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NUCLEAR REGULATORY COMMISSION**

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In the Matter of:

STRUCTURAL ENGINEERING

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1 PUBLIC NOTICE BY THE  
2 UNITED STATES NUCLEAR REGULATORY COMMISSION'S  
3 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS  
4

5 WEDNESDAY, MARCH 30, 1988  
6

7 The contents of this stenographic transcript  
8 of the proceedings of the United States Nuclear Regulatory  
9 Commission's Advisory Committee on Reactor Safeguards  
10 (ACRS), as reported herein, is an uncorrected record of  
11 the discussions reported at the meeting held on the above  
12 date.

13 No member of the ACRS Staff and no participant  
14 at this meeting accepts any responsibility for errors  
15 or inaccuracies of statement or data contained in this  
16 transcript.  
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1 UNITED STATES NUCLEAR REGULATORY COMMISSION  
2 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS  
3

4 In the Matter: )  
5 )  
6 STRUCTURAL ENGINEERING )  
7 )  
8 )

Wednesday  
March 30, 1988

9 Malibu Room  
10 Pacifica Hotel  
11 6161 Centinela Blvd.  
Culver City, California

12 The above-entitled matter came on for hearing,  
13 pursuant to notice, at 8:30 a.m.

14 BLFORE: DR. CHESTER P. SIESS, CHAIRMAN  
15 Professor Emeritus, Civil Engineering  
16 University of Illinois  
Urbana, Illinois

17 ACRS MEMBERS PRESENT:

18 DR. PAUL G. SHEWMON  
19 Professor, Metallurgical Engineering Department  
Ohio State University  
Columbus, Ohio

20 DR. DAVID A. WARD  
21 Research Manager on Special Assignment  
22 E.I. du Pont de Nemours & Company  
Savannah River Laboratory  
Aiken, South Carolina

23  
24  
25

1	<u>ACRS COGNIZANT STAFF MEMBER:</u>	
2	Elpidio Egne	
3	<u>NRC STAFF PRESENTERS:</u>	<u>Page No.</u>
4	Dan Guzy, NRC Research	3
5		
6	<u>PRESENTATIONS BY:</u>	
7	Sam W. Tagart Jr., P.E.	27
8	Technical Specialist	
9	Nuclear Systems and Materials Department	
10	Electric Power Research Institute	
11	3412 Hillview Avenue	
12	Palo Alto, California	
13	William English	62
14	General Electric Company	
15	Nuclear Energy Business Operations	
16	Structural Analysis Services	
17	175 Curtner Avenue	
18	San Jose, California	
19	Sampath Ranganath, Ph.D.	111
20	General Electric Company	
21	Nuclear Energy Business Operations	
22	Manager, Structural Analysis Services	
23	175 Curtner Avenue	
24	San Jose, California	
25		
	<u>NRC CONSULTANTS:</u>	
	Spencer Bush	
	Everett Rodabaugh	

1 March 30, 1988

2 8:30 a.m.

3

4 - - P R O C E E D I N G S - -

5

6 CHAIRMAN SIESS: Good morning. The meeting  
7 will come to order.

8 This is a meeting of the ACRS Subcommittee on  
9 Structural Engineering, and present today, starting on  
10 my right is Paul Shewmon, Dave Ward, and we have two consultants:  
11 Mr. Rodabaugh and Mr. Bush.

12 Today we will review and discuss the EPRI NSRC  
13 Piping and Fitting Dynamic Reliability Program PFDRP--  
14 unpronounceable.

15 The cognizant ACRS staff member for the meeting  
16 is Elpidio Egne, who is seated on my left.

17 The rules for participation by the public at  
18 today's meeting was announced as part of the notice published  
19 in the Federal Registry on March 14. It says here that  
20 the meeting is being conducted in accordance with provisions  
21 of the Federal Advisory Committee Act for the government,  
22 and the Sunshine Act, and we've received no written statements  
23 from members of the public nor any request to make oral  
24 statements.

25 These microphones are not working. He said

1 he might be able to get them fixed during the break. We  
2 are a small enough group that I think the--if the people  
3 sitting out here want to move up a little bit they can,  
4 but let's just try to speak loudly enough to be heard.  
5 I'm a little hard of hearing, so I may be the test for  
6 the volume level, and please give your name the first  
7 time that you speak so that the recorder can get it.

8 Any of the Subcommittee members or the consultants  
9 have any opening remarks that they would like to make  
10 at this stage?

11 [No response.]

12 Just for the record, I would like to point out  
13 that we had the opportunity yesterday to visit the two  
14 sites at which tests are being made at Blue Tech on the  
15 system's test, and at Anco on the component tests, and  
16 there will be essentially no repeat of what we learned  
17 at those visits. We will concentrate today on a brief  
18 review, I think, of the program, but then we will concentrate  
19 on the test results and the analyses and something on  
20 what is being considered for changes in the ASME Code  
21 on the piping.

22 We will start off with Dan Guzy from NRC Research.  
23 We have both NRC and EPRI represented and Mr. Guzy and  
24 Mr. Tagart will lead off this morning.

25 Dan.

1           MR. GUZY:   Let me just emphasize some of the  
2 things that Professor Chet said about the presentation.  
3 We will be covering the summaries of the tests that we  
4 saw yesterday of the systems and the component tests,  
5 plus a little more on the specimen tests that were discussed  
6 briefly yesterday, and Bill English of General Electric  
7 will handle that.

8           Sam Ranganath of General Electric will talk  
9 about our concepts now for changes to the ASME Code, but  
10 the point is I will begin off with a brief talk of the structure  
11 of the program, status, a little about what I consider  
12 the highlights of what has happened from the programmatic  
13 point of view.

14          Sam Tagart will talk a little more about the  
15 technical overview and perhaps give a little more of an  
16 industry perspective on why they are doing this program.

17          Before I begin, I would like to point out that  
18 this program is called the EPRI/NRC Piping and Fitting  
19 Dynamic Reliability Program. The reason that EPRI has  
20 the top billing is--well, actually two reasons: one is  
21 they are contributing more money to this; but more importantly  
22 they have the lead in the planning of the program.

23          The NRC has been involved in this program from  
24 the beginning--from the beginning of the testing and the  
25 analysis, but the lead, in terms of structuring this program,

1 the credit goes to EPRI. The NRC recognizes this is a  
2 good thing to be involved with, and we got involved after  
3 it had been pretty much planned out.

4 As far as the program, I would like to start  
5 off by talking about what the emphasis of this program  
6 is, so there is no uncertainty with what we are trying  
7 to do here. The emphasis of the program is the design  
8 of piping components for dynamic inertia loads. The key  
9 words are design--we are talking about design rules, not  
10 so much inspection rules. Piping components, we are looking  
11 at the stress rules, or the rules for designing elbows  
12 and tees of the piping system, not so much supports and  
13 say nozzles, but that would be considered in our design  
14 roles.

15 Also inertia loads: one of the chief objectives  
16 was to provide a more rational set of rules for dynamic  
17 inertia loads because that seemed to be an area of concern.  
18 We will address other types of loads though, too, such  
19 as anchor motion loads.

20 The objectives of the program have been from  
21 the beginning to identify clearly what the dynamic failure  
22 mechanisms and failure levels are for piping systems under  
23 dynamic loads. It is important to know what the level  
24 is for the large cycle failure and how do they fail so  
25 that we can develop more rational rules for preventing

1 the failure.

2 Also, we are interested in gathering high level  
3 response information so we can know more about what happens  
4 in the area regime of a failure, in terms of parameters  
5 such as damping, ductility, deamplification, we are lacking  
6 information in this area, and this program is providing  
7 some valuable information for things not only in this  
8 program, but for future programs, as far as bench marks  
9 and data that we can use later on.

10 And, the key, final product of this program  
11 will be a recommendation for changes to the ASME Code.  
12 We are talking about changes to the design rules themselves,  
13 as given in subsections MB, MC, and D, stress allowables  
14 for Class 1, 2, and 3 piping.

15 CHAIRMAN SIESS: Dan, you use the term non-  
16 linear response in there. This may be partly semantics,  
17 but it is the way that I think about it.

18 When I look at this, I am really looking at  
19 the inelastic response. Now, I admit that inelastic is  
20 non-linear but nonlinear is not necessarily inelastic.

21 MR. GUZY: Right.

22 CHAIRMAN SIESS: And, I think the inelastics,  
23 that's where your large damping comes from, not from a  
24 nonlinear.

25 MR. GUZY: Okay.

1 CHAIRMAN SIESS: But, that is your thrust. It  
2 is the inelastic.

3 MR. GUZY: Yes.

4 We lack information in the very high levels.  
5 Maybe the emphasis should be on high levels rather than  
6 nonlinear, but that is where we didn't have much information.

7 I have got a list of the cast of characters,  
8 or some of the cast of characters that are involved in  
9 this program, and many you met yesterday. I would like  
10 to highlight the people that you didn't meet yesterday.  
11 Y.K. Tank is also from EPRI. He is program manager for  
12 the tests, for the Anco and the systems test for the EPRI,  
13 and of course Sam Tagart is overall program manager for  
14 the EPRI program. A lot of credit for the development  
15 of the program comes from--the credit should be given  
16 to Sam.

17 I am the NRC person, Dan Guzy, and responsible  
18 for the program in terms of what research programmatic  
19 responsibilities are.

20 From General Electric, I have listed some of  
21 the people--not all of the people, but the main program  
22 manager is Bill English, who you will hear from later.  
23 A person who is not here today, but has been heavily involved  
24 in the analysis is Henry Hwang. Sam Ranganath, who you  
25 will hear from later on, is involved in developing the



1 Code rule changes, and Ed Swain is another General Electric  
2 person who has been heavily involved in these Code changes  
3 also. There are other people from GE that I have not  
4 listed.

5 From Anco Engineers you have met Kelly Merz,  
6 who is here today; also Paul Ibanez you haven't met, at  
7 least at these meetings, and is involved in the program.

8 ETEC, you met Mr. Devita yesterday, Ron Johnson  
9 and a cast of thousands, I guess, at ETEC yesterday.

10 A key part of the program, but not represented  
11 by an individual today is the specimen tests. The main  
12 person for that has been Roy Williams, formally of General  
13 Electric of Schenectady. Now he has his own company called  
14 Material Characterizations Lab, and he is the  
15 one responsible for the specimen tests, and Bill English  
16 will talk about those tests some today.

17 There also have been several consultants involved  
18 with the program who have reviewed it and have given a  
19 few suggestions for changes in the program, and these  
20 included Everett Rodabaugh, who is here today; Bob Kennedy;  
21 Don Landers; Bob Cloud; Doug Munson; Stan Moore from Oakridge;  
22 Bob Bosnak has also served, he is from NRC and has served  
23 as a consultant; and Verne Severud.

24 [Slide]

25 Okay, the program is structured into eight tasks,

1 and I will just briefly go through what they are. We  
2 had a Task 1--and who is involved in it--Task 1 is the  
3 program plan development. This has been the primary responsibility  
4 of General Electric in San Jose.

5 The pipe component test, which you saw yesterday,  
6 is at Anco, and they are responsible for all of the 41  
7 tests that they have run.

8 The pipe system testing has been split into a  
9 number of organizations. The main seismic and hydrodynamic tests  
10 have been conducted at ETEC. You saw the results of these  
11 yesterday. The point I would like to make is the system  
12 1 and the system 2 tests, the red and green tests that  
13 you saw yesterday, have been in integral part of this  
14 program; however, some of the earlier tests, the demonstration  
15 tests, have been part of the NRC's contribution to this  
16 program, although it is not formally a part of the program.  
17 There is a distinction between the tests--maybe it is  
18 just a paper distinction.

19 The water hammer test that you saw yesterday,  
20 of course, was being conducted at ANCO, so that all of  
21 these together consist--comprise of Task 3.

22 The other tasks--okay, the specimen tests at  
23 Schenectady are a separate set of tasks which we will  
24 hear about today.

25 The remaining part of under GE's responsibility.

1 They have done the analysis of the tests. They have taken  
2 the data and ETEC and ANCO and MCL have supplied them  
3 and looked at this data and summarized it, and you will  
4 hear more about that today. They have also been charged  
5 with developing--to identify and justify new design rule  
6 changes based on these test results.

7 And, the final reports are General Electric's  
8 responsibility, although I think ANCO and ETEC have reports--  
9 okay, so that GE is in charge of the final reports and  
10 they will be draft reports that will be supplied by GE  
11 to EPRI. The final reports will be EPRI reports not General  
12 Electric, however the NRC has information, all of the  
13 data, and we just--the burden of publication is not on  
14 us for this one.

15 [Slide]

16 Okay, as far as the status and schedule, the  
17 program itself, in terms of doing anything other than  
18 program planning began in the spring of 1985, three years  
19 ago. All the testing now has been completed except for  
20 the retest of System 1 which you saw ready to go at ETEC  
21 yesterday, so all of the component tests have been completed,  
22 the water hammer test, and the specimen test, so having  
23 been completed--some of these very recently have been  
24 completed, but they are all finished now.

25 The process of evaluating this data and developing

1 Code rules ongoing you will hear about where we are today,  
2 but it has not been finalized yet, so we are still working  
3 with the data and drawing conclusions to make recommendations.

4 The program itself will formally end in June  
5 of this year. General Electric being the main contractor,  
6 that is when their role is over. Other than writing reports,  
7 most of the other subcontractors are completed.

8 Okay, then when the final recommendations are  
9 made to the program, of course they will be reviewed by  
10 EPRI and NRC--at least in NRC Research, and then will  
11 begin the Code revision process through the various organizations  
12 that will be involved in the Code changes.

13 And finally, as I mentioned, the reports will  
14 be published probably sometime this year, I imagine. That  
15 is the EPRI reports.

16 [Slide]

17 Some of the key points that I would like to  
18 make from perhaps more of a programmatic point of view.  
19 This is a formal EPRI/NRC research program. We have a  
20 formal agreement on it. There have been five review meetings  
21 that have been held with the program managers and consultants.  
22 The most recent one was less than a month ago. This is  
23 our way of getting input, by getting everybody together,  
24 getting input on direction and what the results mean,  
25 and it has had an impact on--particularly in the component

1 tests with--there have been some changes made, suggestions  
2 as we reacted to data as it has been coming in.

3 All along there has been interactions with the  
4 ASME and the PVRC standards groups, in a number of ways.  
5 First of all, we have been giving presentations to everybody  
6 at the meetings, and also a number of the members, the  
7 people who have been involved with this program directly,  
8 are also in this core group, so there is direct involvement  
9 by many of the members.

10 CHAIRMAN SIESS: Excuse me, Dan.

11 Does PVRC write standards?

12 MR. GUZY: Well, they--what do they do? Write  
13 recommendations?

14 MR. BUSH: They write recommendations basically.

15 CHAIRMAN SIESS: And, where are they implemented?  
16 In ASME?

17 MR. BUSH: Yes.

18 What we do, for example, is I would write a  
19 letter and transmit it to say Roger Reedy, the chairman  
20 of section 3, suggesting an implementation of a given  
21 action. That is the mechanism. We are not a formal standards  
22 writing body as such. PVRC is the reason they do it...[voice  
23 fades out of hearing range]...certainly do it, but it  
24 ends up going directly into the code.

25 MR. GUZY: There has been some activities that

1 have had an impact on the Code, the Code cases. As a--  
2 using the data from the tests we have to date, a Code  
3 case--a Class 1 Code case effecting BBOB allowables  
4 has been approved through the Code system, essentially  
5 this gives relaxation for inertial load requirements  
6 on OB and overloads at B level--

7 CHAIRMAN SIESS: What does it do to the change?  
8 What dominates the design? OBE versus--

9 MR. GUZY: --this would--if implemented, this  
10 would make the SSE dominant, essentially of less importance  
11 than OB.

12 There is a similar Code case--class--that should  
13 be Code case, not class--for Code case, not class, for  
14 class 2 and 3 piping that is up to the main committee  
15 now in the ASME codes. I believe that section 3 has one  
16 more committee, or two more committees.

17 CHAIRMAN SIESS: Help me a little again.

18 I don't think class 1, 2, 3. The only thing  
19 I think, from what I deal with, is seismic category 1  
20 or not seismic category 1.

21 Does 2 or 3 make any sense in that classification?  
22 Or, is it something else?

23 MR. GUZY: They are both subsets of that classification.  
24 They are all seismic category 1. Class 1 frankly requires  
25 a more rigorous fatigue analysis--

1 CHAIRMAN SIESS: Okay, but--

2 MR. GUZY: --so you don't have that in the--

3 CHAIRMAN SIESS: --2 and 3, in this sense, is  
4 category 1 piping?

5 MR. GUZY: Yes.

6 CHAIRMAN SIESS: It is just a different type  
7 of analysis?

8 MR. GUZY: Right.

9 CHAIRMAN SIESS: Okay.

10 MR. GUZY: And, there are different rules that  
11 have to be changed. The class 2 and 3 rules are pretty  
12 much identical, as far as the design part. Class 1--

13 CHAIRMAN SIESS: In terms of the plant, how  
14 do you decide whether something is class 1, 2 or 3?

15 MR. GUZY: Class 1 has to do with the pressure  
16 boundary--primary system pressure boundary--

17 CHAIRMAN SIESS: Primary system pressure boundary.

18 MR. GUZY: --main loops in the surge lines and  
19 the recirculation loops.

20 Class 2 and 3 are other piping than category  
21 1. The distinction between 2 and 3, I think, is more  
22 of an inspection--maybe that is sort of an arbitrary type  
23 of thing.

24 CHAIRMAN SIESS: So there is an isolation valve  
25 between class 1 and class 2 and 3?

1 MR. GUZY: Right.

2 MR. BUSH: However, for clarification, the utility  
3 has a considerable say in the pipe. There is one utility  
4 that has a system they call class 2, and it doesn't necessarily  
5 say it will be the same--[voice fades out of hearing range]

6 CHAIRMAN SIESS: Mr. Bush, we can't hear you.

7 MR. GUZY: I think the point here is that most  
8 of the piping that would be required is class 2 and 3.  
9 We pay a lot of attention to class 1 and sometimes, even  
10 in this program--

11 MR. BUSH: Don't say that, Dan. That's not  
12 true.

13 CHAIRMAN SIESS: In a PWR--

14 MR. BUSH: Most of the piping--you say safety  
15 related, because don't say "safety related" because that  
16 is not true.

17 MR. GUZY: Yes, yes, that is what I meant. I  
18 am sorry.

19 MR. BUSH: Okay.  
20 Most of the piping now is--

21 MR. GUZY: What I am trying to say is there  
22 is a lot more class 2 and 3 systems than class 1 systems.

23 CHAIRMAN SIESS: All right, but in a PWR, steam  
24 lines are what?

25 MR. GUZY: Class 2.



1 CHAIRMAN SIESS: Class 2.

2 MR. GUZY: Well, PWR is class 2.

3 CHAIRMAN SIESS: Well, PWR is steam lines, and  
4 are class 2.

5 MR. GUZY: All right.

6 CHAIRMAN SIESS: And a BWR, what is class 1N?

7 MR. GUZY: It would be the--

8 CHAIRMAN SIESS: Like a turbine stop valve?

9 No?

10 MR. GUZY: Isolation valve.

11 MR. BUSH: Inaudible.

12 COURT REPORTER: Mr. Chairman, Mr. Enge, I can't  
13 hear Mr. Bush at all. I can't even see him.

14 CHAIRMAN SIESS: That's all right. It wasn't  
15 important.

16 MR. GUZY: If there is any point to be made  
17 here, it is we are concentrating--there is a lot of emphasis  
18 on class 1 piping, and even programmatically we have GE  
19 who is our main contractor; however, we plan to address  
20 class 2 and 3 piping, and this is probably where we will  
21 get the biggest relief in snubbers and snubber reduction,  
22 et cetera.

23 Other than the Code cases there is also an activity  
24 that just started with the PVRC, and is a task frequent  
25 functionality criteria. NRC has a requirement on piping

1 functionality which we think that the results from this  
2 program can support changes to, and that will be something  
3 that PVRC will make a recommendation on, and perhaps the  
4 NRC itself will take care of the standard change on that.

5 Publications, there has been a number of papers  
6 that have been presented, and will be presented, in like  
7 the Pressure Vessel Piping Journal and SMRT. There have  
8 been four semi-annual progress reports and you all should  
9 have received the last one from this program, and that  
10 will be the last progress report. The next set of reports  
11 will be the final reports, and again will be issued by  
12 EPRI.

13 CHAIRMAN SIESS: Dan, let me ask you a slightly  
14 unrelated question, as far as this particular thing is  
15 concerned: the National Research Council Report on the  
16 NRC research program placed a considerable emphasis on  
17 peer review, and in the response to that report the NRC  
18 research seems to have said that the way to get peer review  
19 is to publish in referee journals.

20 Now, I notice here that you have got papers  
21 and journals--I assume that SMRT is more or less referring,  
22 although I question it sometimes, whether they ever threw  
23 anything out, but you have your panel of consultants.  
24 Which serves as peer review in your mind?

25 MR. GUZY: Personally, I think the consultants

1 do a better function of peer review than having it published;  
2 however, it gets to a wider audience by having it published  
3 in the journals.

4 CHAIRMAN SIESS: Do you think publishing in  
5 a journal is a peer review? It is sort of after the fact,  
6 isn't it?

7 MR. GUZY: I personally--I think it is valuable,  
8 but I think it is more valuable to have the right people  
9 review it, in a more formal setting.

10 CHAIRMAN SIESS: Well, once you have said "the  
11 right people" I won't ask you whether you think this is  
12 a peer review setting.

13 MR. GUZY: As far as consultants, I am convinced  
14 that these are the best people we could get to review  
15 the program. I mean, nobody is not on that list that  
16 should be on the list. I think it is an impressive list  
17 of people involved--

18 CHAIRMAN SIESS: Now, whose job is it to see  
19 that they are listened to? Yours and Sam's?

20 MR. GUZY: Yes, sir.

21 CHAIRMAN SIESS: Okay.

22 MR. GUZY: Let's see.

23 Maybe since we are talking about this, there  
24 is planned to be three--I think three main papers that  
25 will come in the near future that will try to summarize

1 and explain what this program has been about, and what  
2 the findings are, and that will be--and there are three  
3 important papers that are planned that will be, you know,  
4 supported by the reports but this is our way of introducing  
5 to the world what we are really doing.

6 CHAIRMAN SIESS: Very good.

7 MR. GUZY: At the end of the program, we realize  
8 that there is a lot of information here that is valuable  
9 that we don't even know about yet, and we plan to do the  
10 best we can of storing this information. It is all available  
11 to the NRC, but we would like to make it available to  
12 everybody else and not throw anything away, and so there  
13 are some plans to archive those ANCO and ETEC tests at  
14 the NE Center in Charlotte, I believe, also the information,  
15 the data, we will try to do the best we can to save all  
16 of that.

17 [Slide]

18 One more slide I would like to present on is  
19 just talking in terms of what the NRC's perspective of  
20 this program has been.

