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RULEMAKINGS AND
ADJUDICATIONS STAFF

March 22, 2004

Secretary
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001
ATTN: Rulemakings and Adjudications Staff

Subject: Comment RIN 3150-AH24 Rulemaking on ASME Seismic Piping Requirements

Dear Secretary:

The attached document provides the ASME Board of Nuclear Codes and Standards response to the Draft Proposed USNRC 50.55(a) rulemaking published in the Federal Register, Volume 69, Number 4 on January 7, 2004. The document specifically responds to six items presented in that draft proposal contained under Section 10CFR50.55a(b)(1)(vi), paragraphs (A) through (F) which are related to the Class 1, 2 and 3 seismic design rules for piping in Section III, Division 1.

The rules for seismic design that are in the Code today were placed in Section III in the 1994 Addenda of the 1992 Edition of the Code. These have been amended slightly since then, as a result of in-depth study and discussion undertaken by the committee members of Section III and its related expert groups established to deal with the questions in this area. It is important to understand the extensive investment that industry, both domestic and international, has made over a 12-15 year period to produce a set of requirements that provide the nuclear industry with the safest seismic design rules for piping. This extensive investment covered two aspects, direct expenditure through experimental and computer studies, domestically and internationally and secondly in the provision of support to committee participants, which included internationally recognized industry experts as well as experts from other countries. The work was undertaken to gain an in-depth understanding of the subject matter so that the rules were truly applicable and safe.

These rules were based on the experience gained from the most recent plant design and operational experience and current research and were a significant step forward in the nuclear piping industry. However, until this proposed rulemaking, the USNRC has not allowed the use of any of these rules. This proposed rulemaking, for the first time, presents the USNRC position and concerns on the specific parts of the Section III seismic rules. ASME committee members have worked with the NRC staff in attempt to understand and address their concerns and since 1994 ASME and the international community have cooperated on research results and brought in internationally recognized personnel in an attempt to respond to these issues. There have been adjustments to these rules as a result of this work. However, the draft rulemaking does not reflect the benefits and progress of the consensus efforts.

It does however provide a forum for ASME to formally respond to the NRC concerns. The attached ASME Position paper does that. I request that the NRC give the highest level of attention to the ASME comments, so the industry can use the best technology for the design of future piping systems resulting in the safest performing piping systems.

Recognizing the size of the ASME Position paper, a summary of the areas of disagreement is provided below:

1. **10CFR50.55a(b)(1)(vi)(C)**

   This proposed rulemaking revises the current Section III seismic requirements for Class 2 and 3 piping in the area of evaluation of seismic anchor motions combined with inertial loads.

   ASME opposes these proposed revisions and the Position paper discusses this in great detail. The ASME Position can be summarized as follows:

   1.1 The proposed rulemaking returns control of seismic design to the Operating Basis Earthquake (OBE) for plants which are required to design for this level of earthquake. The ASME and the USNRC have agreed in the past that the Safe Shutdown Earthquake (SSE) should control seismic design.

   1.2 The proposed rulemaking appears to be in conflict with the current 10CFR Part 52 licensing basis for an Appendix S seismic input. Part 52 allows a licensee not to do a specific analysis for the OBE if the OBE is defined as less than 1/3 SSE. In this case there is only one set of loads that can be applied to the Code equation for OBE and that is SSE. ASME does not agree with this and requests clarification from the USNRC.

2. **10CFR50.55a(b)(1)(vi)D**

   This proposed rulemaking revises the Section III, Appendix N Amplified Floor Response Spectra.

   The ASME position is that this is a licensing issue and should not be a part of this rulemaking. It should be noted that the Appendix N spectra is essentially equivalent to a Regulatory Guide 1.60 Spectra.

3. **10CFR50.55a(b)(1)(vi)E**

   This proposed rulemaking changes the value of the B'_2 stress index for elbows and tees which is used to calculate stresses resulting from moments generated in a piping system during a seismic event from 2/3 B_2 to 3/4 B_2. The B_2 stress index varies as a function of the specific piping component being analyzed.

   The ASME opposes this proposed rulemaking based on the extensive data reduction of the EPRI/USNRC and Japanese test data and the Japanese analyses. A significant portion of the Position paper covers this item since issues such as temperature effects on dynamic strain aging are involved. Addressing this requires consideration of such issues as strain rate effects and ultimate stress to yield stress ratios as a function of temperature and dynamic load.

4. **10CFR50.55a(b)(1)(vi)F**

   This proposed rulemaking changes the evaluation of seismic anchor motions and basically returns the design rules to where they were prior to the 1994 Addenda.

   The ASME opposes this proposed rulemaking and the Position paper points out that the proposal is more restrictive than the Code rules that existed prior to the 1994 Addenda.

There is a significant amount of data and publications that have been generated over the past 10 years related to this issue of seismic design rules for piping in commercial nuclear power generating facilities. A significant portion of this was the result of a joint EPRI/USNRC research project. It is the result of that research effort which provided the initial basis for the Code rules. Since that time, further experimental and analytical work have been carried out by the Japanese to evaluate issues related to strain rate effects, dynamic strain aging and temperature effects.

Because of this extensive industrial investment and the desire to produce safe and effective requirements, ASME requests that where the USNRC disagrees with the ASME position, a detailed written rationale providing the basis for the disagreement be provided to ASME. It is also the position of ASME that it is in the interest of both parties, that the proposed rulemaking be revised to continue to prohibit the use of the existing Code rules. This is based on the position that the two parties will continue the in-depth dialogue and study of each other's positions attempting to arrive at a consensus over next 12 months.

The ASME thanks the USNRC for the opportunity to address your concerns with our current Section III Code requirements related to seismic design of piping.

Very Truly Yours,

CW Rowley

C. Wesley Rowley, PE
ASME Vice President
Nuclear Codes & Standards

ASME Position Paper on Proposed USNRC Rule Making Affecting the ASME Boiler and Pressure Vessel Code, Section III, Division 1 Subsection NB-3600 Subsection NB-3228 , Subsection NC-3600 and Subsection ND-3600 Piping Design Rules

Developed for the
ASME BPVC Subcommittee on Nuclear Power (SC III)
by Members of the
ASME BPVC Subgroup on Design (SCIII)

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March 18, 2004

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Executive Summary of the ASME Position

This position paper presents the ASME position and concerns relative to the proposed USNRC 50.55(a) rulemaking as it applies to NB/NC/ND-3600 of the ASME Boiler and Pressure Vessel Code, Section III, Division 1. Using the information put forth in this position paper the ASME does not agree with and does oppose three of the six rule changes proposed by the USNRC.

Specifically, the ASME does not support the following proposed rule changes:

(a) *10 CFR 50.55a(b)(1)(vi)(C)* Allowable Bending Stresses[(NC-3653.2(d) and ND-3653.2(d)]
(b) *10 CFR 50.55a(b)(1)(vi)(E)* Allowable B_2' stress indices for tees and elbows [(NB-3656(b)(3), NC-3655(b)(3), and ND-3655(b)(4)]
(c) *10 CFR 50.55a(b)(1)(vi)(F)* Evaluation of anchor motions [NB-3656(b)(4), NC-3655-(b)(4), and ND-3655(b)(4)].

The ASME does not support, but would not oppose, the following rule changes proposed by the USNRC:

(a) *10 CFR 50.55a(b)(1)(vi)(D)* Linear Elastic Response Spectrum Analysis [(NB-3056(b)(3), NC-3655(b)(3), and ND-3655(b)(3)].
(b) *10 CFR 50.55a(b)(1)(vi)(A)* Reflected waves caused by Flow Transients (NB/NC/ND-3622)

The ASME does not oppose the following rule changes proposed by the USNRC:

10 CFR 50.55a(b)(1)(vi)(B) Inelastic Analysis for Evaluating Reversing Dynamic Loads specifically as required by NB-3228.6

1.0 Introduction

This position paper presents the ASME concerns relative to the proposed USNRC 50.55(a) rulemaking as it applies to NB/NC/ND-3600 of the ASME Boiler and Pressure Vessel Code, Section III, Division 1. These concerns are based on a review of the presentations made by the USNRC at the August 2003 BPVC meetings, subsequent informal input received at the December 2003 BPVC meetings, and the Draft Proposed Rules published in the Federal Register, Volume 69, Number 4 on January 7, 2004.

2.0 Summary Review of the Proposed USNRC Proposed Rule Changes

(a) *10 CFR 50.55a(b)(1)(vi)(C)* Proposed Rule changes to NC-3653.2(d) and ND-3653.2(d)

Table 2.1 provides a comparison of the current Code rules and the changes that would result from the proposed rulemaking by the USNRC. By reviewing Table 2.1 it is the conclusion of the ASME that the net effect of the proposed USNRC rulemaking is to return the Code to the rules that were used for seismic design of piping prior to the 1994 Addenda to the 1992 Code changes. However, there is one point that is confusing at this time. The proposed USNRC rulemaking requires that moments (including anchor motion) for reversing dynamic loads be included in NC/ND-3653.1 and NC/ND-3653.2 but the proposed rule making provides no guidance on the level of these reversing dynamic loads {Operating Basis Earthquake (OBE), Safe-Shutdown Earthquake (SSE)}. The current Code is structured after a 10CFR Part 52 licensing basis with an Appendix S seismic input. This approach permits a Licensee not to do a specific analysis for the OBE if OBE is defined as less than 1/3 SSE. In this case, there is only one set of reversing dynamic loads and that is the SSE. So does this mean that for the plants having only a SSE (only one set of reversing dynamic loads), the moments due to SSE now must meet Level B limits? This item requires clarification if the rules go forward. Assuming that OBE is the Level B reversing dynamic load and SSE is the Level D reversing dynamic load, the proposed USNRC rulemaking in most cases (> 90% of the time) would return to the situation where the OBE (Level B) will control the design of the piping system. The detailed basis for this conclusion is provided in Section 4.0.

(b) *10 CFR 50.55a(b)(1)(vi)(D)* Proposed Rule changes to Linear Elastic Response Spectrum Analysis [NB-3653(b)(3), NC-3655(b)(3), and ND-3655(b)(3)]

This is a licensing issue between the USNRC and the individual utilities, more than an ASME Code issue. This is most likely to occur in older plants with very conservative floor spectra and low damping values (Housner Spectra). It should be noted that an Amplified Floor Response Spectra generated in accordance with Appendix N is essentially a Regulatory Guide 1.60 Spectra. It would seem that any spectra more conservative then a Regulatory Guide 1.60 Spectra would be "overly" conservative. If a utility wished to use the Appendix N Spectra, the licensing amendment process would appear to be the most appropriate. Therefore, the ASME would suggest that this requirement should not be part of this rulemaking.

(c) *10 CFR 50.55a(b)(1)(vi)(F)* Proposed Rule changes to the Evaluation of Anchor Motions [NB- 3656(b)(4), NC-3655(b)(4), and ND-3655(b)(4)]

The proposed USNRC rulemaking returns the Code to the design rules as they were prior to 1994 Addenda to the 1992 Code. In fact, the proposed rulemaking is a more restrictive than the pre-1994 Addenda to the 1992 Code because the proposed USNRC rulemaking requires the SSE Seismic Anchor Motions (SAM) be designed to what are essentially Level B limits. Prior to 1994 Addenda to the 1992 Edition, the Code imposed no explicit design requirements on SSE SAM'S. It did require OBE SAM's to meet Level B limits, which implied that SSE SAM's were limited from a level of 1.2 S_A to an upper limit of about 2.0 S_A. (It should be noted that 2 S_A using i, is essentially the same as $6S_M$ using C_2). For hot piping, the thermal expansion moments would reduce this effect in that the control of the design would shift back to the Level B equation. In this case, the design would now be controlled by the OBE as was discussed in Section 2.0(a). Therefore, in either case the SAM design is now controlled by the Level B (or OBE) stress limit. The detailed basis for this conclusion is contained in Section 4.0.

(d) *10 CFR 50.55a(b)(1)(vi)(E)* Proposed Rule changes to Allowable B_2 Stress Indices for Tees and Elbows [NB-3656(b)(3), NC-3655(b)(3), and ND-3655(b)(3)]

Before discussing whether the B_2' indices should be ¾ of B_2 ASME would like to point out that NB-3656(b)(3) and NC-3655(b)(3) as printed in the 2001 Edition were incorrect. ASME has processed a set of errata to correct these two paragraphs to be the same as ND-3655(b)(3). That is, in all three Classes, the definitions should read:

$B_2' = 0.87/h^{2/3}$ for curved pipe and butt-welding elbows...
$B_{2b}' = 0.27(R_m T_t)^{2/3}$ and
$B_{2r}' = 0.33(R_m T_t)^{2/3}$ for ANSI B16.9 or MSS-SP-87 butt-welding tees...

Based on extensive data reduction of the EPRI/USNRC test data and the Japanese test data and analysis conducted by the Japanese, the B_2' values as printed in ND-3655(b)(c) and summarized above are correct. They are the values intended by the ASME SWG Seismic Rules and the Subgroup Design. The detailed basis of these statements are provided in Section 4.0

(e) *10 CFR 50.55a(b)(1)(vi)(A)* Proposed Rulemaking for Reflected waves caused by flow transients [NB-3200, NB/NC/ND-3600]

This rule making disallows the classification of reflected waves from flow transients as a reversing dynamic load. The ASME would concur that there is not a universal industry consensus that reflected waves from all possible types of flow transients are reversing dynamic loads. This issue may require more review by the Boiler and Pressure Vessel Code Committees. Therefore, while the ASME does not support this proposed rulemaking, the ASME would not oppose it at this time.

(f) *10 CFR 50.55a(b)(1)(vi)(B)* Proposed Rulemaking to Prohibit the use of the Inelastic Analysis Criteria of NB-3228.6.

This rule making prohibits the use of the inelastic analysis Criteria of NB-3228.6. This rulemaking is consistent with recently approved changes that will be implemented by the ASME in Section III of the Boiler and Pressure Vessel Code, in which the inelastic analysis Criteria of NB-3228.6 was removed form the Code. Therefore, the ASME does not oppose this proposed rule making.

Table 2.1 – Comparison of Current Code and Proposed USNRC Rule Making

NC/ND Section	Current Code	USNRC Rule Changes
NC/ND-3653.1	$B_1 \frac{P\max Do}{2t_N} + B_2\left(\frac{M_A + M_B}{Z}\right) < 1.8S_h$	$B_1 \frac{P\max Do}{2t_N} + B_2\left(\frac{M_A + M_B}{Z}\right) < 1.8S_h$ and $B_1 \frac{P\max Do}{2t_N} + B_2'\left(\frac{M_E'}{Z}\right) < 1.8S_h$ (1)
NC/ND-3653.2 (a)	$\frac{iM_C}{Z} < S_A$	$\frac{iM_C'}{Z} < S_A$ (2)
NC/ND-3653.2 (d)	$\frac{iM_R}{Z} < 2.0S_A$ (5)	*Disallowed*
NC/ND-3655.b (3)	$B_1 \frac{P_D D_O}{2t} + B_2' \frac{M_E}{Z} \leq 3.0S_M$	$B_1 \frac{P_D D_O}{2t} + B_2' \frac{M_E}{Z} \leq 3.0S_M$ *(No Change) (3)*
NC/ND-3655.b (4)	$C_2 \frac{M_{SAM}}{Z} < 6.0S_M$	$C_2 \frac{M_{SAM}}{Z} < 6.0S_M$ or $C_2 \frac{M_{SAM}}{Z} < 3.0S_M$ (4)

(1) M_E' includes weight and Level B reversing dynamic loads (?OBE?).

(2) M_C' should include the same moments that were included in Equation 10 prior to the 1994 Code revision. Equation 11 should also include the same moments that were included prior to the 1994 Code revision This would include a M_{OBESAM} which is the resultant moment due to OBE Seismic Anchor Motion

(3) M_E as currently defined in the Code includes weight and reversing dynamic loads.

(4) Must demonstrate that the global piping response does not create a significant inelastic strain concentration for the use of the 6 S_m value. No demonstration required for stress range less than $3S_M$.

(5) M_R - The Range of resultant moment due to inertia and anchor motion effects

3.0 Summary of the ASME Position on the Proposed Rule Making

3.1 ASME Evaluation of the Overall Effect of the Proposed Rule Making

The proposed USNRC rulemaking returns the Code to the design rules as they were prior to 1994 Addenda to the 1992 Code. In fact, the proposed rulemaking is a more restrictive than the pre-1994 Addenda to the 1992 Code because the proposed USNRC rulemaking requires the SSE Seismic Anchor Motions (SAM) be designed to what are essentially Level B limits. Prior to 1994 Addenda to the 1992 Code, the Code imposed no design requirements on SSE SAM'S. It did require OBE SAM's to meet Level B limits, which implied that SSE SAM's were limited from a level of 1.2 S_A to an upper limit of about 2.0 S_A. (It should be noted that 2 S_A using i, is essentially the same as $6S_M$ using C_2).

Based on the extensive data reduction performed on the EPRI/NRC test data and the Japanese test data and the ASME evaluation of temperature effects, it is the ASME's opinion that the appropriate B_2' multiplier for elbows/bends and tees is $B_2' = 2/3\ B_2$ not $B_2' = 3/4\ B_2$.

It is the ASME's opinion that the net effect of these proposed rule changes is a more conservative, more restrictive design criteria than was in the ASME Code prior to 1994 Addenda to the 1992 Code. In addition for a vast majority (> 90%) of piping systems the control of the design will revert to the OBE loads and the Level B stress limits.

3.2 ASME Position on the Proposed Rule Making

Using the information put forth in this position paper the ASME does not agree with and does oppose three of the six rule changes proposed by the USNRC.

Specifically, the ASME does not support the following proposed rule changes:

- (d) *10 CFR 50.55a(b)(1)(vi)(C)* Allowable Bending Stresses[(NC-3653.2(d) and ND-3653.2(d)]
- (e) *10 CFR 50.55a(b)(1)(vi)(E)* Allowable B_2' stress indices for tees and elbows [(NB-3656(b)(3), NC-3655(b)(3), and ND-3655(b)(4)]
- (f) *10 CFR 50.55a(b)(1)(vi)(F)* Evaluation of anchor motions [NB-3656(b)(4), NC-3655-(b)(4), and ND-3655(b)(4)].

The ASME does not support, but would not oppose, the following rule changes proposed by the USNRC:

- (c) *10 CFR 50.55a(b)(1)(vi)(D)* Linear Elastic Response Spectrum Analysis [(NB-3056(b)(3), NC-3655(b)(3), and ND-3655(b)(3)].

(d) *10 CFR 50.55a(b)(1)(vi)(A)* Reflected waves caused by Flow Transients (NB/NC/ND-3622)

The ASME does not oppose the following rule changes proposed by the USNRC:

10 CFR 50.55a(b)(1)(vi)(B) Inelastic Analysis for Evaluating Reversing Dynamic Loads specifically as required in NB-3228.6

3.3 ASME Suggested Method for the USNRC to Proceed on the Proposed Rule Making

Considering the information put forth in this position paper, the ASME respectfully requests the USNRC reconsider the official issuance of this rulemaking until the concerns put forth can be reviewed and discussed in depth. Further, the ASME would hope the USNRC would continue to work with the ASME BPVC Code Committees in addressing these concerns.

4.0 Technical Basis of the ASME Position

Provided in this section is the technical basis for the ASME concerns relative to the proposed USNRC 50.55(a) rulemaking as it applies to NB/NC/ND-3600 of the ASME Boiler and Pressure Vessel Code, Section III, Division 1. These concerns are based on a review of the presentations made by the USNRC at the August 2003 BPVC meetings, subsequent informal input received at the December 2003 BPVC meetings, and the Draft Proposed Rules published in the Federal Register, Volume 69, Number 4 on January 7, 2004.

4.1 Definition of B_2' as ¾ of B_2 versus 2/3 of B_2 for Elbows and Tees

Allowable B_2' stress indices for tees and elbows (NB-3656(b)(3), NC-3655(b)(3), and ND-3655(b)(3)).

NB-3656(b)(3), NC-3655(b)(3), and ND-3655(b)(3) of the 2001 Edition and the 2002 and 2003 Addenda specify the maximum allowable B_2' stress indices for tees and elbows when using the alternative method for evaluating dynamic reversing loads. The allowable B_2' stress indices specified in ND-3655(b)(3) are not consistent with the allowable B_2' stress indices specified in NB-3656(b)(3) and NC-3655(b)(3). The allowable B_2' stress indices of 3/4 up to B_2 for tees and elbows as specified in NB-3656(b)(3) and NC-3655(b)(3) are acceptable. The NRC is proposing to disallow the use of the B_2' stress indices specified in ND-3655(b)(3), and to require that the allowable B_2' stress indices specified in NB-3656(b)(3) and NC-3655(b)(3) be used instead of the allowable B_2' stress indices specified in ND-3655(b)(3). The NRC is disallowing the use of the B_2' stress indices specified in ND-3655(b)(3) for tees and elbows because the safety margins associated with this application have not been established.

