ES-LPD-82-009

CRBRP SPECIAL STRESS AND CRITERIA CONSIDERATIONS

CRBRP ENGINEERING STUDY REPORT

MAY 1982

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APPLIED TECHNOLOGY

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ABSTRACT

This report provides responses to specific NRC questions on CRBRP stress and criteria considerations.

The methods and procedures by which elastic follow-up is accounted for in the CRBRP component and piping system analyses are presented. It is shown that there is negligible elastic follow-up in the CRBRP main sodium piping system.

In regard to the use of the simplified creep ratchetting bounding rules it is noted that T-1324 (Test 3) is not generally applicable at structural discontinuities but that its use by analysts on a case-by-case basis with justification is not precluded.

Recent changes in Appendix T of the Code are examined and the implications of those changes on the CRBRP design are considered. It is concluded that the changes have no significant impact regarding the safety of CRBRP equipment for elevated temperature service and the structural integrity of the CRBRP is higher than that provided by today's Appendix T.

A review of the design criteria for the core support structure concludes that the structure is completely adequate for the intended service.

TABLE OF CONTENTS

1.0 SUMMARY

This report identifies special CRBRP stress and criteria considerations in response to NRC questions CS 210.1, CS 210.7, CS 250.3, CS 250.6, CS 250.7 and CS 250.8.

Elastic follow-up is defined and the methodology by which it is accounted for in the CRBRP component and piping system analyses is presented in detail. It is shown that there is negligible elastic follow-up in the CRBRP piping.

Use of the simplified creep ratchetting bounding rules is discussed and it is noted that T-1324 (Test 3) is not generally applicable at structural discontinuities but that its use by analysts on a case-by-case basis with justification is not precluded.

The implications on CRBRP design due to recent Appendix T changes are examined in terms of design margins to ensure safety. It is concluded that the changes have no significant effect on the safety of CRBRP equipment for elevated temperature service. The assured structural integrity of the CRBRP is shown to be higher than that provided by Appendix T because CRBRP is constructed to RDT standards as well as the ASME Code.

A review of the design criteria for the core support structure concludes that the structure is completely adequate for the intended service.

2.0 INTRODUCTION

A series of questions was sent to the CRBR Project to address concerns about intended CRBRP materials, high and low temperature regions of the plant, design and analyses approaches, and specific welded joints in the plant, i.e., the reactor vessel transition joint and the IHTS transition joints.

There were five specific questions concerning stress and criteria considerations which are presented below:

CS 210.1 In piping systems at elevated temperatures, local deformation may occur at areas of geometric discontinuity, such as at fittings. Provide methods and procedures for the following:

A. Define elastic follow-up.

B. Evaluate creep rupture and fatigue damage.

C. Justify the use of simplified creep ratcheting bounding techniques used in computer codes.

CS 210.7 Due to the constant evolution of rules in Code Case 1592 (N-47) during the period when the PSAR was prepared, identify any areas where the rules delineated in current Appendix T of Code Case N-47 have not been satisfied. Provide the basis to show that such deviations, if any, are acceptable in terms of design margins to ensure safety.

CS 250.3 Identify the components and supports in the reactor coolant system and connecting systems (including the steam generator) which have been constructed, stating the purchase date and the Code, Standards, and criteria to which they were fabricated. Describe the procedures used for their storage. Indicate the difference in the purchase requirements and the Codes, Standards and criteria in effect at the present time. The use of the components should be justified on the basis that they will provide an equivalent degree of system integrity and safety as if fabricated to the requirements of the current Codes, Standards, and criteria.

CS 250.6 Provide justification for the use of the simplified creep ratcheting bounding methods in Code Case 1592 at structural discontinuities.

CS 250.7 How do you account for the elastic follow-up in elevated temperature component and piping (elbows) system analyses?

CS 250.8 Provide the design criteria for the elevated temperature core support structure, including the welds in the forging and the reactor vessel.

To address these and other questions a CRBRP/NRC meeting was held at Bethesda, Maryland on April 6-7, 1982. There were two topical discussions concerning stress and criteria considerations in CRBRP design: Special Stress Considerations by A. Dhalla of W-ARD and Special Criteria Considerations by A. Snow of W-ARD. The first part of the report addresses NRC questions CS 210.1, CS 250.6, and CS 250.7. The second part addresses questions CS 210.7, CS 250.3, and CS 250.8. Figures 1 and 2 were used in introducing these discussions.

CRBRP HTS MATERIALS AND STRUCTURES

VII. Special Stress Considerations★

- Purpose (CS 250.7)
  - To describe evaluation of elastic followup in piping
- Conclusion
  - Main sodium piping exhibits negligible elastic followup

- Purpose (CS 250.6)
  - To address applicability of simplified creep ratchetting bound
- Conclusion
  - Use of this technique near gross discontinuities requires case-by-case justification

★ Responds to Q CS 210.1.A, CS 250.6, CS 250.7

FIGURE 2.0-1

CRBRP HTS MATERIALS AND STRUCTURES

VIII. Special Criteria Considerations★

- Purpose (CS 250.3)
  - To examine implications of recent changes to the code rules for elevated temperature design
- Conclusion
  - Recent code changes have no implications regarding the safety of components constructed to earlier code effective dates

- Purpose (CS 250.8)
  - To describe the design criteria for core support structures
- Conclusion
  - The CRBRP core support structure design criteria (1592-7) are more stringent than the new ASME code case

★ Responds to Q CS 210.7, CS 250.3, CS 250.7, CS 250.8

FIGURE 2.0-2

SPECIAL STRESS CONSIDERATIONS

By

A. Dha [illegible] (W-ARD)

SPECIAL STRESS CONSIDERATIONS

This presentation addresses the answers to two of the questions given in the introduction. Question CS250.7 asked for consideration or information on how we consider elastic follow-up in our piping evaluation. In our response we note why we think there is negligible elastic follow-up. Question 250.6 concerns the area of the application of the Code's simplified creep ratchetting techniques to certain types of configurations. We'll address that and show how and where we use or we don't use them.

In the process of defining elastic follow-up, first we examine what the code says about the elastic follow-up. This is followed by brief historical background as to where this term "elastic follow-up" came from, and then, in the CRBR application where we have realistic piping systems, we discuss whether we really have elastic follow-up or not.

First we look at low-temperature application (Figure 2). There are three places where the code discusses either elastic follow-up or how thermal expansion stresses in stress calculations should be classified.

At low temperature, NB-3222 on expansion stress intensity, says that, "Expansion stress intensity, P_e, is treated as secondary."

If you go further into piping rules (Figure 2), which is Class I piping, NB-3672, elaborates a little bit more, but it does not use the word "elastic follow-up." It says, "Piping shall be designed to have sufficient flexibility to prevent movements from causing --," "-- failure of piping or anchors from overstress or overstrain." It does not say anything about elastic follow-up.

Apparently in the initial ASME code, they might have used the word "elastic follow-up." Later that reference was removed, because, in Class II piping, we still have the word "elastic follow-up," which is in NC-3672, which (in Figure 2) says, "Weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower-stressed portions."

So, as far as the low-temperature design is concerned, there is not so much concern about elastic follow-up because NB-3222 is very specific that expansion stresses will be treated as secondary. In fact, elastic follow-up is not defined in Section III low temperature rules.

The design philosophy changes at elevated temperatures because there is a concern about the elastic follow-up, as we see from code case 1592 (or N47).

For elevated-temperature application (in Figure 2), paragraph -3138 specifically talks about elastic follow-up, and it says, "The examples of significant elastic follow-up include local reduction in size of a cross-section or local use of a weaker material." It does go further and talks about a second point (Figure 3), where it says that you can expect significant elastic follow-up even in a piping system of uniform size if one portion departs from the line.

As we will see later, most of our main piping systems do not have these two conditions, that is, a sudden change in cross-section or a small portion with a significant departure from the line. So, really, according to the Code Case N-47 definition, there is no elastic follow-up in the main pipelines that we should be concerned about. But, to show that there is really no elastic follow-up, we have done detailed inelastic analyses of a realistic piping system in the primary heat transport system, which will be discussed later.

In Figure 3, Para. -3138 goes further and says, "If possible, the above conditions should be avoided in design. Where such conditions cannot be avoided, the analysis required in -3250 will determine the acceptability of design to guard against harmful effects or consequences of elastic follow-up." If we go to -3250, we see that really those limits are for deformation-controlled analysis, and you would have to meet the deformation control limits anyway, irrespective of whether there is elastic follow-up or not.

If one has to meet the deformation-controlled limits, the elastic follow-up paragraph -3138 does not add much to it. But there is a catch here. Apparently when you go into -3213, where load-controlled and thermal expansion

antities are discussed, it says (in Figure 3) that the secondary stresses
h a large amount of elastic follow-up .... should be assigned to primary
tegory (see the footnote to -3213). The footnote also says, "Note that the
pansion stress P_e, defined in NB-3222," which we discussed earlier in the
-temperature code, "is deleted from this code case, and stresses resulting
om free-end displacement shall be assigned to either primary or secondary
ress categories." Again, it's not very specific, but obviously if a prudent
lyst thinks that elastic follow-up is significant, he will consider the
stic follow-up stresses as primary. If it's not significant, he will
sider thermal expansion stresses as secondary.

y briefly, if we go further into the elevated temperature code case, the
stic follow-up is discussed in T-1320, in satisfaction of strain limits
ng elastic analysis. Again, unless you can show that there is no elastic
low-up, you have to consider thermal expansion stresses as primary (Figure

should be noted that this specific calculation in T-1320 strain limits is
ed upon elastic piping system analysis.

ther place where the elevated-temperature Code Case mentions elastic
low-up is the buckling and stability limits (Figure 4). Where significant
stic follow-up may occur, the load factors applicable to load-controlled
kling shall also be used for strain-controlled buckling.

ore explaining how we determine whether there is elastic follow-up or not,
will look very briefly at the historical background.

und 1955, Robinson presented a paper, and the main purpose of his
sentation was that he was rather disturbed by the ASME code penalty on the
d-sprung piping systems. That's why he wanted to point out that
d-sprung piping systems are no different from a regular piping system
gure 5).

act, if you cold spring the piping system, at elevated temperature it will
operating at lower stress levels, and, because of that, you will have lower

thermal expansion stress during creep, so it's better to use cold-sprung piping systems. But, apparently, the thinking at that time was that cold-sprung piping systems should not be used but that self-sprung piping systems should be. It was thought that the piping system should be erected, be heated up, and the thermal expansion stresses would relax out at elevated temperatures.

Robinson wrote his paper to show that, in some specific instances, if you have a self-sprung piping system, you can get creep strain concentration in some areas, where elastic strains from some other parts of the piping system will be transferred and concentrated in the most highly loaded location in the piping system.

There are two interesting comments in that paper. The first comment was by Robinson (in Figure 5), who said that excessive plastic strain is undesirable. Surely, excessive strain is undesirable, but the point is, how do you calculate that?

In 1955, they did not have the ability that we have now to calculate plastic strains and evaluate our calculated strains against elevated temperature strain limits.

The second comment (in Figure 5) was by Markl in a rather detailed discussion of the paper. He stated that, "Most pipelines work and that design computations must, therefore, be adequate." And that was in 1955! Since then, we have made tremendous progress in predicting inelastic strains in piping systems.

The concept that Robinson described in that paper is rather interesting. He looked at two cases to show when elastic follow-up is present and when it is not.

For example, if you look at a simple bolted joint (in Figure 6), the initial pre-load will relax out because of creep. Creep relaxation occurs because the total strain in the bolt is constant. So the creep strains are exchanged for elastic strains. That's why the stress has to relax out. For example, the parameter on the right-hand side (in Figure 6a), where he plotted bolt creep divided by the initial elastic extension, the value of 1.0 indicates that total strain is equal to creep strain, and there is no elastic strain. If you don't have elastic strain, you cannot get any stress during creep hold time.

On the other hand, when this parameter is greater than one, that means that bolt creep -- in this case it's a bolt, but it could be any structure -- the creep from the strains coming from that could be higher than the initial elastic strains. In that case, there is a concern about elastic follow-up.

Robinson pointed out a specific example of a creep test, where elastic follow-up effects are present (Figure 6b). Robinson said that there is not enough sophistication in running a creep test under constant strain, so Coffin designed a creep test specimen shown in Figure 6b. In that creep test he loaded the specimen in the furnace by a displacement loading (Figure 6b). With the lever and a soft spring attached to it, he was able to keep the applied displacement constant and he attempted to measure creep in his creep test program.

Here we see that, if we have stress plotted against the creep hold time, the stress relaxes but not significantly. That would be a condition of elastic follow-up, when your stresses are not relaxing out and, because of that, the (piping) system might be operating at higher stress levels than what you anticipate. Also you might get creep strain concentration that, in Coffin's case, is more than a factor of ten.

Where is this creep strain coming from? For example, in the bolt that we saw earlier, the total strain is constant. You can only exchange creep strains with elastic strains. If there are no elastic strains transferred into one highly stressed location, the creep strains at that location will be exchanged with elastic strains; and if elastic strains are reduced, the stress and the load will relax during creep hold time.