21 The main thrust of why we are in this comes  
22 from the activities of the piping review committee of  
23 many years ago. The piping review committee looked at  
24 piping design and they identified a number of concerns  
25 about overdesigning for dynamic loads, especially inertial

1 loads.

2 In their reaction to this they made a number  
3 of recommendations; however, because of the state of the  
4 knowledge or information data at the time, recommendations  
5 were mainly in the response areas, and of these the most  
6 significant, the one that has paid out perhaps the best  
7 has been the damping.

8 So, their immediate recommendations for changes  
9 were addressed more to response, because they didn't have  
10 data; however, they realized that they needed failure data  
11 and one of--the highest, the A category priority items  
12 that the piping review committee recommended for research  
13 has been to do pipe tests and this program was mentioned  
14 by name as something we should be involved with, so NRC  
15 research and NRC is involved in this program because our  
16 piping review committee recommended it to us, and I think  
17 it was a wise thing to do.

18 We've had a number of interactions with the  
19 NRC staff and we will continue to have that. There has  
20 been much information sent informally. There has been  
21 presentations and video tapes to staff, to people interested  
22 in what was going on. There has also been meetings, formal  
23 meetings, on other subjects where results from these tests  
24 have been quoted in terms of what's happening with piping?  
25 How is piping going to fail? In particular there was

1 a formal meeting for the staff and people from standards  
2 group on damping code case N-411--

3 CHAIRMAN SIESS: When you say "staff," you are  
4 staff. You mean "other staff."

5 MR. GUZY: I mean the whole staff, and not just  
6 research.

7 CHAIRMAN SIESS: You mean NRR--

8 MR. GUZY: I mean NRR and the licensing people  
9 and people that now inspect the projects are involved  
10 in piping, too--the people outside of the Nicholson Lane  
11 Building.

12 There was also a presentation on this class  
13 1 code case that I mentioned before, and we presented  
14 information from this program in support of these other  
15 changes.

16 We've given presentation at our information  
17 meetings at Gettysburg year to year, and then perhaps  
18 the first really formal presentation of staff, solely  
19 on this subject, was given last September when we gave  
20 detailed briefing of the results and where we were heading  
21 at the time and criteria development.

22 Today is the first meeting with the ACRS. We  
23 are interested in your comments on the program, and any  
24 suggestions or comments you may have on the program once  
25 you hear us out today.

1           We also plan to have future meetings with the  
2 NRC staff, particularly licensing people, and particularly  
3 in terms of the criteria of changes that we probably will  
4 be recommending. Many of the--all of the standard groups  
5 will be involved, the ASME representatives from the NRC.  
6 We like to have feedback from the staff before--get some  
7 direction from the staff before we actually start becoming  
8 involved as an NRC representative to the ASME, so we plan  
9 to have meetings this spring with the staff to present  
10 what we have developed.

11           In terms of how the regulatory changes go, the  
12 Code case, such as the stress allowable Code cases are  
13 endorsed formally through revisions of R.G. guide 1.84--

14           CHAIRMAN SIESS: That is the one that periodically  
15 comes up?

16           MR. GUZY: Yes.

17           CHAIRMAN SIESS: And, updates the reference--

18           MR. GUZY: And, the status now of the Code case,  
19 the class 1 Code case N-451 is published and will be treated  
20 in the next revision, revision 26. That is R.G. guide  
21 1.84, so that will go through the formal NRC endorsement  
22 process for that Code case. The other Code case will  
23 probably be in the next revision to R.G. 1.84.

24           [Slide]

25           However, the changes we are talking about today

1 will be to the Code itself, and the way the NRC endorses  
2 the ASME Code changes is through 10 CFR 50.55A and we  
3 essentially incorporate specific addenda and revisions  
4 to the Code as they come about.

5 CHAIRMAN SIESS: And, that again, you do periodically?

6 MR. GUZY: Do that periodically, and it will  
7 be done through the regulations, so that is the formal  
8 process for endorsing the changes we will be hearing about  
9 today.

10 Also, there are changes that we may make to  
11 the standard review plan, particularly in its functionality  
12 area, also I think the information from this program will  
13 have an impact on many other things we do in the piping  
14 area; perhaps not in a--as a more explicit way for providing  
15 backgrounds, supports a lot of conclusions people have  
16 made, for instance in seismic margin studies, or PRA's,  
17 seismic inertia loads are generally not considered important  
18 if we don't review them.

19 In contrast to the way that we may have reviewed  
20 plants in the past--

21 CHAIRMAN SIESS: Wait a minute.

22 You said in seismic margins they are not considered  
23 important?

24 MR. GUZY: --not considered important. Piping  
25 inertial loads are generally not even--in piping systems--



1 are not considered important because of the experience,  
2 the piping experience--

3 CHAIRMAN SIESS: Oh, okay, simply based on piping  
4 experience and--

5 MR. GUZY: --because of the piping experience,  
6 plus findings from this kind of a program. This supports  
7 piping experience data--

8 CHAIRMAN SIESS: Oh, okay, yes.

9 MR. GUZY: --showing that your margins are much  
10 greater than other things in the plant that will--

11 CHAIRMAN SIESS: Yes, okay, but now you just  
12 mentioned fragility in passing, and that is a big area  
13 of business these days, making PRAs, and certainly there  
14 somewhere they have got to put a fragility in there, don't  
15 that?

16 MR. GUZY: They--

17 CHAIRMAN SIESS: Or, do they just--

18 MR. GUZY: --they do in the piping area, but  
19 they only do in at very high level earthquakes. Sometimes  
20 you can dismiss that without developing it in the piping.

21 CHAIRMAN SIESS: Okay.

22 MR. GUZY: Seismic margin areas, I was going  
23 to contrast to--in the old SEP program you had to reevaluate  
24 everything, a lot of the effort was involved with piping  
25 analysis. In the seismic margin approach now has taken

1 from the SEP program, although they recognize that all  
2 of this piping reanalysis is not necessary. They are  
3 concentrating on things of importance such as the seismic  
4 ankle motions or systems interactions, and not worry so  
5 much about seismic inertial loads.

6 This program supports other data and experience  
7 showing that we can, in the global formal safety scenario  
8 we can downplay seismic inertial loads.

9 CHAIRMAN SIESS: That explains why--

10 MR. WARD: Well, it is--

11 CHAIRMAN SIESS: --couldn't find any failures.

12 MR. GUZY: That's right.

13 MR. WARD: --but a lot of that has been taken  
14 credit for already though--

15 CHAIRMAN SIESS: Yes, that is what he is saying.

16 MR. GUZY: We are supporting--

17 MR. WARD: --and this is confirmatory, actually.

18 [Slide]

19 MR. GUZY: Okay, I have one other slide in my  
20 package on piping resource that I would like to hold on  
21 for later.

22 CHAIRMAN SIESS: Okay.

23 MR. GUZY: I would like to, at this point, take  
24 any questions.

25 Yes.

1           MR. SHEWMON: I am very pleased, as a metallurgist  
2 who makes his living sort of on the fact that metals are  
3 different from glass, seeing these things designed to  
4 take credit for some of the plasticity that is inherent  
5 in the metal that we've paid for and built it out of,  
6 but, as you do this I am some concerned about the fact  
7 that there is no consideration of castings and the fact  
8 that they might have different plastic properties than  
9 the wrought material and the test consisted only of wrought  
10 material.

11           Is there a basis on this that it was just so  
12 much more convenient to work with wrought material? Or  
13 the Code says that castings always must have appreciably  
14 lower stresses? Or that the Code has been able to ignore  
15 it because they do elastically and the plastic properties  
16 don't enter, or what?

17           MR. GUZY: I think--maybe somebody else would  
18 like to speak to this, but--

19           MR. SHEWMON: I ask you, but you can pass it  
20 off. That is your advantage to--

21           MR. GUZY: --it is my understanding--okay, but  
22 my understanding is that, you know, we are looking for  
23 the majority of the piping in the plant, and the majority  
24 of the piping, to my understanding, does not use cast  
25 fittings.

1 MR. SHEWMON: Well, but it is not just the piping.  
2 It is the components in the elbows--

3 MR. GUZY: That is what I was talking about.

4 MR. SHEWMON: --and the valve bodies and the  
5 pump housings, these things often are, and the fact that  
6 if you design your plants with the strongest elements,  
7 it is the weak link that is going to rise up and bite  
8 you, so saying the majority of it is piping, probably  
9 isn't the right way to look out for failures.

10 MR. GUZY: Maybe somebody else can address that,  
11 but it is my understanding that the majority of the fittings,  
12 elbows, and tees, et cetera, were wrought and not cast.

13 MR. SHEWMON: There is a lot of cast that comes  
14 out there. I don't know whether the majority of it is  
15 or not, but if you change the Code--

16 MR. GUZY: The Code will not address that at  
17 this time, because we don't have the data right now to  
18 do--

19 CHAIRMAN SIESS: The Code will be limited to  
20 wrought material?

21 MR. GUZY: Wrought material, yes.

22 MR. SHEWMON: So the Code will distinguish between  
23 wrought and cast--

24 MR. GUZY: Yes.

25 MR. SHEWMON: --in this case?

1 MR. GUZY: That's right.

2 MR. BUSH: Are you sure of that? I don't think  
3 that. I am not quite sure of that.

4 MR. GUZY: Well, maybe later on we will talk  
5 about this, but our data, since we have not tested, particularly  
6 the ratcheting specimens, we have to limit our recommendations  
7 now to things we've tested or somehow address this later.

8 CHAIRMAN SIESS: Can you use the MCL type material  
9 test to make a bridge between the material properties  
10 and the observed behavior of components and systems?

11 MR. GUZY: Yes.

12 MR. TAGART: We have not, at this point done  
13 that.

14 We had a long discussion on this point at our  
15 last review meeting, about potential restrictions of the  
16 first round of rules that we are going to recommend for  
17 the Code. We do expect to have caveats, restrictions,  
18 whatever you want to call them, with respect to the application  
19 of these rules to the materials.

20 We have not completed the process of identifying  
21 exactly which materials that will not be specifically  
22 included; however, comments like the ones that you are  
23 providing will be helpful in our--as an input to that  
24 consideration.

25 CHAIRMAN SIESS: Well, there are two ways to

1 limit materials: one is by naming them; and the other  
2 is by tying it to properties, measurable properties, and  
3 I gather from what you say it will be by name rather than  
4 by the other.

5 MR. TAGART: Yes.

6 We would plan to do it by name, because we have  
7 identified four materials in the materials testing work,  
8 and one of the primary purposes of the materials test  
9 is to bridge the gap between room temperature tests and  
10 elevated temperature tests.

11 None of the tests that you saw in the last two  
12 days were run at elevated temperatures, and the materials  
13 tests were intended to bridge the gap between room temperature  
14 tests and the elevated temperature tests, for the important  
15 failure phenomenon that occurs in the materials, fatigue  
16 ratchet.

17 MR. GUZY: Anything further?

18 CHAIRMAN SIESS: Any other questions?

19 [No response.]

20 No, let's proceed.

21 MR. TAGART: Good morning, ladies and gentlemen.  
22 I welcome this chance to provide the introduction and  
23 overview of this program.

24 The things that I am going to talk about for  
25 the next few minutes involve a brief history of the Code

1 rules relative to piping. I am going to summarize what  
2 we believed we knew in 1985 when we started this program.  
3 I would like to take a few minutes to explain a very simply  
4 way of understanding why piping is so resistant to dynamic  
5 and seismic type loadings, and I would like to summarize  
6 what we know now near the completion of the program.

7 Also, I would like to discuss the challenges  
8 and the opportunities that we think are available as the  
9 result of this program.

10 [Slide]

11 This is not a complete history of piping, but  
12 I wanted to highlight some of the things that I think--  
13 what we've done in perspective.

14 The earliest date here is 1952 when the Mark1  
15 fatigue tests were introduced into the B31.1 Code. The  
16 basis of these tests were semi-static, that is they were  
17 slowly fatigued to determine when various kinds of piping  
18 components would fail in a leaking manner. They became  
19 the basis for the detailed rules and the B31.1 Code.

20 In 1963 the nuclear pressure vessel rules were  
21 introduced into the SME Code where static and fatigue  
22 type loads were considered. The Mark1 work was the forerunner  
23 of the static treatment and the low-cycle heat treatment  
24 of loads for pressure vessels.

25 In 1968 nuclear piping rules were introduced



1 into the ASME Code, which involved static, dynamic, and  
2 fatigue loads.

3 To put a footnote on dynamic--and I want to  
4 emphasize that the basis for the dynamic loading was that  
5 the effects of dynamic loads were handled by static failure  
6 criteria; that is, it was recognized that there would  
7 be dynamic loads, but the criteria for failure under those  
8 loads would be the same as if those loads had been applied  
9 statically. That was a simplification, made at the time.  
10 If we had had the results of this research available then  
11 we would have done that differently.

12 In approximately 1975, Japanese research, which  
13 was aimed at confirming whether--particularly whether  
14 the D-level stress levels in the ASME Code, which goes  
15 somewhat beyond the elastic limit, were acceptable and  
16 safe. In the process of evaluating these D-levels stress  
17 limits, they identified large dynamic margins; however,  
18 their focus was not to find out exactly how large they  
19 were but simply to establish whether the ASME rules for  
20 level-D were acceptable and safe.

21 They also identified fatigue ratcheting, the  
22 swelling of the pipe, as an important part of the failure  
23 mode.

24 In 1982, a PVRC program under the leadership  
25 of Spencer Bush was initiated to improve nuclear piping,



1 and one of the major things that came out of that was  
2 the Code case N-411, which allowed people to begin removing  
3 snubbers.

4 In 1985--Dan has already mentioned--the 1061  
5 piping recommendations, and simultaneously with that was  
6 the beginning of this program.

7 Now we are about to complete these dynamic tests  
8 and we will have a basis for new rules for the ASME Code.  
9 [Slide]

10 To summarize what we knew in 1985:

11 No. 1. We knew that dynamic margins were large,  
12 but we were uncertain as to exactly how large they were,  
13 so the emphasis of these tests was to take them all the  
14 way to failure, and there was considerable thought and  
15 effort put into selecting test facilities that would produce  
16 failures in a relatively few number of load applications,  
17 and our target was no more than five time history earthquakes  
18 being applied to the specimen to produce failure; and,  
19 at the same time we were planning to use more or less  
20 normal pressure loads. Pressure loading was not exaggerated,  
21 only the dynamic loading.

22 No. 2. The fatigue failure mode for reversed  
23 dynamic loading is ratcheting and fatigue, not static  
24 collapse. We knew this from the Japanese research.

25 MR. SHEWMON: Is static collapse what Chet would

1 call "net section collapse" sometimes? Or, what is static  
2 collapse?

3 MR. TAGART: Static collapse--

4 CHAIRMAN SIESS: It is collapse.

5 MR. TAGART: --is the--

6 MR. SHEWMON: It is not failure. It is the  
7 walls coming together?

8 MR. TAGART: No.

9 What I mean by static collapse here is that  
10 if you plot the load deformation behavior of the structure,  
11 the deformation starts becoming large with small increases  
12 in the load. It is well beyond the elastic--

13 CHAIRMAN SIESS: The curve you showed--somebody  
14 showed yesterday--went down versus the one that went up.

15 MR. SHEWMON: Went up, yes.

16 MR. TAGART: The ASME Code has some definitions  
17 of collapse that suggest collapse occurs before you start  
18 going down, so it depends on whose terms you are using  
19 as to what it means. I think it means something slightly  
20 different to civil engineers.

21 CHAIRMAN SIESS: Would that be different if  
22 you left static out?

23 MR. TAGART: It think it is not quite as clear  
24 without the word "static" and I am suggesting static collapse  
25 as a term used in this program to distinguish it from

1 an incremental collapse. Incremental collapse, as you  
2 saw in the films yesterday, could involve step-wise collapse  
3 of the structure. We want to distinguish static collapse  
4 from a one-application of load to cause collapse, between  
5 that which occurs with many applications of load where  
6 it moves slowly.

7 CHAIRMAN SIESS: I am still trying to understand.  
8 Frequently we take repeated loadings and find  
9 that they can be enveloped by a single monotonic static  
10 load.

11 Are you saying that the static collapse would  
12 be that monotonic loading, and that the dynamic collapse  
13 that you are talking about would not be enveloped by that?  
14 Do you visualize what I am talking about? You know, I  
15 will draw you a curve, and it will look like this--[drawing  
16 curve in the air]--they look like this, a static curve,  
17 and a monotonic loading would be right in the upper bound  
18 of it, and this is in certain types of things, not piping  
19 necessarily, but things that I know about. Is that a  
20 distinction you are making?

21 MR. TAGART: It is very hard to make a general  
22 distinction in that way; for instance, in our materials  
23 tests we clearly see what you are talking about. We plot  
24 on a diagram what happens to the reverse loading, and  
25 at the same time we can look what the comparative material

1 behavior is of a uniaxial specimen just being pulled.  
2 There one can see a relationship between a incremental  
3 collapse and a single collapse.

4 CHAIRMAN SIESS: Are you saying that you do  
5 not get that kind of relationship in piping?

6 MR. TAGART: Well, we see it, yes, but there  
7 is a complication in piping, because piping is a fairly  
8 complicated structure, even for example, understanding  
9 an elbow--

10 CHAIRMAN SIESS: Yes.

11 MR. TAGART: --the elbow is one of the more  
12 difficult things to understand because it is a complex  
13 structure and each material in it behaves in a certain  
14 way differently.

15 CHAIRMAN SIESS: But, I couldn't envelop the  
16 dynamic incremental collapse with the static collapse  
17 curve?

18 MR. TAGART: I don't know.

19 CHAIRMAN SIESS: It would be wonderful if you  
20 could!

21 MR. RODABAUGH: Isn't the answer "yes," Sam?

22 CHAIRMAN SIESS: I don't think you can.

23 MR. RODABAUGH: The answer is "yes" because that  
24 is a much bigger envelop than--

25 CHAIRMAN SIESS: No. I mean match it.

1 MR. BUSH: No.

2 CHAIRMAN SIESS: I mean, if I draw the envelop  
3 for the ratcheting of the incremental collapse that that  
4 would agree. I think it would fall well below the static  
5 collapse.

6 MR. TAGART: It is not identical, though, and  
7 I think the behavior of the structure--it is not even  
8 identical for the materials test.

9 CHAIRMAN SIESS: Okay, then I think I understand  
10 what you are saying there.

11 MR. TAGART: All right.

12 Now, the third point here is a conclusion  
13 that we reached in 1985 as a result of some preliminary  
14 thinking about this program. We felt quite strongly that  
15 fatigue ratcheting was the mode of failure, but we didn't  
16 feel that that was well known in the industry, and we  
17 felt that we could support that kind of conclusion analytically  
18 but we felt such a demonstration would not be convincing,  
19 and we concluded that experimental evidence, plus an engineering  
20 understanding of those experiments would be necessary  
21 to effect a change at this point in time, and of course,  
22 the observation that many people came to was that nuclear  
23 plants have too many snubbers.

24 Now, I would like to take a few minutes to describe  
25 a simple explanation of why piping is so resistant to

1 dynamic loads. I am going to talk about a picture that  
2 appears in that fourth semi-annual report, and I'll show  
3 you what the picture looks like first, and then go back  
4 to this diagram.

5 It is this page in the fourth semi-annual on  
6 page 3-208, where we are describing an amplification versus  
7 frequency. The standard kind of thing that appears in  
8 textbooks on force vibration analysis.

9 But, before I discuss that I want to discuss  
10 the assumptions here that go into one of the curves. This  
11 diagram is the force on a single degree of freedom spring  
12 versus the deflection of the single degree of freedom  
13 spring.

14 So, this is the deflection--(referring to the  
15 drawing)--this is the stiffness times the deflection,  
16 or the force. And, this is the simplest model showing  
17 complete plasticity, assuming that there is some value  
18 at which the structure become elastoplastic. At this  
19 point it unloads, become elastic again, goes into reverse  
20 plasticity and absorbs energy through this loop.

21 The component tests are very close to a single  
22 degree of freedom system. The major complication that  
23 could be added to better understand it would be to put  
24 a slope on this curve right here, and to make it elastic  
25 and then strain hardening in both areas. But, for the

1 moment, let's look at perfectly plastic.

2 One of the simplest models that we can use,  
3 which is an approximate dynamic analysis--

4 CHAIRMAN SIESS: That has a mean stress on it,  
5 obviously?

6 MR. TAGART: --no.

7 CHAIRMAN SIESS: Then it is not at zero.

8 MR. TAGART: This is adjusted so that the diagram  
9 centers around this point here, but there is no mean stress  
10 in this. Sam Ranganath will talk a little later about  
11 what happens when we add mean stress to this.

12 MR. SHEWMON: This is an A cycle taken after  
13 you have reached a steady state.

14 MR. TAGART: This is a steady state behavior  
15 with no mean stress.

16 CHAIRMAN SIESS: Okay.

17 MR. TAGART: Now, then we--

18 CHAIRMAN SIESS: I guess that I am still having  
19 a problem.

20 How do you get to this? You have to start at  
21 zero when you go up on that slope and get plastic, and  
22 then it settles down to this loop then?

23 MR. TAGART: Okay, let me describe the problem--

24 CHAIRMAN SIESS: This is the Nth cycle.

25 MR. TAGART: This is sinusoidal excitation

1 of a single degree of freedom system after it gets through  
2 its transient. It settles into some steady state.

3 CHAIRMAN SIESS: Okay.

4 MR. TAGART: And, it is driven hard enough that  
5 it becomes elastoplastic.

6 CHAIRMAN SIESS: In both directions?

7 MR. TAGART: In both directions, right.

8 CHAIRMAN SIESS: Do your component tests become  
9 plastic in both directions?

10 MR. TAGART: Yes.

11 CHAIRMAN SIESS: Then I don't get a ratchet  
12 out of it, do I?

13 MR. TAGART: In this case, no.

14 CHAIRMAN SIESS: Okay.

15 MR. TAGART: If you add a mean stress, you will.

16 CHAIRMAN SIESS: Okay.

17 MR. TAGART: In this model, there are two things  
18 done to the simple equation of motion: one is to approximate  
19 the damping by the energy absorbed in this loop.

20 The second is to put a reduced stiffness in  
21 the single degree of freedom, which is the slope of this  
22 line, and this makes the solution nonlinear; that is,  
23 you now don't know the deflection before hand, and the  
24 equation that will solve this for a sinusoidal  
25 motion has to be solved by some trial and error technique.



1           It is not an exact solution to the problem because  
2   the motion is not sinusoidal,     purely sinusoidal.  
3   when it goes to the elastic plastic, but this makes a  
4   very simple explanation of what goes on, so that is the  
5   assumption that goes into the elastic plastic model, and  
6   the diagram that is in the report shows the results.