Before discussing whether the B_2' indices should be ¾ of B_2, ASME would like to point out that NB-3656(b)(3) and NC-3655(b)(3) as printed in the 2001 Edition were incorrect. ASME has processed a set of errata to correct these two paragraphs to be the same as ND-3655(b)(3). That is, in all three Classes, the definitions should read:

$B_2' = 0.87/h^{2/3}$ for curved pipe and butt-welding elbows...

$B_{2b}' = 0.27(R_m/T_t)^{2/3}$ and
$B_{2r}' = 0.33(R_m/T_r)^{2/3}$ for ANSI B16.9 or MSS-SP-87 butt-welding tees...

This correction was passed too late to be published in the 2003 Addenda. The values shown result in B_2' values equal to $2/3 B_2$.

The reasons behind B_2' = ¾ or 2/3 of B_2 are shown in the explanation that accompanied the original balloting for BC00-113. As indicated in the original background paper, provided as Appendix 1 to this document:

"Dr. Kennedy felt that for almost any reasonable piping geometry a $F_{red}*F_{nl}$ of 1.33 could be justified. Thus, we were left with showing that F_s was about 1.5 for all the test data. Once again, except for EPRI Test 37, Dr. Kennedy was able to show that F_s was > 1.5 for all tests included in the NUREG/CR-5361 ETEC studies, plus the JST tests, so long as the B_2' indices listed below were used <u>with an allowable of 3 S_m</u>. Thus, he proposed the following

- Elbows, Bends, and tees: $B_2' = 2/3\ B_2$ (B_2 for current equation 9 rules)
- Welds at location of abrupt stiffness changes: $B_2' = 4/3\ B_2$
- Other fittings where a reduction is unavailable: $B_2' = B_2$

Thus, based on the data reduction presented by Dr. Kennedy, the appropriate multiplier was 2/3, not ¾.

In addition, the Japanese Seismic Team work showed that a static "Markl" type test would produce the same results (fatigue failure in the same number of cycles) as a dynamic test (see Reference 1). A "Markl" type, or cantilever, test appears to produce the maximum strain concentration/elastic follow up when compared to results from a 4 point bend test (see Reference 4, page 74). Thus, the type of tests used in the correlations produces maximum strain concentration for the given input. Piping systems would typically have characteristics between cantilever and 4 point bend.

However, there was one other concern raised in NUREG/CR-5361 that still appeared to exist: the reduction in fatigue strength/moment capacity of carbon steel at higher temperatures due to dynamic strain aging. As indicated on page 30,

"The one issue not addressed above is the temperature effect. The SWG-SR tried to address this, since we strongly believe this is not a seismic issue alone, but our proposals to the concerned individuals were not accepted. Thus, the SWG-SR proposed a compromise position to that initially put forth by Dr. Kennedy and passed in BC00-184: raise the multiplier of the elbow and tee B_2' to ¾ from 2/3. Using an allowable of 3 S_m, this is the same as the 1994 rule changes with an allowable of 4 S_m. This was viewed as a compromise position, since the potential negative effect due to temperature and dynamic strain aging might be as high as about 25%, and the reduction was from the equivalent of 4.5 to the equivalent of 4.0 S_m, about 12%."

Please note that the members of the SWG-SR were not convinced the temperature effect should be considered. Based on data presented by the Japanese Research Team, it appeared the effect was not significant at the strain and strain rate levels to which the piping would be limited. In the interest of moving forward, however, the SWG-SR proposed the modified position.

At Main Committee, there were four (4) negatives on the ballot as proposed. The main negative (common to all 4) was the reduction taken because of the effect of temperature. It was felt that if this was an issue (and there was no agreement at Main Committee that it was an issue), then it should be addressed on an overall Code Materials basis, not just for seismic stresses.

At this point (September, 2001), the Japanese Research Team provided data they had developed when performing their finite element to test correlation studies (Appendix 3, pages 58-67). They had correlated their modeled data with actual test results for a fictitious elastic stress of 10 S_m (Appendix 3, 61, slide SH-6). The resulting strain range was 6%. They then analyzed the same elbow for an elastic equivalent stress of 6.5 S_m, and found a strain range of 2.3%. Assuming a 4 Hz system, with 0.125 seconds positive peak to negative peak, this works out to strain rates of 0.48/sec and 0.18/sec, respectively.

At 4.5 S_m, one would expect a strain range of about 1%, extrapolating the Japanese Research Team results. Assuming a similar first frequency (4 Hz), which is not unreasonable for piping, gives a strain rate of about 0.08/sec, or about 0.1/sec. If we compare the ratio of yield to ultimate for even flawed pipe (Appendix 3, page 63) at 0.1/sec and 300 °C/570°F to the ratio at a slow rate (~10^{-3}/sec) and room temperature, we find:

Higher rate and 300 °C/570°F : Sy ~ 260 MPa/(38 ksi), Su ~ 420 MPa/61 ksi: Sy/Su ~ 0.62

Lower rate and RT: Sy ~ 340 MPa/(49 ksi), Su ~ 500 MPa/73 ksi: Sy/Su ~ 0.68

While there is some effect, we note that the testing of real components (see Appendix 3, pages 64 - 66), shows that the yield and ultimate are still well above Code minimums.

The Japanese Research Team has also provided a recent response to the temperature and strain rate concerns raised in NUREG/CR-5361. This is provided in Appendix 2, pages 31-57. This later work shows that even at M_{UD}, the Japanese tests had strain rates in the 0.3 in/in/sec – 0.5 in/in/sec range, much less than 1 in/in/sec .

Finally, a point has been made about the effect of temperature on M_{UD}, which is the maximum dynamic moment a component withstands. A measure of this would be the stress-strain curve for the material. Appendix 4 provides the results of Japanese testing of typical carbon and stainless materials at both room and elevated (300°C/[570°F]) temperature. Comparing Appendix 4, Figure 2 (RT) to Figure 3 (300°C/[570°F]) for a similar block step-up (15th to 14th), we find a stress of about 400 N/mm^2 (58 ksi) at about 1.5% strain at RT versus a stress of about 450 - 500 N/mm^2 (65-73 ksi) at the same strain at elevated temperature. A comparison of the two figures at the first block shows there is little difference between the maximum stresses at 1.5% strain (about 375 N/mm^2 each). While this shows there is some effect of dynamic aging, the temperature does not reduce the size of the stress-strain loop, so one would not expect much change in M_{UD} at temperature for the Carbon steel. From the standpoint of stress allowable (3S_m), this is about the same for the SA106B material (S_m changes from 20 ksi at RT to 18.9 ksi at 300C/[500°F])

For a typical stainless steel, the same comparison can be made. Compare Appendix 4, Figure 4 (RT) to Figure 5 (300°C) for the 15th and 18th blocks, respectively. We see about 500 N/mm^2 (73 ksi) at 1.5-% strain at RT, and about 425 N/mm^2 (62 ksi) at elevated temperature, or a reduction of about 15%. This is essentially the same reduction in 3 S_m over that range. For RT to 500°F, the change in 3 S_m is from 60 ksi to 51 ksi, or exactly 15%. At 300°C/570°F, the Code reduction would therefore be greater than 15%. Thus, the effect of temperature on M_{UD} is reasonably accounted for in the Code methodology.

Based on the extensive data reduction performed on both the EPRI/NRC test data and the Japanese test data by Dr. Kennedy, and based on the above discussion of temperature effects, ASME believes that the appropriate B_2' multiplier for elbows/bends and tees is $B_2' = 2/3\ B_2$

4.2 Disallowing the Use of NC/ND – 3653.2(d)

ASME would like to provide more information on the justification for the 2 S_a limit chosen for Level B loads. The 3 S_a limit in ND is a publication error and should be 2 S_a. This will be corrected via errata process. The 2 S_a limit for Level B loads was always the intent for Class 2/3 piping.

First, we would like to point out that the equation used is consistent with the checks used in Class 1, which checks primary plus secondary range and fatigue for reversing dynamic loads. {It is important to note that M_R is the Inertial (primary) stress plus the SAM (secondary) stress, i.e. the "primary plus secondary" stress for Earthquake loading}. In fact, the proposed NRC position for Class 2 and 3 is inconsistent with the position for the more critical plant piping, Class 1, in which there is no primary equation check for Level B reversing dynamic loads.

The use of the 2 S_a limit was based on "typical" number of cycles for Level B dynamic seismic loads, usually 5 events at 10 or 20 cycles per event, although some current plants can be higher. Using Markl's equation for Carbon Steel (which is more limiting than stainless, based on Markl testing), with a SF of 2 on stress:

$iS = 245000n^{-0.2}$ with n = 100, range of the stress (the typical Markl equation is shown as amplitude. By taking the range, we build in a factor of 2 on stress and 32 on cycles).

iS = 97,500 psi, which is clearly greater than 2 S_a for typical carbon steels such as SA106B, which is 51,400 psi.

From a cyclic standpoint, our modified Markl equation would permit:

$iS = 51400 = 245000N^{-0.2}$

N = 2460 cycles

The resulting usage is 100/2460 = 0.04, which is quite small. Thus, fatigue is not an issue. Further, for most common piping materials 2 S_a is approximately 1.3 S_y to 1.5 S_y. A cyclic stress limit of less than 2 S_y insures the material will "shakedown" to elastic cycling [2]. Any failures would be as a result of elastic cycling and would propagate as elastic fatigue failures. This fact coupled with the low usage factor of approximately .04 for the seismic loads, provides a high degree of assurance that a fatigue failure due to OBE seismic loads will not occur. At several Subgroup Design meetings, the fact that the OBE usage over the life of a plant could reach up to .1 had been discussed. Given the conservatism and margin in the NB/NC/ND-3600 fatigue analysis (Factor Safety of 2 on Stress and Factor of Safety of between 20 to 32 on Cycles) this was judged acceptable by the Subgroup.

The ASME would also like to point out that, in the new reactor stress criteria (see, for example, NUREG-1503, Section 3.12.5.15) [3], the NRC has accepted $3S_h$ as a limit for the range of either thermal expansion plus SSE SAM amplitude, or twice the SSE SAM amplitude. {This is a limit on secondary stress only, not primary plus secondary stress as currently required by the Code for level B loading} The limit of 3 S_h is approximately the same as 2 S_a, since $S_a = 1.25\ S_c + 0.25\ S_h$. Currently, the Code does not include the thermal expansion range in the check, but the Code includes the inertial effects in the seismic fatigue limit. In addition, the range of the thermal expansion plus the amplitude of Level B reversing inertia plus SAM and the range of twice the amplitude of Level B reversing inertia plus SAM would be limited to 2 S_a (if thermal expansion were at the S_a limit), or approximately the same limit as in new reactors with inertia now included (inertia was not included in the new reactor range criteria).

Thus, ASME suggests that limiting the RANGE of Level B reversing inertia and SAM to 2 S_a produces a conservative design, and is consistent with the method used for Class 1 Level B loading. In addition, the limit chosen is comparable with and possibly, more conservative than that proposed for new reactor design.

4.3 Restrictions on the use of NB-3656(b)(4) and NC/ND-3655(b)(4)

The proposed USNRC rulemaking states you can use the existing Code rules if "you perform a demonstration that the global piping system response to the anchor motion does not create significant inelastic strain concentrations". As an alternative to this, you can reduce the allowable stress value to 3.0 S_M. The first alternative will require non-linear, inelastic analysis of the piping system and in most cases will be cost prohibitive and technically difficult, if not technically impossible. Therefore, the balance of the discussion will focus on the alternative approach of reducing the capacity to 3.0 S_M. It is very likely that this is the approach (reducing the allowable stress to 3.0 S_M) that would be applied to the design of most piping systems.

The Japanese have done inelastic calculations on elbows that were elastically evaluated to the 6.0 S_M secondary stress limits using a C_2 for elbows [1] in combination with inertial stresses up to 4.5 S_m (elastic equivalent), and conservatively combining both effects absolutely (one would not expect the effects to combine absolutely, since the maximum SAM stress should occur in a rigid location in the system, and be driven by the building frequency, while the inertial stress would occur in the more flexible portions and be driven by the piping frequency). The results show a maximum strain of 1.2% and <u>actual</u> elastic plus inelastic stress level of less than 3.0 S_M. This

1.2% strain on a component test would appear to meet the "does not create significant inelastic strain concentrations" requirement on a essentially global basis. This would support that the 6.0 S_M limit with linear elastic analysis is a safe and acceptable criteria for SSE SAM's. (See pages 153-160 of Reference 1)

Another consideration for NC/ND-3655(b)(4) {Class 2/3} is that the proposed Level B equation uses 'i' and 'S_A' and the proposed Level D equation used "C_2" and "S_M". Therefore, for comparison, a similar basis must be established. Noting that $2i = C_2 K_2$ and if K_2 is taken as 1.0, then $C_2 = 2i$. A review of the Table 4.2 and 4.3 shows that $S_A \approx 1.25$ to $1.5 S_M$; therefore, for further consideration, use a value of 1.38 as average or $S_M = (1/1.38) S_A = .72 S_A$. Making the appropriate substitutions into the NRC proposed Level D equation results in:

$$2i\frac{M_{AM}}{Z} \leq 3.0(.72S_A)$$

or

$$i\frac{M_{AM}}{Z} < 1.08S_A \text{ or } \approx 1.0S_A$$

(The Level B Secondary Stress Limit)

For cold piping systems, the modified equation now limits SSE (Level D) anchor motions to the same stress limits as proposed for the OBE (Level B). A plant applying these rules will be required to design piping systems subjected to SSE (Level D) seismic anchor motions to essentially OBE (Level B) stress limits. For hot piping the thermal expansion moments would reduce this effect in that the control of the design would shift back to the Level B equation. Therefore, in either case the SAM design is now controlled by the Level B (or OBE) stress limit.

It is very important to note that the new Code rules provide a limit on Level D SAM's where none existed prior to the 1994 Addendum to the 1992 Code.. Historically prior to the 1994 Addendum to the 1992 Code there was no explicit limit on the range of SSE SAM's. Prior to the 1994 Addendum to the 1992 Code the range of OBE SAM's was limited. Since SSE was a factor of OBE this resulted in an implicit limit on SSE SAM's but not formal Code check or evaluation was required..

In developing the changes for the 1994 Addendum to the 1992 Code, explicit limits were put in place <u>because</u> of the actual earthquake experience data showing that high SAM's are a major contributor to the few known seismic failures in piping. The ASME was concerned that if there were no Level B reversing dynamic loads for plants licensed to the new Federal rules, then there would be no check for SAM in the ASME rules. Ignoring SAM was not acceptable, thus this Level D SAM limit was used to ensure some control on SAM effects. As can be seen from the Japanese work, the resulting strain is not excessive. As can be seen, the explicit limits added by 1994 Addendum to the 1992 Code ($6S_m \approx 2S_A$) were essentially the same as the implicit limits that had existed in the Code prior to the 1994 Addendum to the 1992 Edition.

In addition, the result, for tees and elbows, is consistent with the 3 S_h SAM limit accepted for the new reactors (See NUREG-1503, the section cited above), since C_2 is equal to about 2i for these typically controlling components. The resulting limit would be:

$C_2 M_{AM} D_o / 2I = 6\ S_m = 2i\ M_{AM} D_o / 2I$

$i\ M_{AM} D_o / 2I = 3\ S_m$, or approximately 3 S_h, which is the same limit as the range of anchor motion stress permitted in new reactor criteria. Again, ASME suggests that the limits currently in the Code are reasonable and provide adequate margin to insure safe piping system design.

4.4 Additional Requirements for Reversing Dynamic Loads Added to NC/ND-3653.1

Table 4.1 provides a comparison of the current Code rules and the changes resulting from the proposed rulemaking by the USNRC. By reviewing Table 4.1 it is the conclusion of the ASME that the net effect of the proposed USNRC rulemaking is to return to the Code rules that were used for seismic design of piping prior to the 1994 Addenda to the 1992 Code changes. However, there is one point that is confusing at this time. The proposed USNRC rulemaking requires that moments (including anchor motion) for reversing dynamic loads be included in NC-3653.1 and NC-3653.2 but the proposed rule making provides no guidance on the level of these reversing dynamic loads (OBE?, SSE?). The current Code is structured after a 10CFR Part 52 licensing basis with an Appendix S seismic input. This approach permits a Licensee to do no specific analysis for the OBE if OBE is defined as less than 1/3 SSE. In this case, there is only one set of reversing dynamic loads and that is the SSE. So does this mean that for the plants having only a SSE, the moments due to SSE now must meet Level B limits, or, if there are no level B reversing dynamic loads then $M_E' + M_{AM}' = 0$? This item requires clarification if the rules go forward.

Assuming that OBE is the Level B reversing dynamic load and SSE is the Level D reversing dynamic load, the proposed USNRC rulemaking in most cases (> 90% of the time) would return to the situation where the OBE (Level B) will control the design of the piping system.

Consider the most common steels used in Nuclear Piping: SA-106B; SA-312, Type 304; and SA-376, Type 304. Tables 4.1, 4.2, and 4.3 provide a comparison of the Level B stress limits (that would be imposed on the OBE) and the Level D stress limits (that would be imposed on the SSE). As can be seen, the ratio of the Level B to the Level D limits range from .5 to .61 for inertial loads and .43 to .5 for anchor motion loads. Traditionally the OBE ground motion has been selected to be ½ the SSE ground motion. Therefore, on the surface if one considers the OBE to be ½ SSE, it would appear that under the proposed USNRC Rule changes, SSE would govern design for inertial loads. Based on Table 4.3, for secondary stresses (SAM), in several cases, control of the design will revert to the OBE. Specifically, (per Table 4.3) for the most common carbon steel currently in use (A106 Gr. B) the design for SAM's would be controlled by the OBE. However, there are several other factors that will effect the ratio of OBE to SSE for inertial loads and these items need to be considered. They are discussed in the following paragraphs.

(a) Pressure Stress

A portion of the piping capacity is reserved for the pressure stress ($B_1*PD_o/2t$) term and the same level of stress is considered for both the OBE and SSE. The net effect of this pressure stress is to reduce the capacity remaining for the moment (reversing Dynamic Load) stress. Since the same fixed value is used in both equations, the net effect is to increase the significance of the OBE loads relative to the SSE load. [$OBE_{Load}/SSE_{Load} > .5$].

(b) Deadweight Stress

A portion of the piping capacity is reserved for the Deadweight Stress $\left(B'_2 \frac{M_w or M_A}{Z}\right)$ and the same level of stress is considered for the OBE and SSE. The net effect of this deadweight stress is to reduce the capacity remaining for the moment (reversing Dynamic Load) stress. Since the same fixed value is used for both equations, the net effect is to increase the significance of the OBE loads relative to SSE loads [(OBE_{Load}/SSE_{Load}) >.5].

(c) Damping

If one assumes that the ground motion starts out as OBE = ½ SSE, then per Regulatory Guide 1.61 for the structural analysis of reinforced concrete structures the OBE analysis is limited to 4% critical damping while the SSE analysis uses 7% critical damping. The structural critical damping values for bolted steel structures are also 4% critical damping for the OBE and 7% critical damping for the SSE. The structural critical damping values are 2% for OBE and 4% for SSE for the structural analysis of welded steel structures. The next consideration is the equipment damping used in the generation of the amplified floor spectra. If N-411 damping is used, the OBE and SSE equipment damping valves are the same and vary from 5% to 2% critical damping. If Appendix N is used the OBE and SSE equipment damping values are 5% for both OBE and SSE. Therefore, while the equipment damping values would not impact the ratio of OBE to SSE, the structural damping values would raise the ratio of OBE to SSE from the initial ground motion values of one-half to a higher value. Therefore, when the appropriate Amplified Floor Response Spectra are generated and used in the piping system analysis, the OBE is closer to 5/8 to 2/3 of SSE rather than the ratio of ½ that exists between the input ground motions.

Figures 4.1 and 4.2 were developed to demonstrate this effect. The figures were developed as follows:

- Typical Horizontal OBE and SSE Amplified Floor Response Spectra (AFRS) were selected from a late vintage Nuclear Power Plant. These spectra were selected at a mid-height elevation in a reinforced concrete reactor building and a reinforced concrete auxiliary building.