So where is the excessive elastic strain coming from in Coffin's test? The test was set up, with a very soft spring, and a rather stiff specimen. So what was happening is that, even though this specimen was presumably a displacement-controlled specimen, during creep the stresses did not relax significantly. As soon as the stress would relax because of the equilibrium that you have to maintain, the soft spring will feed elastic strain into the creep specimen. So that's where the creep specimen (in Figure 6b) was getting additional elastic strains. As soon as you put in more elastic strains, it will creep but the stress will not relax. The stress will just stay up there, and this is the condition of significant elastic follow-up as defined by Robinson.

Robinson said that you don't have such piping systems in a real plant but we can have some strain concentrations, which he presented as examples. One of the examples that he talked about was a piping system that might be loaded in out-of-plane (out-of-plane bending, and out-of-plane torsion loading), not in-plane bending and he said that such a piping system may experience elastic follow-up.

Again, it should be noted that, in 1955, there were no capabilities of performing elastic-plastic analysis of piping systems. Now we have programs to do elastic-plastic analysis, and we can see whether there is elastic follow-up or there is no elastic follow-up under out-of-plane loading.

Shown in Figure 7 is a specific piping system in the CRBR hot leg. The piping is 24-inch outside diameter, half-inch thick. Because of the complex routing of the pipeline, we looked at this piping to see if there is an elastic follow-up effect due to thermal expansion loading. The straight pipes are not that highly stressed but the elbows are highly stressed, and significant plastic as well as creep strains will be accumulated in these elbows. Therefore we have examined specifically the six elbows shown in Figure 5.

The implication in the Code is that if you have elastic follow-up, then you have to consider that quantity as a load-control quantity; that is, you cannot consider thermal expansion stress as a displacement control quantity. To illustrate the concept of load and deformation controlled quantities we plot a eneralized load deformation curve (as shown in Figure 8). According to lastic analysis, for a specified thermal expansion loading, we will calculate oint B.

ow, if thermal expansion is a load-control quantity, the load will not drop, d, because of that, we'll get substantially higher displacement (point C in gure 8) for the same load that is calculated elastically. On the other nd, if the thermal expansion load is something like a thermal radial adient loading, that is, if we consider thermal expansion as a displacement ntrolled quantity, then the same elastic analysis will predict point D in gure 8 if we do an elastic-plastic analysis. So this is the distinction tween the load-controlled quantity and the displacement-controlled quantity.

erefore, this is the first thing that one can look for if we analyze this ping system in the elastic-plastic-creep range, and to find out if we do see me kind of a load-control behavior. These inelastic analyses were performed cording to the procedures described by Dr. Corum of ORNL earlier in this eting. The MARC computer program was used for these analyses.

r example, what is plotted in Figure 9 is the resultant moment in each of e different elbows that I have mentioned versus the applied thermal pansion load. Thermal expansion load 1 indicates that it is an operating ermal expansion load. That means the uniform piping system temperature is creased from 70 degrees to 1015 degrees Fahrenheit operating temperature for is particular pipeline.

an elastic analysis is performed, it will indicate that if the load is creased four times, the moment will increase four times (Point B in Figure . But, because of the plastic deformation capability of the elbow, the load redistributed, and, because of that, one would find that at four times the ad, we don't get four times the moment. We actually get about o-and-a-half times the moment.

the first point of Figure 9 is to show that the thermal expansion load is a load-control quantity as one would have to take if elastic follow-up re present in the piping system.

Another thing is that we don't have any criss-crossing of these resultant moment curves. This shows that, if I keep on increasing the load proportionately, each of these curves are proportionately increased. In other words, elbow loc. 6-2, the lowest curve in Figure 9, does not throw its load to elbow loc. 1-1, the most highly loaded elbow, indicating that there is no transfer of load from lower stressed elbows to the most highly loaded elbows. Thus, we don't see elastic follow-up effect.

Now, if we analyze the same piping system in the creep range, we find again (in Figure 10) that the maximum stress in all these elbows -- of course, elbow 1 is the most heavily loaded elbow -- relax nearly proportionately with creep hold time. Of course, we don't have a direct comparison with uniaxial relaxation curves because in piping elbows the inelastic redistribution is much more complicated. Consequently, the resultant moments are plotted and not specific stress or strain in these elbows.

Briefly, (as shown in Figure 10) the stresses do relax at an applied thermal expansion load of one, with creep hold time of about 10,000 hours. Once again, the curves are not criss-crossing, which indicates that the thermal expansion load is proportionately carried by all the elbows in the piping system.

If the thermal expansion load were increased to four, the stresses would be considerably higher. If the stresses are considerably higher, with the power law relationship of creep rate depending on the nth power of stress, the stresses would relax rather rapidly. This is seen in Figure 11.

If we really had an elastic follow-up type of situation, these stresses, just by increasing the load, may not have relaxed as rapidly as it did here. The moment relaxation is nearly proportional with creep hold time in all these elbows.

This is, to some extent, qualitative, because I'm only looking at one specific piping system subjected to a specific thermal expansion loading; but all of these are uniform thickness elbows and uniform diameter. So from that point of view, it's a rather nice well-balanced piping system. Also, the assumed material properties in all of these elbows are identical.

The question now is what would happen if we assumed one of the elbows to be weak. One way to approach this is to assume the yield stress for that particular elbow as 20 percent lower than the rest of the elbows. Another approach is to assume elbow-1 is of standard strength (as was done in the first analysis) and the rest of the elbows may be assumed to be 20 percent weaker. Basically, these two cases would make elbow-1 20 percent weaker in one case, and this same elbow would be 20 percent stronger in the second case. Inelastic analyses of these two cases can be compared with a certain standard analysis that I've already discussed.

When the results of these three inelastic analyses are examined, an indication of what is really happening in the piping system can be obtained.

Figure 12 shows normalized resultant moments plotted against thermal expansion load. The solid line represents all the elbows of equal strength. If we make only one elbow 20 percent weaker than the rest of the elbows (Analysis III), the moment and the thermal expansion load relationship is as shown by the dot-dash line in Figure 12.

If all the other elbows are weaker and elbow-1 stays at the same standard strength, I find that the moment rotation curve drops even further, as shown by the dotted line in Figure 12.

If we try to use the same analogy by saying that with some elastic analysis, we have elastic prediction of the moment, and the moment drops because of the strain control situation, that still does not answer the question of whether there is elastic follow-up or not.

One way to look at it is this. If one elbow is weakened, the flexibility of the piping system is increased, so more displacements can be accommodated by the piping system as a whole. If I make all the elbows weak but only one of standard strength, then the overall flexibility of the piping system reduces further. Again, if there were really an elastic follow-up, one would find that this behavior would not occur. So, basically, by increasing the flexibility, the thermal expansion load carrying capacity of the piping system is increased and, in fact, the resultant moment actually drops. It does not increase in the most highly loaded elbow-1.

To carry this a little further, consider the strains from only one analysis (Analysis III elbow-1 20% weaker than the rest), because others are very similar. Figure 14 represents Analysis III, plotting the effective plastic strain on the vertical axis and the thermal expansion load on the horizontal axis. If elastic follow-up were present then I would, from some portion in the piping, expect elastic strains from lightly loaded elbows will reduce and transfer into the weakest and most highly loaded elbow-1. In this analysis, the first elbow is weak, so we can see if we do or do not obtain strain concentration in that elbow. These are only plastic strains in Figure 13.

Initial loading yields elbow-1 which is the weak elbow. But because of its strain-hardening capacity, it is strain-hardened, the thermal expansion load is redistributed and carried by other elbows. Then the other elbows start yielding. But, in fact, one of the elbows (elbow-5, not plotted in Figure 13) is still very much elastic; so, if we really had an elastic follow-up sitaution, we would have found that the lower stressed elbows, which are rather lightly loaded, would start transferring the load to the most highly-loaded elbow-1. That is not the case. The plastic strains, after thermal expansion load of 2, increase nearly proportionately with the increase in thermal expansion load.

Another way to look at the same thing is to say that if the plastic strains are analyzed, they more or less meet at a certain point here (dotted lines extrapolated to the horizontal axis in Figure 13). What it really indicates is that, by increasing the thermal expansion load beyond 1.5, which is 1.5 times the operating load, the plastic strains in all the elbows more or less proportionately increase, not just in elbow-1.

Figure 14 is another plot, which shows the creep strain behavior predicted by Analysis III. It plots the creep hold time versus the effective creep rain. In one of the elbows which is not plotted here, the strains are so all that it does not show up on this log-log scale.

ain, the most highly-loaded elbow-1 does see higher creep strain, but other bows also start picking up their share of creep strains, and they do not ansfer their creep strains into the most highly-loaded elbow. So, again, is gives us an indication that there is no elastic follow-up in these types realistic piping systems, which are, in the main, sodium piping systems.

e of the reasons why we had to do these three detailed inelastic analyses is cause it is very easy to show something is present, but it's very difficult show that something is not present.

summary, elastic follow-up was first defined by Robinson in 1955 in context th Coffin's displacement controlled creep test specimen levered to a soft astic spring. Simple calculations by Robinson showed that the follow-up asticity of a soft spring prevents reduction of stress due to creep, which aracterizes the simple (preloaded) bolt in an unyielding flange (Figure 6). a preloaded bolt the total strain is constant; consequently, during creep e creep strains are exchanged with elastic strains. On the other hand, in ffin's experiment, the total strain in the creep specimen is not constant, astic strains from the soft spring are fed into the creep specimen. This is cause equilibrium as well as compatibility in the levered system has to be intained between the soft elastic spring and the stiff creep test specimen. nsequently, when the stress in the creep test specimen relaxes, additional astic strains are fed into it, thus preventing stress relaxation during eep. Thus, elastic follow-up is present in Coffin's test specimen. The d as well as strain in the soft elastic spring are decreased and this low-up elastic strain is transferred and concentrated into the highly ded stiff creep specimen.

low temperature application the ASME B&PV Code Section III considers rmal expansion stresses as secondary or displacement controlled (Figure The Code philosophy changes when we consider the elevated temperature e Case 1592 (or N-47). For elevated temperature application paragraph 38 specifically gives the following examples of elastic follow-up:

a) significant elastic follow-up include local reduction in size of a cross-section or local use of a weaker material, b) in piping system of uniform size ... only a small portion departing from the line (Figures 2 and 3). These two examples are consistent with the elastic follow-up definition presented by Robinson.

To summarize, the following two conditions have to be present for elastic follow-up: (a) in the creep range, a stiff member in the structure should be most highly stressed, and (b) a lightly loaded more flexible member in the system must transfer its elastic strains and simultaneously its load to the highly loaded stiff member. In the main large diameter piping systems in the CRBR plant none of the above conditions are present. Consequently the elastic follow-up according to the Code Case N-47 definition (or Robinson's definition) is negligible in the CRBR main piping systems, Figure 15.

Three detailed inelastic analyses of the CRBR hot leg piping system were performed using the MARC program according to the inelastic analysis procedure described by Dr. Corum of ORNL. These inelastic analyses confirmed that elastic follow-up is negligible and the load or strain is not transferred from the lightly loaded elbows or straight pipes and inelastic strains are not concentrated in the most highly loaded elbow (Figures 7 to 14). Even when the most highly loaded elbow was assumed to be 20% weaker than the rest of the elbows, the plastic and creep strains due to thermal expansion loading were shared by all elbows in equal proportion. This elastic follow-up study was specifically undertaken to satisfy the intent of Code Case N-47 -3138 and to classify thermal expansion load as a displacement-controlled quantity.

Although there is no elastic follow-up in the piping system, it should be recognized that significant stress and strain redistributions do occur in elbows, which in effect are doubly curved shells subjected to complex in-plane and out-of-plane loading conditions. For example, when elbow-1 is 20% weaker than the rest of the elbows (in Figure 13), initially only this elbow experiences plastic strains when others are still in the elastic range. Due to the strain hardening capacity of the material, additional thermal expansion load yields other elbows and this additional load is proportionately shared by other elbows. This plastic redistribution is no different from the plastic edistribution that occurs in a plate with a hole. Furthermore, in structural valuation the strain concentration at the hole is not treated as an elastic ollow-up but as a strain concentration due to plastic redistribution. For xample, Neuber has shown that in the plastic range the strain concentration actor at the hole is K^2, instead of K, which is the elastic stress as well s strain concentration factor for that plate with a hole.

t us go on to the next question - CS250.6 and then return to the question of rain accumulation and creep-fatigue damage evaluation in piping systems uestions CS210.1 -B and -C).

regard to creep ratchetting, we are required to provide justification for ing the simplified creep ratchetting bounding rules (Figure 16). Question 250.6 appears to come from the fact that in Code Case 1592, T1324-3, it ys that this particular test is not applicable at structural scontinuities. It is not generically applicable at structural scontinuities, and it should not be used (Figure 17). On the other hand, e by analysts on a case-by-case basis with justification is possible, Figure , and should not be precluded.

turning to questions 210.1 -B and -C and discuss the overall philosophy of e CRBR main piping system analysis and how we satisfy the Code criteria on rain limits and creep-fatigue interaction. As noted earlier, regarding 1320, "Satisfaction of Strain Limit Using Elastic Analysis," T-1324 Test 3 strictly applicable to "axisymmetric structures subject to axisymmetric ading away from local structural discontinuity." The wording on elastic llow-up in that paragraph is specifically inserted to discourage an initiated analyst from applying this test to situations where axisymmetric nditions are violated. In fact, the elbows are essentially doubly curved ells, they are neither geometrically axisymmetric nor are they subjected to isymmetric loading. The applied loading in the form of dead-weight, thermal pansion and seismic load is not axisymmetric. Consequently, irrespective of ether there is or there is no elastic follow-up, this test cannot be used in tisfying the elastic rules of Code Case N-47. For example, if the elastic strain limit in T-1320 cannot be satisfied (and they will not be in most of the elevated temperature piping systems with flexible elbows), then the analyst cannot and should not use the elastic creep-fatigue rules in T-1430.

