.

16. Brookhaven National Laboratory, NUREG/CR-3811, "Alternate Procedures for the Seismic Analysis of Multiply Supported Piping Systems", August 1984.

17. E. L. Wilson, et.al., "A Replacement for the SRSS Method in Seismic Analysis", Earthquake Engineering and Structural Dynamics, Volume 9, 187-192 (1981).

18. Welding Research Council, Bulletin 300, December 1984.

19. ASME Code Case N-411, "Alternative Damping Values for Seismic Analysis of Piping Section III, Division I, Class 1, 2, and 3".

20. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", October 1973.

21. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design for Floor-Supported Equipment or Components", Revision 1, February 1978.

22. ASME Code Case N-397, "Alternative Rules to the Spectral Broadening Procedures of N-1226.3 for Classes 1, 2, and 3 Piping".

23. Australian Institute of Steel Construction, Australian Standard AS1250-1975.

24. Letter from G. Haaijer, American Institute of Steel Construction, to T. Longlais, Sargent and Lundy Engineers, dated January 15, 1986.

25. Letter from T. Galambos, University of Minnesota, to T. Longlais, Sargent and Lundy Engineers, dated January 9, 1986.

26. American Institute of Steel Construction, "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings", Eighth Edition.

ENCLOSURE 2

SUBJECT: SNUBBER REDUCTION PROGRAM FOR NUCLEAR PIPING SYSTEMS, SONGS UNITS 2 AND 3, REV. 1

REFERENCE: Letter of October 9, 1985 from M. O. Medford (SCE) to G. Knighton (NRC), including attachment QUAD-7-85-023, Rev. 1.

The Mechanical Engineering Branch has reviewed the referenced snubber reduction program proposed by Southern California Edison Co. and finds it acceptable subject to the following conditions:

1. For angle members, the maximum bending stress about either principal axis, determined during emergency and faulted conditions, shall be limited to .60 Sy.

2. The choice of damping values based on the damping curve specified in ASME Code Case N-411 will require the following commitments:

   (a) Commit to use the Case for piping systems analyzed by the uniform response spectrum method only.

   (b) Due to the increased flexibility of the system commit to check all system predicted maximum displacements for adequate clearance with adjacent structures, components and equipment, and that the mounted equipment can withstand the increased motion.

   (c) When the alternate damping criteria of this Code Case are used, they will be used in their entirety in a given analysis and shall not be a mixture of Regulatory Guide 1.61 criteria and the alternate criteria of this Code Case.

3. A commitment will be required that if a subsequent snubber reduction program is instituted for the NSSS equipment and piping equal to or greater than 30 inches in diameter, a review will be performed to determine that piping analyses and snubber reductions performed under the current proposed snubber reduction program have not been invalidated.

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ENCLOSURE 3

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January 09, 1986

Mr. T.G. Longlais, Head
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Dear Mr. Longlais,

This letter is to sum up our discussions and to put down my conclusions on the subject of the Sargent and Lundy design method for single-angle hangers for HVAC ducts in several nuclear power plants. This investigation started with your letter of Nov. 8, 1985, in which you outlined the basis of your method and with which you enclosed copies of previous correspondence on the subject. This correspondence included an exchange of letters between Dr. Hartzman of the U.S. Nuclear Regulatory Commision and myself, in which I made some general observations without specifically addressing the complete details of your single-angle design method. Subsequent to your initial letter we had a further exchange of letters to provide additional clarification, and we had two meetings in my office at the University of Minnesota between you, Dr. S. Fang, and myself (on Nov. 26, 1985 and on Jan. 3, 1986). As a consequence of these letters and meetings, and after considerable study and analysis, I believe that I am quite familiar with both the philosophy and the method used by Sargent and Lundy to design these angles. My comments in this letter are intended to assist Sargent and Lundy in responding to NRC questions and to expand on my previous correspondence with the NRC in June 1985.

Before addressing specific issues I want to state that my comments apply to the particular HVAC angle hangers used by Sargent and Lundy, and they are not meant to be a general design methodology for the design of single-angle beam-columns used in any kind of structural design. There S and L angles are primarily intended for the tension hanger support of HVAC ducts in several nuclear power plants. Their end-framing is such that the ends are constrained about one of the geometric axes of the angle. By dynamic analysis it has been determined that under an extreme seismic event these hangers are subject to end moments about one, or sometimes both, geometric axes, and to small axial compressive forces which are usually (but not always) less than 15 percent of the allowable axial compressive force.

The check for combined bending and compression is covered in Sec. 1.6.1 of the AISC Specification. Two criteria are required to be checked: 1) stability (Eq. 1.6.1a) and 2) cross section strength (Eq. 1.6.1b). If the ratio f_a/F_a is less than 0.15, then only one conservative interaction equation needs to be checked (i.e., Eq. 1.6.2).

My first comments relate to the strength check. There are two questions to be considered:

1) Is it appropriate to compute the flexural stress on the basis of the geometric rather than the principal axes?

2) What is the allowable flexural stress F_b?