- The input OBE ground motion was ½ of the SSE ground motion.
- The OBE AFRS were developed with 4% structural damping and N-411 based equipment damping. The SSE AFRS were developed with 7% structural damping and N-411 based equipment damping. This is consistent with the requirements of or Regulatory Guide 1.61.
- The ratio of the OBE g level to the SSE g was then plotted at all frequencies for both buildings. This is shown graphically in Figures 4.1 and 4.2.

From a review of Figures 4.1 and 4.2 it can be seen that in one case for all frequencies above 3 Hz the ratio of the OBE g levels to the SSE g levels is .6 or greater. For the second case it can be seen that for all frequencies above 6 Hz the ratio of the OBE g levels to the SSE g levels is .6 or greater. Therefore for a majority of the piping response, including the ZPA or "rigid" response, the OBE input g level will be .6 or greater of the SSE. For static analysis where the input is a factor times the peak g's of the AFRS the OBE input g level will almost always be .6 or greater of the SSE. Therefore, for the carbon steel and a large majority of the Stainless Steels shown in Tables 4.1 through 4.3 the design will be controlled by the OBE.

(d) Thermal Expansion Levels

This item was discussed in Section 4.2.

(e) As an example of the effect of items (a) and (b) above, consider a typical Cold 4" Schedule 40 carbon steel pipe (A106B) having a design pressure of 500 psi and supported for Deadweight at the suggested NF support spans. Further, for simplicity, consider a straight pipe remote from welds, elbows, etc., filled with water and not insulated.

<u>Pipe Properties:</u>

OD	=	4.5	in.
t	=	.237	in.
w/L	=	1.36	lb/in.
I	=	7.23	in^4
Z	=	3.21	in^3
B_1	=	.5	
$B_2 = B_2'$	=	1.0	
L_w	=	14 ft. or 168 in.	

<u>Material Properties:</u>

S_h	=	17,100	psi
S_m	=	20,000	psi
E	=	29E6	lb/in^2

$$B_1 \frac{PDo}{2t} = .5 \frac{(500)(4.5)}{2(.237)} = 2373 \text{ psi}$$

$$M_W = \frac{wL^2}{8} = \frac{(1.36)(168)^2}{8} = 4800 \text{ in-lbs}$$

$$B_2 \frac{M_W}{Z} = 1.0 \frac{(4800)}{(3.21)} = 1500 \text{ psi}$$

OBE capacity = 1.8 (17100) – [(2373) + (1500)] = 26,900 psi
SSE capacity = 3.0 (20000) – [(2373) + (1500)] = 56,127 psi

$$\frac{OBEcapacity}{SSEcapacity} = \frac{(26900)}{(56127)} = .48 \qquad (< .5)$$

As can be seen, this is lower than the .5 ratio ($1.8S_H/3.0S_M$) given in Table 4.2. In this case, the OBE will now control the design regardless of the effects of the spectral input discussed in (c) above. This is a low-pressure system with a low value of deadweight stress. Further, the higher the pressure and weight stress, the greater this effect. Therefore, this simple example leads to the conclusion that for typical piping systems OBE will now control the design. When the effects of (c) above are considered (OBE Demand ≈ .6 of SSE Demand) in conjunction with this effect the OBE will control the design for all but a very few low pressure, low frequency piping systems.

While there may be some piping systems where SSE will control design (Estimated to be 10% or less), for the majority of piping systems, the net effect of the proposed USNRC rulemaking is to shift control of the design back to the Level B equations and the OBE. The effect the B'_2 would have on any potential stress capacity increase is a somewhat moot point because under the proposed USNRC rulemaking B'_2 will be used in both the Level B and Level D inertial equations. Again, this assumes there is an OBE. Under 10CFR Part 52 licensing, there in most cases would not be an OBE and in most cases it is unclear from the proposed USNRC changes Level B design criteria would be imposed for Level B for reversing dynamic loads. Further, if there is not an OBE does the USNRC intend to impose and additional requirements of the SSE inertial or SAM loads?

Table 4.1 – Comparison at 500 °F (Inertial Loads)

	S_H	S_M	1.8 S_H	3.0 S_M	$\frac{1.8S_h}{3.0S_M}$
SA-106B	17.1	18.9	30.8	56.0	.54
SA-376, Type 304	16.6	17.5	30.0	51.0	.58
SA-312, Type 304	17.5	17.5	31.5	51.0	61

Table 4.2 – Comparison at AMB (70 °F) (Inertial Loads)

	S_H	S_M	1.8 S_H	3.0 S_M	$\frac{1.8S_h}{3.0S_M}$
SA-106B	17.1	20.	30.8	60	.5
SA-376, Type 304	20.	20.	36	60	.6
SA-312, Type 304	20.	20.	36	60	.6

Table 4.3 – Comparison of Anchor Motion Stress

	500 °F			70 °F		
	S_A	3.0 S_M	$\frac{S_A}{3S_M}$	S_A	3.0 S_M	$\frac{S_A}{3S_M}$
SA-106B	25.7	56	.45	25.7	60	.43
SA-376, Type 304	25.0	51	.49	30	60	.5
SA-312, Type 304	26.9	51	.53	30	60	.5

Figure 4.1
Ratio of OBE g Levels to SSE g Levels
Re-Inforced Concrete Reactor Building

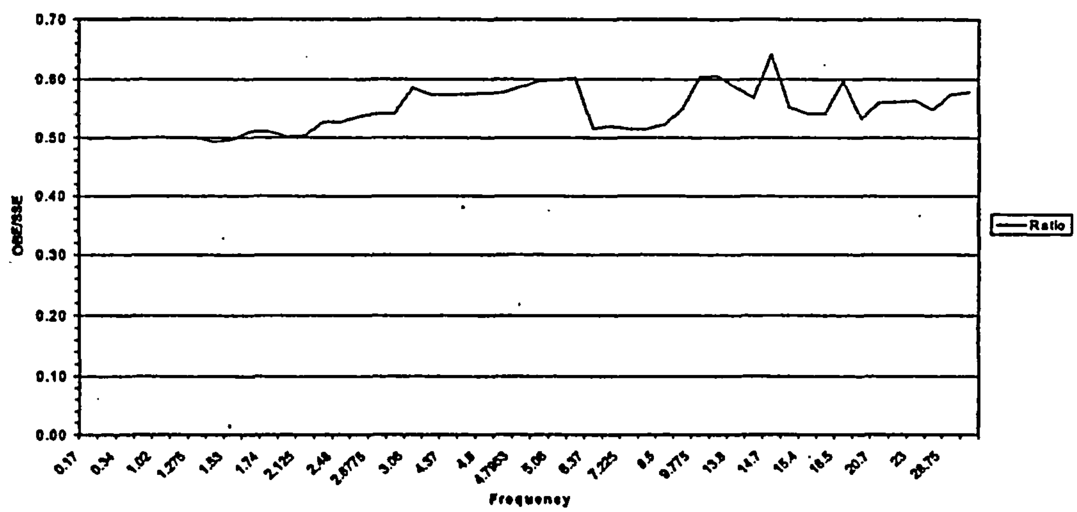
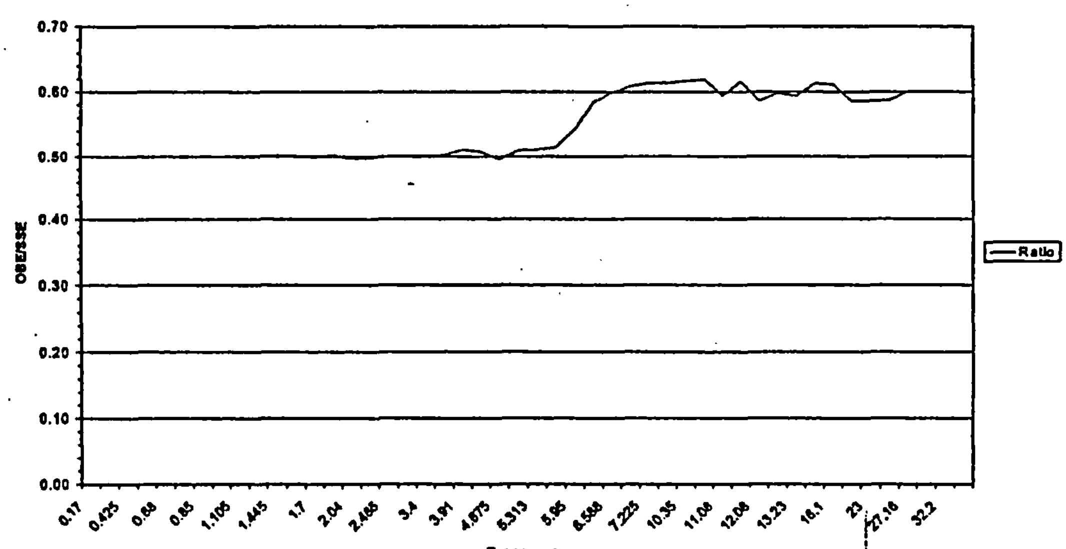


Figure 4.2
Ratio of OBE g Levels to SSE g Levels
Reinforced Concrete Auxiliary Building



4.5 Additional Requirements for NB-3656(b)(3) and NC/ND-3655(b)(3)

This is a licensing issue between the USNRC and the individual utilities, more than an ASME Code issue. This is most likely to occur in older plants with very conservative floor spectra and low damping values (Housner Spectra). It should be noted that an Amplified Floor Response Spectra generated in accordance with Appendix N is for all practical purposes a Regulatory Guide 1.60 Spectra. It would seem that any spectra more conservative then a Regulatory Guide 1.60 Spectra would be "overly" conservative. If a utility wished to use the Appendix N Spectra, the licensing amendment process would appear to be the most appropriate. Therefore, it is suggested it should not be part of this rulemaking.

5.0 Detailed Discussion of the ASME Opinion on the Proposed Rule Making

This opinion begins with an observation made at the ASME BPVC Working Group Piping Design in the early 1990's prior to the 1994 Addenda to the 1994 Addenda to the 1992 Code changes, "When you look at all the test data and all the experience data some relaxation in the seismic design criteria is warranted." If the proposed USNRC rulemaking is implemented the conclusion is that no relaxation in the pre-'94 seismic design criteria was warranted. It is further concluded that the pre-1994 Addenda to the 1994 Addenda to the 1992 Code rules were, in fact, unconservative as there will now be a more restrictive SSE SAM criteria than was in place in the 1994 Addenda to the 1994 Addenda to the 1992 Code. After all the extensive reviews of significant amounts of the test and experience data that were the basis of the development of the current Code rules, the ASME finds it difficult to support such a conclusion.

The ASME suggests that the rules that were put forth in the 1994 Addenda to the 1992 Code were reasonable and will provide safe piping system designs. The test data (all test data, not just the EPRI component test data) and especially the experience data indicated:

(a) A limited number of OBE level earthquakes are not a concern for a piping system from a primary or secondary stress level.

(b) At SSE level earthquakes, the piping undergoes significant inelastic energy absorption prior to failure. While it is difficult to analyze and predict, it was decided it could be accounted for by using 5% critically damped Linear Elastic Response Spectrum Modal Analysis and increasing the stress level to 4.5 S_M from 3.0 S_M.

(c) The ASME acknowledged that the "real" concern for piping failure during an earthquake is SAM, not inertial loads, and the provision of a reasonable SSE SAM limit where none previously existed.

(d) The reduction of the Factor of Safety on Level D (SSE) level earthquakes from somewhere greater than 2.0 to approximately 1.5, which is consistent with the Code's philosophy on Level D primary membrane limits on ultimate strength (1/0.7 ~ 1.5).

As the USNRC is aware, the changes made in the 1994 Addenda to the 1992 Code to implement these rules were not accepted by the USNRC. Since 1996 through the early 2000's, the ASME has worked with the USNRC to try to address their concerns.

On item (b) above, the ASME SWG-SR opted to revert to the pre-1994 Addenda to the 1992 Code limit of $3S_M$ with some capacity increase based on the use of B'_2 vs. B_2 for elbows and tees. In doing this, a penalty was taken by using a higher B'_2 for butt-welds. This was done for the following reasons:

(1) If the limit was left @ $4.5S_M$ piping systems could become a major contributor to Core Damage Frequency and that could have a very negative impact on the industry. The effect was to raise the factor of safety for Level D seismic loads to a value on the order of 2.0.

(2) The effects of the inelastic response observed in the EPRI component tests could not be mathematically and statistically quantified relative to a linear elastic limit of $4.5S_M$. It was "intuitive" that it existed but it could not be numerically quantified on a statistical basis. Therefore, the mathematical and statistical correlation were limited to essentially the maximum elastic moment (M_{UD}) observed in the testing. This consideration coupled with the fact that with $B'_2 = 2/3\ B_2$ for Elbows and Tees, the controlling design items essentially maintained a $4.5S_M$ limit, while most other components were restricted to $3.0S_M$.

(3) A third concern was that the higher limits created problems for Section XI crack growth calculations. Section XI uses the Section III equations for crack growth calculations. The Section XI approach was tailored to the 3.0 S_M limit for SSE stress levels and the 4.5 S_M limit would have required changes to the Section XI methodology and criteria.

The latest proposed rulemaking by the USNRC essentially negate item (a) above and provides a very conservative limit on item (c) above; far beyond the original intent or what the ASME considers to be necessary.

ASME believes that the above discussion points address four of the six USNRC exceptions that are documented in the proposed rule making. ASME does not oppose the remaining two issues on use of NB-3228.6 and reflected wave loading. The ASME Special Working Group on Seismic has worked with USNRC representatives for the past five years in an attempt to reach a workable solution to the excessive conservatism in the pre-1994 Addendum to the 1992 Code seismic rules for piping, while continuing to maintain adequate safety margins. It is ASME's belief that the seismic rules documented in the current Code, with the editorial/errata changes discussed above, provide a sound engineering basis for safe seismic design of piping systems designed in accordance with the rules of ASME Section III.

The ASME thanks the USNRC for the opportunity to address your concerns with our rules and are optimistic that we have satisfactorily demonstrated that the ASME position is well founded and technically justified. Based on this Position Paper and the presentation made at the February 2004 Boiler Code Week in the USNRC Public Meeting the ASME believes it is in the best interest of both the USNRC and ASME that the proposed rule making be delayed until the concerns put forth in this position paper can be reviewed in depth and hopefully resolved without the requirement for any significant limitations to the application of the Code.

6.0 References

[1] ASME PVP Volume 407, pp 115-146 and pp 147-165, presented at the 2000 ASME PVP Conference
[2] ASME, "Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Section III and VIII, Division 2", 1969
[3] NUREG-1503, "SSER for the GE ABWR",
[4] WRC Bulletin 433, Report 2, "Effect of Testing Methods on Stress Intensification Factors," EC Rodabaugh and RJ Scavuzzo

Appendix 1 - Original Discussion (in support of Letter Ballot) on B_2')

PLEASE NOTE THAT WE HAVE ONLY INCLUDED THE ORIGINAL DISCUSSION, NOT THE ATTACHMENTS TO THAT DISCUSSION

Discussion on the Overall Background of the Proposed Code Rules Changes

Background

In the February 2001 proposal for NB-3656, NC/ND-3655, and NX-3622.2, there were a series of changes suggested to address the major concerns with the rules that had been passed in 1994. Some of these changes had been proposed and passed in BC00-184; they have been resubmitted (with the portions previously approved noted), since the Special Working Group-Seismic Rules (SWG-SR) felt that any changes needed to be considered as a whole. The overall changes were intended to address the following major concerns:

- B_2 values for straights and girth butt welds
- The secondary concern from the SWG-SR that the R_w limitation in Nx-3622.2 was unworkable, and unnecessary
- The collapse failure mode exhibited in EPRI Test 37
- The reduction in fatigue strength/moment capacity of carbon steel at higher temperatures due to dynamic strain aging.

The Special Working Group has been reviewing work since 1995. In that time, the NRC has published the results of its review (NUREG-5361) and a Japanese Seismic Team has performed significant additional research (testing, 1997-1998; analysis 1997-2001). The SWG-SR has reviewed all the available data in an effort to resolve many of the significant concerns with the rule changes.

One of the major bases of the proposed changes is the work done by Dr. Robert Kennedy (1995 – 2001) in reviewing both the EPRI component test data and the more recent Japanese Seismic Team (JST) test data. The EPRI component data is summarized in EPRI Report TR-102792-V2, "Piping and Fitting Dynamic Reliability Program – Volume 2: Component Tests" (cited pages are included as Attachment 6). The JST data was reported in the minutes of the Special Working Group – Seismic Rules, beginning in April 1998 and continuing through December 2000, although the bulk of the actual testing was completed in 1998. Since the beginning of 1999, much of the JST work has focussed on resolving analytically the concerns with EPRI Test 37, particularly the differences between the JST predictions and those of the California Institute of Technology (CIT) under Prof. W. Iwan, which are reported in NUREG-5361. The JST studies on EPRI Test 37 form another major basis of the proposed rule changes.

The proposed Code changes use a markup from the latest available Code, which does not yet include the changes approved under BC00-184. Thus, on the markup, we have noted those parts already passed under BC00-184, those parts which are a change from BC00-184, and those parts which are new.

B_2' RESPONSE
ATT. 4 4-1

This Code change consists of six (6) attachments, in addition to this background discussion:

1. The proposed Code changes, with responses to initial comments from Mr. Landers, and responses to SGD negatives from Mr. Slagis, Mr. Jetter, and Mr. Hanrath
2. A copy BC00-184, with its explanation
3. "Establishing the Required Seismic Margin for Piping Systems in Nuclear Power Plants," RP Kennedy, May 1995
4. "Using Component test Data to Assist in Establishing Code Criteria to Achieve the Desired Seismic Capacity Margin for Piping," RP Kennedy, January, 2000
5. "Japanese Position on Test #37 Analysis," Japanese Seismic Team, February 12, 2001
6. Excerpts from EPRI Report TR-102792-V2, "Piping and Fitting Dynamic Reliability Program – Volume 2: Component Tests."

Discussion of Major References, Inputs, and Proposals

As part of his involvement as a NRC Peer reviewer of the 1994 Code changes, Dr. Kennedy suggested that the margin for failure in piping systems (under SSE) be set at 2. This was done in "Establishing the Required Seismic Margin for Piping Systems in Nuclear Power Plants," RP Kennedy, May 1995, subsequently published as Appendix III-B to NUREG-5361, June 1998 (Attachment 3). By doing so, the margin to failure for piping would not dominate predictions of Core Damage Frequency (CDF), and there would be a less than 1/10 of 1% probability of failure for piping under the SSE for the site. The SWG-SR adopted this margin to failure in LB 99-02. We point out that this is MORE conservative than standard Code Level D limits (based on elastic analysis, as the current rules are). The current Appendix F, Level D limits provide a margin of 1.5 on ultimate strength for membrane stresses due to a static load such as pressure (See F-1331.1). Thus, for very low frequency seismic input (similar to a static load), a margin of 1.5 may be more appropriate, but has not been proposed by the SWG-SR because 2.0 is more conservative.

One of the major concerns in NUREG-5361 was the choice of stress indices used by EPRI to predict margin to failure. In many cases, NUREG-5361 proposed that different, much more conservative (lower, in this case) indices should be used, with a lowering of predicted margins, as expected. Dr. Kennedy addressed this in a series of papers, the last of which included both the EPRI test data and the JST test data, excluding EPRI Test 37. This last paper was included as Attachment 2 to the February 2000 SWG-SR minutes, pages 9-33, and was entitled "Using Component test Data to Assist in Establishing Code Criteria to Achieve the Desired Seismic Capacity Margin for Piping." (Attachment 4)

4-2

As proposed by Dr. Kennedy, and adopted by the SWG-SR, the seismic margin of 2 is made up of three parts ($F_s F_{red} F_{nl}$):

- A factor, F_s, for the dynamic strength/fatigue moment capacity (MUD) of the component over the Code permitted moment). This factor would be based directly on the test data.
- A factor, F_{red}, based on the fact that most piping systems are redundant beams. That is, in most areas of piping formation of a plastic hinge at one location does not mean failure has occurred, since a hinge mechanism (typically three hinges) must form. The exceptions to this are those portions of systems similar to Test 37, where there is no redundancy, due to the cantilever arrangement of the geometry. (In all of the tests $F_{red} = 1.0$)
- A factor, F_{nl}, based on the nonlinear dynamic behavior of the system. That is, as the dynamic load tries to drive the system, the piping undergoes plastic deformation, but absorbs more energy in doing so, resulting in both higher damping and a tendency to fall out of the peak of the driving frequency. Again, the exception to this is the case of Test 37, where the piping starts out at a higher frequency than the dominant frequency of the seismic input motion, and "falls" into the peak.