This philosophy of piping system analysis for the CRBR is as follows. Complete piping system elastic analyses are performed for all main pipelines, and the thermal expansion stresses are treated as primary to comply with deformation limits, as indicated in the rules of T-1320. The strain limits can not be satisfied for most of these pipelines with this conservative classification of thermal expansion stress as primary. Therefore, it is necessary to perform detailed inelastic analysis. Although creep and fatigue damages are calculated, assuming once again thermal expansion stress as primary, these values are used only in preliminary screening and assessment to determine the order of severity these pipelines are subjected to according to these elastic evaluations.

The screening procedure, based upon elastic evaluations, implicitly includes a number of parameters characterizing material, geometry, and loading. The piping systems are then grouped (ordered) according to the stress and strain ranges obtained from these elastic analyses. Detailed inelastic analysis is performed on the most highly loaded piping system (the one discussed in this presentation). This detailed inelastic analysis included complete load history specified in the design specifications with minimum material properties idealized as linear variations with temperature.

This most highly stressed, 24-inch diameter hot leg piping system complied with all the inelastic criteria specified in Code Case N-47. Thus, by implication, other piping systems with similar geometry and loading conditions would also satisfy the Code criteria. In fact, this analysis philosophy is also used in structural components other than piping where the most highly stressed areas are analyzed in great detail and thus, by implication, other lower stressed areas, too, would comply with the Code criteria.

In conclusion, the elastic follow-up effects are evaluated to classify stresses due to thermal expansion as secondary to satisfy the load controlled limits of Code Case N-47 -3220. Then the most highly loaded piping system is alyzed using inelastic analysis procedures to satisfy the deformation ntrolled limits of Code Case N-47 -3250. Incidentally, the procedures used re are consistent with those used earlier in the FFTF piping design and alysis.

FIGURE 3.0-1

ELASTIC FOLLOW-UP

- QUESTION: CS 210.1

  ... DEFINE ELASTIC FOLLOW-UP

- QUESTION: CS 250.7

  HOW DO YOU ACCOUNT FOR ELASTIC FOLLOW-UP ...

FIGURE 3.0-2

ASME B&PV CODE SECTION III

(CURRENT STATUS - WINTER 1981)

- LOW TEMPERATURE APPLICATION

  NB-3222.3 EXPANSION STRESS INTENSITY

  - EXPANSION STRESS INTENSITY, P_e, IS TREATED AS SECONDARY.

  NB-3672 EXPANSION AND FLEXIBILITY (CLASS I PIPING)

  - "PIPING SHALL BE DESIGNED TO HAVE SUFFICIENT FLEXIBILITY TO PREVENT MOVEMENTS FROM CAUSING:
    "(1) FAILURE OF PIPING OR ANCHORS FROM OVERSTRESS OR OVERSTRAIN."

  NC-3672.6(b) EXPANSION AND FLEXIBILITY -- LOCAL OVERSTRAIN (CLASS II PIPING)

  "...WEAKER OR HIGHER STRESSED PORTIONS WILL BE SUBJECTED TO STRAIN CONCENTRATIONS DUE TO ELASTIC FOLLOW-UP OF THE <u>STIFFER</u> OR LOWER STRESSED PORTIONS."

- ELEVATED TEMPERATURE APPLICATION

  -3138 - ELASTIC FOLLOW-UP

  "(a)...EXAMPLES INCLUDE:

  "(1) LOCAL REDUCTION IN SIZE OF A CROSS-SECTION OR LOCAL USE OF A WEAKER MATERIAL.

FIGURE 3.0-3

ASME B&PV CODE SECTION III (CONTINUED)

(CURRENT STATUS - WINTER 1981)

"(2) IN PIPING SYSTEM OF UNIFORM SIZE... WITH ONLY A SMALL PORTION DEPARTING FROM THIS LINE.

"(b) IF POSSIBLE, THE ABOVE CONDITIONS SHOULD BE AVOIDED IN DESIGN. WHERE SUCH CONDITIONS CANNOT BE AVOIDED, THE ANALYSIS REQUIRED IN -3250 WILL DETERMINE THE ACCEPTABILITY OF DESIGN TO GUARD AGAINST HARMFUL CONSEQUENCES OF ELASTIC FOLLOW-UP."

-3250 - LIMITS ON DEFORMATION CONTROLLED QUANTITIES

-3213 - TERMS RELATING TO ANALYSIS

"(a) LOAD CONTROLLED QUANTITIES -- ... SECONDARY STRESSES WITH A LARGE AMOUNT OF ELASTIC FOLLOW-UP."

FOOTNOTE 2 - "NOTE THAT THE EXPANSION STRESS (P_e) DEFINED IN NB-3222.3 IS DELETED FROM THIS CODE CASE. STRESSES RESULTING FROM FREE END DISPLACEMENTS SHALL BE ASSIGNED TO EITHER PRIMARY OR SECONDARY STRESS CATEGORIES (SEE -3213(a), -3213(b) AND -3217).

T-1320 SATISFACTION OF STRAIN LIMITS USING ELASTIC ANALYSIS

T-1324 TEST NO. 3.

"(b) UNLESS OTHERWISE JUSTIFIED, ANY STRESS WITH ELASTIC FOLLOW-UP... SHOULD BE INCLUDED AS PRIMARY STRESSES FOR THE PURPOSES OF THIS EVALUATION..."

FIGURE 3.0-4

ASME B&PV CODE SECTION III (CONTINUED)

(CURRENT STATUS - WINTER 1981)

T-1500 BUCKLING AND STABILITY

T-1510(d) "...WHERE SIGNIFICANT ELASTIC FOLLOW-UP MAY OCCUR THE LOAD FACTORS APPLICABLE TO LOAD-CONTROLLED BUCKLING SHALL ALSO BE USED FOR STRAIN CONTROLLED BUCKLING."

FIGURE 3.0-5

ELASTIC FOLLOW-UP

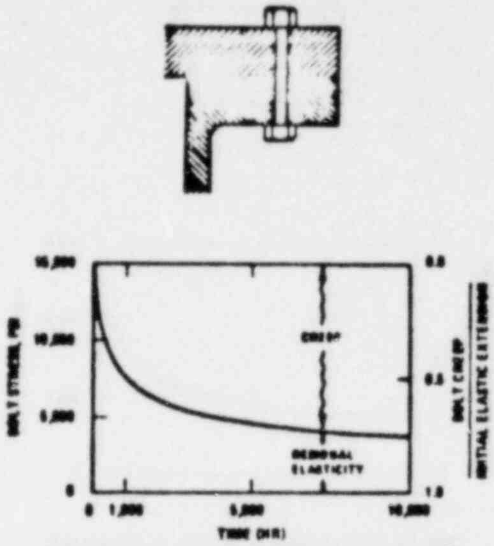
HISTORICAL BACKGROUND

- 1955 - ROBINSON
  - DESIRABILITY OF COLD SPRINGING PIPELINES TO MINIMIZE CREEP STRAIN CONCENTRATIONS
  - DISCUSSED PRINCIPALS GOVERNING RELAXATION OF THERMAL EXPANSION STRESSES DURING SERVICE
  - DEFINED ELASTIC FOLLOW-UP
  - DISCUSSION OF THE PAPER GENERATED OLD ARGUMENTS ON ADVANTAGES AND DISADVANTAGES OF COLD SPRINGING AND SELF SPRINGING

- "EXCESSIVE PLASTIC STRAIN UNDESIRABLE..."
  "MOST PIPELINES WORK AND THAT DESIGN COMPUTATIONS MUST, THEREFORE, BE ADEQUATE."

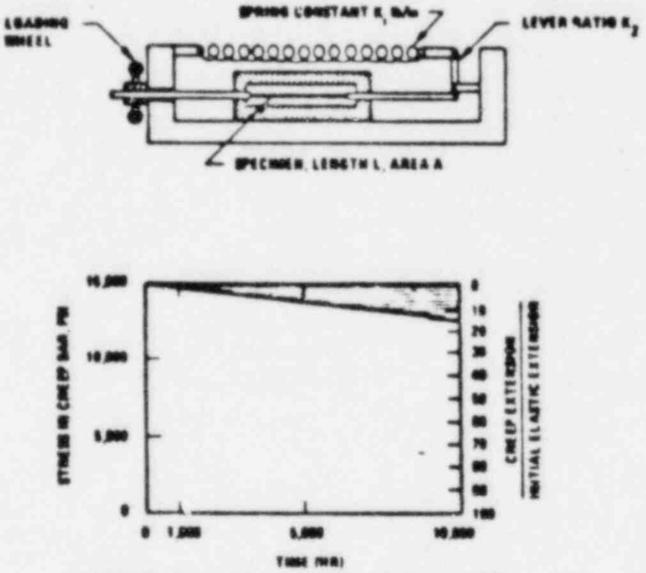
- CONCEPT OF ELASTIC FOLLOW-UP AS PRESENTED BY ROBINSON.

FIGURE 3.0-6



(2.25 PERCENT Cr 1 PERCENT Mo PIPING MATERIAL AT 1000°F
So = 7500   E = 30 000 000   n = 4
INITIAL STRESS 15,000   FINAL STRESS 3730   TOTAL CREEP [illegible] PERCENT.
10,000-HR CREEP IS 0.75 TIMES INITIAL ELASTIC EXTENSION.)

Figure 4a. Behavior of Bolt in an Unyielding Flange [9]



(2.25 PERCENT Cr 1 PERCENT Mo PIPING MATERIAL AT 1000°F
So = 7500   n = 4   E = 30 000 000   (1 + β) = 101
INITIAL STRESS 15,000   FINAL STRESS 12 740   TOTAL CREEP 1.14 PERCENT
NOTE THAT AMOUNT OF CREEP IS ABOUT 20 TIMES AS MUCH AS WOULD
CORRESPOND WITH STRESS REDUCTION IF THERE WERE NO FOLLOW UP
ELASTICITY. 10,000 HR CREEP IS 15.22 TIMES INITIAL ELASTIC EXTENSION.)

Figure 4b. Coffin's Old Spring-Loaded Creep Furnace With Follow-up Elasticity 100 Times That of Specimen [9]

5480-1

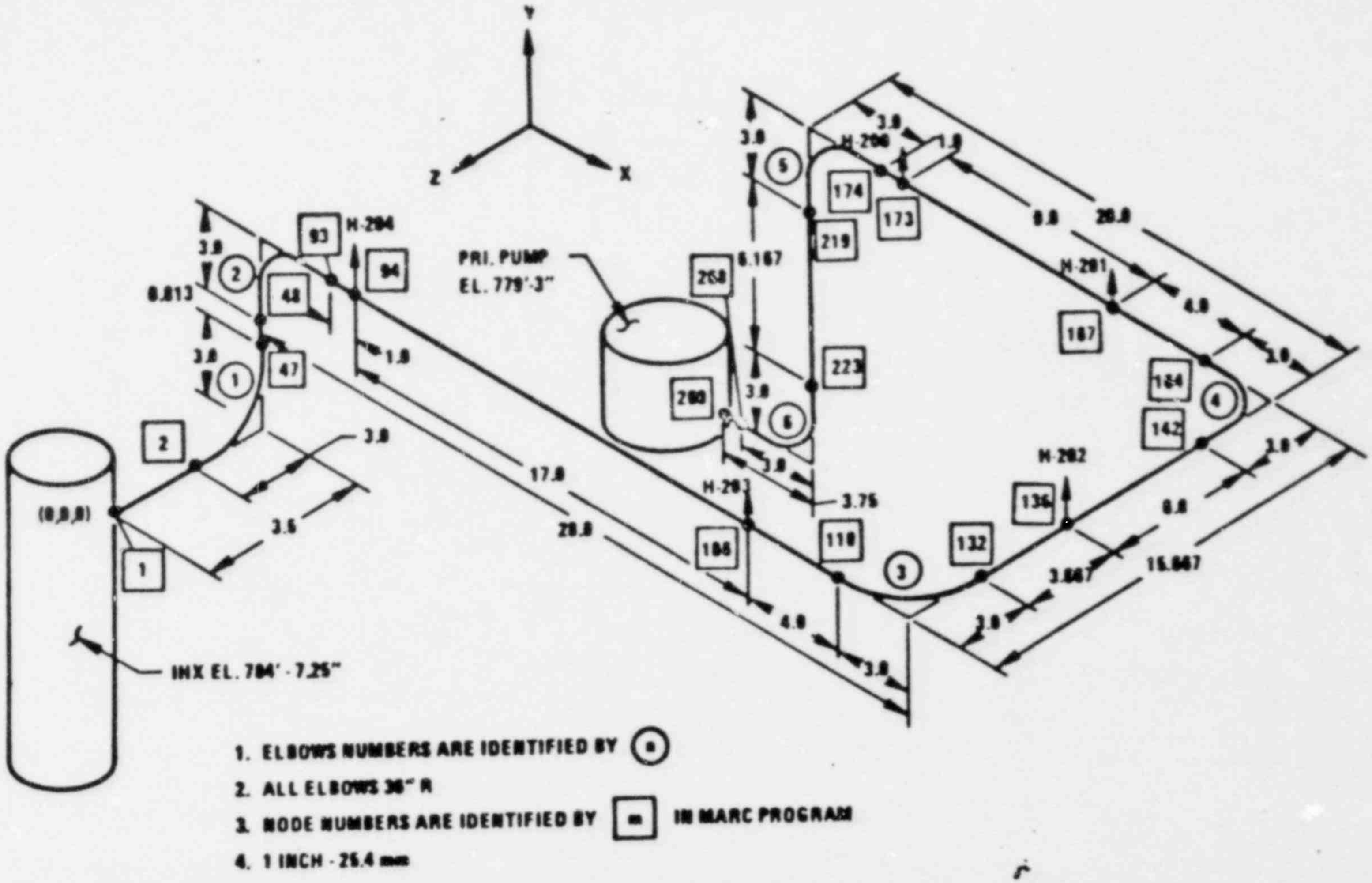


FIGURE 3.0-7 **Elastic Follow-Up Evaluation of CRBR PHTS 24-Inch Piping System Subjected to Thermal Loading**