7           The solid curve is a curve at two percent damping--

8           CHAIRMAN SIESS: I am having a problem.

9           That is a response spectrum, in effect?

10          MR. TAGART: Yes.

11          It is a steady state response spectrum for a  
12   single degree of freedom system--

13          CHAIRMAN SIESS: And, it is the amplification  
14   of what?

15          MR. TAGART: It is the amplification of mass  
16   relative to the ground.

17          CHAIRMAN SIESS: Its acceleration?

18          MR. TAGART: It is the--either the displacement  
19   or acceleration. The assumption here--

20          CHAIRMAN SIESS: What's "A"? It says C over  
21   A in there?

22          MR. TAGART: Okay.

23          "A" is the amplitude of the input motion. See  
24   in the box there--

25          CHAIRMAN SIESS: Okay, okay--

1 MR. TAGART: --"A" is the amplitude of the  
2 sinusoidal displacement.

3 CHAIRMAN SIESS: --I've got it. All right.  
4 I've got it now. That is a displacement versus--

5 MR. TAGART: Right, it is a displacement response.

6 CHAIRMAN SIESS: It is a displacement response,  
7 yes.

8 MR. TAGART: Right.

9 This curve is for the two percent damping case  
10 if it were elastic.

11 The assumption for the picture that I just described:  
12 it is labeled "Tagert's Model  $\Lambda=0$ " meaning no strain  
13 hardening, is this dotted curve right here, and what it  
14 tells us is that we get a frequency shifting from this  
15 point back to this point, the softening effect, and an  
16 enormous lowering of the peak, as you know. This peak  
17 goes way up here, so you get an enormous reduction.

18 This particular case here is pictured for five  
19 times the yield stress--

20 CHAIRMAN SIESS: Wait a minute, wait a minute.

21 Five times the yield stress? Or yield strength?

22 MR. TAGART: Yield strength, yield strength.

23 CHAIRMAN SIESS: Okay.

24 MR. TAGART: I'm sorry.

25 CHAIRMAN SIESS: Does that frequency shift correspond

1 to that dotted line you had on the previous figure?

2 MR. TAGART: Yes.

3 CHAIRMAN SIESS: Okay.

4 MR. TAGART: An exact solution of this same  
5 problem, not an approximation, is also shown on the diagram  
6 by what's called the numerical solution for Lambda to equal  
7 zero. It is this curve right here.

8 Now, that solution is conservative compared  
9 to the exact solution; however, when you put a little  
10 strain hardening into it, in the exact solution it brackets  
11 the approximation, so the approximation is very close  
12 to the reality of what goes on in this single degree of  
13 freedom test, and here we see the effect of the energy  
14 absorption which completely chops off this high resident  
15 peak, and it shifts the response to the left on this diagram.

16 Another very interesting thing that one can  
17 observe from this diagram--which we did not strongly observe  
18 in any of our tests--is that there is a region in here  
19 where elastic analysis will underpredict the response  
20 regardless of what damping you put in it, and that's one  
21 of the reasons why--

22 CHAIRMAN SIESS: It is the frequency shift.

23 MR. TAGART: --yes, it is because of the frequency  
24 shift. That is one of the reasons why we were less enamored  
25 with the idea of making changes by controlling just the

1 damping. The damping certainly has an important effect  
2 because it chops off this peak, but the frequency effect  
3 is also more important, and we think probably the easier  
4 way, the more straight forward way, is to handle both  
5 of these effects in linear analysis by changing the allowable  
6 stress, rather than by trying to deal with the damping.

7 MR. BUSH: Sam, how do you handle the strain  
8 softening aspects, or do you simply--

9 CHAIRMAN SIESS: A little louder, Spence.

10 MR. BUSH: I was asking how you handle the strain  
11 softening aspect, or do you simply cut it off at  $\Lambda$   
12 equals zero?

13 MR. TAGART: The  $\Lambda$  equal zero model is  
14 a--do you mean if the slope were actually to go down rather  
15 than up?

16 Well, strain softening, there are two ways to  
17 think about strain softening. There is strain softening  
18 in a single cycle, or there is strain softening where  
19 successive cycles may have lower stress range than they  
20 had in the earlier cycles.

21 We've addressed that by our materials tests.  
22 We selected four different materials in the materials  
23 test: one to be strain hardening; one to be strain softening;  
24 and two to be more or less neutral.

25 We are concerned about the problem of predicting

1 the ratchet. I think the subject of strain hardening  
2 and softening is most important in the area of how much  
3 ratcheting will occur in each cycle? And, I think Sam  
4 Ranganath is going to cover this in a little bit of detail  
5 to explain what conclusions we've drawn to date on the  
6 ratcheting. I hadn't planned to talk about that at this  
7 part of the discussion.

8 CHAIRMAN SIESS: Fine.

9 MR. TAGART: What I think is useful about this  
10 diagram is that there is a simple physical way to explain  
11 why under the steady state response--and I think you saw  
12 yesterday in these experiments--that you reach some kind  
13 of a steady state. Now, most of those tests were seismic  
14 inputs. We only had a test where we've done sinusoidal  
15 inputs, and we will be able to more directly compare the  
16 applicability of this model to those sinusoidal  
17 inputs, but it is a relatively easy thing for us to put  
18 a non-sinusoidal input into this single degree of  
19 freedom model and get comparisons, and we have done that,  
20 so we've made a lot of progress to understanding those  
21 compliment tests by simply looking at a single degree  
22 of freedom elastoplastic model. That is the point that  
23 I wanted to get across with this diagram.

24 [Slide]

25 I would like to give an overview of what we

1 think we know now, as the result of this program. We  
2 believe that we know why static collapse does not occur--  
3 it does not generally occur, in the dynamic loading situation.  
4 The previous diagram is an elastoplastic system. If any  
5 system could collapse as a single degree of freedom system,  
6 that one would collapse and it generally does not, and  
7 there is a good explanation as to why it doesn't.

8 We know also that there are certain types of  
9 dynamic loads that can collapse the piping. As we saw  
10 yesterday, we were able to produce large deformations  
11 in the water hammer cases where the load holds up long  
12 enough to allow the pipe to mold, so we don't want over  
13 generalizing results. Our objective is to make Code changes  
14 but not to overstate the case relative to certain kinds  
15 of dynamic loads.

16 CHAIRMAN SIESS: So, the type that can cause  
17 it is one that isn't too dynamic?

18 MR. TAGART: That's right. It behaves more  
19 like a static load.

20 We know how to approximately predict the component  
21 results from first principles. I haven't discussed the  
22 ratcheting, but that will be discussed.

23 We know that there are some limitations of linear  
24 dynamic analysis, that previous diagram showed the key  
25 area where there may be some concern about that.

1           We have clarified concepts of apparent damping.  
2   I haven't discussed that much, but if we look at the damping  
3   that is available, the equivalent damping that is available  
4   in that single degree of freedom system, it is very, very  
5   large, on the order of 40, 50 percent is available in  
6   that single degree of freedom system, with sinusoidal  
7   inputs. But, we need to distinguish between the what  
8   we call--Henry Hwang has termed true damping, and apparent  
9   damping--and this word should be true--[referring to the  
10  slide]--I am sorry for the error here, instead of "time"  
11  this should be true damping.

12           Piping systems are fundamentally resistant to  
13  seismic and other dynamic loads because the true damping  
14  is very high at ductility of as low as three, and as a  
15  matter of fact, if you will look at that little degree  
16  of freedom model, which is not an exact solution, it  
17  actually maximizes the damping at a value of three.

18           MR. SHEWMON: Can you tell me what a dynamic  
19  ductility of three means to a stress strain curve?

20           MR. TAGART: It means if the single degree of  
21  freedom system were a mass hung on a tensile bar, then  
22  the yielding of the structure and the yield of the material  
23  would be the same, and if we had a elastoplastic material  
24  and the deformation which occurred was three times the  
25  collapse load, that is what I mean by ductility of three.

1 CHAIRMAN SIESS: Not three times the yield?

2 MR. TAGART: Well, in that case it would  
3 be the same.

4 CHAIRMAN SIESS: That is--

5 MR. SHEWMON: This is three times the strain  
6 of the yield; is that right?

7 MR. TAGART: Well, this is three times the  
8 deformation at which the structure collapses.

9 CHAIRMAN SIESS: On this curve, isn't it the  
10 ratio of that distance to that?

11 MR. TAGART: Yes, yes.

12 CHAIRMAN SIESS: The ratio of--

13 MR. SHEWMON: Thank you.

14 MR. TAGART: We believe that we understand ratcheting.  
15 Ratcheting very simply is a lack of symmetry through the  
16 cycle, and the presence of a mean load means that when  
17 you have half of a cycle, a mean load is adding to one  
18 direction of plasticity and in the opposite direction  
19 it may be subtracting, and therefore there is a net accumulated  
20 plastic strain, or deformation, when one completes a cycle  
21 in the presence of mean loading.

22 CHAIRMAN SIESS: Now, you talk about mean loading--

23 MR. TAGART: Mean stress.

24 CHAIRMAN SIESS: --it is mean stress--

25 MR. TAGART: Right.



1           CHAIRMAN SIESS: Because that mean stress can  
2 be a pressure induced stress--

3           MR. TAGART: Yes.

4           CHAIRMAN SIESS: It doesn't have to be a load  
5 induced stress.

6           MR. TAGART: That's right.

7           CHAIRMAN SIESS: Okay.

8           MR. TAGART: All right.

9           Typically, in the--and most of the applications  
10 we are talking about pressures is the dominant behavior,  
11 although weight is also an important consideration, and  
12 we've seen this in our experiments. The influence of  
13 the weight is a very strong effect in how much ratcheting  
14 will occur.

15           CHAIRMAN SIESS: You mean simply the weight  
16 producing a longitudinal stress in the pipe, or whatever  
17 you test?

18           MR. TAGART: Yes, yes.

19           CHAIRMAN SIESS: Just gravity.

20           MR. TAGART: Yes.

21 [Slide]

22           I would like to spend a couple of minutes on  
23 the opportunities and challenges that present themselves  
24 as the result of completing this research. We will have  
25 a significant Code margin reduction proposed, as a result

1 of this program, that's not necessarily going to be easy.  
2 As I have discussed this with Dan Guzy, he tells me we  
3 shouldn't expect that this is going to happen one week  
4 after we make our proposal. If--I almost hesitate to  
5 say this--but it may take a year or more for these results  
6 to get into the Code, and some of the things that we see  
7 that the regulator will have to look at is managing the  
8 prior and future Code changes.

9 A couple of important things, the Code case  
10 N-411 which got us going relative to snubber reduction--

11 CHAIRMAN SIESS: What is 411?

12 MR. TAGART: Code case N-411 is the one that  
13 increased the damping to five percent--

14 CHAIRMAN SIESS: Okay.

15 MR. TAGART: --at low frequency, and two percent  
16 at high frequency.

17 CHAIRMAN SIESS: Okay.

18 MR. TAGART: The Code case N-451 which was just  
19 recently passed, which took the operating basis earthquake  
20 out of equation--yes.

21 MR. SHEWMON: Would you put some words on significant  
22 Code margin reduction? Would that come later?

23 MR. TAGART: Okay, it will come later, but I  
24 think it is a good point to bring it up now.

25 We are thinking of effectively increasing the

1 allowable stress in the Code somewhere in the order of  
2 50 to 100 percent, and we haven't decided exactly how  
3 much that should be right now.

4 MR. SHEWMON: Double?

5 MR. TAGART: Up to doubling it, at least 50  
6 percent higher than--

7 MR. SHEWMON: That is the seismic component  
8 of the stress? Or the Code?

9 MR. TAGART: The dynamic--the total stress equation  
10 that covers the combination of pressure stress and the  
11 inertia stress from dynamic loading that is of a reverse  
12 type, either seismic or reversed other type that behaves  
13 like seismic.

14 CHAIRMAN SIESS: But, if you are going to increase  
15 the total allowable, how are you going to take care of  
16 the range and ratio between seismic and other stress?  
17 An element that has very little seismic stress, do you  
18 have some other equation that governs that?

19 MR. TAGART: Yes.

20 CHAIRMAN SIESS: Okay.

21 MR. TAGART: There are other equations that--

22 CHAIRMAN SIESS: This would be the only equation  
23 that includes the seismic stress?

24 MR. TAGART: Right.

25 CHAIRMAN SIESS: Load combination--

1 MR. TAGART: Seismic or other dynamic stress.

2 CHAIRMAN SIESS: All right, I got it.

3 MR. TAGART: One of the activities that is going  
4 on is handling the independent support motion with SRSS  
5 and it is currently the subject of research.

6 We have simplified static methods that are now  
7 being seriously considered by the Code. We have non-  
8 linear methods which we know are going to be coming along,  
9 seismic anchor motion modifications, and I mention here  
10 possibly designed by rules. We believe that the results  
11 of this research program are conducive to eventually producing  
12 design by rules in piping, as opposed to design by analysis,  
13 particularly for the seismic effects. We are not recommending  
14 that at this time, but we think it is a fruitful potential  
15 improvement in the future, and our approach, or our recommendation  
16 will be to work with the current rules that are designed  
17 by analysis, make those changes which are appropriate  
18 as the result of those rules, and at some point in the  
19 future explore and examine the possibility of great simplification  
20 in the piping design process for nuclear plants. That  
21 is for the future.

22 I would like to show you something that addresses  
23 a method to optimize piping design. I think that is one  
24 other real opportunity here. In the past the approach  
25 to making changes to the Code has involved trading one

1 conservatism against another, and that's a viable approach,  
2 but it doesn't allow us to optimize the piping system,  
3 and I would like to show you an approach that we have  
4 examined at EPRI in the last year and what I've shown  
5 here is a probabilistic approach to optimizing piping  
6 design, and this is what decision analysts call "an influence  
7 diagram."

8 [slide]

9 A circle on this diagram represents something  
10 that we are uncertain about. A square represents something  
11 that we have control over, that we can make a decision  
12 about. So, at the top of the diagram we focused on snubber  
13 reduction efforts.

14 What we did in this program was attempted to  
15 say if we temporarily removed all requirements for piping  
16 design, and we could trade off the pluses and minuses  
17 relative to how many snubbers we would put into a nuclear  
18 power plant, how many would we put in. We had complete  
19 freedom to do it, and we could make the decision on the  
20 basis of cost, safety, or both--

21 CHAIRMAN SIESS: Knowing what you know now.

22 MR. TAGART: --knowing what we know now, yes.

23 CHAIRMAN SIESS: The early plants didn't have  
24 any--

25 MR. TAGART: Yes.

1 CHAIRMAN SIESS: --knowing what they did then.

2 MR. TAGART: Right.

3 This model is an ambitious model, and it was  
4 done by one of our contractors with the help of a second  
5 one who was very familiar with probabilistic risk analysis,  
6 so we have things in here about the core melt. How does  
7 the pipe failure influence the core melt? And, here you  
8 see in this original diagram, we had things like water  
9 hammer, the seismic loading--

10 CHAIRMAN SIESS: Sam.

11 MR. TAGART: Yes.

12 CHAIRMAN SIESS: What's the significance of  
13 the two circles with a lot of arrows out of them that  
14 don't do anywhere?

15 MR. TAGART: It means they connect to a lot  
16 of other ones, and--

17 CHAIRMAN SIESS: Okay.

18 MR. TAGART: --for instance--

19 CHAIRMAN SIESS: And, you don't know which ones.

20 MR. TAGART: We could connect them to almost  
21 all of them.

22 CHAIRMAN SIESS: Okay.

23 MR. TAGART: It would make the diagram so confusing  
24 to put all of those arrows in there, we are saying the  
25 design and construction errors can--are pervasive through

1 the whole diagram. You can have things go wrong, with  
2 what you know about anything going on in this diagram.

3 Similarly, we have this influence of NRC regulations  
4 on very many parts of this diagram, in other words there  
5 are regulations that effect how each one of these things  
6 are done, and we don't know how those regulations are  
7 going to change in the future.

8 The study that we did simplified this diagram  
9 a little bit, and although it would take too much time  
10 to discuss the complete implications of this study, I  
11 would like to show you some of the results.

12 CHAIRMAN SIESS: Sam, it seems to me that if  
13 you are going to do a true optimization you have got to  
14 know almost everything about everything.

15 MR. TAGART: That's right.

16 CHAIRMAN SIESS: It is obvious that you don't.

17 MR. TAGART: That's right. You are very  
18 uncertain. That is why these are put in circles.

19 CHAIRMAN SIESS: Yes, so it has to be a  
20 probabilistic optimization?

21 MR. TAGART: That's correct.

22 And, what we attempted to do here is a picture  
23 as close to reality as we know it today. We recognize  
24 that some parts of it are very uncertain, but we want  
25 to give the best expected values for each one of the variables

1 in the diagram.

2 CHAIRMAN SIESS: Okay.

3 MR. TAGART: The results of that study, on a  
4 very simple system, extrapolated to an entire plant, and  
5 the costs of an entire plant is a diagram that looks like  
6 this.

7 [Slide]

8 This is where we stand right now, and typically  
9 this might be a plant with, let's say, a thousand snubbers.  
10 We are plotting here the number of snubbers removed, versus  
11 expected lifetime costs of the plant.

12 CHAIRMAN SIESS: Percentage.

13 MR. TAGART: And, for different costs involved  
14 in maintaining snubbers, we have different curves.

15 This is a very high cost snubber, \$7000 per  
16 snubber for the lifetime, annual maintenance cost for  
17 the snubbers.

18 This is a considerably lower cost, and this  
19 is a very low cost.

20 And, what you see here, of course, as you can  
21 well imagine--and we have put the safety costs in this  
22 picture, as well. You will notice down here, we said  
23 if we get a core melt there is some large cost associated  
24 with that core melt. For example, in this case, \$20 billion,  
25 and in this case \$5 billion, and of course it changes



1 the picture.

2 So, this is one diagram that puts the safety  
3 picture and the cost picture on the same diagram. It  
4 shows, for example, that we should be, regardless of what  
5 the cost of snubbers are, we should be moving in the direction  
6 that we are moving, and that is to remove snubbers.

7 If the cost is very, very low, we see a diagram  
8 that reaches some minimum point here and then starts coming  
9 back up again. If the cost is very high, and we were  
10 optimizing on cost, it would come down.

11 [Slide]

12 Now, I would like to show you a diagram that  
13 shows what happens if you forget the cost, and simply  
14 optimize on the safety question. Here is a diagram that  
15 says the lifetime probability of core melt due to pipe  
16 failure, and here is where we stand right now with a large  
17 number of snubbers in the plant. It says that--and or  
18 two probabilities or earthquake--

19 CHAIRMAN SIESS: What earthquake is that, that  
20 you are putting the probability on?

21 MR. TAGART: This is the probability of the  
22 SSE.

23 CHAIRMAN SIESS: Well, that won't cause any  
24 damage--well, I guess it is some probability.

25 MR. TAGART: Okay.

1           The reason that it causes some problem is that  
2   this model says I could have degraded piping. I could  
3   have piping with cracks in it before the earthquake comes.

4           CHAIRMAN SIESS: Well, now, suppose you did,  
5   and a three SSE at 10 to the minus 5--two SSE at 10 to  
6   the minus 5, what would it look like?

7           MR. TAGART: Well, it would change the picture  
8   and I don't want to speculate about how it would change  
9   it.

10          I want to tell you about the results that we  
11   have.

12          CHAIRMAN SIESS: What pipe failure frequency  
13   are you taking for that earthquake? You said degraded  
14   piping, so you must be some way putting in--

15          MR. TAGART: We have a very crude model for  
16   the degraded piping.

17          What we have done, essentially, is look at the  
18   piping as if it can fatigue all the way to a failure point,  
19   with a very simple model. We have a very simple fracture  
20   mechanic's model. The input is not the failure rate of  
21   the piping. The input is part of the equation to describe  
22   the lifetime of the piping as a function of the thermal  
23   loads, the seismic loads, and how big a crack it has.

24          CHAIRMAN SIESS: And, you are assuming that  
25   the earthquake is 1/22nd cycle like you have? No after

1 shocks?

2 MR. TAGART: We are not into that level of detail.

3 CHAIRMAN SIESS: But, you are assuming some  
4 kind of an earthquake, at so many cycles, and on the basis  
5 of what you know that that combined with other things  
6 will cause fractures.

7 MR. TAGART: Yes, yes.

8 CHAIRMAN SIESS: Okay.

9 MR. TAGART: So this model admits the possibility  
10 that the earthquake--and in fact a very crude assumption  
11 was made here. For example, we said if a pipe can get  
12 to a failure point by leakage, that 15 percent of the  
13 cases would break before leak.

14 CHAIRMAN SIESS: Okay.

15 MR. TAGART: Here again, we see that the right  
16 direction to move is to remove snubbers, and these curves  
17 turn up sharply, which was a bit of a surprise when we  
18 first saw that. We thought that perhaps the diagram would  
19 look like this, and come to a point which was below this  
20 point so that if we removed all of the snubbers we'd be  
21 better off than if we kept some in.

22 This is because--and it is dotted here, and  
23 I would emphasize that this is very tentative in nature--  
24 it is because of the degraded pipe question, and we have  
25 another program, the IPERC program which is coming along

1 to examine degraded pipe. We focused on sound pipe. The  
2 degraded pipe program tells us--answers questions about  
3 the uncertainty of unsound piping, and I believe the long  
4 term optimization of piping depends on our looking at  
5 both of these programs.

6 I think it is clear at this point that very  
7 large numbers of reduction will both improve the costs  
8 and improve the safety.

9 CHAIRMAN SIESS: It would seem that--let's take  
10 not the 80 percent point, but your 90 percent point--  
11 it would seem to me that it would make a difference as  
12 to which snubbers were included in that 10 percent window?

13 MR. TAGART: That's true, and what we are assuming  
14 here is that we take out the right ones, too. We are  
15 taking them out in some systematic way--

16 CHAIRMAN SIESS: So, the 20--

17 MR. TAGART: --so we take the right ones.

18 CHAIRMAN SIESS: --percent you are leaving in  
19 are some of the most crucial ones--

20 MR. TAGART: Yes.

21 CHAIRMAN SIESS: --and when you start taking  
22 those out the risk goes up.

23 MR. TAGART: Right.

24 CHAIRMAN SIESS: Okay.

25 MR. TAGART: And, if one wanted to think about

1 further optimizing it, some of the passive restraint devices  
2 could be substituted for those few that really do us some  
3 good.

4 MR. RODABAUGH: Sam, what is it about--is it  
5 possibility of snubber malfunction that makes this curve  
6 go down?

7 MR. TAGART: Yes, that's it, exactly.

8 The snubbers themselves can malfunction, they  
9 increase the stress, and that is why these curves go down  
10 there.

11 MR. BUSH: And, that depends on the types  
12 of snubbers.

13 MR. TAGART: Yes.

14 MR. WARD: Then are these curves--let's see,  
15 the last figure, are those consistent with the previous  
16 figure?

17 MR. TAGART: Yes.

18 MR. WARD: I mean it is the same?

19 MR. TAGART: They are the same.

20 MR. WARD: So the break off is what you see  
21 on the previous one?

22 MR. TAGART: Exactly, right.

23 MR. WARD: What would that previous one look  
24 like with, if you are talking about a new plant capital  
25 costs of snubbers? The same?