Dr. Kennedy felt that for almost any reasonable piping geometry a $F_{red}F_{nl}$ of 1.33 could be justified. Thus, we were left with showing that F_s was about 1.5 for all the test data. Once again, except for EPRI Test 37, Dr. Kennedy was able to show that F_s was > 1.5 for all tests, including the JST tests, so long as the following B_2' indices were used with an allowable of $3S_m$. Thus he proposed the following

- Elbows, Bends, and tees: $B_2' = 2/3\ B_2$ (B_2 for current equation 9 rules)
- Welds at location of abrupt stiffness changes: $B_2' = 4/3\ B_2$
- Other fittings where a reduction is unavailable: $B_2' = B_2$

Note that Dr. Kennedy's data reduction included test 30, which had the same low frequency as EPRI Test 37, and the same input, but had internal pressure, where EPRI Test 37 did not. His reduction of all the EPRI and JST test data (except EPRI Test 37) showed an F_s of 1.53, if the changes proposed above are used (Test 30 had an F_s of 1.83). Thus, using Dr. Kennedy's M_{UD} proposal, all of the available test data (except Test 37) falls into a reasonable set of statistical data, and results in an $F_s \sim 1.5$.

Thus, it appeared by using Dr. Kennedy's proposition at least one of the concerns, the appropriate B_2 index to be used, could be answered. This was passed as BC00-184 (Attachment 2).

4-3

The secondary concern about R_w (the ratio of the dominant driving frequency of the EQ to the natural frequency of the system) came about because the SWG-SR felt the NX-3622.2 prohibition that $R_w < 0.5$ limitation was unworkable. Any piping system has an infinite number of frequencies. Thus, once the modal frequency exceeds a certain value, R_w for that frequency and all higher modes will be < 0.5. While the Code rules strictly state that only the fundamental (lowest) system frequency needs to be considered, this misses the point of R_w. A system could have a locally low frequency (for a vent connection, for example), yet the majority of the response is at higher frequencies, i.e., those for which $R_w < 0.5$.

The reason R_w was originally added was that the EPRI component testing had been done for $R_w > 0.5$. However, there was one test that had a low R_w. Test 23 was a standard elbow test with a strut attached above the elbow, but below the inertial mass. The natural frequency of the supported system was 32 HZ (page B-24 of the EPRI report). The input was the standard PFDR SSE with the peak of the input near 7 CPAs (page 7-4 of the EPRI report), so that when the strut failed, the system would shift into the cantilever mode. Five high-level runs were also done with strut failure prevented. Thus, there were high level runs done at $R_w = 7/32 \sim 0.22 < 0.5$ without failure (see Attachment 6).

In addition to the above, there is analytical data, provided by the JST during their analysis of Test 37, which shows that $R_w < 0.5$ is not necessarily detrimental (February 2001 SWG-SR minutes, Attachment 1, Page 26)(included in this package as Attachment 5). As shown in the JST analysis, which was fully correlated to EPRI Test 37 Runs 4 (half-sled) and 5 (full-sled) results, and agrees quite well with the CIT analyses, there is actually an increase in margin between an R_w of 0.7 and one of 0.5. At $R_w = 0.7$, the total stress just prior to collapse, run C-14, is 6.3Sm (seismic plus weight stress plus zero pressure stress). At $R_w = 0.5$, the total stress just prior to collapse, run C-16, is $7.5S_m$, and increase of about 20%. As indicated in the discussion provided by Mr. Kobayashi of the JST, the reason is that at very low R_w, there's very little increase in input as the component softens. But at a higher R_w (0.7 in this case), the component softens right into the peak. This behavior is also seen in most of the EPRI tests, where the driving frequency was set slightly lower than the fundamental frequency (usually around 0.875 times the component natural frequency), so the component would soften into the peak.

The conclusion should be that R_w is not the driver. If the driving frequency is relatively high, i.e., a normal seismic input, both test 23 and the JST analyses indicate that a low R_w is not a concern. The concern should be perhaps related to the actual driving input frequency itself. Yet even here, there is EPRI test data that refutes the low frequency concern: test 30. As reported in the EPRI report, test 30 was almost identical to EPRI Test 37, with one exception: it was pressurized. Test 30 did fail, but by the more standard fatigue failure instead of collapse. As indicated above, Dr. Kennedy found a strength factor of 1.83 for Test 30, which was above the required strength factor of 1.5.

4-4

Of note is that as the frequency of the driver starts to decrease, it becomes more like a static load. For a static load, the response of the system is reasonably understood. The Code uses a criterion of 1.5 against ultimate for membrane loads, up to ultimate for membrane plus bending load (see Appendix F, paragraph F-1331.1c). While the SWG-SR admits this is not the overall margin of 2, for a static load (the limit $R_w = 0$), a margin of 1.5 is accepted by the Code.

The one issue not addressed above is the temperature effect. The SWG-SR tried to address this, since we strongly believe this is not a seismic issue alone, but our proposals to the concerned individuals were not accepted. Thus, the SWG-SR proposed a compromise position to that initially put forth by Dr. Kennedy and passed in BC-00184: raise the multiplier of the elbow and tee B_2' to ¾ from 2/3. Using an allowable of $3S_m$, this is the same as the 1994 rule changes with an allowable of $4S_m$. This was viewed as a compromise position, since the potential negative effect due to temperature and dynamic strain aging might be as high as about 25%, and the reduction was from the equivalent of 4.5 to the equivalent of $4.0S_m$, about 12%.

For components with no change in B_2, i.e., $B_2' = B_2$, there is no change in allowable from the pre-1994 rules. The only component with a decrease in allowable (over pre-1994 rules, and the current rules for non-reversing dynamic loads) is for welds at Tapered joints, tees, or reducers, where there is a thickness mismatch between the straight pipe and the component. The increase in B_2' to 1.33 is based on Dr. Kennedy's studies.

The change in B_2' also increases the margin for Test 37. Based on the JST analyses, which use the Code B_2, the margin to failure for R_w of 0.7 is 6.3/4.5 = 1.4. This is slightly less than 1.5, for an almost static load, but there are two mitigating factors: there was no pressure in the piping (test 30 had higher margins) and the input time history was extremely artificial, having a length of 110 seconds vs a standard input of about 30 seconds. Thus, there is significant conservatism in the input itself. Based on all of the evidence, the SWG-SR felt that Test 37 was adequately addressed and that R_w could be deleted. Note also that the geometry for Test 37 would not be permitted by the proposed changes, since the D/t ratio for Test 37 is ~~39~~ 49, which is ~~less than~~ > 40.

4-5
8

Appendix 2 - Japanese Research Team Evaluation of Effects of Strain-Rate

STRAIN RATE EVALUATION OF JAPANESE COMPONENT TESTS AND US TEST #37

Prepared by the Japanese Seismic Team

1. Introduction

NRC stated their refusal of revised seismic stress criteria for piping systems at their proposed rule making by 10CFR50.55a at August and December ASME Code meeting. Technical bases of their refusal are;

1) Dynamic strain aging of carbon steel at high strain rate and high temperature condition
2) Low margin at low Rw (Stiff piping system)

In this paper, the calculated max. strain rate was discussed for both test #37, Run5 and typical Japanese component test in order to evaluate the occurrence of dynamic strain aging at elbow or tee of operating plant at seismic event from the viewpoint of strain rate limitation.

Technical discussion on low margin at low Rw piping will be on another paper.

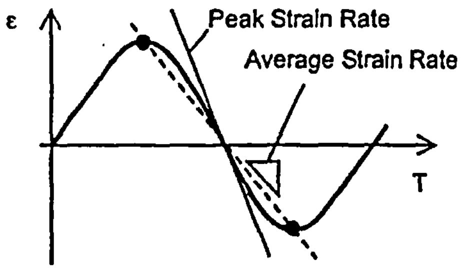
2. Test #37, Run5 of EPRI/NRC test

NRC evaluated the strain rate test 37, run5 as 2/sec. The Japanese Seismic Team (JST) is convinced that this is not correct.

According to our analysis for test#37,Run5 as shown in Fig. 2-1,2,

1) Max peak strain at Run5 is 8% but it is not strain amplitude.
2) Strain amplitude at maximum strain position on Run5 (M_{UD} condition) is 2% (Range is 4%), not 8%
3) Peak strain rate is 0.5/sec. (=0.02*2*3.14*4Hz, referred the NRC equation) (Motion of component is assumed as sinusoidal and strain behavior is also assumed as sinusoidal)
4) Average strain rate is reduced to 0.32/sec. (=0.04/0.125 for 4Hz; same assumption as NRC)
   0.11/sec. (=0.04/0.357 for 1.4Hz;Natural Freq. of #37)

JST believe that average strain rate is better than peak one for the evaluation of occurrence of the dynamic strain aging phenomena. Dr. Wikowski also used average strain rate to discuss strain rate effect on dynamic strain aging phenomena.



Combination of peak strain rate and peak strain is too much conservative. Actually, strain becomes zero at peak strain rate and strain rate becomes zero at peak

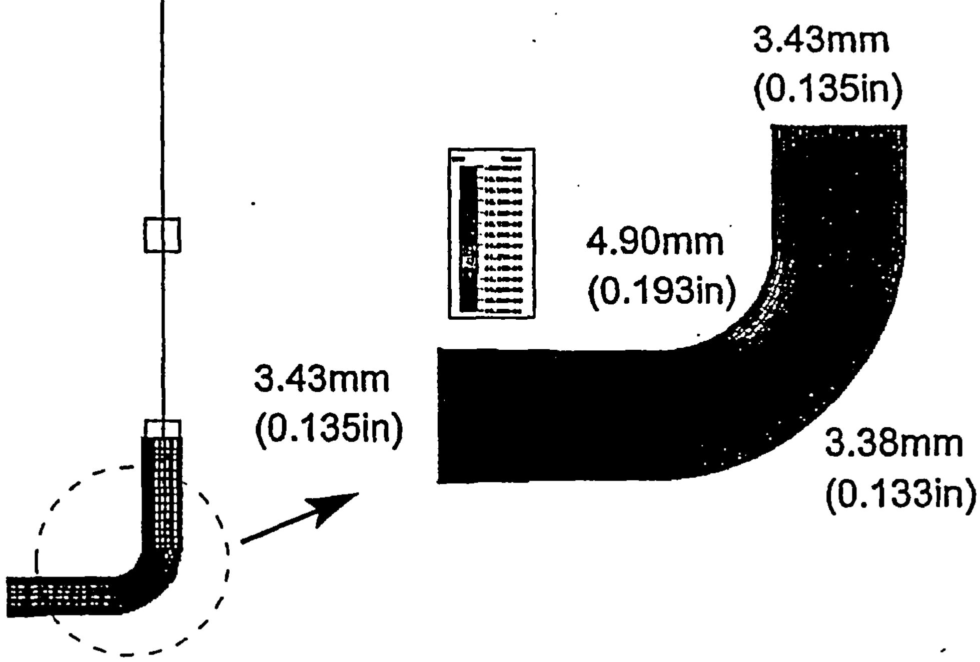


Fig. 2-1 FEM model of shell element for Test #37

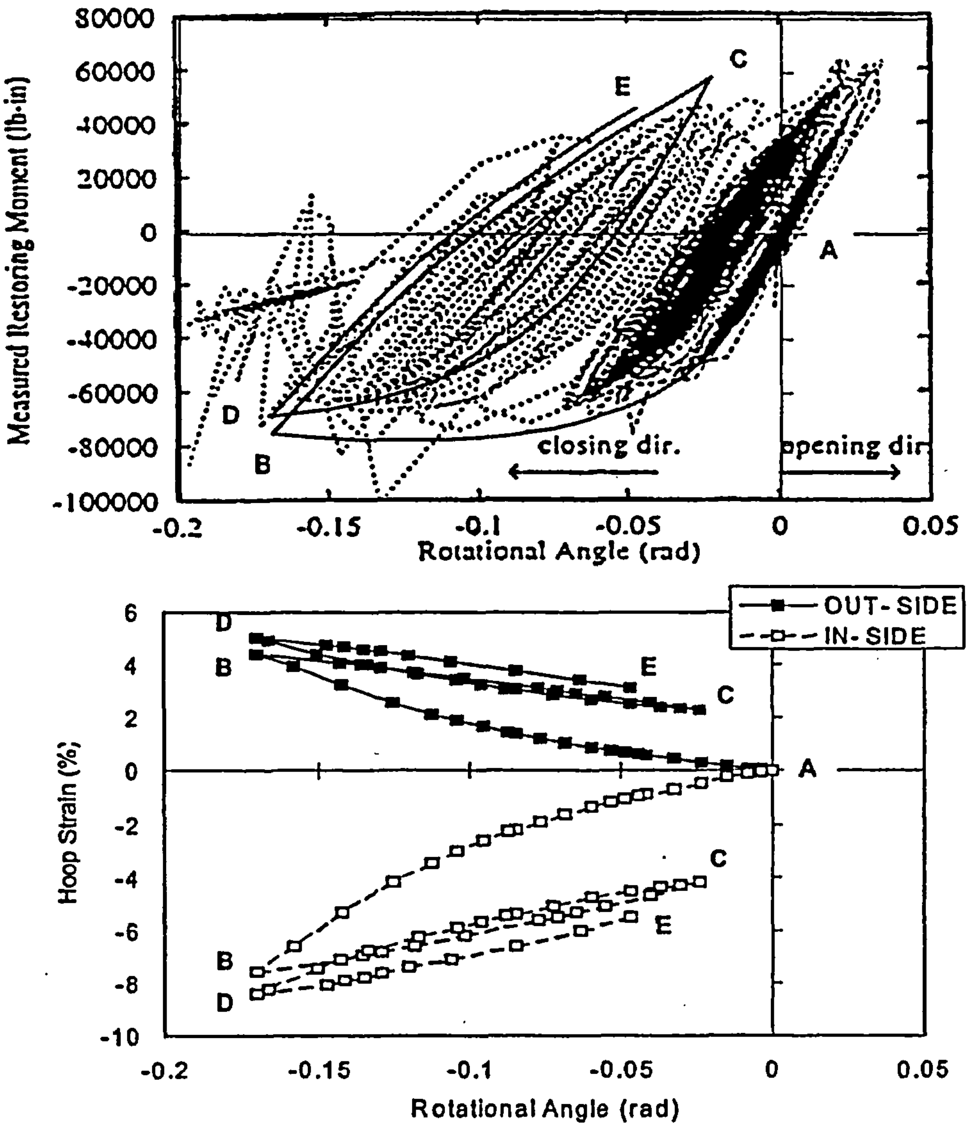
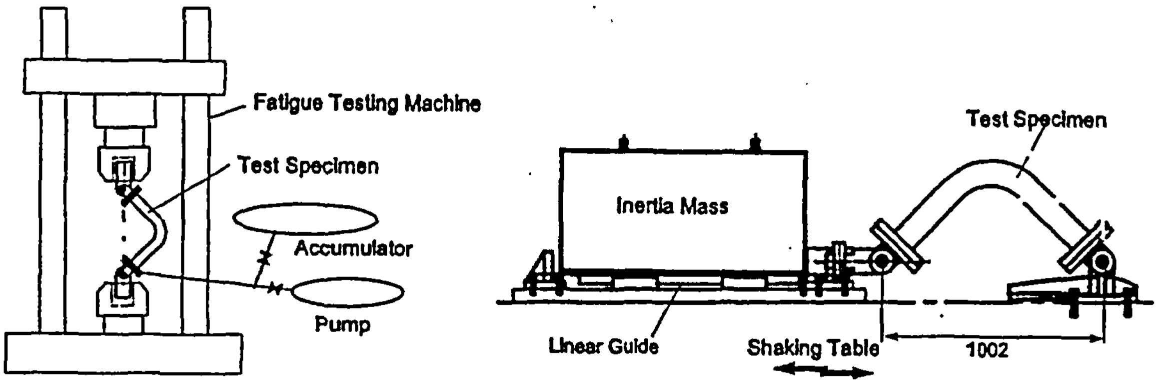


Fig. 2-2 Hoop strain behavior at highest strain point at Run5 of Test #37

3. Strain rate evaluation of Typical Japanese component test
3.1 Strain Rate evaluation at Fs (=Mud/Mcode) of over 1.5
Japanese seismic team carried out the cyclic static and dynamic component test for elbow and tee. From the calculated maximum strain by the verified analysis method by comparison with experimental data, strain rate was evaluated.

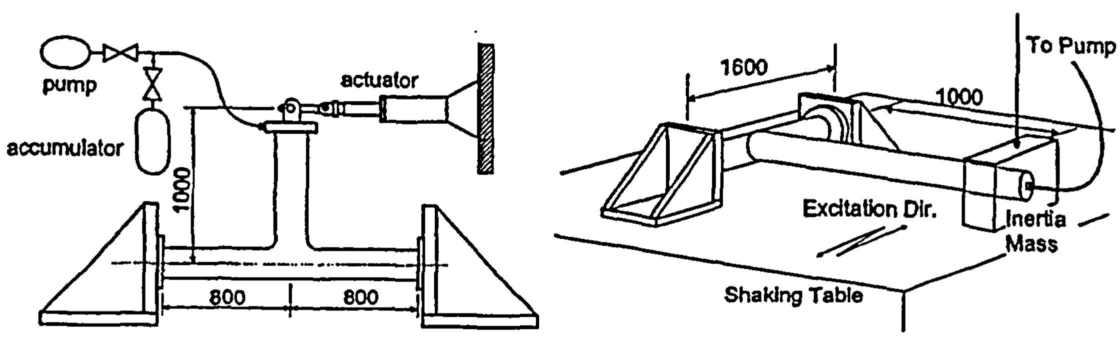
Fig. 3-1,2: Test facility for elbow and tee
Fig. 3-3: Measured load-displacement relationship of C/S elbow
Fig. 3-4: Measured load-displacement relationship of S/S elbow
Fig. 3-5: Measured load-displacement relationship of C/S tee
Fig. 3-6: Typical FEM model & material property
Fig. 3-7: Strain distribution of C/S elbow
Fig. 3-8: Strain distribution comparison of C/S elbow (In-plane compression)
Fig. 3-9: Strain distribution comparison of C/S elbow (In-plane compression)

Test condition, result of cyclic static and dynamic test and strain rate corresponding to the calculated strain range at crack penetrated point obtained by FEM analysis which methodology was verified by the comparison with test results were summarized in Table 3-1. From this table, maximum strain rate of elbow and tee at Mud condition is lower than 0.5/sec. The experimentally obtained Mud is much higher than 1.5 times of Mcode. So, this Mud level eventually satisfy the required minimum margin (Strength Factor for component by Dr. Kennedy).