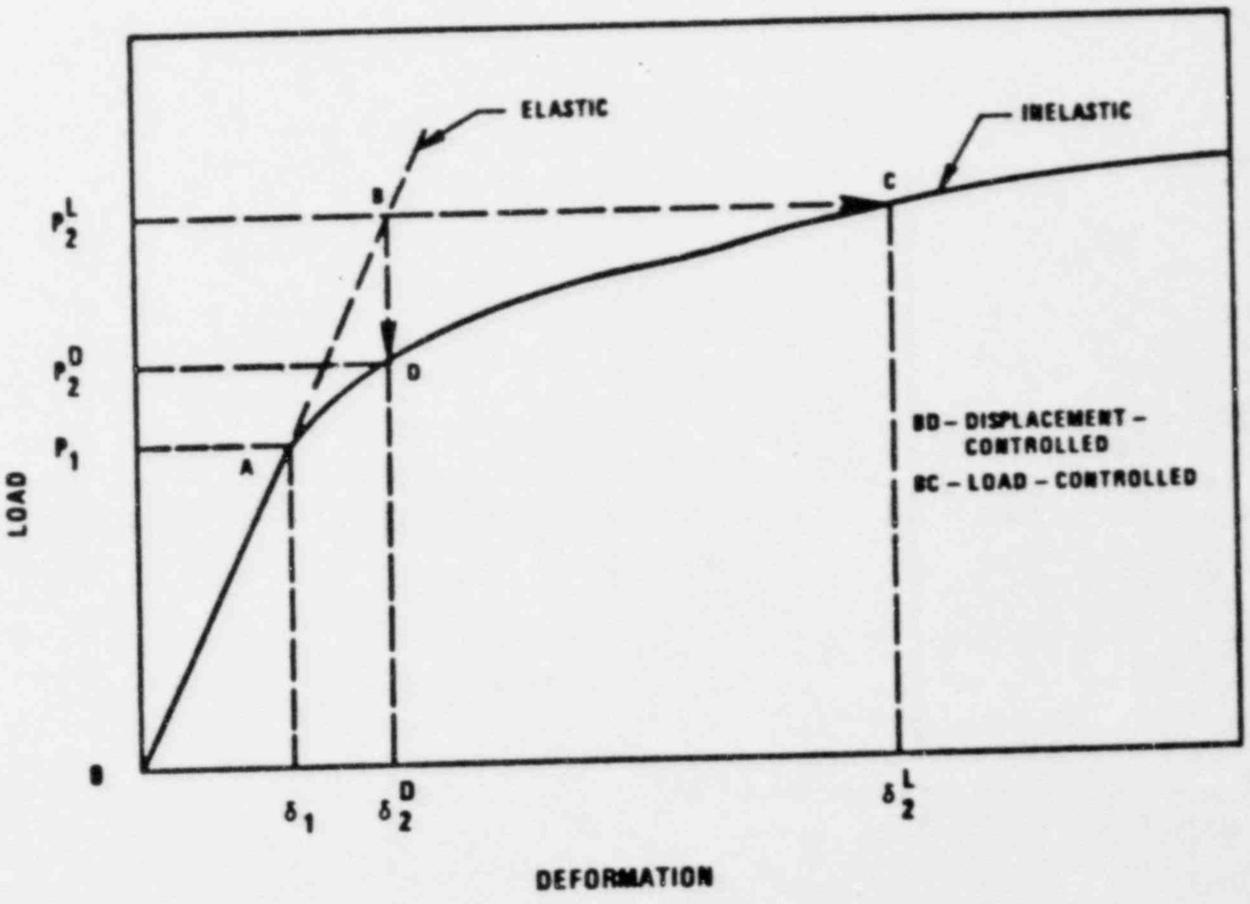
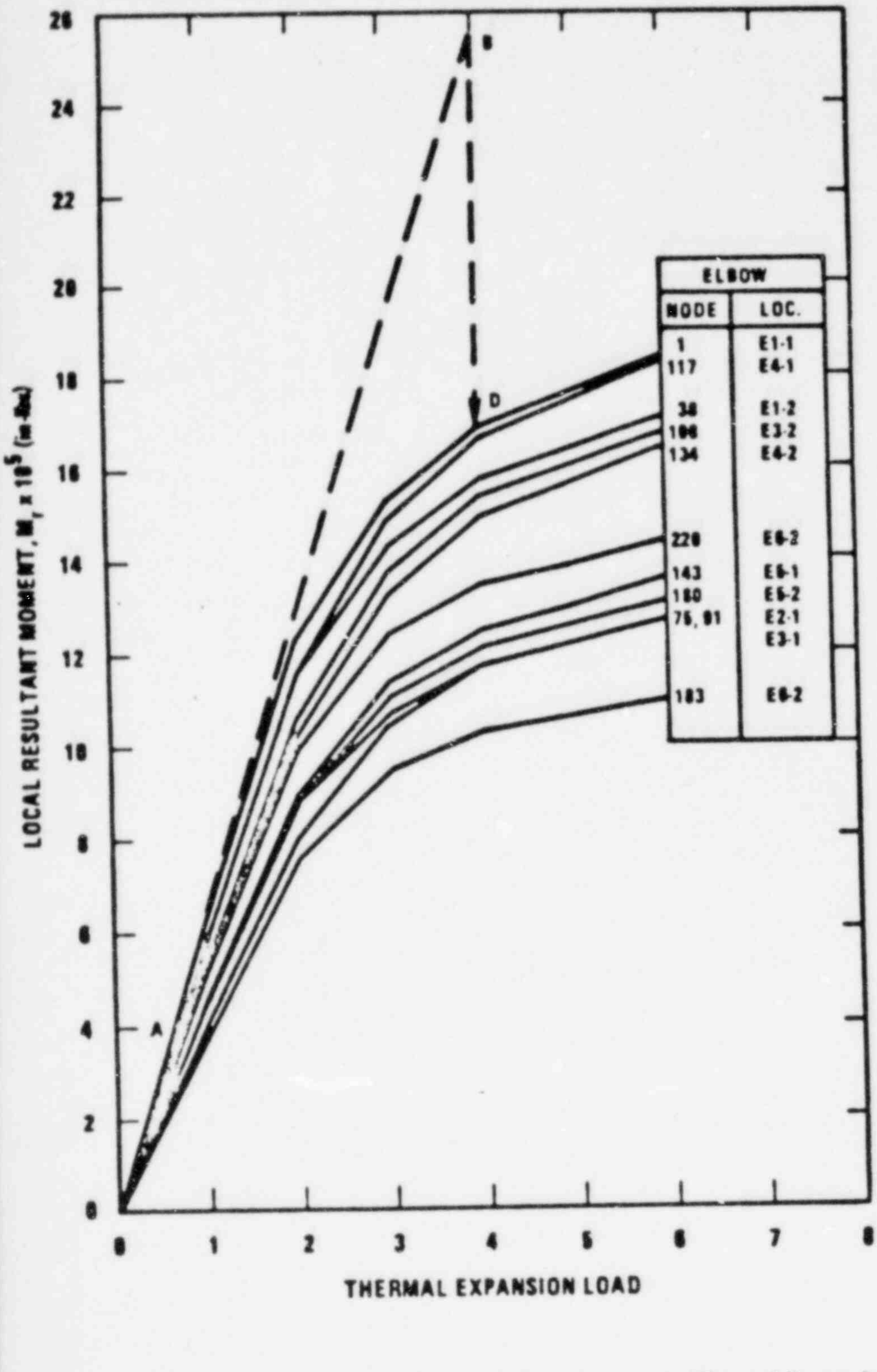


FIGURE 3.0-8 **Schematic Representation of Load - Controlled and Displacement - Controlled Conditions**



9. Rate of Increase in Local Moment Decreases With Increase in Thermal Expansion Load (Analysis I)

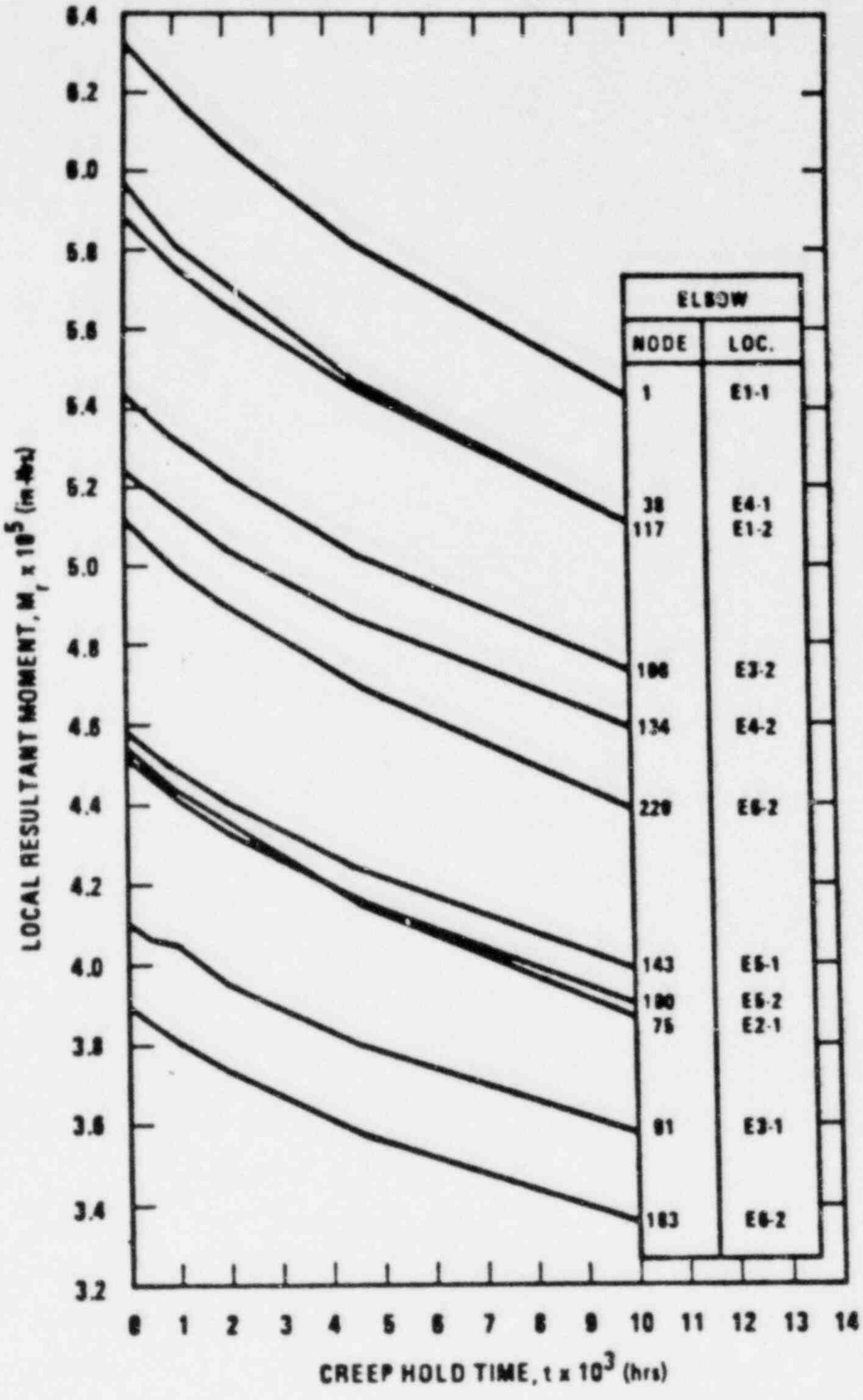


FIGURE 3.0-10. Local Moment Relaxes With Creep Hold Time (Analysis - IA, TE Load = 1.0)