1 MR. TAGART: Which curve would we pick?

2 MR. WARD: Yeah.

3 MR. TAGART: It probably is this middle one  
4 for the cost is more like what we would expect.

5 MR. BUSH: Sam, a question on that curve.

6 I don't know what the maintenance cost are that  
7 it has, because one of the problems, obviously, with the  
8 snubbers is the effect on outage time.

9 MR. TAGART: Yes.

10 MR. BUSH: Which has a, spread over several  
11 years, it doesn't take many days of outage time to increase  
12 to bias the costs considerably.

13 MR. TAGART: Yes. I think we have not considered  
14 a lot of outage time in this, and if outage time got to  
15 be a big factor, these number of course would move more  
16 in this direction.

17 CHAIRMAN SIESS: This is sort of routine maintenance,  
18 then.

19 MR. BUSH: You are talking about \$100 million  
20 roughly, as a zero baseline on that conservative model.

21 MR. TAGART: Yes.

22 CHAIRMAN SIESS: And the snubbers that you can't  
23 test, I assume you are leaving in?

24 MR. TAGART: Pardon me?

25 CHAIRMAN SIESS: The big snubbers that you can't

1 test, I assume those are some that you are leaving in?

2 MR. TAGART: Well, here we are talking about  
3 piping.

4 Some of those big snubbers are on--

5 CHAIRMAN SIESS: Oh, that's right--

6 MR. TAGART: --peak generators.

7 CHAIRMAN SIESS: --they are on peak generators.

8 MR. TAGART: With that, I would like to--I guess  
9 we are at the break?

10 CHAIRMAN SIESS: Yes.

11 MR. TAGART: Anymore questions?

12 [No response.]

13 CHAIRMAN SIESS: Any questions for Sam before  
14 we take a break?

15 [No response.]

16 Okay, let's take about 10 to 15 minutes for  
17 a break, and the audio systems man may be able to fix  
18 the microphones.

19 [Recess: 9:50 a.m. to 10:10 a.m.]

20

21 CHAIRMAN SIESS: All right, you may proceed.

22 MR. ENGLISH: My name is Bill English. I am  
23 from General Electric.

24 I would like to take just a couple of minutes  
25 to discuss with you the portion of the program that I

1 will be talking about today, in a few moments, to describe  
2 some of the objectives that we focused on through the  
3 program, but the bulk of the time I would like to spend  
4 talking about the component test, system test, specimen,  
5 and analysis avoidance test.

6 CHAIRMAN SIESS: Please keep in mind that we  
7 have had a pretty good description of the tests themselves.

8 MR. ENGLISH: Right, right, okay. I will try  
9 to go through those portions of the presentation very  
10 fast, and if I am going too slow, you just speed me up.

11 CHAIRMAN SIESS: All right.

12 Well, I may ask you to just skip some of these,  
13 since we've seen them.

14 MR. ENGLISH: Okay.

15 Today I will be talking about the component  
16 tests of Anco, the system tests at ETEC and Anco, the  
17 specimen fatigue ratcheting tests at MCL--actually started  
18 at the General Electric turbine technology lab with Sumu  
19 Ykowa [sic.] and Roy Williams, and GE got out of the materials  
20 testing business at that particular location, and the  
21 lab was transferred over to--Roy Williams actually bought  
22 the equipment and continued the tests, so we didn't lose  
23 much time on part of the program.

24 And, then task 5 was the analysis of test and  
25 design rules, which was done with GE in San Jose.



1 [Slide]

2 As you've probably heard a number of times,  
3 a major objective of the program was to try to take  
4 advantage of current dynamic margins that we've seen in  
5 metal piping systems, and to devise new, more realistic  
6 ASME Code rules, but in addition to that we wanted to  
7 determine what the actual failure mechanism was in piping.  
8 It is not believed to collapse at the same point now as  
9 fatigue ratcheting.

10 We wanted to measure pipe damping as a function  
11 of different stress levels, with the system configurations  
12 and frequency inputs. We wanted to determine how big  
13 an earthquake the piping systems could tolerate without  
14 failure.

15 [Slide]

16 We would like to develop a lab specimen to quantitatively  
17 predict fatigue ratcheting, and ultimately plan to suggest  
18 changes to the standard review plans, regulations and  
19 codes to account for the margin that we have in piping  
20 of the dynamic loading, and ultimately we would like to  
21 be able to simplify the piping dynamic analysis.

22 [Slide]

23 We felt the focus of the testing program was  
24 really on the component tests. The most severe loading  
25 was in the component tests. It had the most instrumentation,

1 28 to 30 to 32 channels of instrumentation, as compared  
2 to only 80 channels on the system. The component behavior  
3 for a number of different components could be demonstrated,  
4 and we could determine what the actual failure modes were,  
5 show that functionality was not compromised. We could  
6 use the component test results to predict the system test  
7 behavior and we could calibrate the design rules.

8           The main function of the system tests then was  
9 to confirm what we've learned in the component tests,  
10 to confirm that a single component doesn't actually collapse,  
11 the load redistributes, that the mode of failure is not  
12 collapse, that it is fatigue ratcheting, some kind of  
13 incremental kind of form of failure. It confirms the  
14 functionality of the piping system, that the pipes actually  
15 get bigger in diameter rather than smaller, and tend not  
16 to restrict the flow. It helps to design rules and margins  
17 and it provides a lot of benchmark analysis for benchmarking  
18 some of the computer programs used in piping analysis.

19           The specimen tests, on the other hand, are a  
20 very simple method of demonstrating ratcheting, enabling  
21 us to evaluate many different materials at minimal costs  
22 as compared to the component systems tests, and enables  
23 us to determine the effects of temperature.

24           MR. WARD:           Bill, why aren't those--I mean  
25 Paul Shewmon asked earlier about the--

1           CHAIRMAN SIESS: Speak up, please.

2           MR. WARD:                --Paul asked earlier about  
3 the, you know, seems to be a remaining kind of major uncertainty  
4 with the cast materials.

5                Why wasn't the answer given that the specimen  
6 tests are going to give a lot of information about that?  
7 Won't they?

8           MR. ENGLISH: Well, part way through the program  
9 this issue about cast materials came up, and we discussed  
10 it in the context of advising the component test makers,  
11 and at every review meeting we discussed the component  
12 tests matrix to decide what we would like to change, and  
13 it seemed at those meetings when the question of castings  
14 came up that there weren't enough of them to warrant changing  
15 the component test program to include a casting, and maybe  
16 you couldn't draw a significant conclusion from one cast  
17 component.

18               The obvious way to look at this in some detail  
19 would be in the specimen test program, but that was already  
20 established, and maybe at some later date we can get at  
21 cast materials.

22               As Sam pointed out, we would probably restrict  
23 the rules at this point in time to exclude casting.

24           MR. BUSH: I may comment that if that is what--  
25 [voice fades]-- on the basis that it would just make it

1 too difficult from a design point of view.

2 MR. ENGLISH: Just briefly, you probably had  
3 most of this information on the component tests, but the  
4 major objectives were to show once and for all that collapse  
5 was not the failure mode of the components, to measure  
6 the ratcheting and cycles to failure.

7 We had 41 components in the program, all six  
8 inch in diameter, scheduled 10 through 40, with various  
9 combinations of elbows, tees, reducers, and in the original  
10 plan it was devised with Dr. Kennedy's help, was to put  
11 the peak of the input at about a half hertz below the  
12 component natural frequency, such that the component plastic  
13 input would be driven up to a higher peak value, and at  
14 Anco we were able to drive the sleds at the maximum capability  
15 of the sleds.

16 We wanted to get the fatigue ratchet crack to  
17 develop in two to three of these 20 second seismic inputs,  
18 any longer than that we felt would be pretty much just  
19 a fatigue test, so this was a target. Ultimately we eliminated  
20 schedule 80 because it took too many inputs at the Anco  
21 table capacity to generate a crack, and originally we  
22 had planned to do some schedule 160 testing, and that  
23 became obvious early in the program that we wouldn't be  
24 able to crack those components, so we focused on schedule  
25 10, 40 and 80.

1 CHAIRMAN SIESS: In selecting the two or three  
2 inputs, you gave no consideration to what the probability  
3 was of a seismic input of a given duration--

4 MR. ENGLISH: No.

5 CHAIRMAN SIESS: --of frequency?

6 MR. ENGLISH: No.

7 We selected--I'll show you later. We just picked  
8 a typical seismic time history in a BWR. In a BWR--

9 CHAIRMAN SIESS: Yes, I know what you did. I was  
10 just asking.

11 MR. ENGLISH: No.

12 We reviewed that with Dr. Kennedy and we selected  
13 one time history and we used it for all of the tests,  
14 so we had one common basis--

15 CHAIRMAN SIESS: No, but my question you didn't  
16 understand.

17 When we have an earthquake it is one time history--

18 MR. ENGLISH: Right.

19 CHAIRMAN SIESS: --or D earthquake. It may  
20 be longer than 20 seconds, depending on where it is--

21 MR. ENGLISH: Right.

22 CHAIRMAN SIESS: --and there may or may not  
23 be after shocks, and the question of now what happens  
24 to a second earthquake when it has been damaged by the  
25 first one? And, I wondered if that was a consideration

1 in the two or three--

2 MR. ENGLISH: No.

3 CHAIRMAN SIESS: --or just getting enough cycles?

4 MR. ENGLISH: No.

5 We just put in the same earthquake two or three  
6 times, with no consideration that the subsequent ones  
7 might be different in frequency counts.

8 CHAIRMAN SIESS: Okay.

9 [Slide]

10 MR. ENGLISH: The next two or three pages provide  
11 a capsule summary of the 41 component tests, and I didn't  
12 want to go over all of these with you, but only to describe  
13 what these headings are, and you can refer to them and  
14 ask any questions as we go along.

15 We show the number of the test here, the type  
16 of component, the material--as you can see, it is either  
17 carbon steel or stainless steel--and the schedule of the  
18 pipe. The residual strain, it was a cumulative ratchet  
19 strain that we measured in the component at the completion  
20 of the test.

21 In some cases we have no data because early  
22 in the program the high elongation of the gauges tended  
23 to come off of the component before the test was completed,  
24 and later we put scratch marks on the components so to  
25 be sure of getting a measurement of the cumulative strain.

1           The pressure is the internal pressure in the  
2 component, and typically the pressure is selected such  
3 that it creates a stress of 1 S of M loop stress in the  
4 component which is the ASME Code limit. Some of the  
5 lower stresses were to get immediate data points that  
6 were less than the Code limit.

7           The load direction is either in plane or out  
8 plane, typically. The ratio here of the dynamic moment,  
9 that is the measured moment in the test compared to the  
10 static limit moment, and you can see in most cases that  
11 we actually exceed the static limit moment without causing  
12 collapse of the component.

13           There are three types of loads: SSE is a seismic  
14 load. We used mid-frequency loads on a couple of components,  
15 and water hammer loading on a couple of components, and  
16 we had two static tests, but most of them were seismic  
17 tests.

18           The peak-to-peak cyclic strain is the maximum  
19 strain that was measured on the exterior surface of the  
20 component, at what we believe to be the maximum strain  
21 location, or high stress location of the component.

22           Now, the input times level D, this is the number  
23 of times the ASME Code faulted limit that the input represented.  
24 That is, if we took the input from the sled, did a linear  
25 response spectrum analysis with two percent damping, 15

1 percent broadening--just like you would have to do in  
2 a typical piping analysis--and calculated the stress in  
3 the elbow: in case 1 it would be 15 times the ASME Code  
4 allowable.

5           The number of times histories is the number  
6 of times histories that were input--20 second times histories  
7 at full amplitude of the sled before failure was induced,  
8 or before we stopped the test.

9           Typically, we would not go more than five inputs.  
10 NF means that we got no failure. FR means there was a  
11 fatigue ratchet failure.

12           Without going into any detail on these different  
13 tests, there are a couple that I might point out that  
14 were significant. If you look at 6, 7, and 8 on the first  
15 page, that was an attempt to determine the effect of mean  
16 stress on fatigue ratchet failures. You see that they  
17 are all stainless schedule 40 elbows, and test 8 has zero  
18 internal pressure, test 7 has a 1000 psi, and test 6 has  
19 1700.

20           And, if you will look over to the far right,  
21 under the number of time histories required to fail the  
22 component, you can see that as the pressure increases  
23 it took less input times to fail the component, so in  
24 effect, as we all knew, mean stress had some effect on  
25 the actual failure of the component.



1           There was one other component that I might point  
2 out that we introduced as a result of recommendations  
3 from Ev Rodabaugh. It took some convincing to convince  
4 everyone that we couldn't collapse the piping as the result  
5 of dynamic loading, and Everett suggested that one component  
6 test, Test 37, which would probably convince him, would  
7 be if we took a very low frequency component--in this  
8 case it was 1.4 hertz--and as you understood I am sure,  
9 the lower the frequency you get the closer you get to  
10 just a static collapse test--so we tested a component  
11 at 1.4 hertz with zero internal pressure--and with no  
12 internal pressure you don't get any stiffening effect  
13 from the pressure--and with that test we felt that was  
14 the bounding test of this whole program to show that collapse  
15 was not a credible mode of failure.

16           And, in this test it was somewhat excessive,  
17 in the sense that we had a very large weight stress--  
18 10,000 psi in this particular component, not the typical--  
19 in the normal operating reactive plane, and because of  
20 space limitations at Anco it couldn't--to get the frequency  
21 low, they had to put a large weight on the inertia arm,  
22 rather than bringing the inertia arm along, so we had  
23 a very large weight stress, and even with that we could  
24 not induce a collapse failure. We got what is called  
25 ratchet buckling incrementally because the large weight

1 stress it tended to bend significantly.

2 CHAIRMAN SIESS: Did you convince Mr. Rodabaugh?

3 MR. ENGLISH: I hope so.

4 MR. RODABAUGH: Yes, that did it.

5 CHAIRMAN SIESS: Good.

6 MR. ENGLISH: And, the final page of this series  
7 is just more or less a legend that indicates what the  
8 terminology is.

9 [Slide]

10 I am sure you probably have seen this. Kelly's--  
11 at Anco yesterday, he probably showed you this, where  
12 we use the interia arm to--

13 CHAIRMAN SIESS: Yes, that we heard about.

14 MR. ENGLISH: --okay.

15 [Slide]

16 This was a time history that is input on almost  
17 all of the tests. It is representative of a RPD steam  
18 nozzle, typical PDW plant.

19 [Slide]

20 You can see the response spectrum of that time  
21 history as we tune the component just slightly to the  
22 right of the peak, with the input such that it softens  
23 as it is driven up.

24 [Slide]

25 This is the mid-frequency input. It is representative

1 of a safety relief valve discharge on a BWR. It is a  
2 two-second duration. It is interesting that there is  
3 a small 7 hertz peak in this response spectrum, when the  
4 bulk of the responses we've seen in the components is  
5 the result of this peak, and practically none from the  
6 30 hertz portion of the spectrum.

7 We found that if we tilt it out at this small  
8 peak here, and only applied true mid-frequency input to  
9 the component, we have negligible response.

10 [Slide]

11 This is just to give you an example of the kind  
12 of data that we get from Anco's use of four channels out  
13 of 28 that we would be examining. On a typical component  
14 test we spread the time histories out considerably more  
15 than the Anco data. We are able to look at the cycle.

16 I show this one just to show that you can see  
17 that as the relative displacement from the top of the  
18 sled to the bottom increases, those are these peaks, and  
19 you can see the ratcheting actually occurring in the elbows.  
20 When the peaks are small there is no ratcheting. When  
21 the peaks increase again, the ratcheting is back up to  
22 a point where, in most of these cases, it will shake down.

23 [Slide]

24 Now, this slide shows that as you increase the  
25 sled acceleration for these component tests, the cyclic

1 strain initially increases relatively fast, and then tends  
2 to level off and become asymptotic somewhere between two,  
3 three, four percent cyclic strain. We believe that is  
4 because the component becomes so plastic up in this region  
5 that the plastic energy is absorbed by damping in the  
6 plastic deformation.

7 CHAIRMAN SIESS: How did you draw that curve?  
8 Whoever drew it didn't make it become asymptotic.

9 MR. ENGLISH: Well, maybe I shouldn't use the  
10 word asymptotic. It does tend to show that it doesn't  
11 increase--

12 CHAIRMAN SIESS: Well, I suspect that it might,  
13 but that looks like that these squares fit.

14 MR. SHEWMON: Is what you have there, is cyclic  
15 strain the same thing as the rise in the mean strain increases?

16 MR. ENGLISH: No, it is a cyclic peak-to-peak  
17 strain.

18 MR. SHEWMON: Okay.

19 MR. ENGLISH: We distinguish between cyclic  
20 strain and cumulative strain. Cumulative is the rise,  
21 and I'll show you that in the next slide.

22 MR. SHEWMON: Okay.

23 MR. ENGLISH: Okay.

24 [Slide]

25 This is the ratcheting strain or the cumulative

1 strain that we measure on the exterior surface of the  
2 component, and these are the number of high input runs  
3 that the component was subjected to, and it shows that  
4 the majority of the ratcheting strain occurs in the very  
5 first time history input. It also shows the effect of  
6 pressure increasing, the internal pressure, the cumulative  
7 ratcheting strain tends to increase.

8 CHAIRMAN SIESS: Does the end point represent  
9 failure?

10 MR. ENGLISH: Yes.

11 MR. SHEWMON: What is the Code allowable pressure  
12 in this piping?

13 MR. ENGLISH: 17--well, these are two different  
14 kinds, two different schedules. This is schedule 40;  
15 this is schedule 10. The Code allowable is 1700 for this  
16 schedule 40, and 800 for the schedule 10.

17 MR. SHEWMON: Okay, yes.

18 MR. ENGLISH: This is a plot that shows that  
19 as the cyclic strain on the exterior surface of the component  
20 increases the damping increases.

21 We are talking, the SSE level D is down in this  
22 low region here. These are much higher strains than would  
23 be permitted to have at level D. But, also--even though  
24 we don't have a great deal of data--it appears that the  
25 damping--for a given strain, the damping is greater in

1 these thicker pipes than in the thin scheduled 10 pipe,  
2 which implies that maybe more energy is being absorbed  
3 in the thick-walled pipe for a given surface strain than  
4 in a thin-walled pipe.

5 Now, these damping values here are strictly  
6 material damping, and you have a lot greater damping in  
7 a piping system of insulation, gaps, sliding, friction.  
8 [Slide]

9 This is a typical hysteresis loop that in this  
10 case just shows moment versus displacement for one of  
11 the components, and you can see that the curve flattens  
12 out which would tend to indicate that you have reached  
13 some kind of limit moment, but the curve reverses before  
14 the displacement can actually cause physical collapse  
15 of the component.

16 CHAIRMAN SIESS: What is that vertical line  
17 over on the right?

18 MR. ENGLISH: It has no significance.

19 MR. RODABAUGH: That's their plotter.

20 MR. ENGLISH: That's the plotter, right.

21 CHAIRMAN SIESS: That's the plotter, okay.

22 MR. ENGLISH: Yes.

23 CHAIRMAN SIESS: And, they forgot to put the  
24 zero in--

25 MR. ENGLISH: Okay.

1 [Slide]

2 Now the next couple of slides show the effect  
3 of the--or the comparison of the linear elastic analysis  
4 that we do with two percent, five percent damping--

5 CHAIRMAN SIESS: Excuse me.

6 MR. ENGLISH: --yes.

7 CHAIRMAN SIESS: Could you go back to that previous  
8 slide for just a minute.

9 MR. ENGLISH: Yes.

10 CHAIRMAN SIESS: That is the one that I was  
11 looking for.

12 MR. ENGLISH: Okay.

13 CHAIRMAN SIESS: Where does it start?

14 MR. ENGLISH: Somewhere down in here. I am  
15 not sure that it is very clear.

16 MR. RODABAUGH: I think it is a little bit above  
17 the end of that diagonal line, right across from zero.  
18 You had your pencil almost on it.

19 MR. ENGLISH: Down in here?

20 MR. RODABAUGH: Down a little bit.

21 MR. ENGLISH: Here.

22 MR. RODABAUGH: Now, up that diagonal, there.

23 CHAIRMAN SIESS: What about that little peculiar--

24 MR. ENGLISH: Well, it strain hardens as you  
25 go along.

1 CHAIRMAN SIESS: What is that little peculiar--

2 MR. ENGLISH: This was one of the better looking  
3 ones. The rest of the looked real strange. I don't think  
4 we can--

5 CHAIRMAN SIESS: I put the zero axis on it.  
6 I couldn't figure out which one it started at.

7 MR. ENGLISH: Yes.

8 CHAIRMAN SIESS: The first small loop is practically  
9 all over in the upper left quadrant.

10 Okay, go ahead.

11 MR. ENGLISH: All right.

12 [Slide]

13 As Sam indicated earlier, the elastic analysis  
14 can be non-conservative at ratios of the peak of the seismic  
15 input to the natural frequency of plus of one, and so  
16 we investigated that and at some of the component tests  
17 found that for two percent, five percent, damping with  
18 peak broadening we were able to conservatively predict  
19 the moment, compared to the measurements, so I think the  
20 peak broadening used in the calculations probably insures  
21 that the elastic calculations that we've done on these  
22 component tests are conservative.

23 CHAIRMAN SIESS: No, I'm sorry.

24 This is peak?

25 MR. ENGLISH: This is the peak of the input--



1 the frequency of the peak of the input divided by the  
2 natural frequency of the component.

3 CHAIRMAN SIESS: Okay, I see.

4 MR. ENGLISH: And, this is not linear. These  
5 are just three data points.

6 CHAIRMAN SIESS: I see.

7 MR. ENGLISH: Probably could be better represented  
8 with a bar chart.

9 [Slide]

10 This is a similar calculation showing the displacement  
11 versus the frequency ratio.

12 [Slide]

13 From the component tests we--

14 MR. RODABAUGH: I would like to make a point,  
15 I think for the benefit of--

16 CHAIRMAN SIESS: Speak a little louder, will  
17 you please.

18 MR. RODABAUGH: --some of the other committee  
19 members.

20 In some of your other tests, don't you have  
21 measurements that would not be conservatively predicted  
22 by two percent damping, or two percent broadening--displacement  
23 is what I am thinking about.

24 MR. ENGLISH: Yes.

25 The displacement is the one that--the moments

1 are--

2 MR. RODABAUGH: The moments are okay.

3 MR. ENGLISH: --always conservative, yes, but  
4 some of the displacements were a little bit screwy at  
5 times.

6 MR. RODABAUGH: Well, I think that is an important  
7 point.

8 I didn't see it on the graph here, is what I  
9 am saying.

10 MR. ENGLISH: I had to cut down the presentation  
11 to something within the time constraints.

12 MR. RODABAUGH: Yes.

13 MR. SHEWMON: Well, is your point, Ev, that  
14 the designer also specifies the maximum displacement,  
15 and that this is used and important?

16 MR. RODABAUGH: The displacement could be important  
17 in the sense that--as we were discussing yesterday--you  
18 have a motor operated valve with some cable, a certain  
19 amount of slack, now as you took off snubbers, for example,  
20 the displacement would increase. You would like to know  
21 what that displacement is so that you can look at your  
22 cable, electrical cable, and see whether it has got enough  
23 slack in it.