(a) Static Cyclic Test (b) Dynamic Test

Figure 3-1 TEST FACILITIES (Bent Pipe)



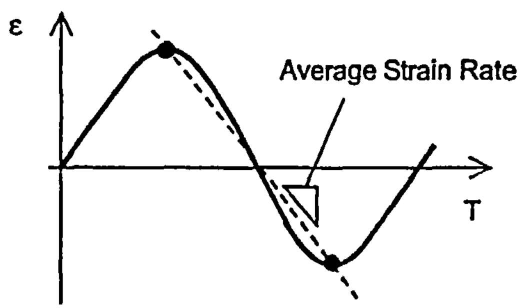
(a) Static Cyclic Test (b) Dynamic Test

Figure 3-2 TEST FACILITIES (Tee)

Table 3-1 Test Summary & Calculated Strain Rate of Japanese Component Test Specimen

Type	Test Condition				Static Cyclic Test					Dynamic Test (Shaking Table)					
	OD	t	Mat.	Int. P*1 (MPa)	Exp. No.	Applied Load Displ. (mm)	Mud*2 (kNm)	$Mcode_{(nom)}$*3 (kNm)	Strain Range*4 ε (%)	Exp. No.	Measured Response Displ. (mm)	Mud*2 (kNm)	$Mcode_{(nom)}$*3 (kNm)	Response Frequency f (Hz)	Average Strain Rate*5 ε/(1/2f) (1/s)
Bend	4B 114.3mm	S40 6.0mm	C/S	13.7	No.1	±33	32.9	12.1	4.84	No.1	±33	31.8	12.1	4.7	0.45
Bend	4B 114.3mm	S40 6.0mm	S/S	15.0	No.2	±33	34.3	13.3	3.53	No.2	±33	45.2	13.3	4.7	0.33
Tee	4B/4B 114.3mm	S40 6.0mm	C/S	13.7	No.12	±50	28.0	12.7	3.4	No.11	±50	24.2	12.7	3.5	0.24

*1 : S_m equivalent (Hoop Stress)
*2 : Mud was calculated from the experimentally measured moment.
*3 : Calculated Code allowable moment by using nominal diameter, thickness and Code S_m value.
*4 : Calculated max. strain range at crack penetration point by FEM which methodology was verified by the comparison with experiment.
*5 :



Seismic Capacity margin Rcp=FsFnlFredFs
Fs: Strength Facter of component
Fs=Mud/Mcode (should be greater than 1.5)
Fred: Redundancy Factor
Fnl: Additional factor due to Nonlinear dynamic behavior

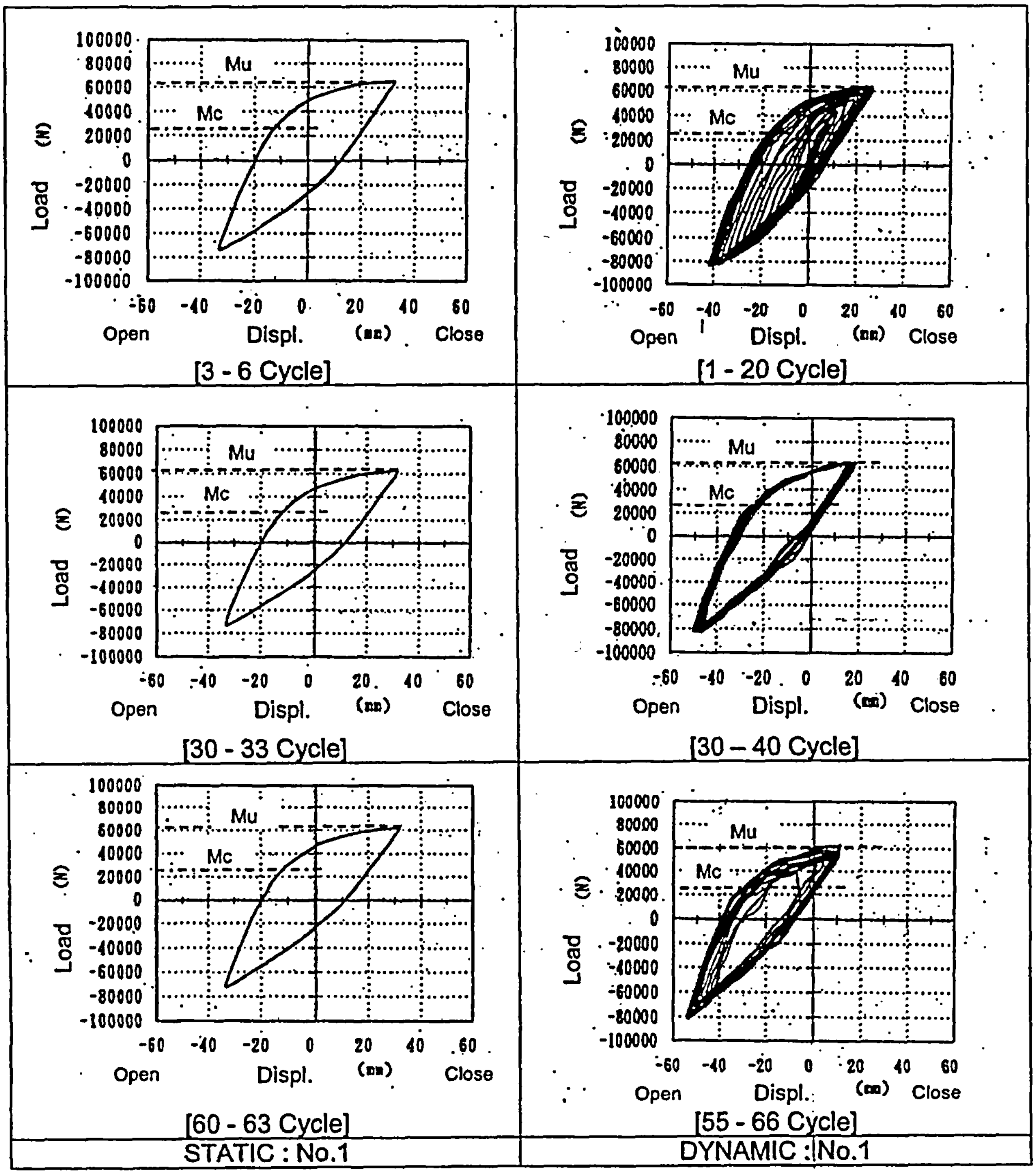


Figure 3-3 Measured Load – Displacement Relationship: C/S Bent (No.1)

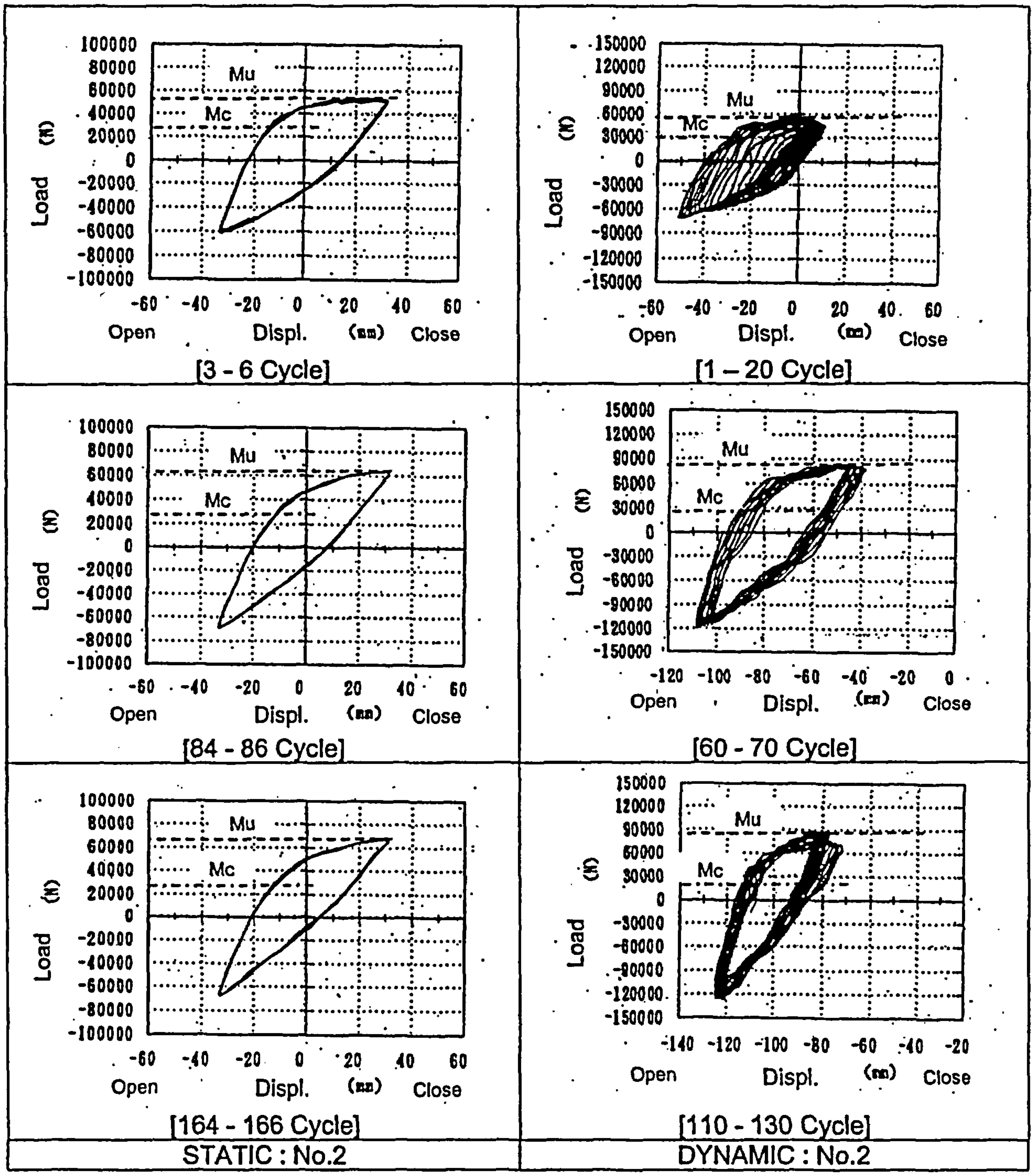
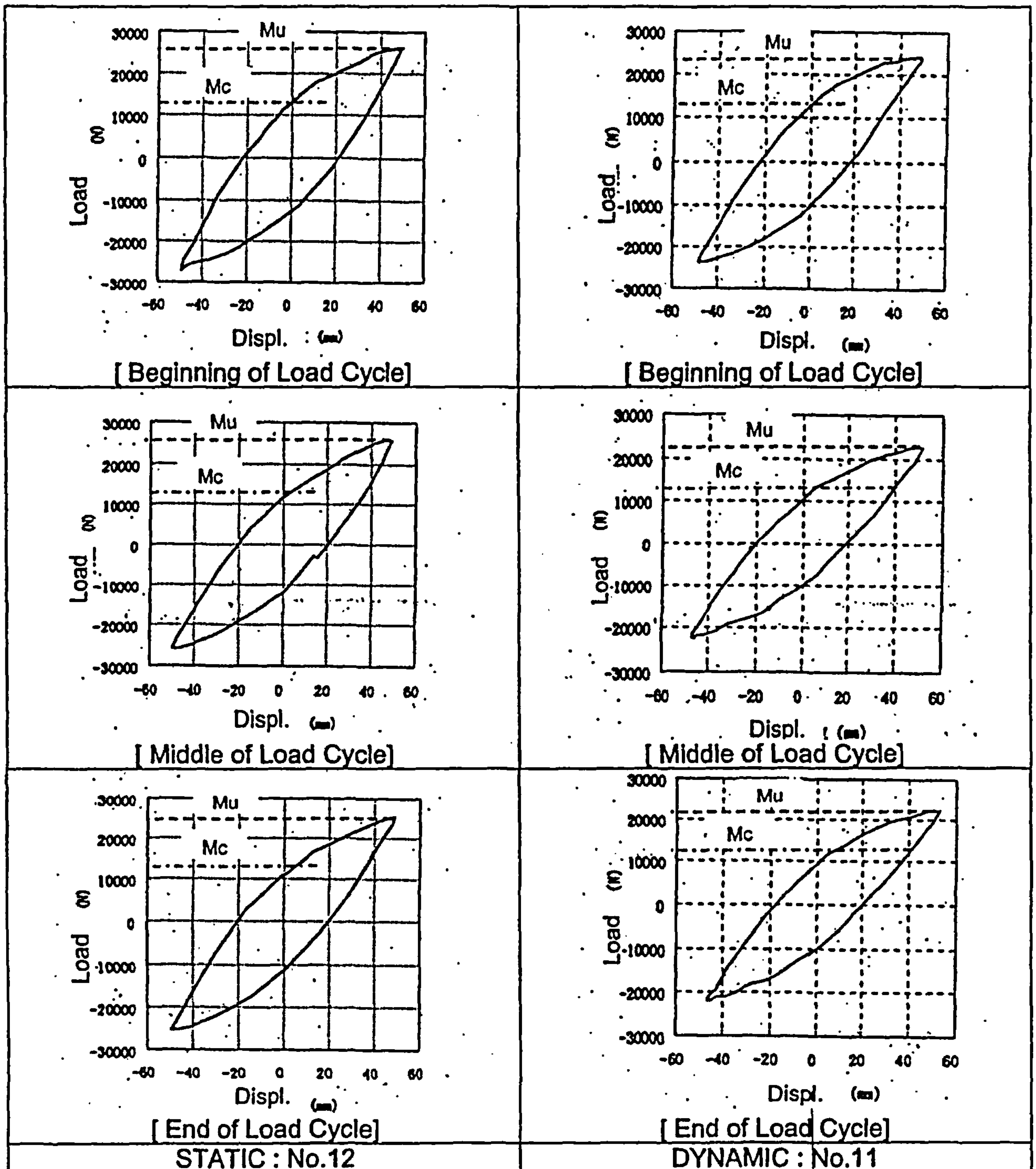


Figure 3-4 Measured Load – Displacement Relationship : S/S Bent (No.2


Mu
Mc
Load
Displ.
[Beginning of Load Cycle]
[Beginning of Load Cycle]
[Middle of Load Cycle]
[Middle of Load Cycle]
[End of Load Cycle]
[End of Load Cycle]
STATIC : No.12
DYNAMIC : No.11

C/S Tee

Figure 3-5 Measured Load – Displacement Relationship : C/S Tee (No.12, No.11

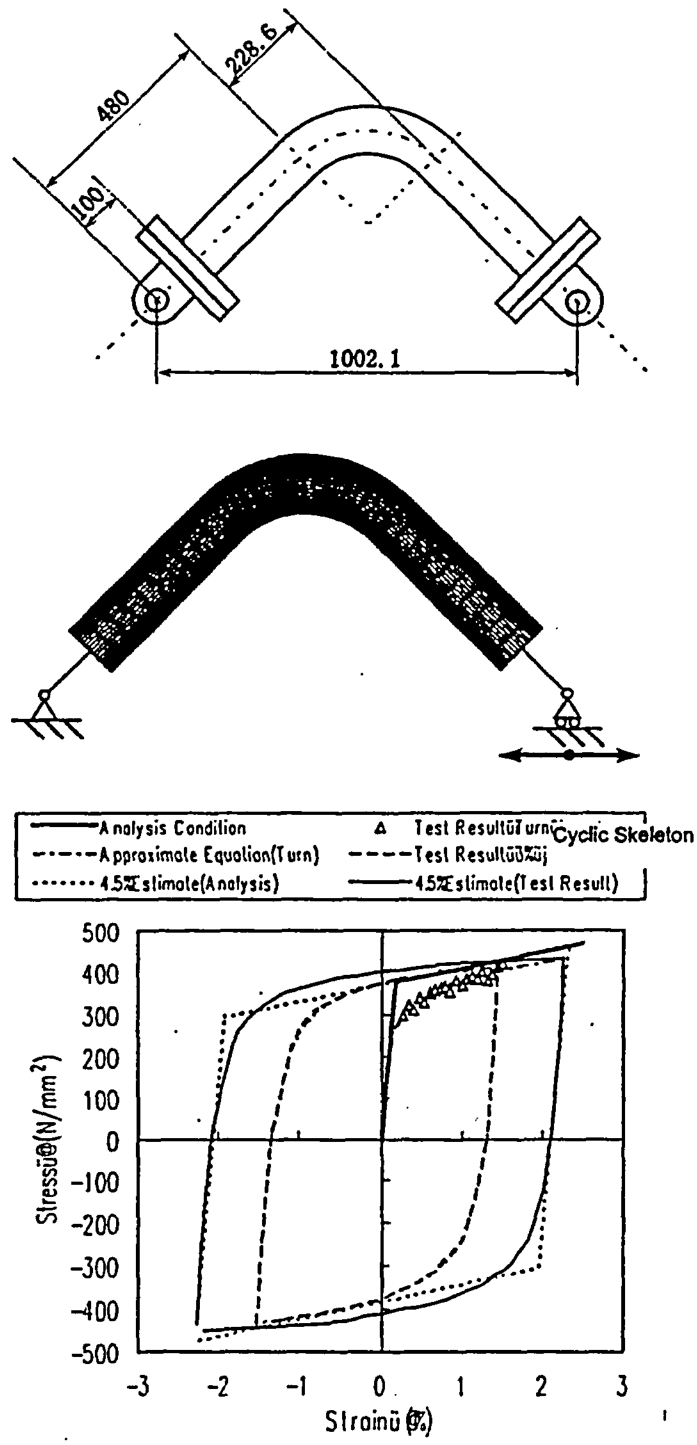
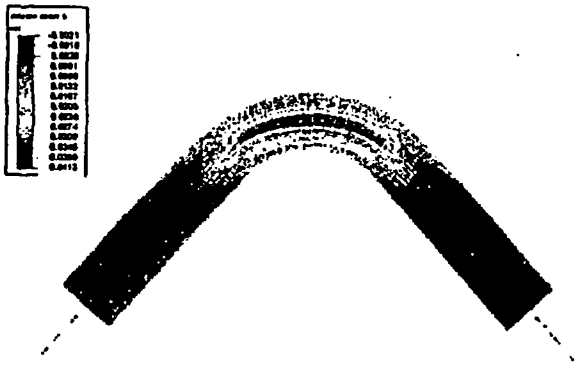
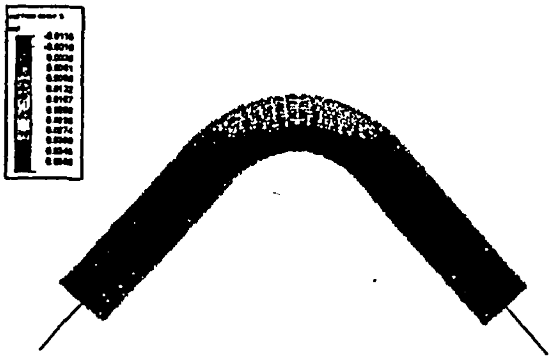


Figure 3-6 Typical FEM model & material proper

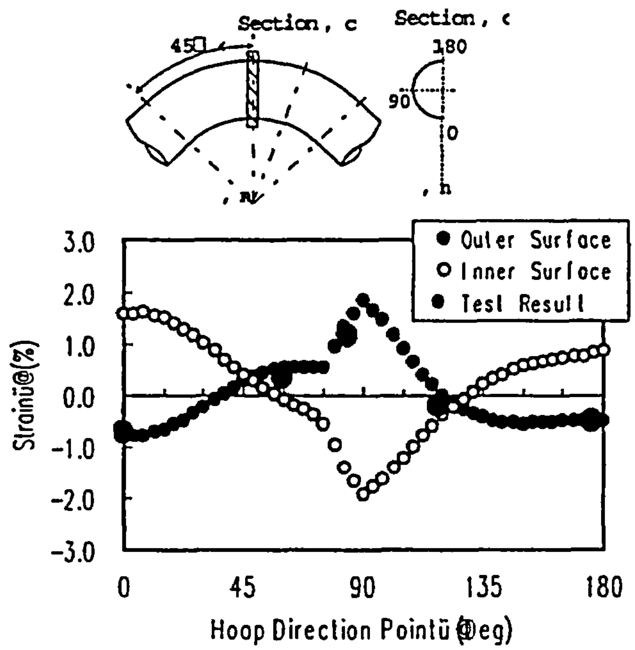


Hoop Strain Distribution

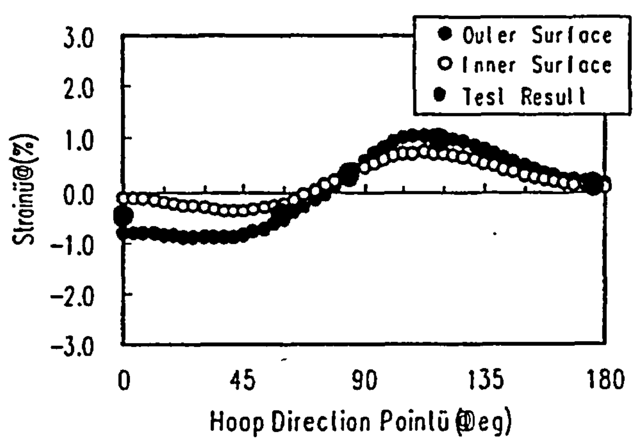


Axial Strain Distribution

Figure 3-7 Strain distribution of Bend No.1 (Outer Surface)

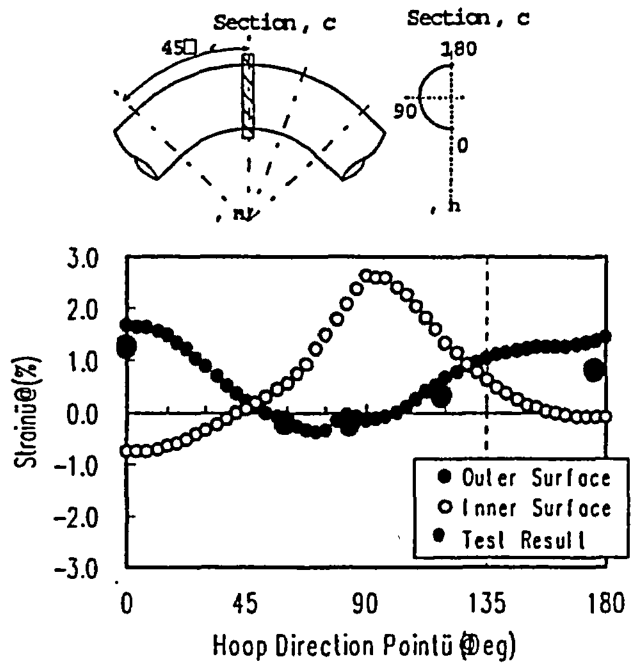


Hoop Strain Distribution

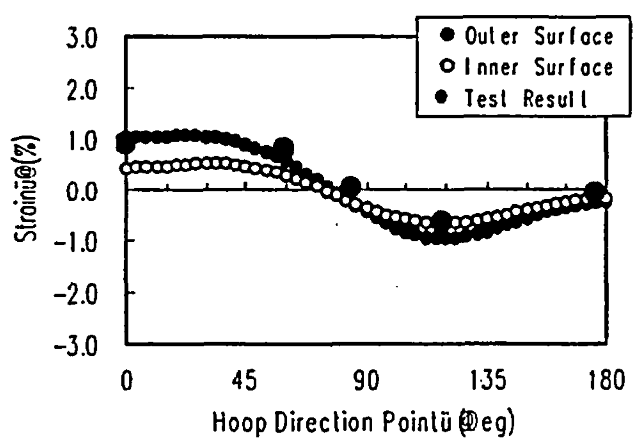


Axial Strain Distribution

Figure 3-8 Strain Distribution Comparison of Bend No.1
(Section D, 1cycle, In-plane Compression)



Hoop Strain Distribution



Axial Strain Distribution

Figure 3-9 Strain Distribution Comparison of Bend No.1
(Section D, 1cycle, In-plane Tension)

3.2 Strain Rate evaluation at allowable stress limit(4.5Sm)

In-plane bending tests of elbows shown in Fig.3-1 were analyzed. In analyses, reversing bending loads (displacement) correspond to 6.5Sm (fictitious) and 10.5Sm (fictitious) were applied to the elbow model, respectively. The load of 6.5Sm corresponds to 2.0Sm (fictitious) for SAM (seismic anchor motion stress limit of amplitude and Bs stress index instead of range and C2 (*))plus 4.5Sm (fictitious) for inertia load.