5480-4

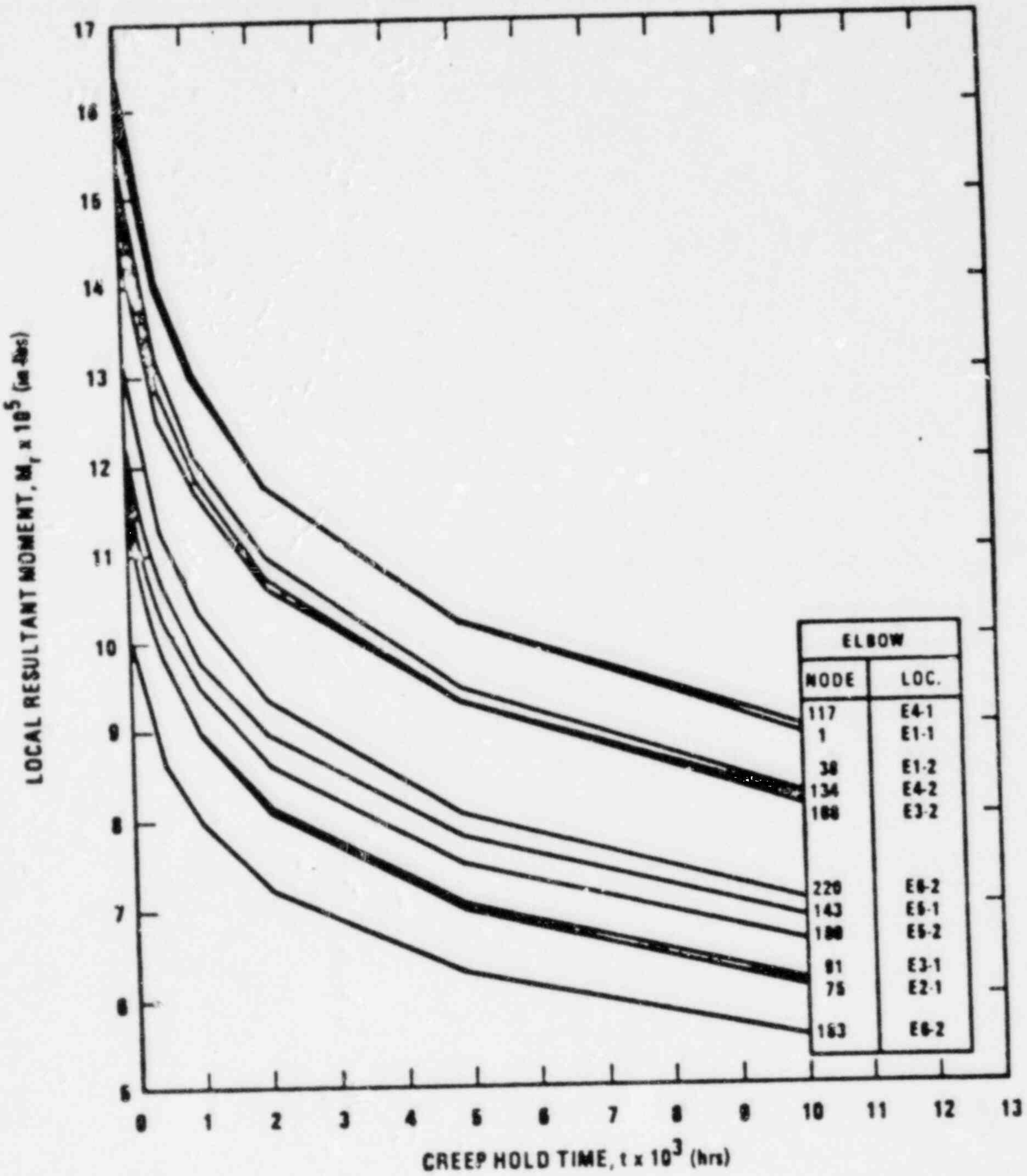


FIGURE 3.0-11. Local Moment Relaxes With Creep Hold Time (Analysis IB, TE Load = 4.0)

5480-5

5480-11

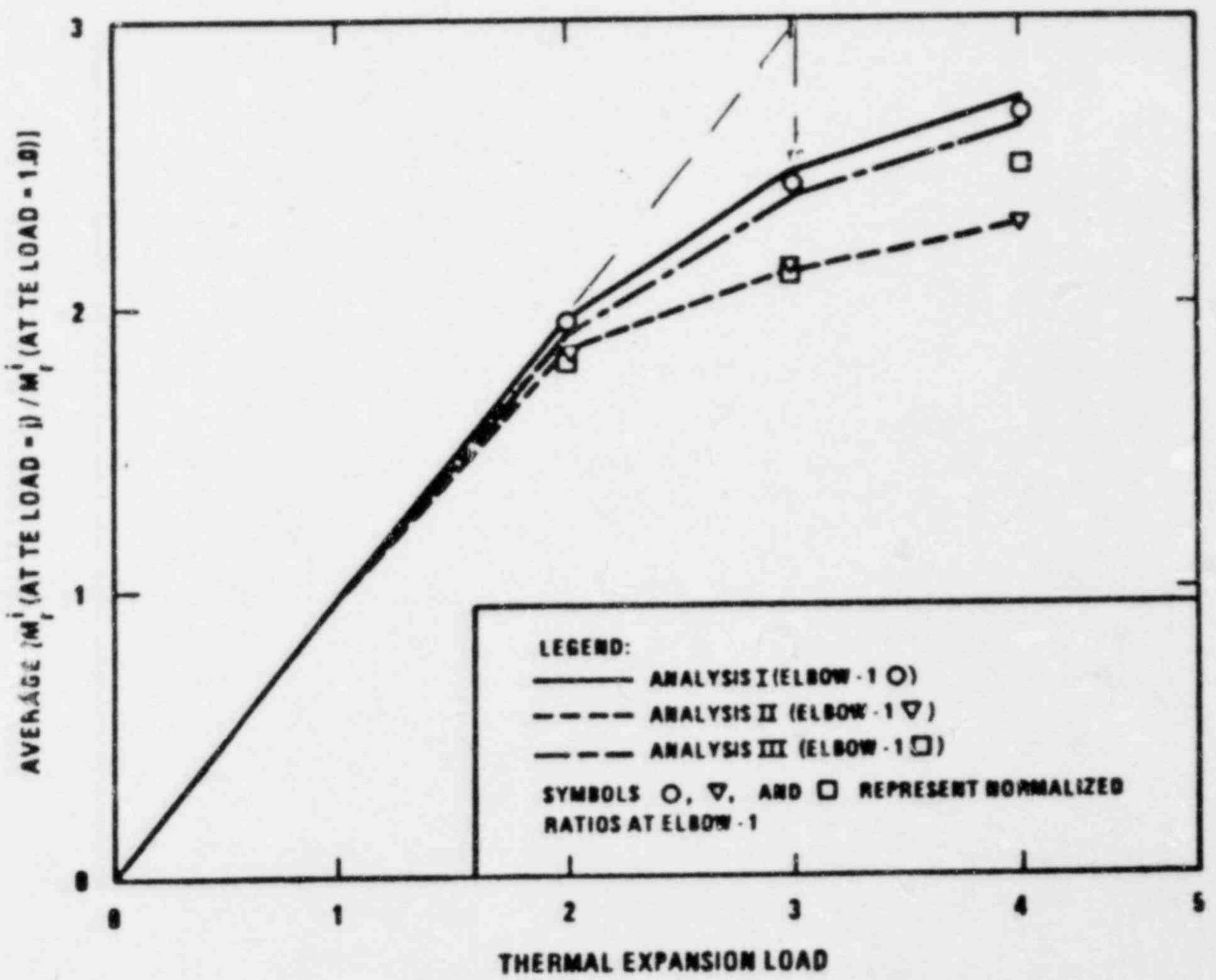
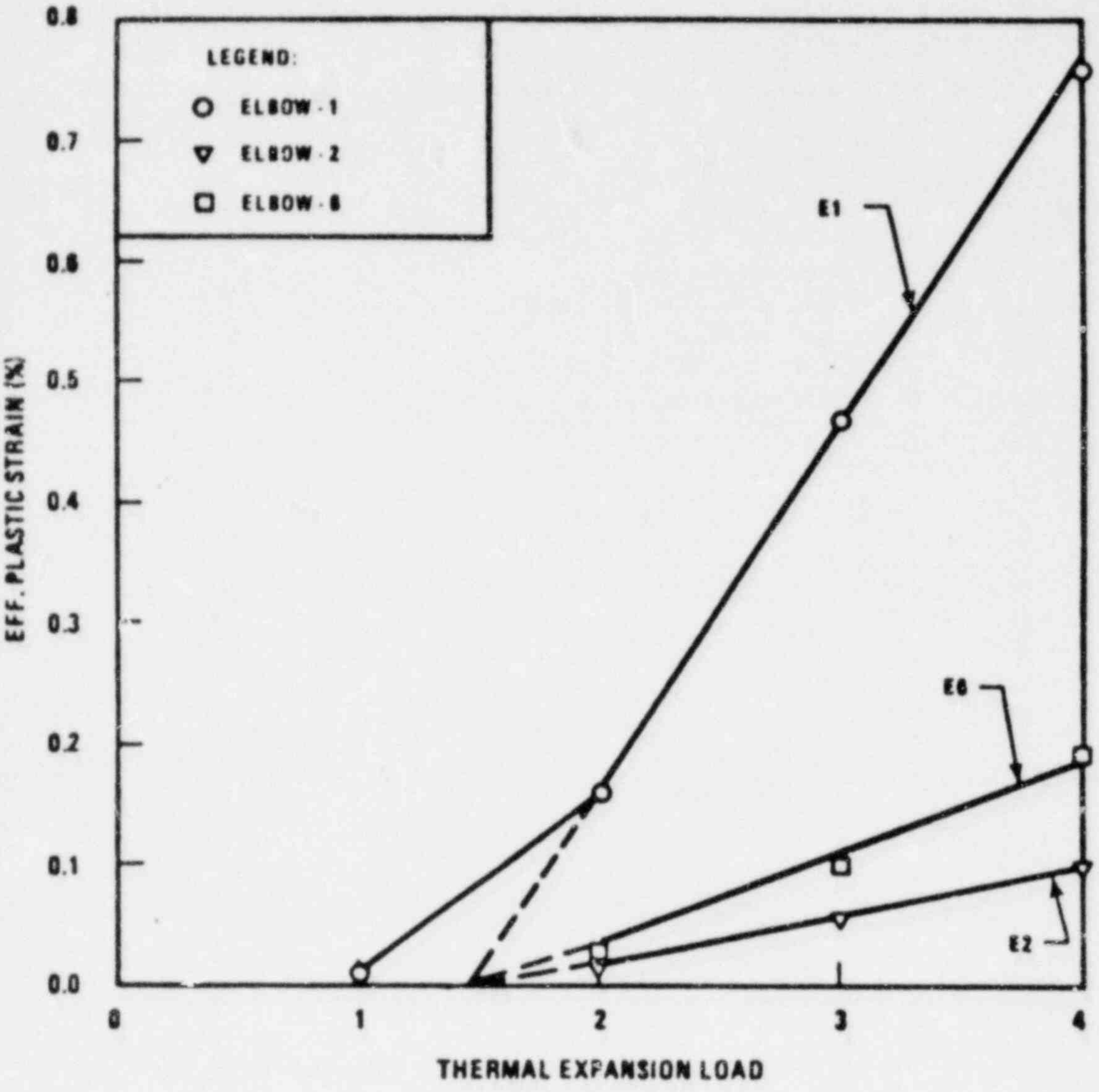


FIGURE 3.0-12. **Average Normalized Resultant Moment Decreases With Increased Flexibility in One or More Elbows in Piping System**



URE 3.0-13. lastic Strain Increases Linearly With Increase in TE Load Beyond 1.5 (Analysis II)