24 MR. SHEWMON: Okay.

25 MR. RODABAUGH: And, there are many other examples

1 of that type of thing--

2 MR. ENGLISH: Well, as Sam pointed out that  
3 is an area of non-conservatism down there and some of  
4 the calculations showed that we were okay, and others  
5 it was questionable.

6 CHAIRMAN SIESS: Put that last figure back on.

7 MR. ENGLISH: Okay.

8 CHAIRMAN SIESS: It is interesting, and I don't  
9 quite understand it.

10 This is the ratio of the applied frequency to  
11 the natural frequency--

12 MR. ENGLISH: Yes.

13 CHAIRMAN SIESS: --and that I understand, and  
14 that is the displacement.

15 MR. ENGLISH: Yes.

16 CHAIRMAN SIESS: Now, one of those curves is  
17 the measured displacement?

18 MR. ENGLISH: Right.

19 CHAIRMAN SIESS: And, then the others are the  
20 computed displacements--

21 MR. ENGLISH: At different dampings.

22 CHAIRMAN SIESS: --elastic analysis, single  
23 degree of freedom--

24 MR. ENGLISH: Yes, that is it.

25 CHAIRMAN SIESS: --at different damping, okay.

1 Now, I understand, thank you.

2 MR. ENGLISH: Okay.

3 We are not implying that we are--that elastic  
4 analysis is good across the board. As Sam pointed out,  
5 that's an area of concern which we are still trying to  
6 decide whether to use peak broadening, or what is supposed  
7 to be done. In these couple of cases, it looked like  
8 we had done a pretty good job. We haven't looked at every  
9 single case by any means.

10 [Slide]

11 So the observations from the component tests  
12 are that the dynamic load reversal, we believe, is what  
13 prevents collapse. The seismic loads behave more like  
14 secondary than primary, and the ratchet failure loads  
15 are much greater than the SSE. The ratcheting doesn't  
16 impair functionality, the diameters tend to increase,  
17 rather than decrease.

18 The damping for large dynamic loads, bigger  
19 than the SSE is certainly greater than the reg guide would  
20 permit. The amplified high frequency SRV loads cause  
21 negligible response to the component.

22 So, the bottom line we were trying to show from  
23 these component tests was that failures were not collapse  
24 type failures as the current Code indicates they might be,  
25 but rather fatigue and fatigue ratcheting types of failures.

1 [Slide]

2           The system tests main objectives were more confirmatory  
3 to confirm that the failure mode was as observed on  
4 the component tests, using either three or four sleds,  
5 and confirmed the effects of low- and mid-frequency loadings.  
6 To determine a system damping for a number of different  
7 kinds of configurations we looked at systems with balanced  
8 stress, high stress everywhere, unbalanced stress, different  
9 time histories inputs at different sleds, with or without  
10 snubbers and struts.

11           We also wanted to confirm that the functionality  
12 was not violated, compromised, and conformed the design  
13 rules and margins that we'd observed--

14           CHAIRMAN SIESS: Now, when you say "functionality"  
15 you are limiting yourself to the pipe?

16           MR. ENGLISH: Yes.

17           CHAIRMAN SIESS: And, not the valve operators.

18           MR. ENGLISH: Yes, yes, that is right.

19           CHAIRMAN SIESS: Okay.

20           MR. ENGLISH: Okay.

21 [Slide]

22           The major focus on this program has been piping,  
23 and it has been indicated that it would be nice to look  
24 at supports, too, but--

25           CHAIRMAN SIESS: And, the valves were there

1 simply to provide loadings.

2 MR. ENGLISH: And, to get a little bit more  
3 information--it was kind of a, you know, piggy back type  
4 test.

5 CHAIRMAN SIESS: Right.

6 MR. GUZY: I think we should point out in that  
7 system 1 test, there was a valve that we operated--

8 CHAIRMAN SIESS: Yes, yes.

9 MR. GUZY: --and we do have limited information  
10 on that.

11 CHAIRMAN SIESS: That was the piggy back.

12 MR. GUZY: Right.

13 MR. ENGLISH: So, you have seen this. There  
14 is an operational hanger and an operational valve. This  
15 pressure vessel has a vesselette that simulates--

16 CHAIRMAN SIESS: We saw that.

17 MR. ENGLISH: --and it has an R over T ratio  
18 that is typical of a reactive pressure vessel, even though  
19 it is very small.

20 [Slide]

21 I think you have seen this stress summary--

22 CHAIRMAN SIESS: No, we haven't.

23 MR. ENGLISH: The only thing I wanted to--

24 CHAIRMAN SIESS: No, we haven't seen that.

25 MR. ENGLISH: --oh, you haven't seen this?

1           Okay, this was a pre-test calculation, mainly  
2   to try to identify the location of where a failure would  
3   likely occur, and to make sure that the stresses in this  
4   particular system are relatively high, and relatively  
5   uniform throughout the system.

6           This was a high-stress system. Stresses were  
7   calculated using ASME Code techniques, and we identified  
8   this short radius elbow as the highest stress location.  
9   The 1 means the highest stress; 2 means the next highest  
10   stress location.

11           So, the Code calculation, in fact, was successful  
12   in predicting the failure location for this particular  
13   test.

14           MR. BUSH: Bill, can I ask you a question?

15           MR. ENGLISH: Yes.

16           MR. BUSH: It is kind of a follow-up on something  
17   that I said earlier.

18           Now, in this instance you had a--I think this  
19   is the one where they had a valve--

20           MR. ENGLISH: Yes, correct.

21           MR. BUSH: --okay, and on the basis of either  
22   a pump or a valve on the inherent thickness--or inherent  
23   stiffness, it is necessary to provide the function. In  
24   other words, you can't have the body of the pump weaving  
25   all around or it won't pump water, and the valve the same

1 thing is true, so as the result they are much, much thicker  
2 than would be calculated on the basis of Code allowable.

3 It would seem to me that on a simple analytic  
4 basis you could pretty well establish that the body of  
5 a pump or of a valve, whether cast or wrought--and most  
6 of them are cast, and whether stainless or ferritic--  
7 probably is not a factor--

8 MR. ENGLISH: Because the stress is so much  
9 lower.

10 MR. BUSH: --because the stresses are so low  
11 that you can basically--it is just like a rigid object  
12 sitting there, and you could probably, in a relatively  
13 straightforward fashion dismiss them, which would remove  
14 about 95 percent of my concern with regard to the system,  
15 because I worry if you kind of ignore pumps and valves,  
16 because there are an awful lot of valves in this pipeline system.

17 MR. ENGLISH: I might point out that this valve  
18 did not lose pressure integrity through the whole test,  
19 and it was identified as a high stress location. And,  
20 in any event it saw G loadings well in excess of what  
21 its rating is.

22 [Slide]

23 These are the various runs that I am sure that  
24 Spence discussed with you yesterday. We looked at uniform  
25 input, and we looked at independent support motion input.



1 [Slide]

2 These are the tables, all the way up to full  
3 table capacity.

4 [Slide]

5 And, I think you probably saw the fail component,  
6 the crack initiated in the elbow bent center, and propagated  
7 around the elbow, which is where the ASME Code calculations  
8 had predicted it would occur.

9 [Slide]

10 This is a summary of system test 1 at that short  
11 radius elbow. You can see, depending upon whether you  
12 assume two percent damping or five percent damping, the  
13 stress was a large number times the total allowable fault  
14 conditions. The stress at the SSE input was about half  
15 a level D limit. There was no ratchet strain at that  
16 level. At three to five times the level D limit we only  
17 had a quarter percent ratchet strain, and no ratchet displacement.  
18 The staff was questioning us back in September about how  
19 much ratchet displacement in the piping system as the  
20 result of these large dynamic loads, and it wasn't until  
21 we got up to very large loads, up to half the table capacity,  
22 that we got any significant ratchet displacement in the  
23 piping system.

24 CHAIRMAN SIESS: Why was the ratchet strain  
25 larger at half than full?

1 MR. ENGLISH: This is the strain during that  
2 run, and the component failed early.

3 MR. SHEWMON: What are the units on these first  
4 set of numbers up there?

5 MR. ENGLISH: These?

6 MR. SHEWMON: Yes.

7 MR. ENGLISH: They are non-dimensional, just  
8 a multiple times level D.

9 CHAIRMAN SIESS: So it is a multiple of level  
10 D, okay.

11 MR. ENGLISH: Yes.

12 CHAIRMAN SIESS: So, the SSE was 8/10ths?

13 MR. ENGLISH: Yes, 8/10ths of level D, right.

14 MR. SHEWMON: Now, then I guess I am--the inputs  
15 known, and if you assume a five percent damping, then  
16 it is 24 X D--

17 MR. ENGLISH: Right.

18 MR. SHEWMON: --and if you assume at two percent,  
19 it is 42--

20 MR. ENGLISH: Right, yes.

21 MR. SHEWMON: --okay, I see.

22 MR. ENGLISH: It is how you calculate it, really  
23 determines what the ratio is.

24 I think the other significant thing here is  
25 that at these relatively low stress levels the damping

1 wasn't any higher than the N-411 would permit you to use  
2 today, even though, again, this is material damping, and  
3 damping at the plant would be considerably higher than  
4 that.

5 CHAIRMAN SIESS: What would you call relatively  
6 low? The SSE? Well, even the five SSE--

7 MR. ENGLISH: Yes.

8 CHAIRMAN SIESS: Yes.

9 MR. ENGLISH: These two.

10 CHAIRMAN SIESS: Yes.

11 MR. ENGLISH: This is not relatively, it is  
12 relatively low compared to the full table.

13 I think the one message from these system tests  
14 that it just takes one hell-of-a-lot of load, seismic  
15 load, to break a piping system, or even to damage it.  
16 [Slide]

17 I did have a couple of slides here that again  
18 Spence may have shown you yesterday. This is the strain  
19 gauge on the elbow that failed, and it shows that the  
20 half table run, the ratcheting that occurs, and in fact  
21 the ratcheting continued on up after the sensor departed  
22 the scene.

23 [Slide]

24 And, this is the accompanying ratchet displacement  
25 at the top of the piping system. You can see these large

1 swings of 14 inches, or so, peak to peak, the top of the  
2 piping system, and when it finally came to rest after  
3 a half-table input, the final displacement was only about  
4 an inch from where it started initially, so that ratchet  
5 displacement of these piping systems doesn't seem to be  
6 of concern.

7 The zero is right here in the middle.

8 CHAIRMAN SIESS: Computers are funny that way.

9 MR. RODABAUGH: That one ratcheting figure here  
10 that you showed us, this is gauge failure?

11 MR. ENGLISH: Yes.

12 MR. RODABAUGH: Then the sensor apparently kept  
13 saying it was a high strain, even though it failed?

14 MR. ENGLISH: That is what it looked like.

15 MR. RODABAUGH: Yes, okay.

16 CHAIRMAN SIESS: At least it shows a high resistance.

17 [Slide]

18 MR. ENGLISH: This is again an attempt to show  
19 that the linear elastic analysis that we do in piping  
20 gives conservative results, especially conservative at  
21 the high input levels. We calculated the moments. The  
22 moments are what we use to calculate the allowable stresses--  
23 or calculate the stresses in the piping system.

24 Once again, as Ev has pointed out earlier, the  
25 displacement calculations don't have that much conservatism

1 in them, but they are a pretty good approximation of the  
2 displacement at low inputs, and somewhat conservative  
3 at the high inputs--at least with the specter that we  
4 use.

5 MR. SHEWMON: Now, is moment, the calculated  
6 moments that you have here is something you get from a  
7 stress--a strain you would get out of a strain gauge,  
8 or what?

9 MR. ENGLISH: These moments are calculated--  
10 yes, they are.

11 MR. SHEWMON: Okay.

12 MR. ENGLISH: They are an adjacent part of the  
13 component that remains elastic. We had a big thick component  
14 adjacent to the elbow that stays elastic.

15 MR. SHEWMON: I see.

16 MR. ENGLISH: Okay.

17 [Slide]

18 A system two was a system of unbalanced stress,  
19 and it used a fabricated nozzle rather than a forged nozzle,  
20 and it had a snubber, and all of the valves in this system  
21 are simulated there, they are no operational valves.

22 Four sleds were used in system 2, rather than  
23 three, and we used stainless steel as the material. I  
24 don't know whether they mentioned to you yesterday that  
25 we were attempting to simulate 316 nuclear grade material,

1 and we did that by selecting 316 L with 316 mechanical properties  
2 which is the least expensive way to try to simulate 316  
3 nuclear grade.

4 MR. BUSH: [out of hearing range]

5 MR. ENGLISH: Well, it was low carbon and high  
6 strength. It was hand picked for the components.

7 MR. BUSH: Yes, but did you use ELC grade? Or  
8 did you use the 316?

9 MR. ENGLISH: The 316 L, hand selected--

10 MR. BUSH: Okay, I misunderstood, so what you  
11 really had was what is in the upper part, the right hand,  
12 so you are closer to what you'd expect to get--

13 MR. ENGLISH: Right.

14 MR. BUSH: --in the increased strength because  
15 of that.

16 MR. ENGLISH: Yes.

17 [Slide]

18 This is a stress summary for a system 2, and  
19 you can see this nozzle was the area of high stress. It  
20 was a factor of two higher than anyplace else in the piping  
21 system, and again the ASME Code calculations correctly  
22 predicted the location of the failure in this system.

23 Again then--

24 MR. BUSH: And, that nozzle must have been a  
25 fairly stiff one so that the load was pretty much translated

1 to the interface between the nozzle and the vessel?

2 MR. ENGLISH: Yes, yes.

3 [Slide]

4 These are the inputs that are essentially the  
5 same as we used in system test 1, with the exception of  
6 the sine sweep input, and it turns out that the fatigue  
7 usage introduced into the nozzle was significantly increased  
8 by this sine sweep input, as compared to even the full  
9 table input. Sinusoidal input has a much more marked  
10 effect on the tee uses than the random nature of the seismic  
11 inputs.

12 CHAIRMAN SIESS: You get more maximum cycles.

13 MR. ENGLISH: And, in fact, I am sure they indicated  
14 to you yesterday, they started to see surface cracking  
15 right after the sine sweep input.

16 [Slide]

17 And, this is just to show you that the cracks  
18 actually occurred on the side of the fabricated nozzle  
19 out at this--adjacent to the well, the vessel interface.

20 CHAIRMAN SIESS: What was ISM correlated?

21 MR. ENGLISH: That is--

22 CHAIRMAN SIESS: To the input side?

23 MR. ENGLISH: --independent, oh, okay.

24 MR. ENGLISH: Inputs in the different sleds,  
25 and we had an inface, outface.

1 CHAIRMAN SIESS: Okay.

2 MR. ENGLISH: Again, I wanted to show you this  
3 relationship.

4 [Slide]

5 The relationship between the local ratchet strain  
6 and the high stress component and the net residual displacement  
7 in the piping system, such that even though we get a large  
8 residual, local strain, ratcheting strain on the component,  
9 the piping system itself comes back to its initial starting  
10 position in this particular case.

11 CHAIRMAN SIESS: Go back one.

12 [Slide]

13 MR. ENGLISH: This is the ratchet strain in  
14 that nozzle that failed.

15 MR. ENGLISH: Okay.

16 Now, what is the big step in there?

17 MR. ENGLISH: You have this high displacement,  
18 you immediately get large ratcheting, local ratchet strain,  
19 but that doesn't translate into a large displacement of  
20 the piping system. The piping system, even though it  
21 is vibrating, it could be 16 inches peak to peak, it still  
22 comes back to rest because the load is redistributed and  
23 there is no permanent deformation of the piping system.

24 CHAIRMAN SIESS: Okay.

25 MR. ENGLISH: Okay.



1 [Slide]

2 This again is an attempt to show that linear  
3 elastic analysis is very conservative at the high load  
4 level and reasonably good at the low load level, again  
5 with peak broaden in all of these calculations. That  
6 is a displacement in the moment calculations.

7 [Slide]

8 So the observations from the system test, I  
9 think, could be summarized as followed: We confirmed  
10 that fatigue ratcheting again was the failure mode, as  
11 we expected. Failure loads are much greater than the  
12 SSE. The functionality was not impaired. Damping was  
13 very large, much greater than R.G. at these levels that  
14 we obtained failure.

15 MR. SHEWMON: Now is the Reg Guide the same  
16 as what was called the Code case N-411?

17 MR. ENGLISH: No, that is five percent damping.  
18 They are a little different.

19 MR. SHEWMON: Oh, okay.

20 MR. ENGLISH: The damping is also bigger than  
21 the Reg Guide--

22 MR. SHEWMON: Yes.

23 MR. ENGLISH: --also than the Code case--

24 MR. SHEWMON: I was just wondering if the Reg.  
25 Guide had caught up with the Code case yet?

1 MR. ENGLISH: It is catching up, but it is not  
2 there yet.

3 And, the amplified safety relief valve loads  
4 are very small. When we filtered out that small seven  
5 hertz peak we got practically no response.

6 I think, again, the bottom line is that piping  
7 is the result of--in seeing these tests--just extremely  
8 difficult to fail, and I am sure you all realize by now  
9 that the building will fall long before the piping system  
10 is going to fail.

11 MR. SHEWMON: I am not so sure of that.

12 MR. BUSH: Well, the great Alaska earthquake  
13 pictures.

14 CHAIRMAN SIESS: Well, I'll admit, you found  
15 more buildings that fall down during earthquakes than  
16 you ever found piping that failed.

17 MR. ENGLISH: Yes.

18 [Slide]

19 I've separated out the water hammer testing  
20 because we've come to somewhat different conclusions from  
21 the water hammer testing than from the seismic and low  
22 frequency testing.

23 We have two component tests that are really  
24 two small loops, about 50 long, six inch in diameter,  
25 carbon steel and they have been tested with and without

1 supports.

2 CHAIRMAN SIESS: Well, we saw both of those.

3 MR. ENGLISH: You saw both of those yesterday?

4 The mini-system test is considerably longer  
5 and it has supports, branches, vessels, thin pipes.

6 [Slide]

7 And, these are different kinds of loads that  
8 we have conducted--Anco has conducted--simulated steam  
9 hammer, hard system acoustic test, the water slug, and  
10 various gravity pressures.

11 MR. BUSH: In the steam hammer, you are--

12 CHAIRMAN SIESS: Little louder, Spence, we can't  
13 quite hear you.

14 MR. ENGLISH: Steam hammer is more like the hard  
15 systems test, you have a pipe that is just full of air  
16 and you pressurize it up stream at 1000, 2000 psi, compress  
17 the diaphragm and watch the reflective wave in air, rather  
18 than in water. It is not steam, but it is a gas rather  
19 than a liquid.

20 MR. BUSH: And, the loads from that steam hammer?

21 MR. ENGLISH: The lowest of the three categories  
22 of loading.

23 [Slide]

24 Now, you stop me if you have seen all of this.

25 CHAIRMAN SIESS: Well, we've seen the next two

1 slides, yes.

2 MR. ENGLISH: Okay.

3 [Slide]

4 Okay, these are the preliminary observations  
5 from the water hammer test, and I say they are preliminary  
6 because the second mini-systems test was just finished  
7 yesterday, or the day before.

8 But, at any rate, as the result of what we know  
9 already, the water slug definitely the primary type loading  
10 that can cause collapse of piping systems, and we would  
11 probably say in equation 9, and in fact maybe all of these  
12 water hammer loads should be in equation 9 with some kind  
13 of a relief on the allowable.

14 MR. SHEWMON: Equation 9?

15 MR. ENGLISH: It is a piping design, sort of  
16 a fundamental piping design equation which is based on  
17 collapse of the component.

18 MR. RODABAUGH: I will write you later, but  
19 I will reserve judgment on that, because I am not so sure  
20 that water hammer is that much different than earthquake.

21 MR. ENGLISH: Good, glad to hear that.

22 Well, I think the steam hammer and the hard  
23 test certainly behave more like secondary loading. They  
24 didn't collapse the pipe, even though the limit moment  
25 was exceeded and so we tend to be more inclined to categorize

1 those as secondary.

2 CHAIRMAN SIESS: Which was the loading that  
3 picked that pipe up, up against the--

4 MR. ENGLISH: That is the water slug test.

5 CHAIRMAN SIESS: That is the water slug test.

6 MR. ENGLISH: Yes.

7 MR. SHEWMON: I'm interested to see Everett's  
8 letter on the water slug test.

9 MR. RODABAUGH: What I am thinking about, Chet,  
10 is remember this is a loop that went all around that building,  
11 and the end, when you got down to the end was free.

12 MR. ENGLISH: Right.

13 MR. RODABAUGH: Now, if you compare that with  
14 your elbow test, where you had that long, I think, but  
15 very, very short length of pipe when compared to this  
16 huge loop.

17 MR. ENGLISH: Yes.

18 MR. RODABAUGH: I would like to think about  
19 it a bit more before I said that there is really that  
20 much difference between the two.

21 MR. ENGLISH: All right.

22 MR. BUSH: Are you arguing about the primary  
23 versus the secondary, or about the test per se?

24 MR. RODABAUGH: Well, both.

25 I think other people have brought up the point

1 that if you had a pipe that long you would surely have  
2 a second anchor someplace.

3 MR. ENGLISH: Yes, yes, this was definitely  
4 more severe than you would expect to see in a power plant.  
5 We have had that comment made by others, that in the power  
6 plant the piping terminates at a heat exchanger pump,  
7 or vessel, or something. It doesn't just hang out in  
8 the breeze like that one did.

9 MR. RODABAUGH: Or a containment--

10 MR. ENGLISH: Or containment, yes.

11 MR. RODABAUGH: --and it breaks there.

12 MR. ENGLISH: Right.

13 [Slide]

14 We also found that supports could tolerate dynamic  
15 loads up to ten times more than a rated load, and it looks  
16 like, based on the telephone conversations yesterday with  
17 Anco, that piping can tolerate transient pressures maybe  
18 one to two times the burst pressure without actually rupturing.

19 We had a section of schedule 10 pipe put in  
20 the second mini-system test and we were unable to break  
21 that with the loads that they tested.

22 I think, at this point, that the basic rule  
23 is still to design to avoid water hammer.

24 CHAIRMAN SIESS: When you say two times the  
25 burst pressure, that is the static burst pressure?

1 MR. ENGLISH: Yes.

2 CHAIRMAN SIESS: And, the design pressure would  
3 be at what ratio of that?

4 MR. ENGLISH: The burst pressures are, I think,  
5 around 4700 psi, and design pressure would be 800.

6 CHAIRMAN SIESS: So, there is that kind of a  
7 factor in there?

8 MR. ENGLISH: Yes.

9 MR. BUSH: Let me ask an embarrassing question.  
10 When you consider a straight section 10, if  
11 you would have put a section 10 elbow at that first location,  
12 what do you think would have happened?

13 MR. TAGART: Do you mean schedule 10?

14 MR. BUSH: I'm sorry, not section, schedule.

15 MR. ENGLISH: I don't think it would have ruptured.

16 MR. BUSH: Well, I am much less optimistic than  
17 you are.

18 CHAIRMAN SIESS: Are you making calculations  
19 that will enable you to answer that kind of a question?  
20 Or, is this strictly empirical?