It is my opinion that because the applied force and the restraint at the member ends is directed along one of the angle legs, i.e., along one of the geometric axes, the flexural stress should be computed for the geometric axes. The applied force will produce forces in both the hanger angle and in the restraining members. The background arguments for this are presented in Sec. 11.4 of the book "Basic Steel Design" by Johnston, Lin and Galambos (3rd ed., Prentice-Hall, 1985).

The value of F_b to be used for angles is not specifically defined in the AISC Specification. A value of $F_b = 0.66F_y$ is recommended for compact wide-flange shapes bent about the major axis, and $F_b = 0.75F_y$ for minor axis flexure. These two values contain allowance for the different plastic shape factors for major and minor axis bending, i.e. 1.10 and 1.55 respectively. It can be shown that the shape factor for a compact angle is about 1.8 when bending is about a geometric axis, and 1.75 when bending is about the minor principal axis. These values are larger than those for wide-flange shapes, so the use of $F_b = 0.66F_y$ is conservative for angles. The use of $F_b = 0.66F_y$ for compact angles is thus entirely within the intent of the AISC Specification.

The next comments refer to the questions related to the stability check. The stability interaction equation in the AISC Specification is in a stress-format for reasons of convenience and convention. The original formulation of the interaction equation is in terms of forces (design and ultimate compression and flexural forces; see, for example, Chap. 11, in "Structural Steel Design", editor L. Tall, Ronald Press, 1974) which are translated into stresses. If, for example, the allowable flexural moment for the limit state of lateral-torsional buckling is formulated for flexure about a geometric axis, as was done by Leigh and Lay in their paper, then the actual and the allowable stress may be normalized from moments about the geometric axis also. Thus it is permissible, for reasons of convenience, to use the stresses f_b and F_b in Eq. 1.6.1a with reference to the geometric axes. A similar interpretation is used by the Steel Joist Institute for the design of eccentric single-angle webs in prefabricated trusses. Several dozen angle columns were tested under three different end conditions about 15 years ago at Washington University to substantiate this method of design (see paper by Usami and Galambos, IABSE Memoirs, 1971). This design method has been successfully used for over ten years, and tests on full scale trusses performed by John Leigh for his Master's thesis at Washington University showed it to result in a safe structure.

The next question in connection with the stability check has to do with the value of F_b to be used in Eq. 1.6-1a. The AISC Specification is silent on this

subject, but a recent AISC lecture series acquainted American engineers with the work of Leigh and Lay on the subject. This work was performed in 1970 at the BHP Steel Company Laboratory in Melbourne, Australia. Both Leigh and Lay are my former students, and I reviewed their work when I visited Australia in 1970. I have the highest regard for their research. I have again reviewed their study and rederived their equation in the past weeks. It is my opinion that F_b can be safely determined by the criteria given in the Australian SAA Steel Structures Code AS1250-1981 Sec. 5. For the case of wide-flange beams I have compared the Australian design criteria with the new AISC Load and Resistance Factor Design rules and I found the Australian method to be more conservative in all cases I checked. The Australian buckling criteria assume that the cross-section plastifies when the elastic buckling stress equals or exceeds three times the yield stress if a wide-flange beam is bent about the major axis. This is a typical approach used on all types of buckling criteria in the Australian steel design specification, and it is justified in a number of papers by Max Lay and Nick Trahair (see also the figure on p. 109 of Vol. II of the book by Atsuta and Wilfred Chen). Modern U.S. Specifications do not explicitly formulate the limits of plastic behavior in quite the same way, but the result is just about the same. For the single-angle beam the assumption of plastification under factored loads when $F_b = 0.66F_y$ and the elastic buckling stress is $3F_y$ is, of course, quite conservative because of the high shape factor of about 1.7 to 1.8. Thus even the criterion of $F_b = 0.95F_y$ carries with it a factor of safety of about 1.9 against plastification, while $F_b = 0.66F_y$ has a safety factor of about 2.7. These remarks concern the behavior of compact angles (i.e., $b/t < 65/ F_y$). for non-compact angles we must use $F_b = 0.6F_y$, or if $b/t > 76/ F_y$, $F_b = 0.60QF_y$. For the cases the Australian design equation must be topped out at $0.6F_y$ or $0.6QF_y$, as appropriate.

It is my opinion that the use of the Australian criteria for determining F_b in Eq. 1.6-1a by Sargent and Lundy for the single-angle HVAC hangers is appropriate and conservative, resulting in safe designs.

The use of AISC Eq. 1.6-1b assures adequate strength at the ends of the hangers where the moments are maximum, while compliance with Eq. 1.6-1a checks the lateral-torsional stability of the member as a whole. For most of the practical angles for steel with $F_y = 36$ ksi, and for the compact angles for steel with $F_y = 50$ ksi only the strength equation needs to be checked if the ratio of length to thickness is less than 400.

The AISC interaction equations apply when the forces acting on them are acting concurrently. They would result in unduly conservative designs if the maxima of several load sets, which do not act simultaneously, were to be assumed to be applied.

The moment caused by the eccentricity of the axial force which is applied through one leg should be considered in design. This moment, however, is shared by the restraining members in proportion of the relative stiffnesses. The Usami experiments on restrained-end single angles, and the Leigh truss tests

demonstrated the effectiveness of this assumption. With the relatively low axial forces in the Sargent and Lundy hanger angles and the participation of the restraining members the effect of the eccentricity is expected to be quite small.