5480-23

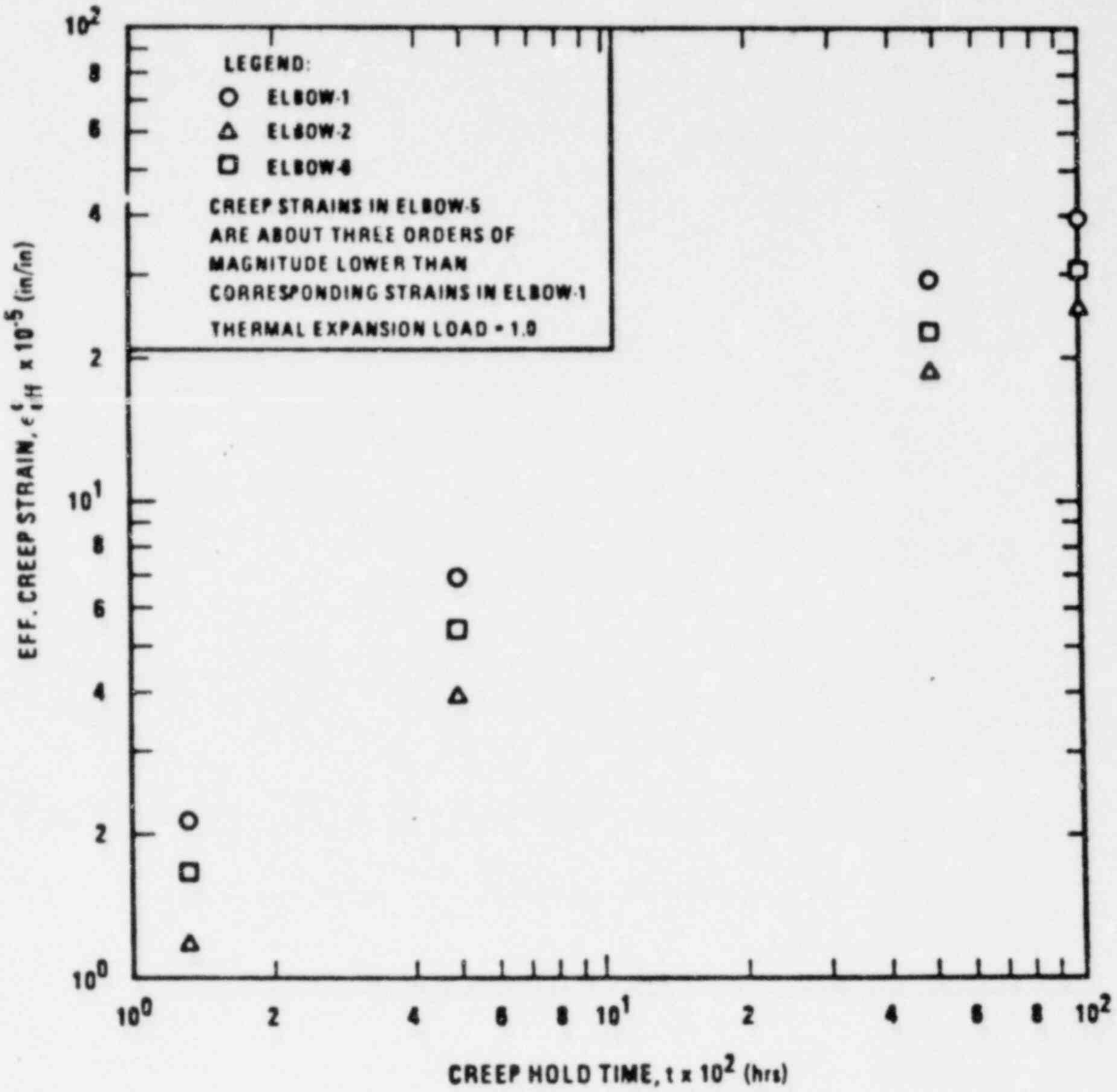


FIGURE 3.0-14. Creep Strains Increase Proportionately in Elbows (Analysis III)

5480-24

FIGURE 3.0-15

CONCLUSION

ELASTIC FOLLOW-UP EFFECTS ARE NEGLIGIBLE IN MAIN SODIUM PIPING SYSTEMS.

FIGURE 3.0-16

CREEP RATCHETTING

QUESTION: CS250.6 - PROVIDE JUSTIFICATION . . .

FIGURE 3.0-17

- T-1324 (TEST 3) IS NOT GENERICALLY APPLICABLE AT STRUCTURAL DISCONTINUITIES.

- USE BY ANALYSTS ON A CASE-BY-CASE BASIS WITH JUSTIFICATION IS NOT PRECLUDED

SPECIAL CRITERIA CONSIDERATIONS

By

A. Snow (W-ARD)

SPECIAL CRITERIA CONSIDERATIONS

his presentation centers around a series of questions that were raised in the ebruary 9-10, 1982 meeting with the NRC on structural design. One of the uestions was what are the implications of recent changes to the Code rules. e will discuss those implications, and specifically, the conclusion which we ill present is that those Code changes that have occurred since the ublication of the bases we used in the design of our equipment, have no ignificant implications regarding the safety of our equipment for elevated emperature service.

he second specific question with regard to criteria that was raised in the eeting was perhaps a somewhat simpler question, specifically, what are the riteria used for the design of our core support structure. The review of hose criteria will show that the criteria we used are, in fact, more tringent than those in the ASME Code today.

et us first look at the Clinch River core support structure design criteria, nd secondly, consider the implications of Appendix T changes (Figure 1 and a).

he question that was asked (CS250.8) was: "Provide the design criteria for he elevated temperature core support structure, including the welds in the orging and the reactor vessel".

he direct response to that question is Code Case 1592-7 in the ASME Boiler ode, as supplemented by NE (RDT) Standards F9-4T, F9-5T, and E15-2NB-T Figure 2). E15-2NB-T is the NE (RDT) Standard supplement for Subsection NB, ust as F9-4 is a supplement for the High Temperature Code Case. This is the upplement for the Low Temperature Class 1, RDT Standard.

here are two exceptions which are noted and will be explained. This is the ode Case for Class 1 components, elevated temperature components, not Class S components. And, in general, this is slightly more restrictive than Class S components. So, what was chosen was the highest quality class that was vailable. Secondly, at the time the core support structure design was initiated, there were no elevated temperature core support structure criteria within the Code. So, we used the only, as well as the best, criteria.

The Clinch River core support structure is comprised of a stainless steel barrel, the top of which operates in the creep domain. The bottom of the barrel is connected to a large ring forging on the inside of which (connected by a weld) is a perforated plate. On the outside of the ring forging there is a cone that goes upward to the reactor vessel wall and supports the core support structure (Figure 3 and Figure 4).

In Code Case 1592, in some cases, one can drop back to using the low temperature analysis rules for low temperature portions of the core support structure. In that case, they would drop back to Subsection NB rules and, hence, supplement with the appropriate RDT standard, which, in this case, is NE (RDT) Standard E15-2NB-T.

There are two exceptions to Code Case 1592-7 rules that have been utilized for the core support structure (Figure 5). One, a reduced creep damage rule for compressive hold periods, and the weld factor modification.

For the creep fatigue damage summation, Code Case 1592-7 asks that you sum the fatigue damage and the stress rupture damage. Here, we separate the stress rupture damage under tensile conditions from that under compressive conditions, and it requires that that sum be less than quantity "D".

Using the Materials Data Base information provided by Dr. Brinkman for compressive stress hold periods, the deleterious effect of the hold period on the fatigue life is much reduced compared to tensile hold periods. This one fit lower bounds (or conservatively bounds) the data for compressive holds.

In this case with the core support structure, we are dealing with a non-pressure boundary component. You are dealing with a component which, at the start of construcion, did not happen to be covered by the Code. This factor reflects all of the data that we have seen, and we are applying it only to stainless steel, only to cases where all of the principal stresses are nonpositive, only when the temperature is less than 1200 F, and only when some rm of inelastic analysis is performed, so you have some confidence in the gn of the stresses. We limit the use of the reduced damage rule to the main where the data supports its use. Thus we feel that this approach is ceptable.

e other element where we took an exception to Code Case 1592-7 was in the ld from the core support structure forging to the core support plate, a very ick weld (Figure 4). It was about a 20-inch depth weld between the plate d the ring forging. In that particular case, radiographic inspection, which uld be in accordance with the rules of Class 1 components, was not deemed asible, nor was it deemed to give us a reasonable evaluation of the adequacy the weld.

felt that the sensitivity would not be very good. In this particular case remember this is at the bottom of the core support structure where it is sentially a low-temperature component -- there are only a few short periods time during which this temperature goes above 800°F. For this case we have opped back to use progressive penetrant inspection, and we have gone to ble NG-3352-1, Subsection NG, where they give you weld joint efficiency ctors based on the level of inspection. This is a full penetration weld, d we did progressive PT. The weld joint efficiency numbers from this table re then used in our assessment of the static strength and the fatigue rength. So the joint is rated per that table, and the whole evaluation is sically a low-temperature procedure.

nsidering the fluences in this area, Mr. Falk showed that the bottom of the wer inlet modules are at about 2 or 3 x 10^{19} at the very center. By the me you get out to where this weld is, it may be even less.

in this case, we used the best available design/construction criteria, de Case 1592 and Subsection NB. Supplemental criteria were invoked and RDT ndards. Thus, two exceptions are taken which have been noted and justified gure 6). Our conclusion is that the core support structure is structurally equate for service.

The next item is the implications of the changes in Appendix T of the High-Temperature Code Case as posed in Question CS210.7 (refer to page 2). The design of the CRBRP core support structure was identified to be of particular concern in this regard.

The only reasons to consider the bottom of the core support structure to be an elevated temperature component is because, under hypothesized accident conditions, the temperature can, for a relatively short period of time, rise into the high temperature regime. Its normal operation is at a low temperature.

The design temperature for the reactor vessel inlet is 775 F. During all of the specified Normal, Upset, and Emergency Operating Conditions only two types of events result in the bottom of the core support cone exceeding 800 F:

EVENT	T_{MAX}°F	t_{MAX}
RV-3E(B)	825	300 sec x 6 = 1800 seconds
RV-7U(B)	840	500 sec x 1500 seconds
Maximums	840	1 Hour

Clearly this temperature/time combination (304SS) does not require explicit creep considerations.

We will answer a paraphased question on the implications of Appendix T changes (Figure 7). That question is: Is the level of assured structural integrity of Clinch River items the same as that provided by today's Appendix T?

The answer is yes, with one qualification that we will go into. We consider that the integrity is actually a little bit higher than that provided by N-47-20, simply because we have chosen to use NE (RDT) Standards, as well as the ASME Code. This conclusion can be arrived at by going through the changes, subparagraph by subparagraph, that have occurred between 1592-4 and today's Code Case N-47-20, recognizing two things. One is that there are a variety of different code cases that have been utilized for different omponents. The Code Case for the piping may not be the same as the reactor essel, and it may not be the same as for the valves. But this covers almost very one of the high temperature components.

e will go through Appendix T by subparagraph, noting the kinds of changes hat have occurred, and giving an assessment of the significance to structural ntegrity of the changes noted (Figure 8). For example, going down through igure 8, we find the first changes in 1122, a wording change. This change ccurred when what had been called Normal, Upset, Emergency, and Faulted vents were replaced by A, B, C, and D. There is no structural significance o this change.

imilarly, with a change from calling someone a Manufacturer, now they are alling him an N Certificate Holder. Not a significant change (Figure 9). In Figures 9 and 10, "LR" means slightly less restrictive.)

oing down to General Requirements, there is now a reference to T-1325. That s also insignificant.

he former phrase, Operating Conditions, has been changed to Service onditions. This, too, is not a significant change again. On T-1322, there s no change.

T-1324, Test No. 3, we come to our first potentially significant change. hat used to say to sum the total strains using procedures in T-1324, and keep hem less than your strain limits. The words have now been changed to read, lculate the "creep" strains and keep those less than the strain limits. So, this case, we now have a slightly less restrictive wording in N-47-20 than had in 1592-4. In my view, there is no structural significance to the hange, but it has become slightly less restrictive.

Test No. 4, there have been some minor word changes, which have no gnificant effect. There are some wording changes, definitions, arifications, and an added note, but nothing of great significance.

In Table T-1420-1A is the design fatigue curve for 304 stainless steel for continuous cycling applications. Here, two changes have occurred. First, the data base for 304 stainless steel was reviewed since 1592-4, and it was found that 304 behaved a little bit differently than for the data base for 316. So, a new design fatigue curve for 304 stainless steel was devised. It was slightly above the previous combined curve. At the same time, a Poisson ratio correction was made which has its greatest significance, which is nil, at the high cycle end. Thus, the high cycle end was lowered, but the entire curve was raised. Numerically, there would be small changes in calculated fatigue damage. They could be either a little above or a little below those which would have been calculated with 1592-4, but they simply are not significant in regard to the integrity of the component.

In the case of the continuous cycling design fatigue curve for 316 stainless steel, the same curve is used as in 1592-4 except that the values are modified to account for a Poisson ratio effect. That very slightly lowered the values. You can see the changes in the high-cycle end but there is no effect in the low-cycle end. Again, this was a minor correction, and has no significant effect on the structural integrity of the resulting product.

The ASME Boiler Code is in the process of revising and extending to high cycles the low temperature design fatigue curve for austenitic stainless and high nickel alloys. This Code change has not, to my knowledge, been approved by Council and is not now in effect. It is entirely possible that it may be substantially changed before it is approved. Thus this response has been limited to comparisons of 1592-4 vs. N-47-20.

There are some other changes that occurred in T-1400 (Figure 10). There is a little change of no significance in T-1431 and in T-1432, which is the fatigue damage evaluation based on the elastically calculated stresses. In T-1433, there have been both significant wording changes and equation changes but in general, these changes, in my opinion, either result in no change, or they result in a more accurate, but less conservative, calculation. So, while these changes might well result in lower calculated damages if we were using N-47-20 as compared to 1592-4, it doesn't mean that the -4 values were wrong.

just means that they were not as accurate, and they were judged to be too servative. Thus the Code sharpened up the way in which they calculated the ages.

come down to buckling (Figure 10). There were a few minor word changes. word "catastrophic" was pulled out, and "Operating Condition' became rvice Condition." There was no effect on the integrity of the component.

ally, when we get to the special limits, there are no changes except for 711, and that has no significance at all (Figure 11).

far, the comparison I have given you is 1592-4 versus N-47-20. The reactor sel, however, did use 1592-2. Based on what we saw previously, there n't any significance in changes under 1592-4. But in 1592-2, there is ething that was significantly different than in 1592-4 (Figure 12): the kling design factors for the time independent buckling. When we are king about elastic-plastic buckling, 1592-2 said that the actual buckling should be at least 2 1/2 times the largest load seen in service; 1592-4 it should be 3 times, and this factor of 3 is consistent with what is now the N-47-20.

there was a change from 1592-2 to 1592-4. It is conceivable that a ponent could have been built with no excess design margin against e-independent buckling and, hence, the 3.0 load factor could not be met. s thus conceivable for the 1592-2 to 1592-4 change to be significant.

he case of the Clinch River reactor vessel, the 2 1/2 factor was used in time-independent evaluation of the vessel under OBE seismic loadings since that case, we were dealing with a long cylinder in bending. We were erned about maximum axial stress (average through the thickness) on the of the cylinder that was in compression. The buckling would be dominated lasticity in that case, and as a result, the buckling load would be nsitive to imperfections. We are extremely comfortable with this 2 1/2 or and we feel that the actual safety margin inherent in the 2 1/2 factor ertainly as great as you will have in some other code structures; for ple, the externally pressurized thin sphere buckling in the elastic domain.