21 MR. ENGLISH: I would say that it is pretty  
22 much empirical at this point.

23 [Slide]

24 Incidentally, there is a typo in your handout,  
25 this 1 dash was left out, and there was another typo.

1 I have forgotten where it is.

2 CHAIRMAN SIESS: What is that?

3 MR. ENGLISH: One to two. We know the pressure  
4 is higher than the burst pressure, but we don't know,  
5 you know, we are just getting the information over the  
6 phone at this point, so perhaps we shouldn't have even  
7 put that in there. We haven't seen the data yet.

8 [Slide]

9 And, on this systems test 2, the damping down  
10 at the bottom of the page, there are a couple of errors  
11 there, particular, the five and a five and a 22, that  
12 should be 5.235.

13 [Slide]

14 Okay, the specimen test, as I indicated earlier,  
15 that the objective was to develop a lab specimen that  
16 could give us some quantitative evaluations of fatigue  
17 ratcheting with mean stress.

18 We also wanted to be able to correlate the behavior  
19 specimen with the components, and extrapolate conclusions  
20 from the four test materials--the four materials that  
21 were tested to other piping materials, and as Roy indicated  
22 in one of the progress reports, that two of the materials  
23 are non-strain, softening or hardening. One is strain  
24 softening, and one is strain hardening, and two are stable,  
25 and we wanted to investigate the fatigue ratcheting effects



1 at 550, which you could really on do practically with  
2 specimen tests.

3 [Slide]

4 This is a matrix of the specimen test--excuse  
5 me, I'm sorry.

6 MR. SHEWMON: All those materials that you used  
7 for strain hardening in the tensile tests, so when you  
8 say they are strain softening, you are implying after  
9 a certain number of cycles and certain kind of a test.

10 Would you define that a little bit better? How  
11 may cycles?

12 MR. TAGART: It is a cyclic fatigue test.

13 MR. SHEWMON: Yes.

14 MR. TAGART: You do a low-cycle fatigue test,  
15 and the stress range increase for a given strain range  
16 as you progress--

17 MR. SHEWMON: And, this is a distress with--  
18 low cycle is anything under 1000 cycles of failure, as  
19 I recall.

20 So, you are in that range with a lot of cycles,  
21 is that it?

22 MR. TAGART: Well, it varied, depending on what  
23 strain range you put on it initially, but they are all  
24 characterized--when we say softening we mean that after  
25 some initial hardening it begins to lower the stress range

1 with the number of cycles.

2 CHAIRMAN SIESS: Now, these are controlled strain  
3 tests?

4 MR. TAGART: Yes.

5 CHAIRMAN SIESS: So the stress--

6 MR. ENGLISH: Now there are 140 component tests  
7 here, of which 48 were--excuse me?

8 CHAIRMAN SIESS: Forget it, go ahead.

9 MR. ENGLISH: The majority of the tests were  
10 two-bar tests.

11 [Slide]

12 This is a two-bar milimodel where you have two  
13 bars with rigid ends, you apply a fixed-mean load and  
14 you cycle one of the two bars, let's say by heating, such  
15 that that bar is in compression with other bars in tension,  
16 and it turns out in this testing program the bar that  
17 is being heating is simulated by a computer and the testing  
18 is done on a single-uniaxial specimen.

19 Most of the testing in the program, as you can  
20 see, is done using this two-bar technique, and then the  
21 verification test done with beams and pressurized pipe,  
22 to show that the two-bar tests are conservative.

23 CHAIRMAN SIESS: Now, the two-bar test are not  
24 two bars.

25 MR. ENGLISH: It is just one bar.

1 CHAIRMAN SIESS: I see.

2 MR. ENGLISH: It is just this bar with the testing  
3 machine, computer controlled to simulate the effects of  
4 the second bar on this first bar.

5 CHAIRMAN SIESS: What is the object of the two-  
6 bar test, originally?

7 MR. ENGLISH: It is a simple way of measuring  
8 ratcheting, mean stress.

9 And, that two-bar test was verified with--

10 CHAIRMAN SIESS: Before you had computer controlled  
11 testing machines?

12 MR. ENGLISH: Yes.

13 [Slide]

14 The rectangle beam specimen looks like this  
15 and it is tested with an applied axial load and an alternating  
16 bending load, and that fits into this machine, in this  
17 region here. these springs apply the static load and then  
18 the full-point bending is done by the actuator here.

19 CHAIRMAN SIESS: Is that a strain control?

20 [General discussion by several speakers.]

21 MR. RODABAUGH: Chet asked the question: is this  
22 strain controlled, and he said, "Yes."

23 CHAIRMAN SIESS: A little louder, Ev, please.

24 MR. RODABAUGH: You asked the question: is it  
25 strain controlled? And--

1 MR. ENGLISH: I guess it--is it load control?

2 MR. RODABAUGH: --no, it is some of both, is  
3 the point.

4 MR. RANGANATH: It is initially strain controlled.

5 MR. RODABAUGH: The bending is strain controlled,  
6 but see those big springs on the end--

7 MR. RANGANATH: That is prime mean load.

8 MR. RODABAUGH: --yes, it is load controlled.

9 MR. ENGLISH: So, it is attempting to simulate  
10 the ratcheting.

11 [Slide]

12 The observations from the specimen tests to  
13 date are that the two-bar test is a conservative representation  
14 of the ratcheting on cyclic life. The beam and pipe specimens  
15 confirmed that the two-bar test is conservative. We found  
16 that if you have controls on the cumulative ratchet strain,  
17 that is if you don't permit significant large ratcheting  
18 to occur, you get in fact a fatigue type failure, and  
19 that with controls on the ratchet strain the mean stress,  
20 then the temperature doesn't effect the cyclic fatigue  
21 life.

22 And, we observed some cyclic creep in these  
23 tests that were done at MCL, and the creep occurs in the  
24 testing which is done at about two minutes per cycle.  
25 It is a very slow test. We've identified some creep

1 in these tests, but we don't think it is going to be present  
2 in the seismic test.

3 CHAIRMAN SIESS: This is creep in the axial  
4 direction?

5 MR. ENGLISH: Yes.

6 MR. SHEWMON: Are the basis for these conclusions  
7 written up in a paper that has been submitted, yet?

8 MR. ENGLISH: No.

9 MR. TAGART: No, not yet.

10 MR. ENGLISH: The whole program will be written  
11 up soon.

12 MR. TAGART: This will be one of three papers.

13 MR. SHEWMON: Okay, I would like to see this  
14 one.

15 CHAIRMAN SIESS: What rate are these run at?

16 MR. ENGLISH: These are run at a rate of 1000  
17 times faster frequency--higher frequency than these tests,  
18 so we think the cyclic creep that has been observed in  
19 these low frequency tests probably won't be present in  
20 any significant degree in the seismic tests.

21 CHAIRMAN SIESS: How many cycles?

22 MR. ENGLISH: Well, these tests are two minutes  
23 per cycles, and the seismic tests are like eight cycles  
24 per second.

25 CHAIRMAN SIESS: And, now many cycles did you

1 get per failure?

2 MR. ENGLISH: In these tests?

3 CHAIRMAN SIESS: In these specimen tests?

4 MR. ENGLISH: Oh, gosh, it depends on the strain  
5 range, but hundreds, thousands.

6 CHAIRMAN SIESS: Hundreds, yes.

7 MR. BUSH: You don't distinguish whether  
8 you are talking about--on that last bullet, on room temperature  
9 or elevated temperature, or both?

10 MR. ENGLISH: Both.

11 MR. BUSH: It is both. I thought it might  
12 be, but I wasn't sure.

13 MR. ENGLISH: Okay.

14 MR. RODABAUGH: Bill, you have one other type  
15 of test, the pipe test, pressurized pipe test.

16 MR. ENGLISH: Pressurized pipe test?

17 MR. RODABAUGH: The last in your list of specimen  
18 tests.

19 MR. ENGLISH: Oh, oh, yes. I didn't show that  
20 picture. I don't have a cross-sectional drawing, but  
21 it is just a small piece of steel pipe, and it failed  
22 at the grips where the pipe is being held by the testing  
23 machine.

24 MR. RODABAUGH: I was mentioning the rubberband  
25 aspect of it.

1 MR. ENGLISH: Oh, yes.

2 It turns out in the specimen test, the pressurized  
3 pipe test, the rubberbands on the exterior--oh, you have  
4 already heard about that?

5 CHAIRMAN SIESS: No, no, go ahead. I would  
6 like to hear it again.

7 MR. ENGLISH: I am not sure--

8 MR. RANGANATH: It is on page 374.

9 MR. SHEWMON: On 374?

10 MR. RANGANATH: On 3-74.

11 MR. ENGLISH: It is pretty interesting to see  
12 that a rubberband could actually cause deformation in  
13 a pressurized pipe.

14 CHAIRMAN SIESS: Well, is that good or bad?

15 MR. ENGLISH: I'm not sure.

16 [General discussion]

17 MR. BUSH: It is surprising.

18 MR. TAGART: Damping is very difficult to predict  
19 exactly, and ratcheting is very difficult to predict exactly.

20 CHAIRMAN SIESS: Does that conclude your presentation?

21 MR. ENGLISH: Yes.

22 CHAIRMAN SIESS: Are there any further questions?

23 [No response.]

24 MR. ENGLISH: Sorry to run over.

25 CHAIRMAN SIESS: No, no, you were right on schedule.

1 We started late. We are doing real good, unusually good.

2 Okay, Mr. Ranganath.

3 MR. RANGANATH: Thank you.

4 [Slide]

5 I am going to briefly cover potential design  
6 rule changes that we may look at as the result of the  
7 data that we have generated here.

8 I want to emphasize the word "potential" because  
9 we are still evaluating it, and what I am going to talk  
10 about, it kind of gives you a flavor of the direction  
11 we are going in. We may in fact change some of the exact  
12 numbers that we have, either recommendations, that I will  
13 explain here.

14 Now, I am going to talk about three items, kind  
15 of like what were the conclusions from these component  
16 and system tests, and regards to design rule development?  
17 What did we learn from the specimen fatigue and ratcheting  
18 tests? And, I also am going to give you a little more  
19 of a description of the single degree of freedom model  
20 analysis that we did as it relates to the inelastic dynamic  
21 response as well as ratcheting.

22 And, from that I will try to make some conclusions  
23 relative to the elastic analysis, make some proposals  
24 on rule changes, and briefly remark on what the long-  
25 term goal might be in terms of this proposed design rule



1 changes.

2 CHAIRMAN SIESS: Let me interrupt you for just  
3 a minute.

4 MR. RANGANATH: Yes.

5 CHAIRMAN SIESS: Could you at some point give  
6 us a little picture of what the design rules on now, for  
7 example, what equation 9 is, and how it relates to equations  
8 1 through 8?

9 I am sure that some of the people at the far  
10 end of the table are quite familiar with this, and some  
11 in the middle may be.

12 MR. RANGANATH: Yes, I am going to do that.

13 [Slide]

14 Now, this has been said many times: the component  
15 system test, we just couldn't fail the thing, even though  
16 we went to well in excess of what the level D allowables  
17 might be, and in fact we could not have any collapse effect,  
18 so no limit load--

19 CHAIRMAN SIESS: Level D is faulted?

20 MR. RANGANATH: --level D is faulted--

21 CHAIRMAN SIESS: That is everything you can  
22 think of?

23 MR. RANGANATH: Right, right.

24 CHAIRMAN SIESS: Thrown in there?

25 MR. RANGANATH: Right.

1 CHAIRMAN SIESS: That is the highest level?

2 MR. RANGANATH: That is correct.

3 CHAIRMAN SIESS: It doesn't get any worse than  
4 D, then?

5 MR. RANGANATH: Yes.

6 CHAIRMAN SIESS: Okay.

7 MR. RANGANATH: We didn't see any limit load  
8 failures, and again maybe this is the time to talk about  
9 the equation 9. Equation 9 just says that in effect we  
10 can call it without confusing the issues. There are some  
11 constants,  $M$  over  $Z$ , less than some allowable, call it  
12 here 1.5  $S$  of  $M$ .

13 What it is then, this is the pressure stress,  
14 okay, this is the actual pressure stress, this is the  
15 bending moment that includes the seismic weight and so  
16 on, and these are generally multiplied by a figure which  
17 was determined in large part by some tests done by Markl  
18 in the beginning, and Ev Rodabaugh himself lead to a lot  
19 of these indices. These are called B-2 indices.

20 CHAIRMAN SIESS: Are they factored greater or  
21 less than one?

22 MR. RANGANATH: Some are less than one, but  
23 most of them are greater than one.

24 CHAIRMAN SIESS: Now, just to let you know what  
25 level you are talking to, what is  $S$  of  $M$ ?

1 MR. RANGANATH: S of M is what's called as a  
2 design stress intensity that established by the ASME Code.  
3 It is generally quoted to the lower of two-thirds of the  
4 yield strength, or one-third of the ultimate.

5 So, anyway, it says you have a factor of three  
6 margin on pressure for ultimate strength.

7 CHAIRMAN SIESS: Well, they call it a stress  
8 intensity, and the units are stress?

9 MR. RANGANATH: That's correct. It is nothing  
10 to do with the stress intensity factor.

11 CHAIRMAN SIESS: It is a stress?

12 MR. RANGANATH: Right.

13 CHAIRMAN SIESS: It is an inelastic strain.

14 MR. RANGANATH: Right.

15 So, and again these are all done on a pseudo-  
16 elastic basis so if you look at--

17 CHAIRMAN SIESS: Then 1.5 S of M, might be the  
18 yield stress?

19 MR. RANGANATH: For carbon steel it is. For  
20 stainless steel it is a little higher than the yield strength,  
21 but as a rule it is--

22 MR. RODABAUGH: Since Chet asked about level  
23 D, specifically, you have been talking about SSE, why  
24 don't you put a 3 out there?

25 MR. RANGANATH: Right, okay.

1           This is for what is called a design condition,  
2   and 3 S of M is what is called as the level D.

3           CHAIRMAN SIESS: Design, in terms of seismic  
4   would be OBE?

5           MR. RANGANATH: That is correct.

6           CHAIRMAN SIESS: But, there are some other things  
7   also that are in there, design and--

8           MR. RANGANATH: Right, yes, it will be the design  
9   pressure plus all of the loads.

10          CHAIRMAN SIESS: Yes.

11          MR. RANGANATH: Now, when we did get failure,  
12   failure was predominantly due to a combination of fatigue  
13   and ratcheting, so that accounts for emphasizing that  
14   we ought to be focusing on those.

15          But, even when we did get failures by fatigue  
16   and ratcheting, we were able to have the number of cycles  
17   it took to cause failure was well in excess of what you  
18   would, for example, expect in one level D event, like  
19   many of the tables that Bill showed you had two, three,  
20   four times full cycles of this level D transient, so that  
21   shows that you have got a lot of margin even there, too.

22          Analysis of the test shows that elastic prediction  
23   are generally conservative for response spectrum analysis  
24   with peak broadening for up to five percent damping. You  
25   know, you recall that Bill showed you this comparison

1 of displacement and moment, and--

2 CHAIRMAN SIESS: I am not sure that I buy the  
3 two or three cycles, the two or three inputs, as well  
4 in excess of an SSE.

5 That could be an SSE plus one good after shock,  
6 or two after shocks, and if I recall we've had earthquakes  
7 where the second shock was much greater than the first,  
8 and I think there have been three well up in there. Now,  
9 there can be considerable time between the first and the  
10 second--

11 MR. SHEWMON: A year.

12 CHAIRMAN SIESS: --not this one, as one was  
13 in December and one was in January.

14 [laughter]

15 Now, if we had the first earthquake, obviously  
16 the plant would be shut down, but the second one could  
17 bust some pipe and they may be required to move the KE  
18 except there would be a lot less, but again we frequently  
19 get an after shock within a day or two, and sometimes  
20 within hours. It usually is smaller than the first one.

21 But, again, I am, you know, we are sort of--

22 MR. RANGANATH: Yes, but the key though is that  
23 we didn't get--all of the core calculations are based  
24 on primary loads. If you apply the the same load enough  
25 number of cycles, yes we can expect cracking, but the

1 magnitude of the loads themselves you can tolerate numbers  
2 well into excess of--

3 CHAIRMAN SIESS: Well, if you talk about that,  
4 yes, the magnitudes.

5 MR. RANGANATH: Yes.

6 [Slide]

7 You also heard Bill's conclusions relative to  
8 the fatigue ratchet cycles, the testing that was done,  
9 and ratcheting occurs when you have a combination of primary  
10 means stress, and cyclic dynamic stress.

11 And, here are some conclusions that we can get  
12 from Dan Miller's original model which was originally  
13 intended for thermal stresses. It turns out that these  
14 are applicable even for mechanical loading with seismic  
15 inputs, but the two-bar and the bent tests showed in addition  
16 to the normal ratcheting predictions that you would get,  
17 some time dependent behavior, which caused us some concern  
18 in the beginning when we looked at it. The cycles were,  
19 as Bill pointed out, relatively very low frequency when  
20 compared to the earthquake's and since then we have done  
21 some additional work--Roy Williams has done some additional  
22 work at higher frequencies, and what he found was that  
23 indeed the extent of the time difference in cyclic deformation  
24 was much lower, so that gives us reason to believe that  
25 the time different type of behavior was more symptomatic

1 of the very low frequencies, and is the kind of behavior  
2 that you would not expect at high frequencies.

3 MR. RODABAUGH: How high is higher?

4 MR. RANGANATH: He has done this at .5 cpm,  
5 and he went to ten times that frequency, which is five  
6 cycles per minute, and whereas the real earthquake you  
7 would be looking at five to ten hertz.

8 CHAIRMAN SIESS: What are you calling time dependent?  
9 What he called creep?

10 MR. RODABAUGH: Sam, I think there is  
11 something wrong with your first bullet equation, and your  
12 combination of mean stress and cyclic, dynamic stress,  
13 your bounds are not complete, but I'll write you a letter  
14 about it.

15 MR. RANGANATH: We can talk further about that,  
16 okay?

17 MR. RODABAUGH: Okay.

18 MR. RANGANATH: All right.

19 [Slide]

20 Failure is either by fatigue or excessive ratcheting.  
21 He observed some situations--

22 CHAIRMAN SIESS: You are still talking about  
23 the specimen tests?

24 MR. RANGANATH: --beg you pardon?

25 CHAIRMAN SIESS: You are still talking about

1 the specimen tests?

2 MR. RANGANATH: I am still talking about the  
3 specimen test, where he had, after he had enough number  
4 of ratchet cycles, he found that in fact he could neck  
5 this specimen, even though he was doing fatigue testing,  
6 when he had enough ratcheting accumulated the failures  
7 became more like a rupture failure in a tension test,  
8 and so he had kinds of failure.

9 One, was where the classic symptoms of some  
10 nice, fine, smooth, shiney surface of fatigue failure,  
11 whereas the others were loss of ductility, rupture type  
12 of failures, okay.

13 So, what he found was when he excluded all of  
14 the data points where the failures occurred by necking  
15 and loss of ductility, he found that the data points fell  
16 very nicely on fatigue curve that is close to the mean  
17 data curve that is used in the ASME Code.

18 So, what it is saying is that as long as you  
19 don't allow your ratchet strain to get out of control,  
20 whereby might get failure by necking and excessive deformation,  
21 the ratcheting in itself does not have substantial impact  
22 on fatigue cracking.

23 CHAIRMAN SIESS: The ASME curve is a high cycle  
24 fatigue?

25 MR. RANGANATH: It is a combination of a low



1 and high cycle, but they were all done with zero means  
2 stress and certainly did not have ratcheting.

3 So, this is an important conclusion because  
4 what it is saying is, well, ratchet is something to be  
5 worried about, as long as you have reasonable confidence  
6 that the total ratchet strain is small, you can still  
7 use the fatigue rules for prediction.

8 [Slide]

9 I am going to very quickly go over the single  
10 degree of freedom model analysis.

11 [Slide]

12 Some of it Sam has already covered, so I really  
13 don't have to go into in any detail. This is the standard  
14 single degree of freedom system, and we put the structural  
15 damping here, and if you were looking at elastic behavior,  
16 the kind of response spectrum that most of you--all of  
17 you are probably aware of--is what you'd get here.

18 CHAIRMAN SIESS: That is the one that he had  
19 to cut off down there by five.

20 MR. RANGANATH: That's correct, right.

21 Now, what we then did was we said the components  
22 are well described by single degree of freedom system,  
23 so what would happen if you do elastic plastic analysis  
24 and here is the elastic plastic analysis.

25 [Slide]

1           This is where we now did an analysis based on  
2 the elastic perfectly plastic behavior. This is the--  
3 Sam Tagart described it, it is his model--and essentially  
4 what we did was we came up with an effective stiffness  
5 and an effective damping based on a hysteresis slope like  
6 this, and we performed the evaluation of the response  
7 of the system in an elastic manner.

8           To compliment that, we also did an elastic plastic  
9 model. This was a numerical model where we modeled the  
10 material by a bilinear spring, with two slopes. We assumed  
11 kinematic hardening, and we also later on applied a static  
12 force, in order to simulate what would happen in a ratchet  
13 type of condition, so this is what you would call as a--  
14 with the limitation of bilinear stress strain curve, and  
15 the assumption of kinematic hardening what you call as  
16 an exact solution to the problem.

17           CHAIRMAN SIESS: Your "P" is his lambda?

18           MR. RANGANATH: That is correct, that is correct,  
19 yes. Lambda is a non-dimensional slope.

20           And again--

21           CHAIRMAN SIESS: Is kinematic hardening, of  
22 what English was talking about as a strain hardening fatigue  
23 curve sort of a behavior, or what?

24           MR. RANGANATH: The kinematic hardening is  
25 what I mean as the unloading and subsequent loading. It

1 operates between these two lines.

2 MR. TAGART: It is the conservative description  
3 of hardening when talking about--there are two models  
4 talked about--isotropic hardening, and kinematic hardening.  
5 Isotropic hardening assumes that the whole--

6 MR. RANGANATH: The isotropic--

7 MR. TAGART: --expanse increases with cycles,  
8 and the kinematic ones does not increase with cycles.

9 MR. RANGANATH: The kinematic--

10 MR. SHEWMON: So, there is no work hardening?

11 MR. RANGANATH: --well, there is work hardening,  
12 but what it is what you gain on the tensile portion of  
13 the curve, you lose--in effect, it accommodates the--

14 MR. SHEWMON: It is strain hardening, but it  
15 doesn't change with number cycles.

16 MR. RANGANATH: Right, that is correct, so that  
17 is the assumption that was made in the elastisisa most  
18 materials, maybe after about ten cycles the initially  
19 show hardening, where you get increase in both tension  
20 and compression, but after a few cycles you don't get  
21 this continuous increase, and this is what you would have.