In summary, while the AISC Specification does not contain explicit rules for the design of single-angle beam-columns, the Sargent and Lundy design method is rational, it is conservative, and it meets the intent of the AISC Specification. I believe it to be a safe approach for the design of these hanger angles. In conclusion I would add that the safety of these hangers is further enhanced by the fact that compression occurs only during a transient seismic event, and not always as in a gravity-type building column.

I am satisfied that the Sargent and Lundy design method is safe and adequate for the single-angle HVAC hanger.

Sincerely yours,

Ted Galambos

T. V. Galambos
Professor of Civil Engineering

TVG:sbh

January 15, 1986

Mr. Thomas G. Longlais
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Dear Tom,

Your letter of December 23, 1985 addresses several questions related to the design of single angle supports, which were raised by the Nuclear Regulatory Commission (NRC). Apparently, our previous comments in correspondence with you and Mr. Hans Ashar of NRC did not satisfy the latter. Before answering your questions, it is important to point out that the American Institute of Steel Construction, Inc. is not a regulatory body that prescribes design rules and practices. The Specification and Code of Standard Practice are voluntary concensus documents. Specifically, the Committee on Specifications consists of structural engineers with wide experience and high professional standing, representing a wide geographical distribution throughout the United States. The membership of the committee is made up of approximately equal number representing design engineers in private practice, engineers involved in research and teaching, and engineers empĺoyed by steel fabricating companies and suppliers. The Specification developed by this committee, as approved by the AISC Board of Directors, is widely used by designers and code authorities. However, AISC recognizes the authority and responsibility of the licensed professional for the design of structures within his or her scope of expertise.

To aid design professionals in exercising their authority and responsibility, AISC publishes design aids, manuals and the Engineering Journal. Reference is often made to the worldwide literature on steel design.

1. The AISC Specification is indeed silent on the design rules for laterally unbraced angles subject to bending. AISC, however, has frequently referenced the Australian research on this topic (1,2) in a national series of seminars entitled "Steel Design Current Practice" beginning in late 1983. In addition, the Australian article "Safe Load Tables for Laterally Unsupported Angles" has been reprinted in the First Quarter, 1984 AISC Engineering Journal with the permission of the Australian Institute of Steel Construction. This design methodology is based on an earlier version of the Australian Standard AS 1250-81(3) in the absence of angle-beam criteria in the present AISC Specification. The Australian methodology for the design of single angles subject to bending is being used for an example in the 1986 First Edition of the AISC Load and Resistance Factor Design (LRFD) Manual.

2. In the proposed LRFD Specification, the flexural design capacity of a double angle beam is constant at the yield moment value until the onset of elastic buckling. There appears to be no need for an inelastic transition done because of the absence of major internal residual stresses in angle sections.

   A minimum inelastic rotation capacity of 3 is a common criterion for limiting slenderness ratios in the AISC Specifications (see pg. 34 on new LRFD Specification). This is approximately equivalent to the requirement that the computed elastic critical stress be at least 3 times as large as the yield stress, to ensure that the plastic moment will be reached. Thus, the Australian recommendation that single angle flexural yielding will control in the slenderness zone wherein the computed elastic buckling moment is at least 3 times the yield moment is valid. Furthermore, compact angles have a high shape factor to justify use of a $0.66F_y$ allowable bending stress.

3. AISC interaction equations 1.6.1a and 1.6.1b are intended for the design of beam-columns subject to concurrent axial loads and biaxial moments. In the design of beam-columns, it is recognized that either yielding or stability may control member behavior.

Equation 1.6.1a checks stability with maximum moments along the length of a beam. Equation 1.6.1b is intended to be a stress strength check against yielding. In this latter situation, stresses should be combined at the critical member support cross-section and should not be based upon the maximum moments along the member length as in equation 1.6.1a.

Also, equations 1.6.1a and 1.6.1b are intended for the simultaneous application of concurrent static loads. If a member is subject to time dependent dynamic loads, i.e., seismic loads, then a rational method which accounts for the nonconcurrence of maximum axial bending moments about the two axes and axial loads may be utilized when employing equations 1.6.1a and 1.6.1b.

4. We agree that in cases where lateral support of unsymmetric sections is provided at the location of concentrated loads, simple bending theory will apply, i.e., the horizontal and vertical axes (geometric) of the angle may be used to compute the bending stresses. Otherwise, the principal axes of the member must be used in the interaction equations.

Sincerely yours,

Nestor Iwankiw

for Geerhard Haaijer

GH/cd

cc: N. Iwankiw

REFERENCES

1. Leigh J.M. and Lay M.G., "The Design of Laterally Unsupported Angles", BHP Technical Bulletin 13(3), Nov. 1969, pp. 24-29

2. Thomas, B.F. and Leigh, J.M., "The Behavior of Laterally Unsupported Angles", BHP Melbourne Research Laboratory Report MRL 22/4, Dec., 1970

3. Australian Standard AS 1250-81, Australian Institute of Steel Construction