The actual safety factor provided by the ASME code rules for the externally pressurized thin sphere we think is probably lower than the actual safety factor that we have here. So, this is one place where the design load factor here is a little less than we currently have in the code. We feel that the component has entirely adequate margins and we have no qualms about it at all.

The loads in this case are generated by the seismic (excitation) which causes lateral motion, and the vessel is subjected to net overturning bending. We look at the maximum (axial) compressive stress averaged through the wall, at the worst point around the circumference. That is the calculation that we did and we met the 1592-2 value. We probably don't meet the N-47-17 value, but we are quite close to it. For loads other than seismic, the reactor vessel wall (which is 2-3/8 inches thick and 240 inches in diameter) won't be in net compression. This is a time independent calculation, by the way.

The reactor vessel was treated as if it were in uniform compression. In fact, that is not the case as a result of experiment. The experiment shows that the critical stress has to be somewhat higher in the bending case to get buckling.

We have some results for bending and cylinders and buckling for checking R/T. We get a 1.2 value and there is some enhancement. While 1.2 x 2.5 = 3.0, I am not sure whether we can show a load factor of 3.0. The results on cylinders with R/T less than 4.0 support the 1.2 value. The CRBRP vessel R/T is between 40 and 50. We are about to run some matched cylinder tests in that range to see if we get a 1.2 factor. The Japanese, by the way, are using a factor of 1.3. Our buckling load estimate came from large displacement elastic and plastic analyses of an axially loaded cylinder. So we are very confident that we have a real load factor above 2.5. We have all looked at the application and we have no concern about it at all. We believe that the structure is entirely adequate and that it has safety margins consistent with other buckling limits that have long been used by the Code. The 2.5 factor applies to the OBE (limit Level A and B) seismic load and was calculated using an elastic-plastic `arge deformation analysis.

in summary, (Figure 13) there have been some minor changes between 1592-4 N-47-20. There were some changes that were less restrictive in this area, some changes here that were perhaps more restrictive. None of them, in opinion, are significant at all to the integrity of the component. There a potentially significant difference in the time-independent stic-plastic load factor by buckling, 2 1/2 to 3.

conclusions are that the changes that have occurred do not significantly er the level of assured structural integrity; that in the case of the nch River reactor vessel, where we had this potential difference, while could alter the level of assured integrity, we believe that the luation we have is convincing. We believe that the component has ample gin of safety, and results in a high level of assured structural integrity.

the question, "Are there new criteria that are not met by the existing gn?," the answer is straightforward.

he first place, the design met 1592, which is a high quality standard. ndly, based on what we saw in the second presentation, 1592 gives ntially the same level of assured structural integrity as N-47-20. So, conclusion is that the Clinch River core support structure has essentially same level of assured structural integrity as today's criteria, which s me feel very comfortable.

e are one or two highlights I can show you on the differences between s 1 rules and Core Support Structure rules. This is kind of a status rt, but the point is that it gives you an idea of what the interesting ents are in the core support structure cases (Figure 14). Of course, at temperatures, Subsection NG is available, and the threshold between ection NG and high temperature is 800°F for stainless steel; 700°F for itics.

rmediate temperature core support Code Case N-201-0 was approved by cil in 1980, and is in effect. It extends NG design procedures to ated temperatures for limited time durations. What it basically does is with these limited time durations, you can just go back and use low erature design procedures and the stress limits that are supplied.

In addition this Code Case adds delta ferrite limits, uses the hold-time effect reduced fatigue curves and gives buckling limits and intent, which is the same as the Class 1. It flags the area reinforcement, which is only for pressure loadings. That is already in place for Class 1.

It warns about re-solution annealing; that is, you lose some of your yield strength if you re-solution anneal the whole component if it is stainless steel. So, we have added the warning there.

Further it warns about the use of stress ratio analysis. These things are picked up in NE (RDT) Standard F 9-4, by the way. It requires a minimum carbon content for stainless steel and a quench, which is all in N-47. It also applies a creep correction factor to simplified elastic and plastic analysis. That is handled a little bit differently and conservatively in N-47. Finally this case applies to limited materials just as N-47 does.

There is an elevated temperature case, which is part way through the Code, and these are its elements, as it currently stands. It's being reviewed by a Subcommittee on Design. It maintains those rules for this limited time-temperature domain, and it suggests Class 1 elevated temperature rules for true elevated temperature service. So, here we are coming right back to the 1592 (N-47) rules.

It provides elevated temperature bolting limits that reflect core support structure philosophy, which is less restrictive in Class 1; but there are not any bolts in Clinch River core support structure, so that is of no concern here. It allows only N-47 materials for true elevated temperature service.

Here are some philosophical comparisons that may be useful in your consideration between Class 1 and Class CS (Figures 15 and 16). Class 1 is primary pressure boundary. Class CS is merely core support. It has to do that job without any question, but in the case of a leak, Class 1 results in a radioactive release. In the case of Class CS, it does not result in a radioactive release. It's just the flow of coolant from one portion of the reactor vessel to another.

The object of the bolting rules, in Class 1, is both structural and unctional. They want the joints to not break. They want the joints to not eak. In the case of Class CS, they are merely concerned with the ot-breaking aspect. We are not concerned with the leak for the CRBR core upport application.

ressure loads are always significant for Class 1. In Class CS, in the ntroduction, it says pressure loads are not always significant. They are not lways a more significant load. So, in a couple of places, pressure loads are e-emphasized a little bit. For example, regarding mandatory pressure tests, lass 1 requires them, Class CS does not. In the case of the Clinch River eactor core support structure, we imposed a pressure test on that component fter it was installed on the reactor vessel and it passed. So, we used the ressure tests even though it was a core support structure.

o, we again went beyond the philosophy of the core support structure criteria nd we required it.

inally, considering the weld joint efficiency, Class 1 says you always must T and can use a value of 1. Class CS says you may use a variable factor epending upon your level of inspection, and we, in that one instance, did use different inspection method; but we did it because we felt that RT would not ive us good inspection. We used what we felt was the very best inspection echnique for that particular joint.

his has been sort of a comparison of the philosophical approach. That is why e believe that the use of Class 1 rules for core support structure gives us a igh-quality product.

FIGURE 4.0-1

SPECIAL CRITERIA CONSIDERATIONS

April 6-7, 1982

Presented by:
Alfred Snow
Westinghouse Electric Corporation
Advanced Reactors Division

APPLIED TECHNOLOGY

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FIGURE 4.0-1a

SPECIAL CRITERIA CONSIDERATIONS

- CRBR CORE SUPPORT STRUCTURE DESIGN CRITERIA
  (CS 250.8)

- CRBR IMPLICATIONS OF APPENDIX T CHANGES
  (CS 210.7)

- CRBR CORE SUPPORT STRUCTURE DESIGN CRITERIA

CS 250.8

PROVIDE THE DESIGN CRITERIA FOR THE ELEVATED TEMPERATURE CORE SUPPORT STRUCTURE, INCLUDING THE WELDS IN THE FORGING AND THE REACTOR VESSEL.

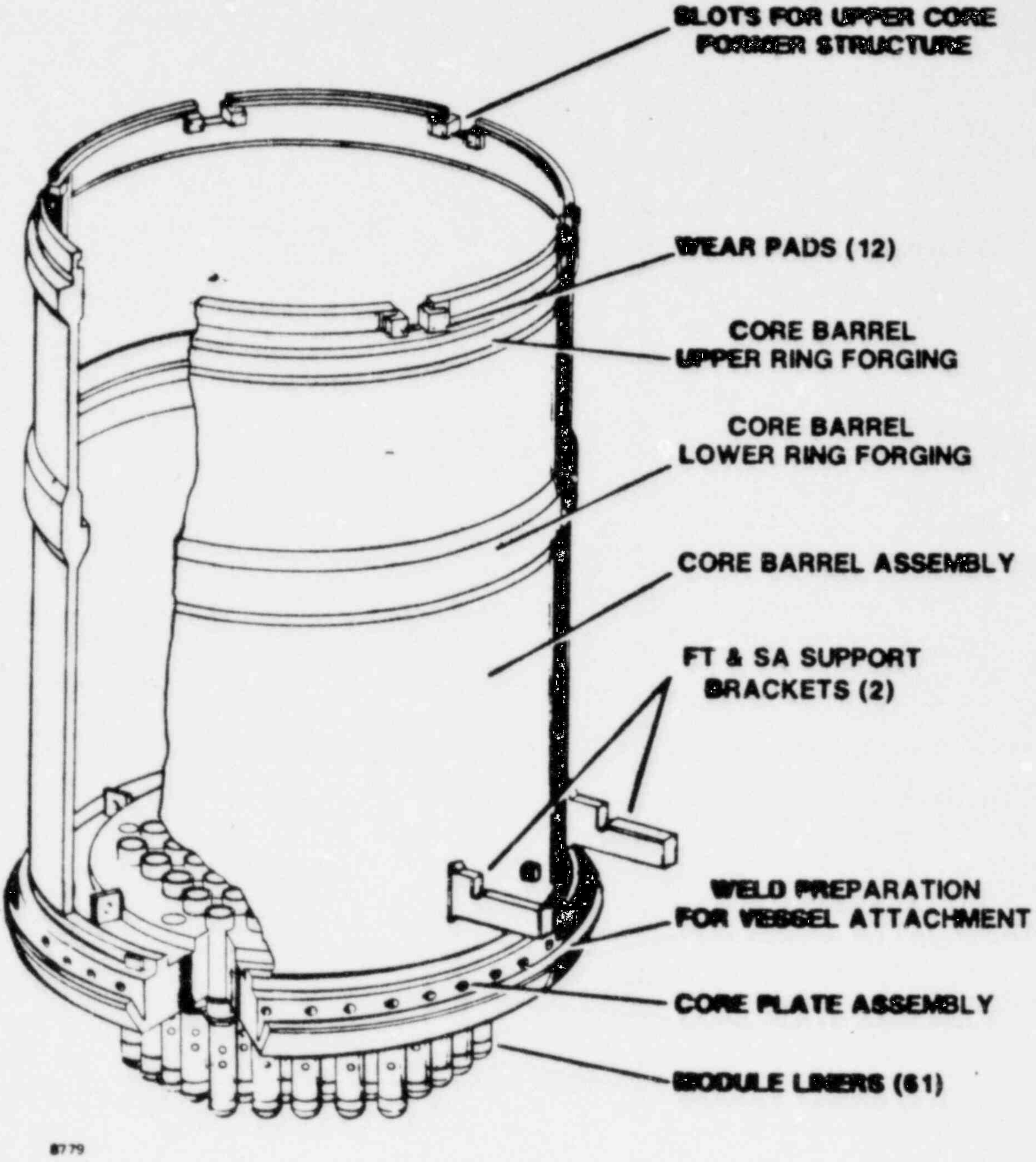
RESPONSE

CODE CASE 1592-7 OF THE ASME BOILER CODE AS SUPPLEMENTED BY RDT STANDARDS F9-4T, F9-5T, AND E 15-2NB-T. TWO EXCEPTIONS ARE NOTED AND WILL BE EXPLAINED.