22 [Slide]

23 So, again then to very quickly go over--Sam  
24 already went through this thing. What it is is here we  
25 are plotting the relative amplification. In non-dimensional

1 terms this could be viewed as a strain in the spring,  
2 and this is dimensional frequency, and one thing we see  
3 very clearly is if you account for elastic ; astic behavior,  
4 there is substantial reduction in the amplification. The  
5 peak strains are significantly lower.

6 And, what you do see, though, is the shift in  
7 the peak and that goes with the fact that the slope corresponding  
8 to plastic behavior, the effect of stiffness, is somewhat  
9 lower so you can see that there is a shifting to the left.

10 And, depending upon the extent of deformation  
11 that you allow, or in other words the ductility that you  
12 can tolerate, you see that if you go to higher ductility,  
13 in fact, the peaks are lower, but there is a region in  
14 the response spectrum where the elastic analysis can be  
15 somewhat non-conservative, and this is something we have  
16 talked about earlier.

17 CHAIRMAN SIESS: What is that less than one  
18 by elastic?

19 MR. RANGANATH: Well, what he is saying is he  
20 is non-dimensionalizing this with the--

21 CHAIRMAN SIESS: Oh, okay, I see.

22 MR. RANGANATH: --and he is saying that is less  
23 than one.

24 CHAIRMAN SIESS: Right.

25 MR. RANGANATH: So, that kind of gave us a good

1 understanding, Sam's model couple with an exact analysis,  
2 and now we feel like we understands what happens in terms  
3 of the elastic behavior, inherently the higher the strain  
4 the more the damping, and therefore it acts like a self-  
5 limiting type of behavior.

6 Now, the second thing we did was to see if we  
7 could predict what would happen in terms of ratcheting.

8 [Slide]

9 You can see we used the same model with the  
10 elastic plastic behavior, you know, and in relation to  
11 that we applied a static force to simulate the mean stress,  
12 if you will, say due to pressure or dead weight in the  
13 system.

14 Again, we found, for example this is typical  
15 response here, this is the support motion. This  $F = .5$   
16 means that we applied a force equal to one half of the  
17 yield force on the spring, and  $L = .1$  meaning the slope  
18 of the plastic portion is one-tenth the slope of the elastic  
19 portion.

20 So, with that, you can see the strain--dimensional  
21 strain, in fact, goes up very rapidly, and after awhile  
22 you end up just cycling once you obtain a mean value.

23 Now, if you look a the same thing--

24 CHAIRMAN SIESS: What was the mean value here?

25 MR. RANGANATH: This is what--this is steady

1 ratchet strain.

2 CHAIRMAN SIESS: No, you said you applied a  
3 mean stress.

4 MR. RANGANATH: The mean stress was one-half  
5 of the yield.

6 CHAIRMAN SIESS: And, so this went into yield  
7 in both directions when you applied the cyclic?

8 MR. RANGANATH: Yes, I think it will show you  
9 here.

10 [Slide]

11 CHAIRMAN SIESS: Okay, sure.

12 MR. RANGANATH: This is che--this shows, for  
13 example, it is kind of a--well, we felt like we understood  
14 the model much better once we started looking at it from  
15 the simple spring mass system.

16 What it is, is the mean stress act like an asymmetric  
17 on the stress strain hysteresis load, so all you do, as  
18 long as you shift the hysteresis load so that it can support  
19 this mean stress, and now you have a symmetrically heavy  
20 load over the--so this hysteresis load in fact moves up  
21 along the cyclic stress change--

22 CHAIRMAN SIESS: You are only yielding in one  
23 direction, now?

24 MR. RANGANATH: There is yielding in the reverse  
25 direction, also, you can see.

1           Some of these data points--

2           CHAIRMAN SIESS: Very little, though.

3           MR. RANGANATH: There is some yielding, yes,  
4 but as you can see, more of it, of course, is on this  
5 side.

6           CHAIRMAN SIESS: This is dimensionless? What  
7 is it? Ratio to yield?

8           MR. RANGANATH: This is dimensionless, right.

9           CHAIRMAN SIESS: But, what is the ratio?

10          MR. RANGANATH: This is ratio to the yield strain.

11          CHAIRMAN SIESS: So, I look at the bottom part  
12 of that and I am not reaching yield. It looks more like  
13 a--

14          MR. RANGANATH: Well, this would be the elastic  
15 unloading and then--

16          CHAIRMAN SIESS: Well, how far does it go? That  
17 is what I can't tell.

18          I take one of the early cycles--

19          MR. RANGANATH: Un-huh.

20          CHAIRMAN SIESS: --and when you went up you  
21 moved over about a foot on that screen, and when you came  
22 down you essentially went very little--

23          MR. RANGANATH: Yes, yes, there is less yielding  
24 on the compression side than on the tensile side but there  
25 is yielding.

1 CHAIRMAN SIESS: Even though the stress is not  
2 yield?

3 MR. RANGANATH: That is correct. What it is,  
4 is you can yield on the compressive stress at a lower  
5 stress level because of this Bauchelder [sic.] effect that  
6 we are talking about.

7 CHAIRMAN SIESS: All right, when I get over--

8 MR. RANGANATH: Yes, kinematic.

9 CHAIRMAN SIESS: --to this right-hand side,  
10 is that one big loop there.

11 MR. WARD: Trace the loop on the right-hand  
12 side.

13 CHAIRMAN SIESS: I couldn't tell whether--

14 MR. RANGANATH: I think it is kind of hard to--  
15 I think it is hard because it goes up like this and then  
16 back--

17 CHAIRMAN SIESS: Okay.

18 MR. RANGANATH: --and after awhile it just starts--  
19 you can see these dark lines are when you no longer had  
20 a shift in the hysteresis loop it kept revealing itself,  
21 so this is the final hysteresis loop.

22 CHAIRMAN SIESS: The other thing that bothers  
23 me is why, if you have an applied mean stress, you still  
24 got your line going through the origin--

25 MR. RANGANATH: Now, this is what--here is the



1 where we--here is the applied--

2 CHAIRMAN SIESS: Okay, that is your static point--

3 MR. RANGANATH: Right.

4 CHAIRMAN SIESS: --I see.

5 MR. RANGANATH: Right, right.

6 CHAIRMAN SIESS: You got up to there and then  
7 put the other one in--

8 MR. RANGANATH: And, now we are cycling this--

9 CHAIRMAN SIESS: And, what is the one that doesn't  
10 come down all of the way?

11 MR. RANGANATH: Here?

12 CHAIRMAN SIESS: The first unloading.

13 MR. RANGANATH: Oh, I think that was more--

14 it is a plot and--we use Lotus to pick up points, so it  
15 is an aberration caused by the--we didn't pick up every  
16 point because there are so many points to calculate.

17 CHAIRMAN SIESS: That one should come down a  
18 little.

19 MR. RANGANATH: Right, that is correct.

20 So what it is showing is, this nice, simple,  
21 strain-stress model can in fact--we can understand ratcheting  
22 as it happens in a structure when you have primary mean  
23 stresses in seismic type of loading.

24 [Slide]

25 But, we did find that the predicted ratchet--

1 CHAIRMAN SIESS: Excuse me, excuse me.

2 Go back, because you have got something defined  
3 on that previous one. The diagonal line, sloping line,  
4 would be E of P.

5 MR. RANGANATH: Right.

6 What we found out was that the--you can make  
7 a prediction of the cumulative ratchet strain by just  
8 taking your applied mean stress and divide it by the plastic  
9 slope of the stress-strain curve.

10 CHAIRMAN SIESS: Is that the slope of the--

11 MR. RANGANATH: Right, this is the plastic slope  
12 of the stress-strain curve.

13 CHAIRMAN SIESS: Oh, that is the plastic slope  
14 of the stress-strain curve.

15 MR. RANGANATH: Right.

16 CHAIRMAN SIESS: It is almost parallel to the  
17 envelop.

18 MR. RANGANATH: It is parallel.

19 CHAIRMAN SIESS: It is parallel?

20 MR. RANGANATH: It is parallel.

21 CHAIRMAN SIESS: Okay.

22 MR. RANGANATH: So, we found out this was kind  
23 of a phenomenal observation that we could come up with  
24 a prediction for the hysteresis and it turned out that  
25 the Dan Miller Model which was based on thermal stresses

1 gave us essentially the same kind of prediction.

2 CHAIRMAN SIESS: So, if I look at the top line  
3 there that would be what I would get in a static monotonic  
4 test?

5 MR. RANGANATH: This would be--yes, yes, if  
6 you used a, you know, a cyclic stress strain.

7 CHAIRMAN SIESS: Okay.

8 MR. RANGANATH: Okay.

9 [Slide]

10 Now, when we--

11 MR. SHEWMON: You might have to run it through  
12 several cycles.

13 MR. RANGANATH: Right, that is correct.

14 You see, because you may have a yield material  
15 that has somewhat lower yield strain.

16 [General discussion]

17 Right, but anyway, these are some of the conclusions  
18 then from the single degree of freedom system model. We  
19 felt that the single degree of freedom system model was  
20 somewhat conservative because we applied axial loads of  
21 tremendous stress, the real piping is subjected to more  
22 lending behavior, and the whole answer is, of course,  
23 a strong functional, how you compute this plastic slope  
24 in a bilinear model, depending upon which part of the  
25 stress-strain you match you can get different answers,

1 but the usefulness of this is in terms of understanding  
2 what's happening in the ratcheting condition.

3 CHAIRMAN SIESS: Does this thing get very difficult  
4 when you take tri-linear or multi-linear curves?

5 MR. RANGANATH: I think--we did all of this  
6 on a personal computer, so I think we can--

7 CHAIRMAN SIESS: You have an equation, then  
8 you can--

9 MR. RANGANATH: I think so. We can do them  
10 much better.

11 And, I said, well, what do we do in terms of  
12 predicting ratchet strains for all of the component tests.

13 [Slide]

14 So, what we did was we wanted to plot all of  
15 the data that we had where we had ratcheting, and in many  
16 of these cases we didn't quite get the ratchet strain  
17 but we have enough number of data points that we use to  
18 predict the condition under which ratcheting would occur.

19 [Slide]

20 The next plot--it is kind of a busy plot--shows  
21 then the ratchet threshold. This was for carbon steel.  
22 Let me take a minute to explain it.

23 Here we are plotting the mean stress, that is  
24 the pressure stress, plus the strain times the Young Smartings  
25 [sic.], you know, okay, so this is, in a sense, if you

1 ignore the mean stress, ' ' 's almost all the seismic  
2 stress, or seismic strain. f you will, and these were  
3 several runs, so the axis really doesn't have any meaning.  
4 It is more like a bar chart.

5 CHAIRMAN SIESS: These are several different  
6 specimens?

7 MR. RANGANATH: Several different tests, or  
8 in some, several different runs on one specimen, you know.

9 And, what the engineer who did this analysis  
10 did was he looked at the actual records, and find the  
11 point when he got ratcheting, so these pluses are shown  
12 just the onset of ratcheting. Below the plus would mean  
13 he didn't see any ratchet; above that, you know, he saw  
14 some ratchet.

15 Then, the squares are points where--

16 CHAIRMAN SIESS: That is the strain at which  
17 he saw?

18 MR. RANGANATH: That is right, that is correct.

19 So, the squares are where the was ratcheting.  
20 All we wanted to do was, we wanted to find out--not only  
21 wasn't it enough to just say no ratcheting, we followed  
22 and concluded that we can tolerate some ratcheting, so  
23 what we said was--I took arbitrarily ten percent. I concluded  
24 that ten percent was the strain level that I could live  
25 with, for example, in a level D faulted effect. For a

1 level B normal operation I may settle for this one, 'hat  
2 is, I don't want to see ratcheting under normal conditions--

3 CHAIRMAN SIESS: Ten percent of what?

4 MR. RANGANATH: Ten percent strain.

5 CHAIRMAN SIESS: Oh, ten percent strain?

6 MR. RANGANATH: Ten percent strain--ratchet strain.

7 CHAIRMAN SIESS: Oh, I see.

8 MR. RANGANATH: So, this would be a faulted  
9 condition. The idea being if you have a faulted event,  
10 a one-time occurrence, then it is okay to have some ratcheted  
11 strain.

12 CHAIRMAN SIESS: And, the pluses are much, much  
13 less than ten percent?

14 MR. RANGANATH: The pluses, we could not get  
15 any--just the onset of ratcheting.

16 The open squares are less than ten percent,  
17 and the solid squares are greater than ten percent--again,  
18 ten percent is somewhat of an arbitrary number that I  
19 just use for the purpose of the discussion here.

20 And, I concluded that the ten percent I could  
21 live with it, if you had a one-time event.

22 And what the cycles show is they tell you how  
23 much ratchet increment occurs per cycle. I made the assumption  
24 that in a typical SSE event a very conservative number  
25 is to say there are 50 cycles, so I said 10 cycles of

1 the highest--ten seconds at the highest stress strain  
2 and 500--so I came up with 50 cycles as the maximum number  
3 of peaks cycles that you could get. I think it is a conservative  
4 number, but that is what I use in making this plot.

5           So, then this told me that if I wanted to look  
6 at condition--first of all, we didn't get any limit load  
7 failures, so all we have concern about is ratcheting,  
8 and if you allow your stress to be below 2  $S_m Y$  for  
9 example, then you would not get ratcheting, say for level  
10 B type of conditions; and if you allow your stress to  
11 be less than say 4  $S_m Y$  then you would get some ratcheting,  
12 but the ratchet of strain would not be large enough to  
13 cause any concerns on structural integrity due to the  
14 faulted event.

15           And, again, the numbers 2 and 4 may in fact  
16 change over time, but this is the concept that I am proposing.

17           CHAIRMAN SIESS: Now, I don't recall having  
18 seen the number of cycles in the component tests. It  
19 is always giving the number of inputs. Did any of the  
20 component fail at less than 50 cycles?

21           MR. TAGART: Well, they are different amplitudes.  
22 I think 50 is a very large number for any of those component  
23 tests.

24           I would say that probably it is 50 is the upper  
25 limit of what we've seen in the component tests. We took

1 five component tests and said you had ten maximum amplitudes  
2 equivalent cycles in those tests. That adds up to--

3 CHAIRMAN SIESS: Is that about what you got?  
4 About ten for an input?

5 MR. TAGART: Close to the maximum limit. I'd  
6 say ten was the upper limit.

7 CHAIRMAN SIESS: That is what I didn't know.

8 MR. TAGART: It is more like six, would be a  
9 better number.

10 CHAIRMAN SIESS: Yes, I see.

11 MR. BUSH: Sam, would you interpret your horizontal  
12 axis. I don't understand it.

13 MR. RANGANATH: All right.

14 The horizontal axis really does not have any  
15 meaning. They are all--that was plotted as bar charts,  
16 you know. These were all different runs, that's all.  
17 This was one set, where he ran it at half sled range,  
18 and then full range, and so on, but in itself the X axis  
19 does not have any meaning.

20 CHAIRMAN SIESS: Are those all of the tests?

21 MR. RANGANATH: We, in many cases, could not  
22 get meaningful data because the strain gauges came off.

23 He looked at all--many of them, and picked those  
24 where he had good data that went all the way to the higher  
25 str... ..



1 CHAIRMAN SIESS: Each plus is a different test?

2 MR. RANGANATH: Each test maybe a different  
3 run in a test.

4 Remember, they kept increasing the amplitude  
5 at one elbow, with a lower forcing function and they kept  
6 increasing it, so each point is a different run there.

7 CHAIRMAN SIESS: Okay.

8 MR. RANGANATH: Now, I did the same thing.

9 [Slide]

10 This was for carbon steel, but I express it  
11 in terms of  $S_m Y$ --

12 MR. RODABAUGH: Sam, before you say it, for  
13 the benefit of the subcommittee, when you divided by  $S_m Y$ ,  
14 what  $S_m Y$  were you using?

15 MR. RANGANATH: I use the Code minimum  $S_m Y$ ,  
16 okay. This material probably has  $S_m Y$  levels that were  
17 higher than the Code minimum value.

18 To that extent it can be construed as the somewhat  
19 non-conservative, but when you also recognize that when  
20 this thing is going through the cyclic behavior it doesn't  
21 take a whole lot of time before it strain hardens itself,  
22 so I don't know that that distinction is that critical.

23 MR. RODABAUGH: I think that you would be better  
24 off to use your best estimate of  $S_m Y$  from your material  
25 mill test reports.

1 CHAIRMAN SIESS: Would that vary with the different  
2 tests?

3 MR. RODABAUGH: Yes.

4 MR. RANGANATH: Yes, it would vary for different  
5 tests, and--

6 CHAIRMAN SIESS: If the materials were enough  
7 different that the actual yield stress, compared to the  
8 specified minimum would vary?

9 MR. RANGANATH: I would say most cases the specified  
10 minimums were much lower than the actual--

11 CHAIRMAN SIESS: No, that is not my point.

12 If you went in with each of these specimens,  
13 and used the specimen--used the actual yield stress, measured  
14 yield stress, was the ratio of measured yield stress,  
15 the specified minimum--or Code stress as you call it--  
16 would that be fairly constant, or would these different  
17 heats--

18 MR. RANGANATH: I would guess it is constant,  
19 but I will let Kelly answer it. He probably has a better  
20 idea.

21 MR. MERZ: Some of the specimens were taken  
22 from the same heat, okay. The mill test is for that heat,  
23 okay.

24 In terms of elbows, tees, pipe, I would say  
25 there is probably 20 different heats, okay, all with

1 probably about 10 KSI above the specified minimum, approximately.

2 CHAIRMAN SIESS: Mill test.

3 MR. MERZ: Yes, above the mill test.

4 Now, that is the mill test, of course, is for  
5 the specimen before it is forged, not after it is forged,  
6 really. It is for the piece of pipe that it is forged  
7 from, usually.

8 Now, Mr. Rodabaugh can probably answer that  
9 more correctly.

10 CHAIRMAN SIESS: Since all you ever know, in  
11 designing, is the Code specified minimum, the question  
12 then remains is this a representative sampling of the  
13 variations you could get between the specified minimum  
14 properties and the actual properties?

15 MR. RANGANATH: All right--

16 MR. RODABAUGH: Yes, that is the question, Chet.

17 Their materials, rather typically, were about  
18 20 percent higher yield strength, for example--20 or 25--  
19 but if you look at statistics on the materials, like stainless  
20 steel, you will find some small percent, one percent,  
21 is right at the minimum, even a little percent below minimum.

22 CHAIRMAN SIESS: What I was thinking is, that  
23 suppose you went back and took say mill tests, which are  
24 not the right answer, they are not the properties the  
25 material is formed into the elbow, but supposed you took

1 the mill tests that did fluctuate, and you did this and  
2 your scatter decreased? Let's just be real optimistic  
3 and say, you know, you have got all of these in a very  
4 narrow band, what would you do with them? You still wouldn't  
5 be able to use--

6 MR. RODABAUGH: I think, Chet, the very next  
7 slide is going to be the key to my thought here.

8 Eventually these stress limits are going to  
9 be shown in terms of  $S_m E_p$ . Now, that is a minimum. If  
10 it turns out that--

11 CHAIRMAN SIESS: What is that?

12 MR. RANGANATH:  $S$  of  $M$  is a design stress intensity.

13 MR. RODABAUGH: Design stress intensity, which  
14 may be either based on yield strength, or ultimate strength.

15 In general, the Code philosophy is to base your  
16 design on the minimum properties.\* Now we have got some  
17 tests which are tests of components that had higher than  
18 minimum properties. A rather straightforward completely  
19 defensible way to evaluate the data is to adjust it to  
20 the difference between what you tested and the Code values,  
21 then you have a very straightforward four-story and you  
22 don't have to go back and say, " Well, if we had a minimum,  
23 we still think we are in our stato--

24 MR. RANGANATH: You are right, and in fact one  
25 of the action items that I have is to redo these results

1 in terms of the actual--

2 CHAIRMAN SIESS: Then you can decide whether  
3 you want a five percent cutoff or a ten percent value.

4 MR. RANGANATH: And, again that is--the ten  
5 percent that I took was arbitrary--

6 CHAIRMAN SIESS: Not on the stress, the yield  
7 stress.

8 MR. RANGANATH: Yes.

9 Now, here is the same plot for carbon steel  
10 that was based on S of M.

11 [Slide]

12 And, again this is showing about 6 S of M may  
13 be okay for Level D; maybe 3 S of M is okay as opposed  
14 to the current limit for level B, which is 1.8 S of M,  
15 you know, so again it indicates there is some room for  
16 improvement.

17 [Slide]

18 I'll show you--

19 CHAIRMAN SIESS: You mean the solid squares  
20 then to represent level D?

21 MR. RANGANATH: Rather than ten percent, right--  
22 no, solid squares are the stress amplitude that I have  
23 to have--

24 CHAIRMAN SIESS: Yes, but I then you said you  
25 thought 6 was good enough for--I thought you said level B?

1 MR. RANGANATH: Level D, right.

2 CHAIRMAN SIESS: Level?

3 MR. RANGANATH: D, faulted.

4 CHAIRMAN SIESS: And, 3 for what?

5 MR. RANGANATH: Normal, level B--no upset requirements,  
6 upset, upset.

7 So you can do the same thing again. For stainless  
8 steel we kind a somewhat fewer points on stainless steel,  
9 and again the same comments that Ev brought up apply here,  
10 too.

11 This is expressed in terms of S of Y, and here  
12 we have the same thing expressed in the terms of S of M.

13 MR. SHEWMON: Tell me again what you have been  
14 telling me for ten minutes.

15 I don't understand--we've gotten an S mean,  
16 plus some small, I hope, adjustment to the elastic treatment--

17 MR. RANGANATH: Oh, no.

18 All we did was S mean is the pressure stress.

19 MR. SHEWMON: Okay.

20 MR. RANGANATH: The strain amplitude is the  
21 strain amplitude that was measured, from constrain gauges,  
22 you know. It was multiplied by E, right, to get the pseudo-  
23 elastic stress.

24 MR. SHEWMON: I understand that.

25 Then this is the ratio of that times the design

1 stress--

2 MR. RANGANATH: Right.

3 Maybe it would be a better way to look at it  
4 would be in terms of S of Y. That means four times S  
5 of Y.

6 MR. SHEWMON: Well, but there is always as many  
7 pluses above your lines as there are below, so I don't  
8 quite see any threshold for ratcheting.

9 [General discussion]

10 CHAIRMAN SIESS: You can get the open squares  
11 for his bottom line margin, that is ten percent--less  
12 than ten percent, and the solid squares for his top ones.

13 MR. SHEWMON: Right, right.

14 MR. RANGANATH: See, we have--let's look at  
15 no ratcheting at all.

16 That means I should not have any squares. I  
17 did have two squares here. When we went back to check  
18 it the strain was very small. It was almost close to  
19 no ratchet, so I am saying--on the level B conditions  
20 I wouldn't want to see any ratcheting, and that is saying  
21 that maybe 2 S of Y is a good limit for level B.