Strain range under 6.5Sm (fictitious) is 0.023 (2.3%) as shown in Fig.3-10 &11. Accordingly, strain rate for 4Hz is 0.18/sec (see Table 3-2).

(*) See ASME PVP Vol.407, P153-160, presented at 2000ASME PVP conference

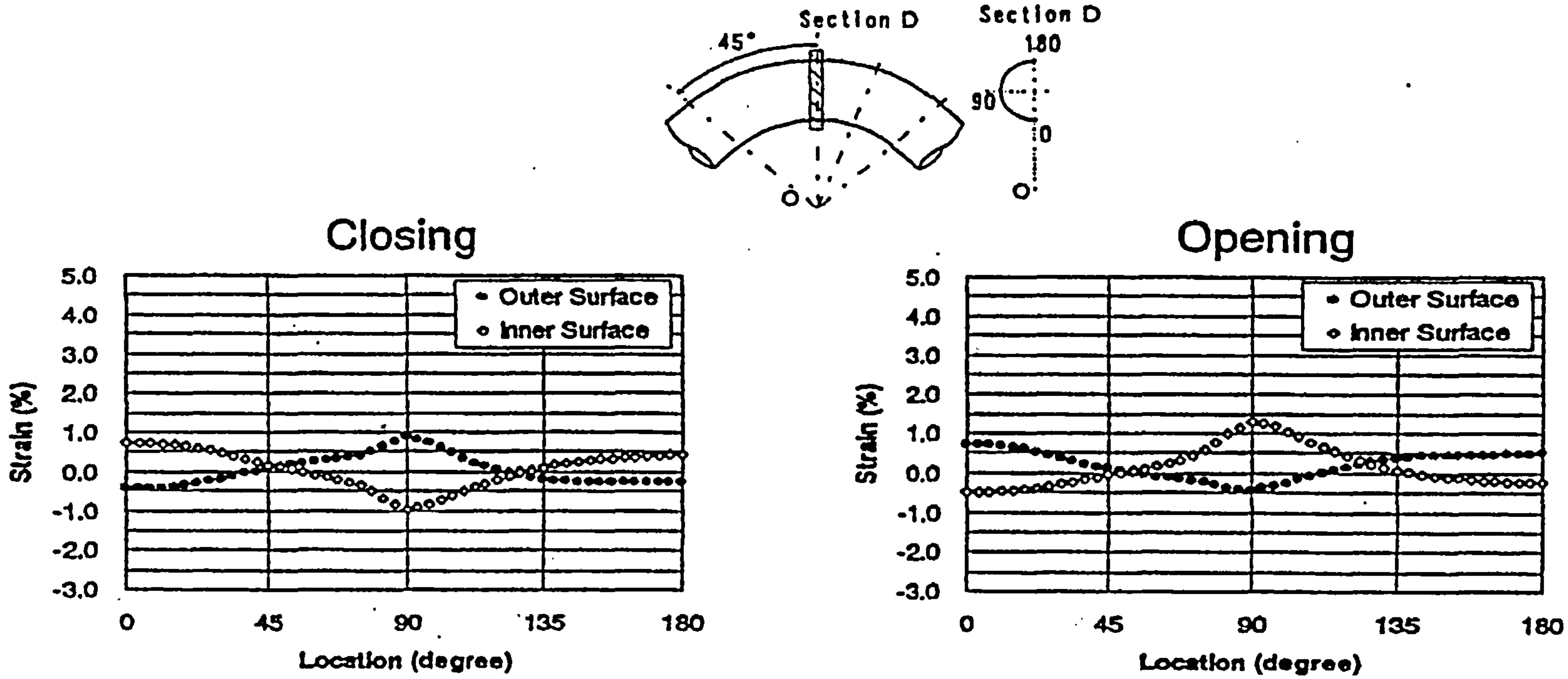
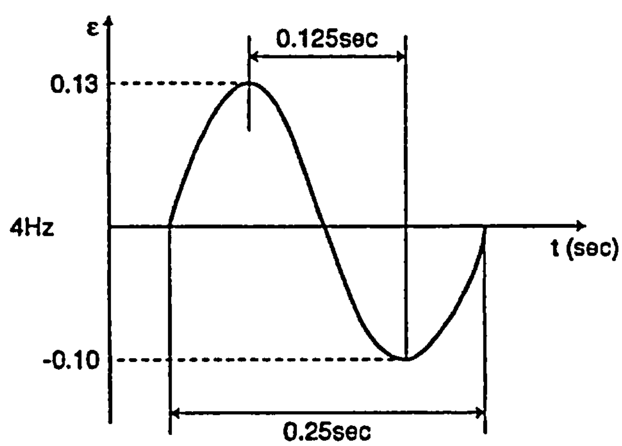


Fig.3-10□Hoop Strain Distribution Corresponding to 6.5Sm□Fictitious□

□Analysis Result□

Table 3-2□Strain Rate Evaluation

Nominal Stress Level Fictitious	Assumed Natural Frequency Hz
6.5 Sm	Strain Range 0.013.. 0.010 0.023□ Strain Rate $0.023 \times \frac{1}{0.125}$ 0.18 sec



4. Evaluation of strain rate effect on $\sigma_{0.2}/\sigma_u$ for Japanese Carbon Steel

The strain rate effect on $\sigma_{0.2}/\sigma_u$ (0.2% offset yield strength/ultimate tensile strength) is evaluated by using high speed tensile test data of STS410 carbon steel[1] and above-mentioned calculated strain rate data. Fig.4-1 shows the strain rate effects on $\sigma_{0.2}$ and σ_u at room temperature and 300 [1]. From Fig.4-1, relationships between $\sigma_{0.2}/\sigma_u$ at room temperature and 300 and strain rate are obtained as shown in Fig.342. Strain rate for 6.5Sm (fictitious) is also shown as a dotted line in Fig.4-2. Summary of the evaluation is shown in Table 4-1.

G. Wilkowski pointed out that$\sigma_{0.2}/\sigma_u$ of carbon steels increases up to 0.77 at the 1.0 to 10sec^{-1} strain rates and LWR temperatures. According to the fact, he has some concerns about the dynamic strain aging effect on nuclear piping made of carbon steels in LWR temperature range [4].

However, the strain rate for 6.5Sm (fictitious) is extremely smaller than 1.0sec^{-1} and $\sigma_{0.2}/\sigma_u$ at 300□ is only 0.66. Furthermore, $\sigma_{0.2}/\sigma_u$ at 300□ is smaller than that at room temperature.

In this connection, the frequency corresponding to 6.5Sm (fictitious) and 1sec^{-1} is 22.2Hz. Accordingly, dynamic strain aging effect can be neglected for realistic piping systems. Also as shown in Fig.3-1, $\sigma_{0.2}$ and σ_u at 1.8×10^{-1}sec^{-1} and 300 are greater than Sy and Su, respectively.

From above-mentioned evaluations, it is concluded that dynamic strain aging effect on seismic strength of nuclear piping at high temperature is negligible small.

Table 4-1□Effect of Dynamic Strain Aging on the Ratio of 0.2% Offset Yield Strength to Ultimate Tensile (Strength for STS410 Carbon Steel□Japanese Material□)

model		JST Elbow		Test#37	
Freq.		4Hz	4Hz	1.7Hz	4Hz
Response level		6.5Sm	Fs of over 1.5	Run5	Run5
Strain rate		0.18	0.45□Max□	0.11	0.32
Temp.	RT	0.70	0.62	0.70	0.68
	300 C	0.66	0.66	0.68	0.68

5. Evaluation of Dynamic Strain Aging Effect for A106Gr.B Carbon Steel

Relations of $\sigma_{0.2}$ and σ_u of A106Gr.B carbon steel at 288 are shown in NUREG/CR-6226[2]. Assuming that the strain rate obtained in section 3 and 4 is applicable to A106Gr.B carbon steel, the relationship between $\sigma_{0.2}/\sigma_u$ strain rate was estimated. Evaluation results are shown in Fig.5-1, 5-2, & 5-3. $\sigma_{0.2}/\sigma_u$ at 4Hz and 6.5Sm (fictitious) is 0.73 and this value is smaller than 0.77. That is, dynamic strain aging effect of A106Gr.B carbon steel is practically not so severe in seismic evaluation of nuclear piping.

6. Dynamic Strain Aging of Japanese Carbon Steel

Generally, Japanese carbon steels do not show significant dynamic strain aging different from U.S. made ones. However, some people in Special Working Group on Seismic Rules pointed out that dynamic strain aging was observed even in Japanese carbon steels, referring to a SMiRT paper[3].

In the paper, two 4-point bending tests using 4-in. diameter piping with a circumferential crack made of STPT480 carbon steel were carried out. Test temperature was not shown in the paper, but actually it was ambient. Displacement speed was 0.1m/sec. In one of the tests, slight load drop during loading process exceeding elastic limit was observed on the load vs. cross-head displacement chart. In this case the maximum load was 166kN. On the other hand, the maximum load obtained by the test which showed the smooth load vs. cross-head curve was 163kN. Accordingly, the maximum load level was almost same in both tests. In addition, load drop level was only several kN. Generally speaking, dynamic strain aging takes place at high temperature. On the contrary, the above-mentioned tests were carried out at room temperature.

Even if the load drop is induced by dynamic strain aging, it is very small and practically negligible. That is, their opinion is not correct in engineering level and dynamic strain aging effect of Japanese carbon steels is not so significant.

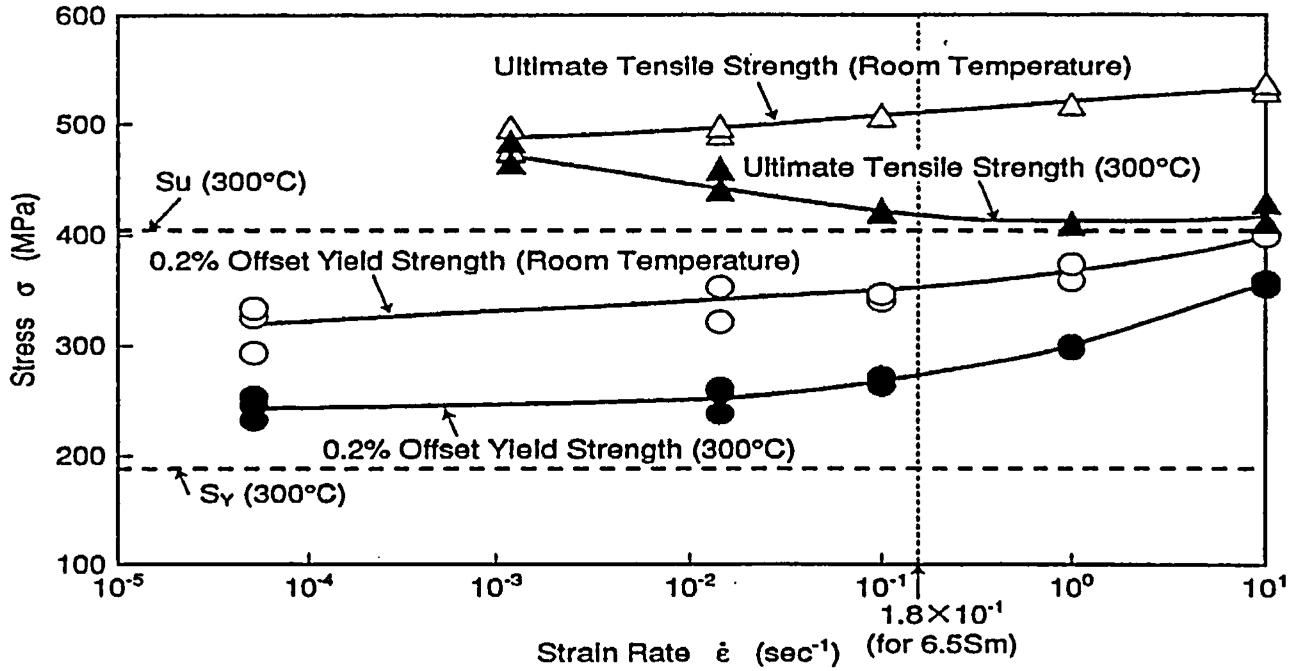


Fig.4-1 Results of High-Rate Tensile Test STS410
From CRIEPI Report T92044 (1993), "Evaluation of Dynamic Fracture Strength of Domestic Flawed Carbon Steel Piping

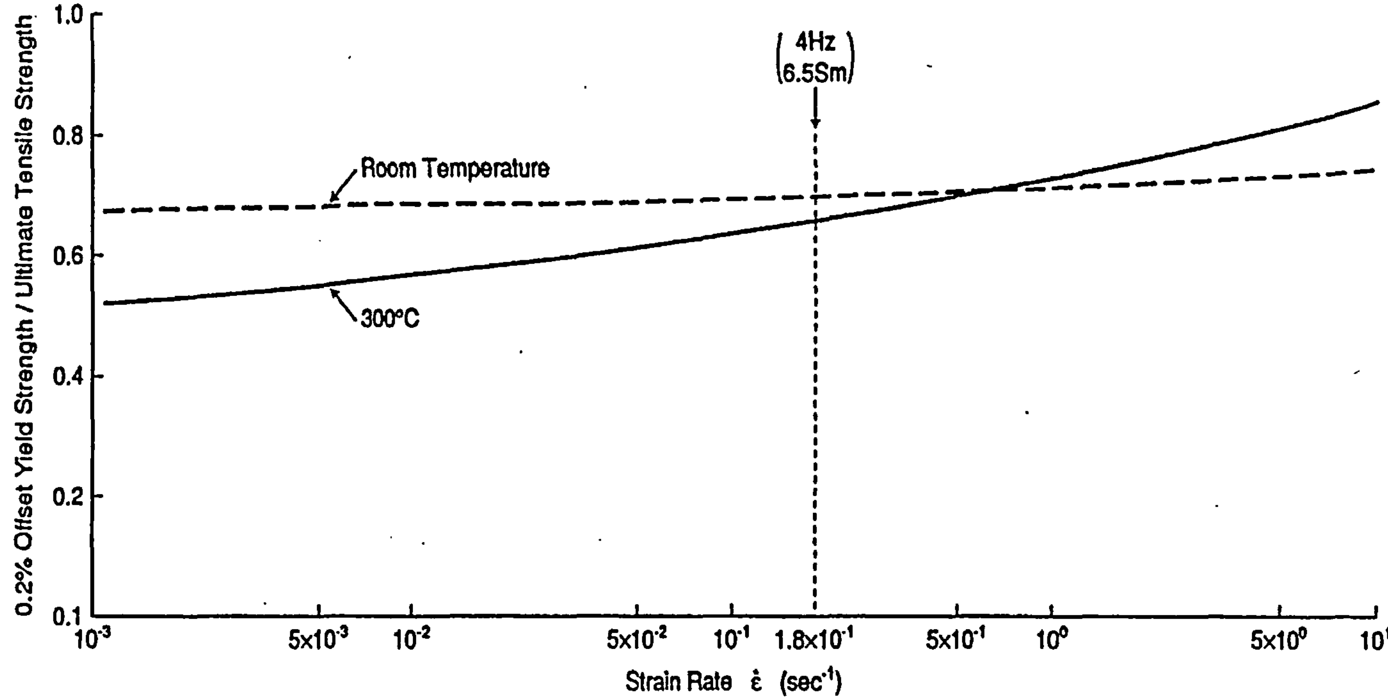


Fig.4-2 Effect of Dynamic Strain Aging on the Ratio of 0.2% Offset Yield Strength to Ultimate Tensile Strength for STS410 Carbon Steel

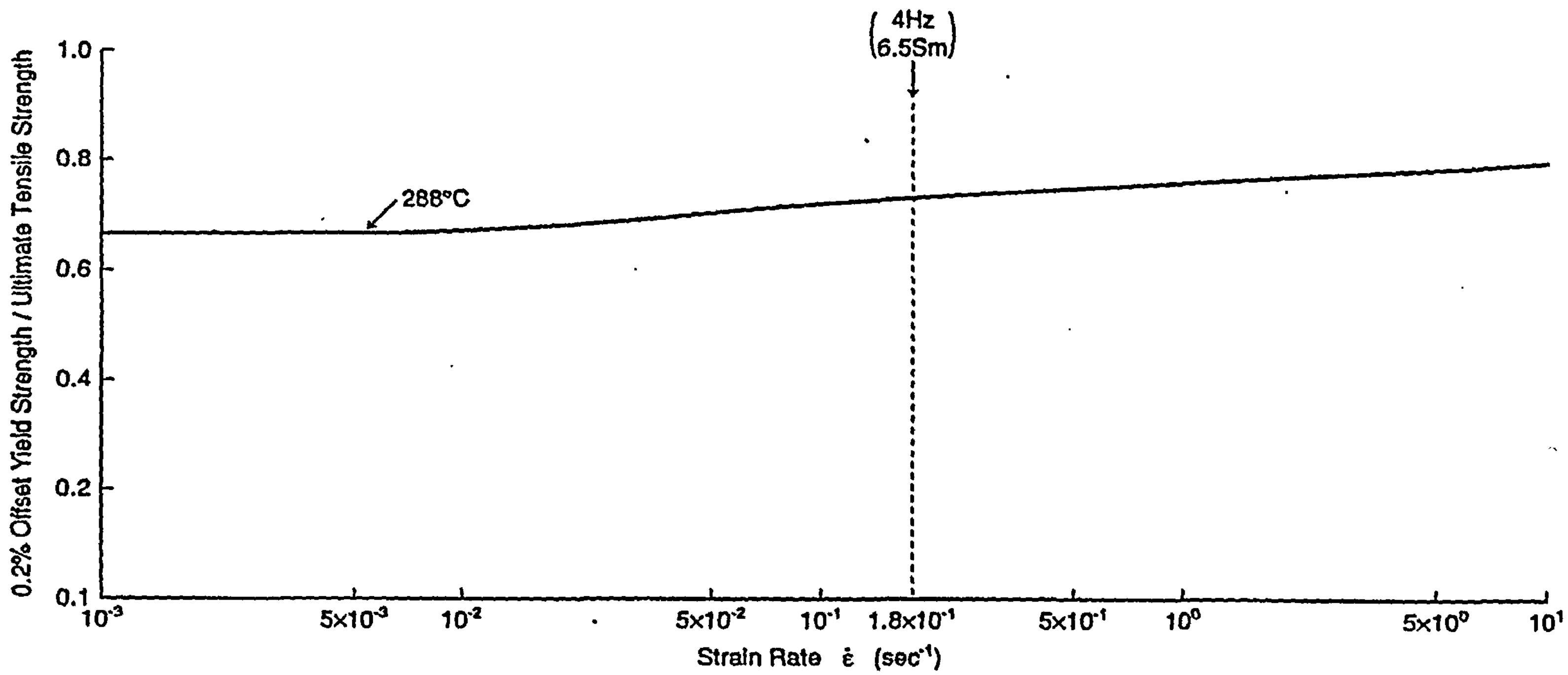


Fig. 5-1 Effect of Dynamic Strain Aging on the Ratio of 0.2% Offset Yield Strength to Ultimate Tensile Streng