FIGURE 4.0-2

FIGURE 4.0-3

CORE SUPPORT STRUCTURE



CORE SUPPORT STRUCTURE DIFFERENTIAL PRESSURE MODEL

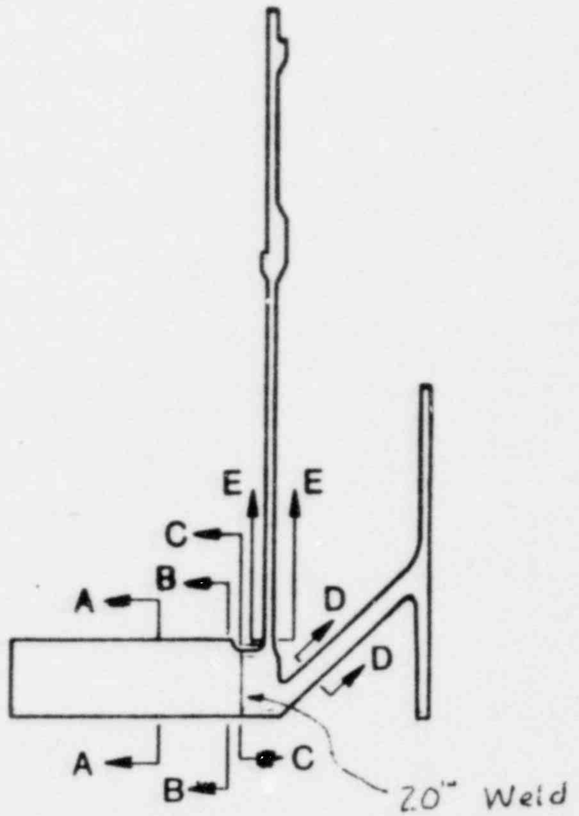


FIGURE 4.0-4

6802-2

FIGURE 4.0-5

TWO EXCEPTIONS TO CC 1592-7 RULES

- REDUCED CREEP DAMAGE RULE FOR COMPRESSIVE HOLD PERIODS

$$\Sigma\left(\frac{n}{N}\right) + \Sigma\left(\frac{t}{T_d}\right)_{\text{tensile}} + \left(\frac{1}{5}\right)\Sigma\left(\frac{t}{T_d}\right)_{\text{comp.}} \leq D$$

COMPRESSIVE: $\sigma_1 \leq 0$
304/316 SS
$T \leq 1200$°F
INELASTIC ANALYSIS

REF: TID-26135 (FIG. 3.42)
NASA-TN-D-60[illegible]

- USES NG WELD FACTORS FOR PLATE/RING WELD

JOINT 20^{IN} THICK
RT (PER CLASS 1) NOT FEASIBLE
USED PROGRESSIVE PT (PER NG)
DERATED JOINT STRENGTH PER NG
LOW TEMPERATURE

REF: TABLE NG-3352-1

FIGURE 4.0-6

CRBR CORE SUPPORT STRUCTURE

SUMMARY

- THE BEST AVAILABLE DESIGN/CONSTRUCTION CRITERIA WERE USED (NB + CC 1592)
- SUPPLEMENTAL CRITERIA WERE INVOKED
  RDT STANDARDS
- THE TWO EXCEPTIONS ARE STRONGLY JUSTIFIED

CONCLUSION

- THE CRBR CORE SUPPORT STRUCTURE IS STRUCTURALLY ADEQUATE FOR SERVICE

FIGURE 4.0-7

CRBR IMPLICATIONS OF APPENDIX T CHANGES

QUESTION CS 210.7 (PARAPHRASED)

IS THE LEVEL OF ASSURED STRUCTURAL INTEGRITY OF THE CRBRP THE SAME AS IS PROVIDED BY TODAY'S APPENDIX T (N-47-20)?

ANSWER

YES (WITH ONE QUALIFICATION).

IT IS A BIT HIGHER BECAUSE THE CRBRP IS CONSTRUCTED TO RDT STANDARDS AS WELL AS THE ASME CODE.

FIGURE 4.0-8

APPENDIX T COMPARISON: 1592-4* vs N-47-20

ITEM		CHANGE	INTEGRITY SIGNIFICANCE
1100	INTRODUCTION	NONE	-
1110	OBJECTIVE	NONE	-
1121	TYPE OF ANALYSIS	NONE	-
1122	ANALYSIS REQUIRED	NUEF→ABCD	NONE
1200	DEFORMATION LIMITS FOR FUNCTIONAL REQTS.	NONE	-
1210	STATEMENT IN DESIGN SPECIFICATION	MFG.→N. CERT. HOLDER	NONE
1220	ELASTIC ANALYSIS METHOD	NONE	-
1230	USE OF INELASTIC ANALYSIS	NONE	-
1300	DEFORMATION LIMITS FOR STRUCTURAL INTEGRITY	NONE	-
310	STRAIN LIMITS FOR INELASTIC ANALYSIS	NONE	-
320	SATISFACTION OF STRAIN LIMITS USING ELASTIC ANALYSIS	NONE	-
321	GENERAL REQUIREMENTS	REF. TO T-1325 NUEF→ABCD OP. COND.→SERVICE COND.	NONE
322	TEST NO. 1	NONE	-

CLUDING ERRATA.

FIGURE 4.0-9

APPENDIX T COMPARISON: 1592-4 vs N-47-20 (CONTINUED)

ITEM	CHANGE	INTEGRITY SIGNIFICANCE
T-1323 TEST NO. 2	NONE	-
T-1324 TEST NO. 3	STRAIN→CREEP STRAIN OP. COND.→SERVICE COND.	NONE (LR)
T-1325 TEST NO. 4	MINOR WORD CHANGES	NONE
T-1400 CREEP-FATIGUE EVALUATION	NONE	
T-1410 GENERAL RULES	NONE	
T-1411 DAMAGE EQUATION	NUEF→ABCD	NONE
	"t" → "Δt"	NONE
	DEFINED q, σ_{eff}	NONE
	CLARIFIED T_d	NONE
	ADDED NOTE	NONE
T-1412 EXEMPTION FROM FATIGUE ANALYSIS	NONE	
T-1413 EQUIVALENT STRAIN RANGE	"STRAIN"→"STRESS"	NONE
T-1414 ALTERNATIVE CALCULATION METHOD - EQUIVALENT STRAIN RANGE	NONE	
T-1420 LIMITS USING INELASTIC ANALYSIS	NONE	
TABLE T-1420-1A 304 SS FATIGUE	RAISED ALL, LOWERED HIGH CYCLE	NONE (MR)
TABLE T-1420-1B 316 SS FATIGUE	LOWERED VALUES BY FACTOR TIMES $\Delta\epsilon_t$@ 10^6	NONE (MR)
T-1430 LIMITS USING ELASTIC ANALYSIS		

FIGURE 4.0-10

APPENDIX T COMPARISON: 1592-4 vs N-47-20 (CONTINUED)

ITEM	CHANGE	INTEGRITY SIGNIFICANCE
1 GENERAL REQUIREMENTS	DELETED "THRU-WALL GRADIENT" AND ADDED ν EQUATION	NONE (LR)
2 FATIGUE DAMAGE EVALUATION	EQN. (7) CHANGED OTHER ALTERNATIVES	NONE (LR)
3 CREEP DAMAGE EVALUATION	NUEF→ABCD CLARIFY S_K CLASSIFICATION	NONE
T-1430-1A, 1B	VERY SMALL DECREASES	NONE
4 CALCULATION OF STRAIN RANGE FOR PIPING	NONE	NO
0 BUCKLING AND INSTABILITY		
0 GENERAL REQUIREMENTS	ADD NG-3133 WARNING DELETES "CATASTROPHIC" OP. COND.→SERVICE LOAD SLIGHT WORD CHANGES	NO NO NO NO
0 BUCKLING LIMITS	OP. COND.→SERVICE LOAD	NO
1 TIME-INDEPENDENT BUCKLING		
2 TIME-DEPENDENT BUCKLNG		
0 SPECIAL REQUIREMENTS		
0 SPECIAL STRAIN REQUIRMENTS AT WELDS		

FIGURE 4.0-11

APPENDIX T COMPARISON: 1592-4 BS N-47-20 (CONTINUED)

ITEM		CHANGE	INTEGRITY SIGNIFICANCE
T-1711	SCOPE	NORMAL→A	NO
T-1712	MATERIAL PROPERTIES	NONE	
T-1720	STRAIN REQUIREMENTS FOR BOLTING		
T-1721	STRAIN LIMITS	NONE	
T-1722	CREEP-FATIGUE DAMAGE ACCUMULATION	NONE	

FIGURE 4.0-12

QUALIFICATION

- CC-1592-4 (OR LATER) USED ON CRBR COMPONENTS
- REACTOR VESSEL USES CC 1592-2
- BUCKLING DESIGN FACTORS WERE LESS RESTRICTIVE IN 1592-2 THAN 1592-4.

ITEM	DESIGN LOAD FACTORS (TIME INDEPENDENT) 1592-2	1592-4
ELASTIC	3.	3.0
ELASTIC+PLASTIC	2.5	3.0

- THE FACTOR WAS INCREASED FOR CONSISTENCY
- THE 2.5 FACTOR WAS USED IN RV/SEISMIC
- STRONGLY FEEL THAT 2.5 FACTOR FOR TIME-INDEPENDENT ELASTIC-PLASTIC BUCKLING OF CYLINDERS IN BENDING IS SUFFICIENT

FIGURE 4.0-13

APPENDIX T COMPARSION: 1592-7 vs N-47-20

SUMMARY

MINOR CHANGES

LESS RESTRICTIVE	TABLE T-1420-1A TABLE T-1420-1B EQN. 7 (T-1432) T-1431 ADDED Y EQUATION T-1325
MORE RESTRICTIVE	TABLE T-1430-1A, 1B TABLE T-1420-1A

POTENTIALLY SIGNIFICANT DIFFERENCE

TIME-INDEP. ELASTIC/PLASTIC LOAD FACTOR

1592-2: 2.5

N-47-20: 3.0

CONCLUSIONS

- 1592-4 TO N-47-20 CHANGES DO NOT SIGNIFICANTLY ALTER THE LEVEL OF ASSURED STRUCTURAL INTEGRITY
- 1592-2 TO N-47-20 BUCKLING LOAD FACTOR CHANGE COULD ALTER THE LEVEL OF ASSURED STRUCTURAL INTEGRITY
- 1592-2 BUCKLING LOAD FACTOR RESULTS IN A HIGH LEVEL OF ASSURED STRUCTURAL INTEGRITY AS APPLIED TO CRBR R.V.

FIGURE 4.0-14

CURRENT STATUS
CORE SUPPORT STRUCTURE RULES

- LOW TEMPERATURE - SUBSECTION NG IS AVAILABLE
  - T ≤ 800°F FOR SS
  - T ≤ 700°F FOR FERRITICS

- INTERMEDIATE TEMPERATURE - CODE CASE N-201-0
  - APPROVED COUNCIL - 1980
  - EXTENDS NG DESIGN PROCEDURES TO E.T. FOR LIMITED TIME DURATION
  - ADDS DELTA FERRITE LIMITS
  - USES HOLD-TIME EFFECT REDUCED FATIGUE LIMITS
  - GIVES BUCKLING LIMITS AND INTENT
  - FLAGS AREA REINFORCEMENT FOR PRESSURE
  - WARNS ABOUT RESOLUTION ANNEALING
  - WARNS ABOUT USE OF STRESS RATIO ANALYSIS
  - REQUIRED 0.04% C MIN. FOR 3XX SS
  - REQUIRES 1900°F QUENCH FOR USE ABOVE 1000°F
  - APPLIES CREEP CORRECTION TO SIMPLIFIED ELASTIC & PLASTIC ANALYSIS
  - LIMITED MATERIALS

- ELEVATED TEMPERATURE - CODE CASE N-201-X
  - BEING REVIEWED BY SC/DESIGN
  - MAINTAINS N-201-0 RULES FOR INTERMEDIATE TEMPERATURE
  - SUGGESTS CLASS 1 ET RULES FOR TRUE ET SERVICE
  - PROVIDES ET BOLTING LIMITS THAT REFLECT CSS PHILOSOPHY
  - ALLOWS ONLY CC-N-47 MATERIALS FOR ET SERVICE

FIGURE 4.0-15

PHILOSOPHICAL COMPARISON

ITEM	CLASS 1	CLASS CS
LEAK RESULT	RADIOACTIVE RELEASE	NOTHING
OBJECT BOLT RULES	STRUCTURAL & FUNCTIONAL	STRUCTURAL
PRESSURE LOADS SIGNIFICANT	ALWAYS	NOT ALWAYS
PRESSURE TEST MANDATORY	YES	NO
WELD JOINT EFFY	1.0/MUST RT	VARIABLE DEP. ON INSP.

FIGURE 4.0-16

MPARISON OF CLASS 1, CLASS CS, AND CRBRP CORE SUPPORT STRUCTURE RULES

ELEMENT	CURRENT CLASS 1		CURRENT CLASS NG		CRBR	
	LT	ET	LT	IT	IT	ET
BA	✓	✓	✓	✓	✓	✓
PPER TEMP.	800	1500	800	1020	1020	1500
L/DC	✓	NO	NO	NO	✓	NO
$_{m}/_{A,B}$	NO	✓	✓	✓	✓	✓
$_{m} + P_{b/A,B}$	NO	✓	✓	✓	✓	✓
P IN FATIGUE EXEMPTION	✓	NA	NO	NO	✓	NA
EVEL C LIMIT A						
EVEL C PLASTIC A						
EVEL C STRESS R. A.						
EVEL C P_m	$\left\{\begin{matrix}1.25S_m\\1.0\,S_y\end{matrix}\right\}_H$	$1.2S_m$	$1.5S_m$	$1.5S_m$	$1.2S_m$	$1.2S_m$
LD JOINT Q & E FACTORS	NO	NO	✓	✓	NO	NO
					(EXCEPT FOR ONE WELD)	
GHER BOLT LIMITS	NO	NO	✓	✓	NA	NA
SOLUTION ANN. WARNING	NO	NO	NO	✓	✓	✓
EA REPLACEMENT WARNING	✓	NA	NO	✓	✓	✓
NERAL BUCKLING GUIDANCE	NO	✓	NO	✓	✓	✓
RESS RATIO WARNING	NO	NO	NO	✓	✓	✓
ESSURE TEST	✓	✓	NO	NO	✓	✓
SIDE SURFACE ALIGNMENT	✓	✓	NO	✓	✓	✓