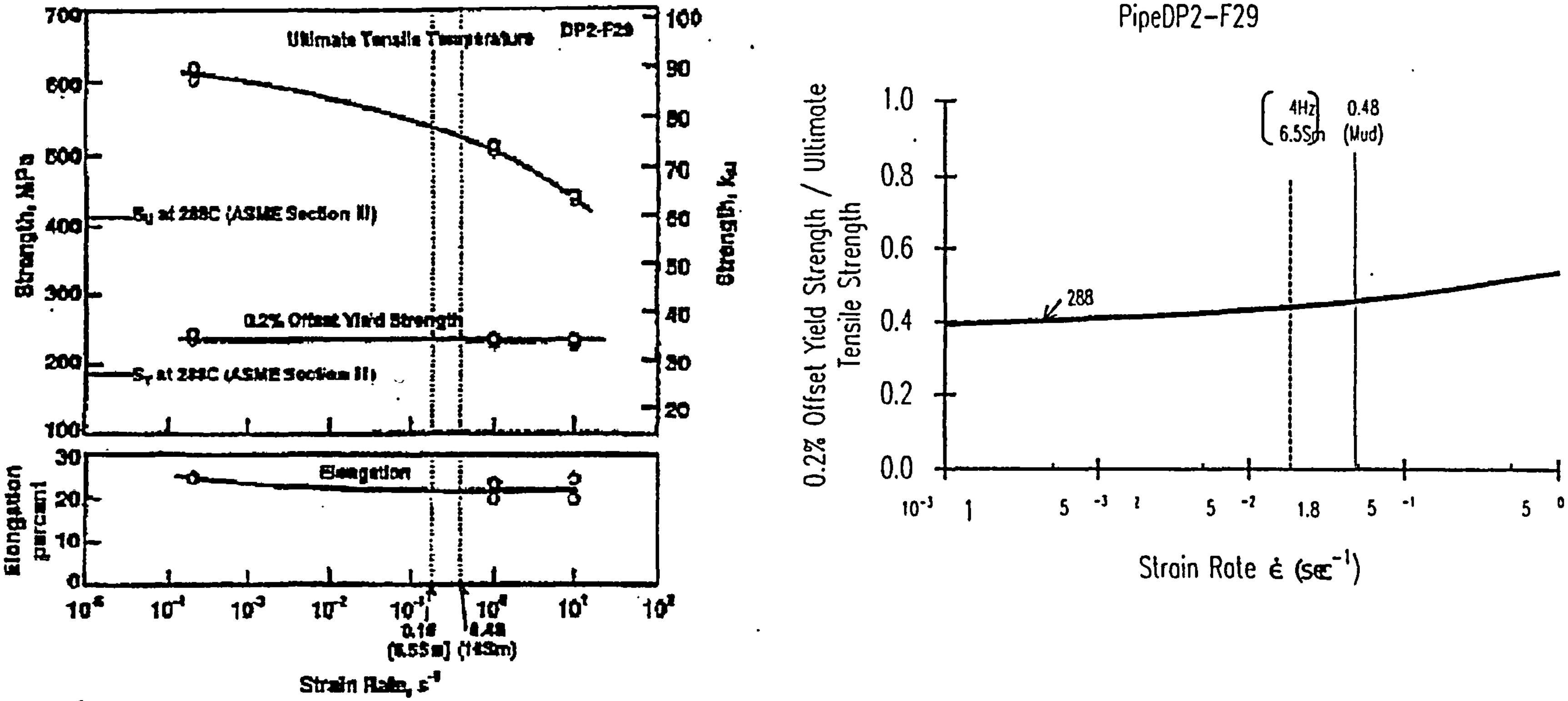


Figure 5-2 Tensile Property and stress ratioe oat 288 C (588 F) vs. Strain Rate for Pipe DP@-F29 (a106 Gr. B)

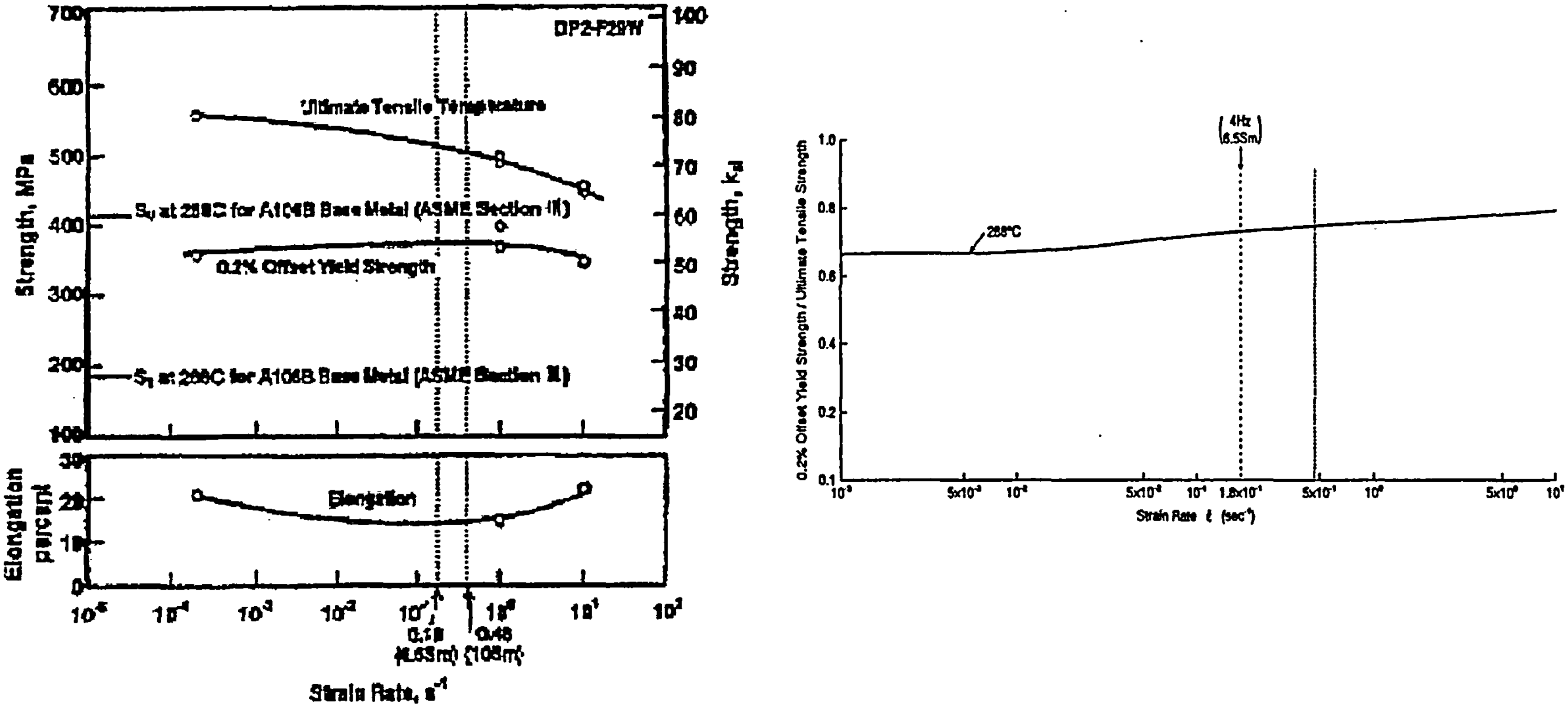


Figure 5-3 Tensile Property and Stress Ratio at 288 C (550 F) vs. Strain Rate for Submerged Arc Weld DP@-F29W(A106 Gr. B)

7. Conclusion

Dr. Wilkowski pointed out in the page III-F-3 of NUREG /CR-5361 that:
........Low carbon steels at 300-600F. These materials experience dynamic strain aging, also known as blue embrittlement. This causes changes in the ultimate strength, strain hardening and toughness of the material as a function of temperature and strain rate.........At higher strain rates and LWR temperatures, all of the ferritic steels tested to date in the IPIRG-I & II have had slightly higher yield strengths but much lower ultimate strengths. Typically, the ultimate strengths of ferritic base metal at 1 /sec to 10 /sec strain rate are lower by about 15-30 percent than at quasi-static rates.......

The evaluated strain rates of piping components such as elbow and tee tested both in USA (Test#37) and in Japan at Mud condition with sufficient margin is much lower than 1/sec that is the limit of dynamic strain aging by Dr. Wilkowski.

We can conclude that dynamic strain aging never occur in piping components in operating NPP of LWR temperature and at seismic event and that dynamic strain aging issue does not disturb to set 4.5Sm (fictitious) as the allowable primary stress intensity limit for seismic evaluation of nuclear piping systems.

References

(1) N. Miura, T. Fujioka, K. Kashima, S. Kanno, M. Hayashi, M. Ishiwata and N. Gotoh, "Evaluation of Dynamic Fracture Strength of Domestic Flawed Carbon Steel Piping under High Temperature", CRIEPI Report T92044, 1993, P.11, (in Japanese).

(2) C. W. Marschall, R. Mohan, P. Krishnaswamy and G. Wilkowski, "Effect of Dynamic Strain Aging on the Strength and Toughness of Nuclear Ferritic Piping at LWR Temperature", NUREG/CR-6226 (BMI-2176), 1994.

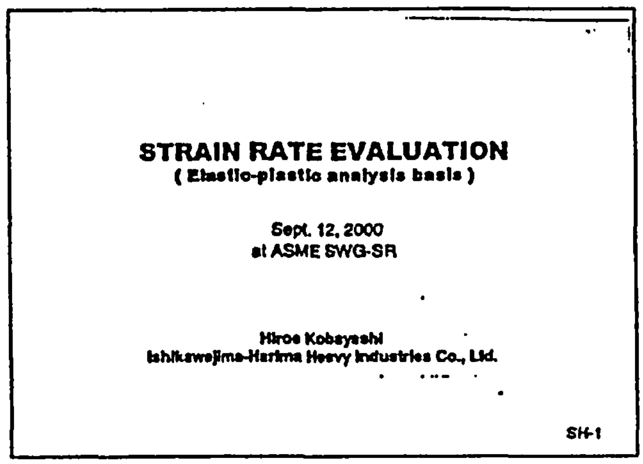
(3) N. Oritani, K. Sakata, K. Miyazaki, T. Tsuda and F. Eguchi, "Study on LBB Evaluation of Main Steam System Piping in Tokai-II Power Station, SMiRT 14th, G07/5, pp.277-284, Lyon, France, August 17-22, 1997.

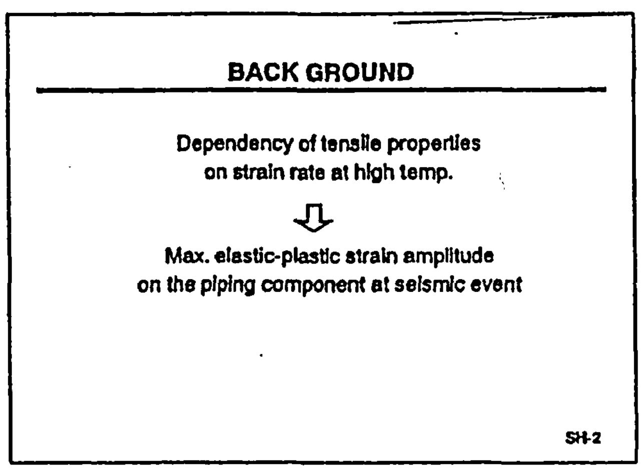
(4) NUREG/CR-5361, P-III-F-3, May 1998.

(5) NUREG/CR-6233

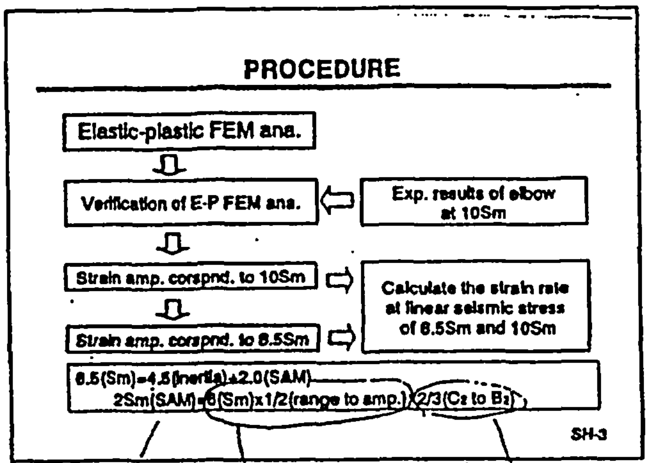
(6) ASME PVP Vol.407, P153-160, presented at 2000ASME PVP conference

Appendix 3 - Japanese Research Team Direct Response on Strain Rate Effects





B2' RESPONSE
ATT. 5
5-1



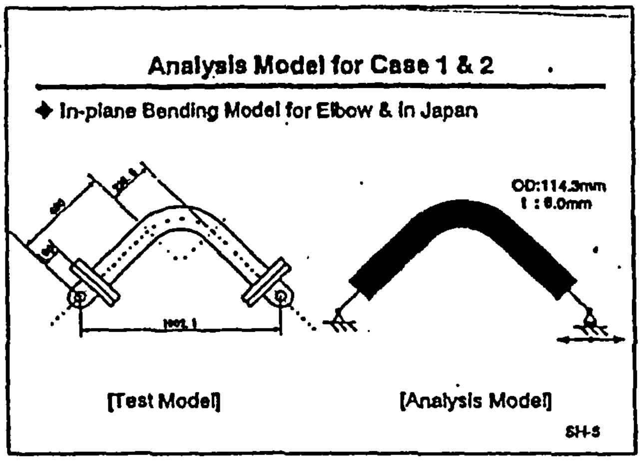
Seismic Anchor Motion

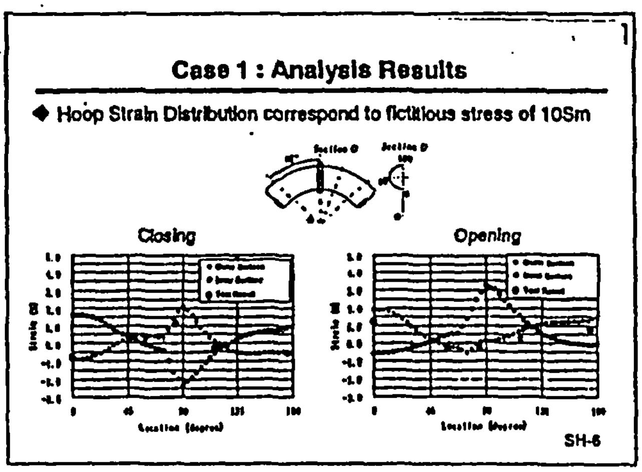
ANALYSIS CONDITION

Case1:
- Specimen : Elbow
- Force dir. : In-plane bending
- Stress level : 10Sm (Fictitious)
- verification of the analysis method to obtain the strain amp.

Case2:
- Specimen : Elbow
- Force dir. : In-plane bending
- Stress level : 6.5Sm (Fictitious)

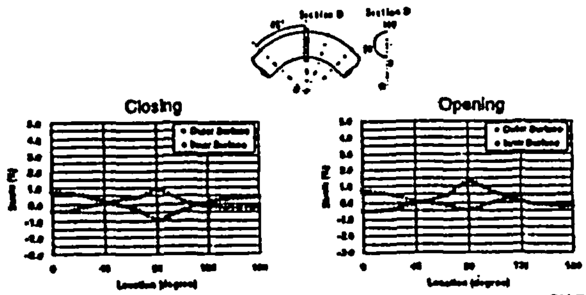
SH-4


Analysis Model for Case 1 & 2
◆ In-plane Bending Model for Elbow & in Japan
OD:114.3mm
t : 6.0mm
[Test Model]
[Analysis Model]
SH-5


Case 1 : Analysis Results
◆ Hoop Strain Distribution correspond to fictitious stress of 10Sm
Closing
Opening
SH-6

Case 2 : Analysis Results

- Hoop Strain Distribution correspond to fictitious stress of 6.5Sm



SH-7

STRAIN RATE EVALUATION

Assumed natural frequency : 4Hz

Case 1 (for 10Sm)

Strain range = 3.5 + 2.5 = 6.0%(0.06)

$$\text{Strain rate} = 0.06 \times \frac{1}{0.125} = 0.48/\text{sec.}$$

Case 2 (for 6.5Sm)

Strain range = 1.3 + 1.0 = 2.3%(0.023)

$$\text{Strain rate} = 0.023 \times \frac{1}{0.125} = 0.18/\text{sec.}$$

SH-8

資料-5-2

(From CRIEPI Report T92044 (1993), "Evaluation of Dynamic Fracture Strength of Domestic Flawed Carbon Steel Piping under High Temperature")

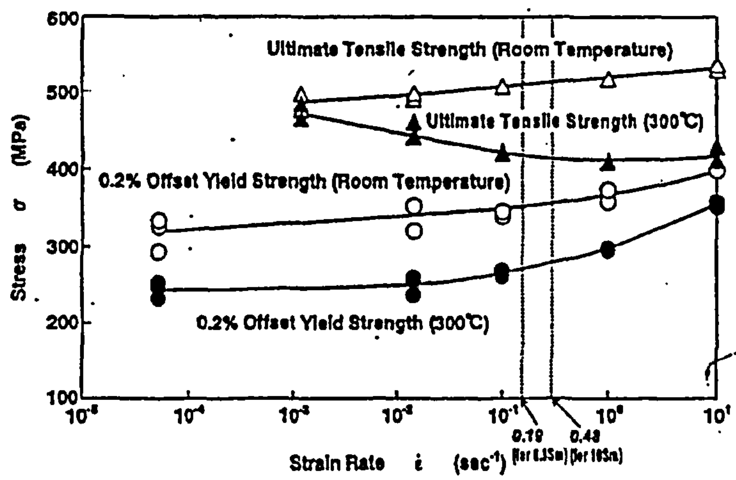


Fig. Results of High-Rate Tensile Test (STS429)

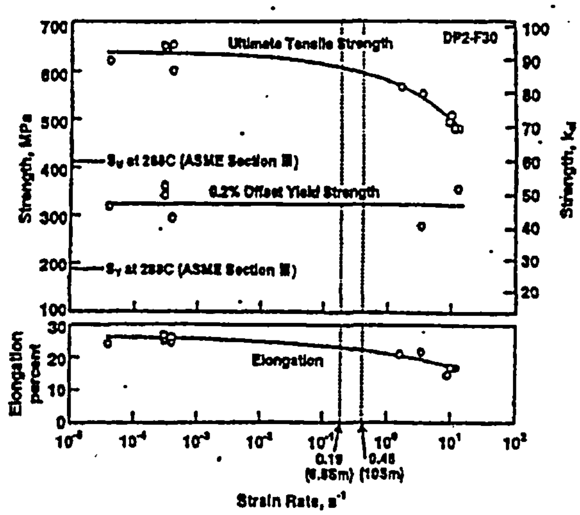


Figure 2.13 Tensile properties at 288 C (550 F) versus strain rate for Pipe DP2-F30 (A106 Grade B carbon steel) (From NUREG/CR-6226)

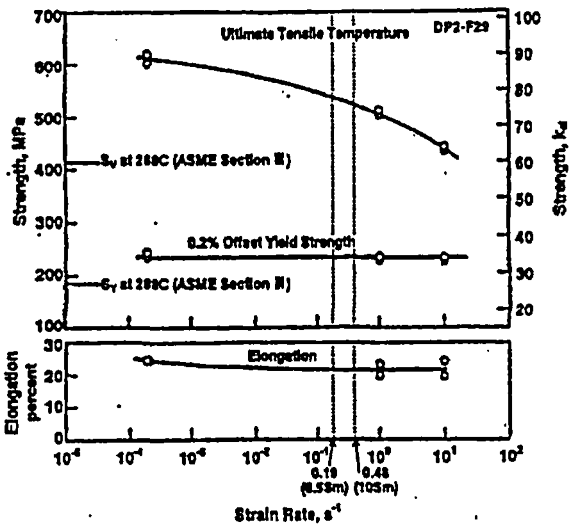


Figure 2.15 Tensile properties at 288 C (550 F) versus strain rate for Pipe DP2-F29 (A106 Grade B carbon steel pipe) (From NUREG/CR-6226)

5-7

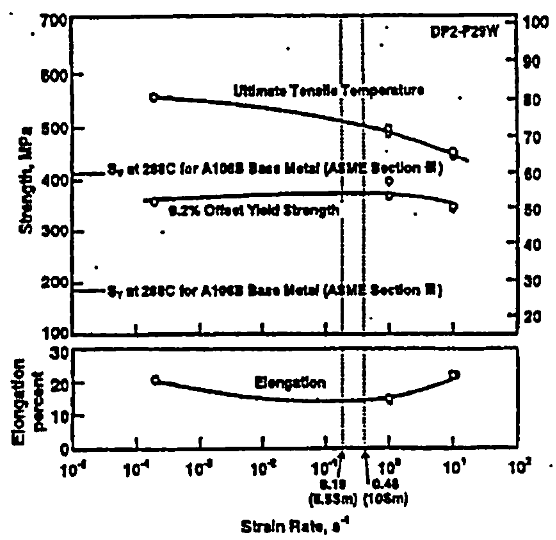


Figure 2.17 Tensile properties at 288 C (550 F) versus strain rate for a submerged-arc weld (DP2-F29W) in A106 Grade B carbon steel pipe (From NUREG/CR-6226)

Conclusion

Strain rate effect on strength of carbon steels is considerably small even when 6.5Sm or 10Sm seismic load is applied.

5-9

Appendix 4 - Japanese Research Team Data on Stress-Strain Curve Variation with Temperature

Japanese High Temperature Test Data
(Cyclic Material Test Data)

Jan.22, 2004, Japanese Seismic Team

1. Objectives

Cyclic stress-strain relationship under room temperature and 300deg.C (570deg.F) condition was compared experimentaly.

2. Test Condition:

Material: SA106 Gr. A, SA312 TP304
Temp.: RT & 300deg. C (570deg. F)
Max. Strain range: 1.5%
Strain rate: 0.001/sec

3. Test Results

As shown in Fig. 1 to 5, difference of cyclic stress-strain relationship of carbon steel at between RT and high temperature condition is negligibly small.
These tests were conducted at low strain rate condition, not at high strain rate as to occur the dynamic strain aging. So, these test data is considered to be only supplementary.

Reference: H. Yokota, et. Al., Study on seismic design of nuclear power plant piping in Japan Part 2: material test results, PVP-Vol. 407, Pressure Vessel and piping Codes and Standards-2000, ASME 2000, July 23-27, 2000

B2' RESPONSE
ATT. 7 7-1

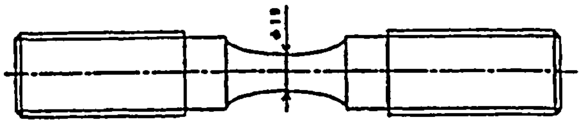


Figure 10 Stress-strain hysteresis test piece

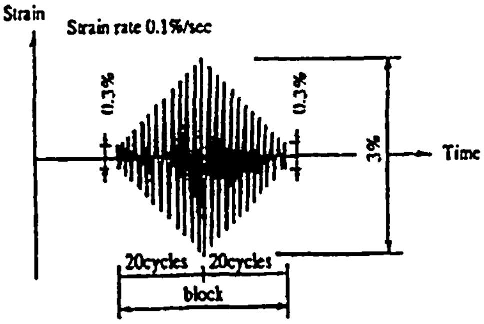


Figure 11 Strain condition in an incremental step method

Fig1 Cyclic material test method and condition

7-2

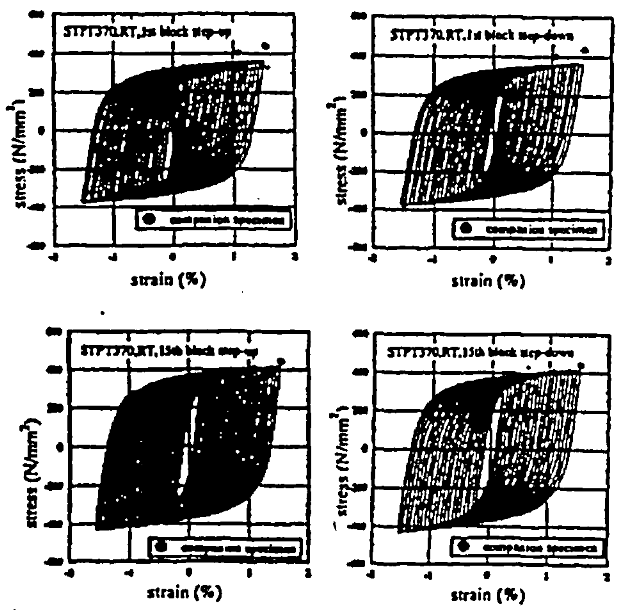


Figure 12 Stress strain hysteresis loop
(Carbon steel, STPT370, RT)
(Upper : 1st black
lower : 15th block)

Fig2 Cyclic material test Stress strain hysteresis loop
(SA106 Gr. A, RT)

7-3

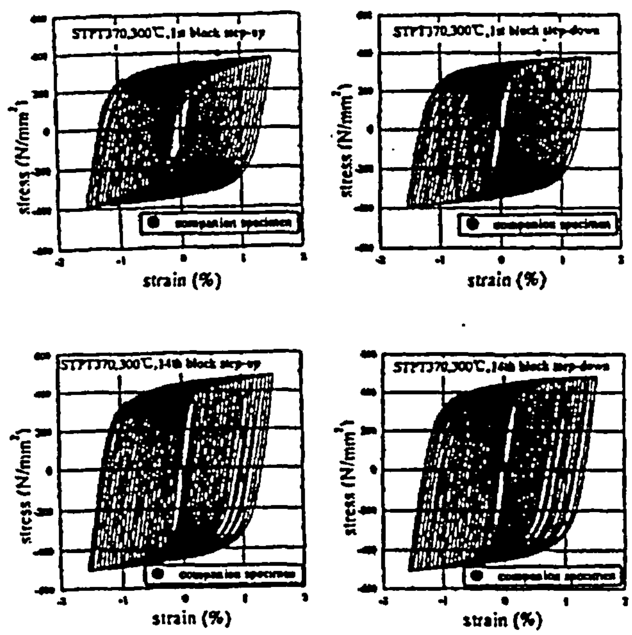


Figure 13 Stress strain hysteresis loop
(Carbon steel, STPT370, 300℃)
(Upper : 1st black
lower : 14th block)

Fig. 3 Cyclic material test Stress strain hysteresis loop
(SA106 Gr. A, high temperature)

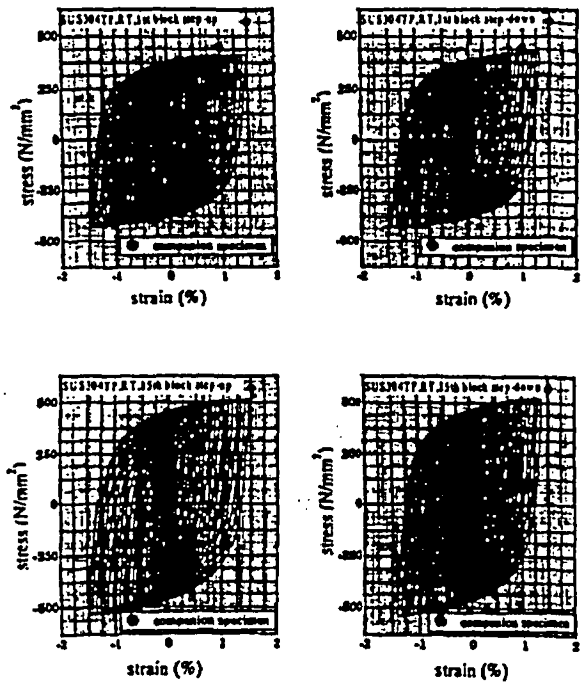


Figure 14 Stress strain hysteresis loop
(Stainless steel, SUS304TP, RT)
(Upper : 1st black
lower : 15th block)

Fig. 4 Cyclic material test Stress strain hysteresis loop
(SA312 type304, RT)

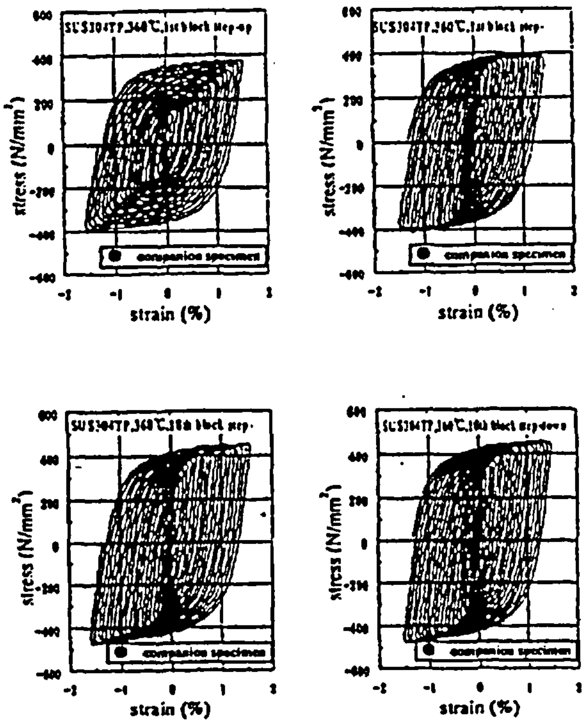


Figure 15 Stress strain hysteresis loop
(Stainless steel, SUS304TP, 360℃)
(Upper : 1st black
lower : 18th block)

Fig. 5 Cyclic material test Stress strain hysteresis loop
(SA312 type304, high temperature)

Appendix 5 - Japanese Research Team Data Additional Answers to Dr. G. Wilkowski's Concerns

An Answer to Dr.G.Wilkowski and Mr.R.Olson's Comment in NUREG-5361 Report

- From the Viewpoint of High Temperature Issue -

Y.Urabe and K.Hasegawa

September 12, 2000

Wilshire Grand Hotel, Los Angeles, CA.

. Objective

The objective of this document is to answer to Dr. G. Wilkowski's comment in NUREG-5361 from the viewpoint of the so-called high temperature issue.

. G. Wilkowski's Comment

G. Wilkowski's main comment on the high temperature issue in as follows:

> Low carbon steels at 300 to 600 F. These materials experience dynamic strain aging, also known as blue embrittlement. This causes changes in the ultimate strength, strain hardening and toughness of the material as a function of temperature and strain rate. For instance, the ANCO tests done on the ferritic components had yield-to-ultimate strengths of approximately 0.58 to 0.68 at room temperature. At higher strain rates and LWR temperatures, all of the ferritic steels tested to date in the NRC's International Piping Integrity Research Group programs (IPIRG-1 and IPIRG-2) have had slightly higher yield strengths, but much lower ultimate strengths. Typically, the ultimate strengths of ferritic base metals at 1 sec⁻¹ to 10 sec⁻¹ strain rates are lower by about 15 to 30 percent than at quasi-static rates. Thus, the yield-to-ultimate strengths can change from 0.45 at quasi-static rates to 0.77 at the 1 to 10 sec⁻¹ strain rates. The change is even more significant for ferritic weld metals. Hence, ferritic steels at LWR temperatures and dynamic loading will have less strain hardening than ferritic steels at room temperature under dynamic loading.

3. Answer to Dr. G. Wilkowski's Comment

3.1 Tensile Properties of A106 Gr. B Carbon Steel

In the IPIRG program, tensile properties of A106 Gr. B carbon steel were investigated. Obtained tensile test data at 288 (550F) are shown in Table 3.1 and Fig.3.7. These test data show that the 0.2% offset yield strength is almost constant but the ultimate tensile strength decreases as the strain rate is higher. However, the 0.2% offset yield strength and the ultimate tensile strength are still beyond Sy and Su in ASME Sec. , respectively, even though the strain rate is close to $10^{0}S^{-1}$. Accordingly, the tensile property of A106 Gr. B carbon steel in high strain rate does not violate the ASME Sec. code value of Sy, Su and Sm.

3.2 Pipe Fracture Test Data

In the IPIRG program, quasi-static and dynamic fracture tests were carried out using cracked pipes made of A106 Gr. B carbon steel.

Table 1 shows the typical test data on the quasi-static cyclic and dynamic cyclic (stress ratio R=-1.0)pipe fracture tests.

In Fig.1, the solid line and the one dotted chain line show the moment in tension side vs. crack rotation relations obtained by the dynamic cyclic and the quasi-static pipe fracture tests, respectively.

As the pipe diameter used in the dynamic cyclic test is slightly smaller than that in the quasi-static cyclic test, the moment of the dynamic cyclic test is corrected in order to compare with the quasi-static test data. The solid line is the corrected moment vs. crack rotation relation of the dynamic cyclic pipe fracture test. The corrected moment is calculated in eq.(1)

$$\text{Mcorrected} = \text{M exp} \times \left(\frac{Z_s}{Z_d}\right) \quad (1)$$

, where Mcorrected : corrected moment
Mexp : experimentally obtained moment
Z_s : Z of the pipe used in the quasi-static cyclic test
Z_d : Z of the pipe used in the dynamic cyclic test

The corrected maximum moment in the dynamic cyclic test is slightly lower than that in the quasi-static cyclic test. However, the difference is only 8.5%. Accordingly, the dynamic cyclic effect on the maximum moment (that is, loading capacity) is very small, even for the large cracked pipes.

4. Conclusion

(1) Tensile properties of A106 Gr. B carbon steel do not violate the ASME Sec. code values even in the high strain rate region.

(2) The dynamic cyclic effect on the loading capacity in piping is very small.

Table 1 Testing Conditions of Pipe Fracture Experiments

	Experiment 1.2-4	Experiment 1.2-6
Pipe Materials	A106 Gr.B Carbon Steel	A106 Gr.B Carbon Steel
Actual Outside Diameter	168mm (6.60inches)	168mm (6.60inches)
Actual Wall Thickness	14.0mm (0.550inches)	13.0mm (0.501inches)
Crack Length/Pipe Circumference	0.36	0.36
Crack Depth/Pipe Thickness	1.0	1.0
Test Temperature	288 (550F)	288 (550F)
Load-Line Displacement Rate	0.051 to 0.102mm/sec (0.002 to 0.004in/sec)	12.5mm/sec (0.50in/sec)
4-Point Bending Inner Span	610mm (24inches)	610mm (24inches)
4-Point Bending Outer Span	1524mm (60inches)	1524mm (60inches)
Experimental Moment at Crack Initiation	34.57kNm (305,930in-lb)	25.31kNm (340,050in-lb)
Maximum Experimental Moment	42.71kNm (377,965in-lb)	36.94kNm (327,200in-lb)
Tensile Yield Strength	320MPa (46.4ksi)	320MPa (46.4ksi)
Ultimate Tensile Strength	621MPa (90.0ksi)	621MPa (90.0ksi)

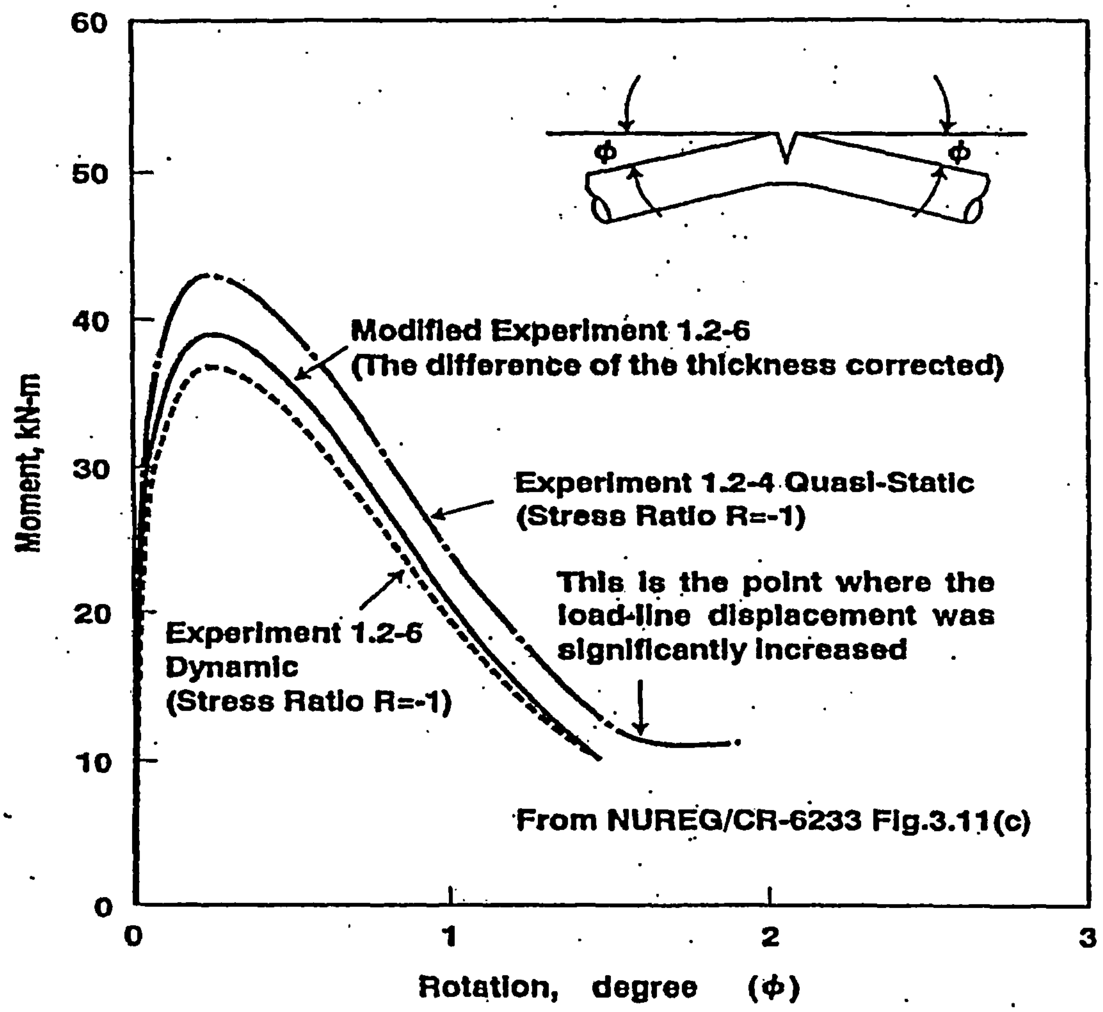


Fig. 1 Moment vs. Rotation Based on Load-Line Displacement for IPIRG Experiments 1.2-4 and 1.2-6

A Comment on Dr. G. Wilkowski's letter to the Secretary of SWG on Seismic Rules

1. Dr. G. Wilkowski stated in NUREG/CR-6098 that three different nominal strain rates (10^{-4}, 1.0 and 10 S^{-1}) were employed and the two higher rate were selected to approximate the strain rates existing near the crack tip in dynamic C(T) and pipe tests in Task 1.0, as shown bellow:

> **1.1 Selection of Displacement Rates in Material Characterization Tests**
>
> Displacement rates in material characterization tests were selected to provide data useful to the designers and analysts of Task 1.0 pipe fracture experiments. The pipe fracture experiments employed cyclic loading at a frequency of nominally 3 Hz, with the expectation of crack initiation after approximately 10 cycles. The material characterization tests, on the other hand, employed monotonically increasing displacement.
>
> Three different nominal strain rates were employed in uniaxial tensile tests of Task 1.0 materials: 10^{-4} s^{-1} (quasi-static), 1 s^{-1}, and 10 s^{-1}. The two higher rates were selected to approximate the strain rates existing near the crack tip in dynamic C(T) and pipe tests in Task 1.0.

That is, his concern is the dynamic strain behavior near the crack tip under the dynamic loading and not the global dynamic behavior of the uncracked pipe. Our concern is the strain rate effect on the global piping load capacity without crack.

From: "Kevin Ennis" <EnnisK@asme.org>
To: <SECY@nrc.gov>
Date: Tue, Apr 20, 2004 11:34 AM
Subject: Comments on RIN 3150-AH24

Gentlemen:

Attached are comments on proposed rule 10CFR50.55a. This transmittal corrects an oversight in the attachment to the original letter. Some of the information in the attachment originally mailed March 22, 2004 included a statement that a portion of the material was proprietary. This issue has been resolved and the statement has been removed from the appropriate portions.

Kevin Ennis
Director, Nuclear