22 For level D, I will say, yes, I can tolerate  
23 some ratcheting, and I just arbitrarily picked ten percent  
24 in 50 cycles, and that saying if I am below 4 S of Y--

25 MR. SHEWMON: Okay, fine.

1 MR. RANGANATH: --I wouldn't get ten--

2 MR. SHEWMON: Thank you.

3 CHAIRMAN SIESS: Now, you know that line, you  
4 could have drawn at five, couldn't you?

5 MR. RANGANATH: That is what Sam Tagart also  
6 asked me, you know, and I can do that, and again I just  
7 picked ten for this case. We can do that. I think it  
8 would be one of those numbers that will have to check  
9 with our consultants and come up with something that is  
10 acceptable.

11 So, with that we sent 3 S of M for level B,  
12 and 6 S of M for level D, okay.

13 [Slide]

14 So, let's take a look at design rule changes  
15 that we might propose. And, one design rule that--this  
16 is the pressure, remember I told you--showed you the equation  
17  $\frac{PD}{4P} + \frac{M}{2}$ , where M is the earthquake moment.  
18 Now, right now, that includes the seismic loading also,  
19 and these are the current limits. It is the lesser of  
20 this or this, that is what we have today.

21 And, what we might change is--

22 CHAIRMAN SIESS: Now, 3 S of M, if it is two-  
23 thirds S Y, that is what the right-hand side governs?

24 MR. RANGANATH: Yes, close to.

25 CHAIRMAN SIESS: Okay.



1 MR. RANGANATH: In some cases, you know, it  
2 is a little different because it is the lower of one-  
3 third of alternate, or two-thirds of yield, and so this  
4 changes.

5 CHAIRMAN SIESS: So that is equal really to  
6 ultimate or two times the yield, if I look at level D?

7 MR. RANGANATH: Yes.

8 CHAIRMAN SIESS: Right?

9 MR. RANGANATH: Yes.

10 So, that is where we are today. That includes  
11 the seismic loads also.

12 What we might look at in terms of a proposal  
13 for new Code limits, you don't have to do any special  
14 analysis for ratcheting, and so on, provided you make  
15 these limits for, you know, with the new proposal, 3 S  
16 of M to 6 S of M, 3 for level B, and 6 for level D. And,  
17 again this is something that we would probably have to  
18 reiterate on, but this is the direction we are going to.

19 CHAIRMAN SIESS: And, 6 is two times ultimate?

20 MR. RANGANATH: Right.

21 CHAIRMAN SIESS: Okay.

22 MR. RANGANATH: And, again the numbers we are  
23 talking about are pseudo-elastic stress.

24 CHAIRMAN SIESS: Oh, yes.

25 MR. RANGANATH: It is measures of strain.

1           CHAIRMAN SIESS: I know, it is a measure of  
2 strain caused by--

3           MR. RANGANATH: Yes, and the non-seismic loading  
4 portion will still be limited by the current Code, so  
5 weight, water hammer, and pressure, and so on, would still  
6 be controlled by this.

7           So, you know, how can we implement it in the  
8 Code? One thing we were looking at was we have some options,  
9 and this again we will have to decide in it with some  
10 more interpretation. Should be make a blanket change  
11 in the Code? Or, should we be more restrictive in terms  
12 of a Code case approach where we say you can use these  
13 rules provided you use response spectrum analysis, provided  
14 you use peak broadening, provided you don't use damping  
15 in excess of five percent, provided you don't have castings,  
16 and so on, so that may be one way to look at it.

17 [Slide]

18           And, right now we will not need any firm decisions  
19 on which way to go, the above spells it out.

20 [Slide]

21           And, finally, looking at it from the long term  
22 viewpoint, where, you know, do we go from here? Clearly  
23 the current Code approach has been shown to be very conservative,  
24 and it is kind of does not make sense, and one of things  
25 that the limits on the primary stresses, on equation 9,

1 lead to excessive snubbers.

2 Snubbers, and so on, very fancy analysis, and  
3 we can probably reduce design costs, hardware costs, and  
4 really other potential problems associated with snubbers--  
5 failing and so on--can be reduced, and so I think we can  
6 get a simple, more cost effective system--

7 CHAIRMAN SIESS: Now, you had a caveat before  
8 about the response spectrum analysis, so you are not going  
9 to change the analysis costs there much?

10 MR. RANGANATH: Oh, okay, in the long term,  
11 that kind of let's me up to the third bullet--

12 CHAIRMAN SIESS: Let's stay up at the second  
13 bullet.

14 I am trying--

15 MR. RANGANATH: I agree.

16 CHAIRMAN SIESS: --to visualize, given those  
17 Code changes in stresses, what would be different in the  
18 plant? What would be different the design? What would  
19 be different physically in the plant?

20 They would have fewer snubbers and steel pipe  
21 supports--

22 MR. RANGANATH: Right.

23 CHAIRMAN SIESS: Would the pipe sizes be different?

24 MR. RANGANATH: No.

25 CHAIRMAN SIESS: The schedule wouldn't be different?

1 MR. RODABAUGH: No.

2 CHAIRMAN SIESS: That is based on pressure,  
3 so it would be mainly supports and snubbers--

4 MR. RANGANATH: Right.

5 CHAIRMAN SIESS: --and the maintenance that  
6 goes with snubbers--

7 MR. RANGANATH: That is correct.

8 CHAIRMAN SIESS: --and the problems that go  
9 with supports and so forth?

10 MR. RANGANATH: That is right.

11 MR. GUZY: It should be noted that the designing  
12 of the piping system, support design, is the major factor  
13 in this, so you have less support design--

14 CHAIRMAN SIESS: Yes, I know.

15 MR. RANGANATH: And, in the long run--

16 CHAIRMAN SIESS: Thousands--

17 MR. RANGANATH: --as I--

18 CHAIRMAN SIESS: --you didn't finish your last  
19 bullet there.

20 MR. RANGANATH: Yes, I will get to that in just  
21 a second.

22 As you can see here, if you look at the plastic  
23 plastic response they are almost getting to a factor of  
24 1, you know, so what this is saying is--and a lot of the  
25 experts like Bob Kennedy are saying, you know, the old

1 way of doing things where we just did it in a static manner,  
2 and in fact is okay, and this elastic plastic--

3 CHAIRMAN SIESS: An equivalent static.

4 MR. RANGANATH: --analysis has shown that that  
5 is okay.

6 CHAIRMAN SIESS: An equivalent static.

7 MR. RANGANATH: --right, equivalent and static  
8 method.

9 CHAIRMAN SIESS: At the workshop on Appendix  
10 B that was held a couple of years ago, somebody proposed  
11 an equivalent static. Was it Bob Kennedy?

12 MR. TAGART: I am not sure about that meeting,  
13 but equivalent static has always been in the Code. The  
14 problem with it is it has always taken a 1.5 factor peak  
15 of the response spectrum as the equivalent static--

16 CHAIRMAN SIESS: Well, that is not equivalent  
17 static, then--

18 MR. TAGART:--and that is just way too conservative--

19 CHAIRMAN SIESS: Yes.

20 MR. TAGART: --and recently there is a proposal  
21 by John Stevenson to introduce an equivalent static approach  
22 that is more realistic.

23 CHAIRMAN SIESS: Thank you, that is who it was.

24 And, then somebody suggested, you know, simplify  
25 that and put a little more effort into steam generator

1 supports, and vessel supports, in places where the consequences  
2 would really be serious.

3 It was Stevenson at that meeting, I guess.

4 Well, I tell you, there are real benefits in  
5 getting back to that sort of an approach, because you  
6 have got a heck of a lot better feel for what--

7 MR. RANGANATH: Bring in the understanding.

8 CHAIRMAN SIESS: --you are doing, yes, I mean  
9 this stuff all comes out of the damn computer and if there  
10 is a mistake then nobody has any feel for it.

11 MR. SHEWMON: Tell me what drives snubbers now?  
12 Is it displacement? Or does decrease mean stress? Or  
13 what?

14 MR. RANGANATH: Stress-strain reduction is the  
15 one that drives, although--

16 MR. TAGART: Equation 9 right now, which is  
17 a stress equation on the pipe.

18 MR. SHEWMON: And, so if you put a snubber in  
19 you decrease the dynamic stress?

20 CHAIRMAN SIESS: You also change the frequency,  
21 too, don't you? Shift off of the peak.

22 MR. SHEWMON: Now, the frequency didn't come  
23 into that equation, as he drew it?

24 CHAIRMAN SIESS: No, but in the analysis it  
25 does.

1 MR. SHEWMON: Yes.

2 CHAIRMAN SIESS: For smaller pipes, it just  
3 support it to get it above 33 hertz, and there is no amplification.

4 MR. RANGANATH: That is the last one, some kind  
5 of a design by rule test, Sam was talking about, and the  
6 whole idea is mainly these experts believe there is a  
7 very simple ways of designing piping that is quite effective  
8 and still maintain the safety margins.

9 CHAIRMAN SIESS: Well, again, don't we have  
10 some evidence from SKRUG [sic.] that at best was design  
11 equivalent static?

12 MR. TAGART: Yes, there is a lot of evidence to  
13 that effect.

14 CHAIRMAN SIESS: What causes the failure?

15 MR. TAGART: The only problems that would cause  
16 failures is where you have seismic anchor motions that  
17 weren't accounted for in the design.

18 CHAIRMAN SIESS: Yes, but you can do those by  
19 equivalent static and probably better than anything else  
20 can, and the anchors are something else.

21 MR. GUZY: Also, connections with the piping,  
22 when we talk about threaded piping, then there may be  
23 a problem.

24 CHAIRMAN SIESS: Okay.

25 MR. SHEWMON: To go back and try to understand

1 these two curves, I find they come in pairs, where the  
2 data points are the same but the answers change.

3 MR. RANGANATH: That is correct.

4 MR. SHEWMON: Or the numbers on the left axis--

5 MR. RANGANATH: Right, we have the same data  
6 point, and in one we express it as a ratio of the yield  
7 strength, and the other way we express it--

8 MR. SHEWMON: Okay, fine.

9 MR. RANGANATH: --as the ratio of the design  
10 stress--

11 MR. SHEWMON: He just defines strength--

12 MR. RANGANATH: Thank you.

13 CHAIRMAN SIESS: Well, I have got on comment  
14 about the proposed Code changes: lots of luck!

15 It is hard to change it, but I think everything  
16 we know says that we are awfully conservative in what  
17 we are doing, and not necessarily that we are getting  
18 a conservative power plant as the result of it, and that  
19 kind of bothers me, and if there is some way of arriving  
20 at a better design that is just as safe I sure we could  
21 do it.

22 Gentlemen, that concludes the presentations  
23 that are being made to us, except Dan had one slide left  
24 he wanted to bring in at the end. I am not sure if he  
25 forgot about it or not.



1           MR. GUZY: It was just to talk about the rest  
2 of the research that we are doing.

3           From a research point of view, I just sort of  
4 wanted to put this into context along with some other  
5 things that we are doing in piping.

6           First of all, we are developing a new piping  
7 research plan that will include--the type of work we talked  
8 about today--response design rules for piping, as well  
9 as cracked piping, so that there will be a forthcoming  
10 NUREG, and the pad has only addressed, like the degree  
11 of piping program now, only it will be more comprehensive  
12 and will include things we are doing that use to be in  
13 the old cycling plant--that should be familiar to you.

14          In addition to this work, which I consider the  
15 most important and certainly the major part of our research  
16 in the design area, we are still doing work in the piping  
17 response method area. We have done work in the past on  
18 damping. We are supporting work that is being done now  
19 at Vectal [sic.] and through EPRI on the new damping criteria,  
20 and there will be some forthcoming actions on the Code  
21 bodies to revise this Code case, and hopefully to make  
22 it easier to use. Right now only half the plants can  
23 qualify for using the damping criteria--

24          CHAIRMAN SIESS: Why?

25          MR. GUZY: Because the NRC in their endorsement

1 of Code case N-411 put a number of limitations on it,  
2 for instance, you have to use a modern spectra, ground  
3 spectra. If you use a--

4 CHAIRMAN SIESS: Oh, yes.

5 MR. GUZY: --and that can't be used in the conservative.

6 Also, there is activity now in the ISM response  
7 method area, and we are doing some regulatory and Code  
8 work on that, hopefully to resolve it and bring some of  
9 this research to a head, a change in what our current  
10 position is.

11 There is also doing some work on the treatment  
12 of high frequency modes, how you can--with response analysis,  
13 and better treatment of closely spaced modes response  
14 analysis, and there is work in the nonlinear response  
15 area, supportive work at federal. There is some--a number  
16 of small projects in response to this area, so are continuing  
17 to do work in these areas.

18 I think in the response margin methods areas,  
19 it is not as big as it was a couple of years ago.

20 CHAIRMAN SIESS: Now, these two middle bullets,  
21 is that going to involve experiments?

22 MR. GUZY: We can use some experiments as benchmarks,  
23 but primarily analytical.

24 One of the advantages of these most recent system  
25

1 tests is that we do have physical evidence for support,  
2 and in the past there hasn't been that many piping benchmarks  
3 that included that, so this is good.

4 CHAIRMAN SIESS: The high frequency thing, I  
5 guess I will never quite understand the concern about  
6 some of the high frequency because of such small energy  
7 content.

8 MR. GUZY: That's--I mean, our program, the  
9 test program is showing that they are not of much concern.  
10 If we could make it go away, using these results, then  
11 we wouldn't have to worry about it, but on paper high  
12 frequency modes do pose a problem at least in licensing  
13 cases, and there may be some better way to combine--it  
14 has to do with correlation of the modes and the plants,  
15 and maybe there is some analytical way we can do that  
16 through research.

17 Okay, my point was that piping response methods,  
18 we have done work--a lot of it recommended by the piping  
19 review committee--that work is kind of winding down, but  
20 there still are things that we are doing.

21 We have a major effort now at Oakridge, research  
22 is sponsoring now at Oakridge on nozzle flexibility and  
23 design, and there has been--it is having some impact now  
24 on some of the Code activities, and I think it will have  
25 a future impact.

1           There has also been work that EPRI has sponsored  
2 for this area. There are some definite Code activities  
3 going on now, in the nozzle area, to provide some relief.  
4 The point is that when we change the piping stress rules  
5 then nozzles, or supports we are talking about here, in  
6 the nozzle area we are doing something, and the support  
7 design will be a new area, and we are just trying to get  
8 our hands around this now.

9           There is some PBRC activities, we will make  
10 recommendations, and improve the support design. EPRI  
11 is having a workshop on support design every month--

12           CHAIRMAN SIESS: Pipe supports?

13           MR. GUZY: Pipe support, pipe support design.

14           There is--

15           CHAIRMAN SIESS: How do they determine the force?

16           MR. GUZY: How to design what you know of the  
17 forces, okay, so that this is--

18           CHAIRMAN SIESS: That is a structural engineering  
19 problem that I thought the steel people had solved a number  
20 of years ago.

21           MR. BUSH: They have to a degree, in fact, the  
22 PBRC effort would end up looking at a package with the  
23 suggestion that effectively what you do is remove NF from  
24 the Code, which represents a tremendous load, particularly  
25 for inspection and so forth.

1           CHAIRMAN SIESS: It seems to me that you've  
2 got two choices on support design: you design them to  
3 take the loads without yielding; and the other is you  
4 design them to yield and absorb energy.

5           MR. GUZY: That is the--

6           CHAIRMAN SIESS: The first one people ought  
7 to know how to do, and the second one is a little bit  
8 more of a problem.

9           MR. GUZY: There are a number of areas that  
10 are involved in support design, one is the concept of  
11 supports that are used, you know, when they fail they'd  
12 better fail first.

13           What I am trying to note is that we are planning  
14 on doing research in this area and there are a number  
15 of recommendations to be made.

16           CHAIRMAN SIESS: Yes.

17           MR. GUZY: The use of piping experience data,  
18 we are doing a test through Oakridge in this area, research  
19 is, and we are following a project that EQE had done for  
20 EPRI, which followed the project that Don Stevenson had  
21 done for us. We are still trying to use the piping experience  
22 data from SCRUG [sic.]--essentially the same plants as  
23 SCRUG [sic.] and essentially to try and bring it into  
24 more of a regulatory process.

25           MR. BUSH: That sounds like you are limiting

1 it pretty much to seismic response?

2 MR. GUZY: Yes.

3 MR. BUSH: And not just piping experience--

4 MR. GUZY: Yes, there is some element of what  
5 the operating conditions were and how it is inspected  
6 and if you can show that you are enveloped by industrial  
7 plants, then you can feel more comfortable.

8 In terms of degraded piping, or the IPIRG program,  
9 it does have an element of--

10 CHAIRMAN SIESS: What is IPIRG?

11 MR. GUZY: --it is the International Degrading  
12 Piping Program, but I don't know what that--

13 CHAIRMAN SIESS: Okay.

14 MR. GUZY: But, it will include an element of  
15 dynamic testing, in fact, there is some simple tests now  
16 set up for essentially dynamic failed piping with known  
17 cracks in it--

18 CHAIRMAN SIESS: Degraded piping.

19 MR. GUZY: Degraded piping, yes.

20 Then the last bullet is piping liability studies.  
21 Sam showed you earlier some things that EPRI has sponsored.  
22 We, NRC, may become more involved in this also. We see  
23 that way of integrating new piping information, like what  
24 we've just talked about, the program, and say information  
25 /////

1 on the degraded piping will be--probably could be most  
2 economically once we know the basis data on it and--

3 CHAIRMAN SIESS: Now, is that PRA related?

4 MR. GUZY: --I don't know how probabilistic  
5 it will be.

6 I see us as maybe improving our full commercial  
7 type program. Sam would see it as an extension of the  
8 things he was talking about this morning.

9 CHAIRMAN SIESS: Now, you skipped one.

10 MR. GUZY: I skipped one? Oh, cumulative effects  
11 of piping criteria changes, this is something that the  
12 licensing staff has asked for for a long time and we had  
13 a hard time getting our arms around it.

14 The way it is envisioned now would be sort of  
15 a response margins approach where you would show how you  
16 would trade these, and we've had a hard time getting this  
17 off of the ground, and my feeling is if we can effectively  
18 use the information from this test program we may not  
19 have to do that.

20 CHAIRMAN SIESS: Well, I think that is very  
21 important, because I think that anything we can do to  
22 improve piping design, reduce some of the problems we  
23 have with snubbers, is excellent, but we have gotten an  
24 awful lot of comfort out of the margins we have.

25 Now, we are finding the margins are tremendously

1 large, but let's don't get the margins down to the point  
2 where when somebody wants to up an earthquake hazard,  
3 we get another earthquake in the eastern U.S., now our  
4 comfort has disappeared, and that comfort is hard to qualify.  
5 It is a fairly important aspect of this, and we make all  
6 of these changes and somebody needs to take a look and  
7 say, "Now, okay, where are we now?"

8 I don't know if that is easy to do, but--

9 MR. GUZY: I think the last project, the piping  
10 reliability studies, which would attempt to do that--

11 CHAIRMAN SIESS: I think that will tie in.

12 MR. BUSH: Dan, could I have a comment, because--

13 CHAIRMAN SIESS: You don't have margin in there,  
14 as such, but that is what I am thinking.

15 MR. BUSH: It depends on what you put in the  
16 last one, because as I visualize it what you really need  
17 is something--a cut across, at a minimum--three of those:  
18 piping experience data, the cumulative effect of changes,  
19 and the piping reliability study, and somehow they have  
20 to be integrated.

21 MR. GUZY: Yes, and I think--

22 MR. BUSH: And, if they don't, if they aren't  
23 integrated, you may not accomplish what you need.

24 MR. GUZY: Yes, I think that ideally, if we  
25 can get something going that we should include--especially



1 the piping experience, I think that is something that  
2 has to be brought in more than it has been in the past.

3 CHAIRMAN SIESS: Would the piping reliability  
4 studies take the cyclic approach?

5 MR. GUZY: I think they would take--cyclic,  
6 maybe like Sam was showing this morning, maybe some frequency  
7 of core melt type of--

8 CHAIRMAN SIESS: Well, yes, okay.  
9 That approach just emphasized the uncertainties.

10 MR. TAGART: Quantifies and deals with the uncertainties.

11 MR. GUZY: So that is briefly what we are doing  
12 in my branch.

13 CHAIRMAN SIESS: Now, this is all--what's current,  
14 and what's for the future?

15 MR. GUZY: Well, I would--let's see--everything  
16 is sort of current, except for support design, which should  
17 happen fairly soon. The cumulative effects, which we had  
18 not started and the piping reliability studies, which  
19 Sam has already started--

20 CHAIRMAN SIESS: And, these are all withstanding  
21 the budget cuts?

22 MR. GUZY: Yes.

23 CHAIRMAN SIESS: I think that concludes the  
24 presentations.

25 Are there any questions or last words?

1 [No response.]

2 I would hope that Mr. Rodabaugh, who has threatened  
3 you with a letter will provide us with a copy, and I would  
4 appreciate anything from Spence Bush in the way of comments  
5 on the meeting that you can pass on to the rest of the  
6 committee.

7 MR. GUZY: Will the committee be making recommendations?  
8 Or what will you do?

9 CHAIRMAN SIESS: You haven't asked for any.  
10 We don't now have any particular input into the budget.  
11 If it comes up, obviously, we would be prepared.

12 MR. GUZY: We've heard your concerns over cast  
13 versus stainless steel, and that will be addressed in  
14 the program--

15 CHAIRMAN SIESS: What we will do is I will probably  
16 make a brief report at the next full committee meeting,  
17 and if they are interested in hearing more about this  
18 as a committee we might ask for some presentation at a  
19 future committee meeting.

20 I think it might wait until it gets to some  
21 regulatory action, you know, if we brief the full committee  
22 on what's going on now, and the regulatory action comes  
23 two years from now, we start over.

24 I think the subcommittee should be kept abreast,  
25 but to try and keep the full committee addressed in

1 advance doesn't always work. Ten other things come up  
2 with them.

3 Thank you, gentlemen. It has been very fine  
4 presentations. I think you covered a lot of territory  
5 and answered the questions we had today, and I say lots  
6 of luck with the Code changes.

7

8 Adjourned: 12:30 p.m.

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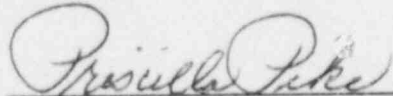
REPORTER'S CERTIFICATE

STATE OF CALIFORNIA     )  
                                  )     ss.  
COUNTY OF VENTURA     )

I, PRISCILLA PIKE, an official hearing reporter for the State of California, do hereby certify that the foregoing pages 1 through 162, inclusive, constitutes a true and correct transcript of the matter as reported by me.

I FURTHER CERTIFY that I have no interest in the subject matter.

WITNESS my hand this And day of April, in the County of Ventura, State of California.

  
\_\_\_\_\_  
Priscilla Pike  
Pike Court Reporting Services  
3639 E. Harbor Blvd. Ste. 203-A  
Ventura, California 93001  
(805)568-7770

~~Sam Taggart~~  
Don Gudy

## PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

### EMPHASIS

DESIGN OF PIPING COMPONENTS FOR DYNAMIC INERTIAL LOADS

### OBJECTIVES

IDENTIFY DYNAMIC FAILURE MECHANISMS AND LEVELS

PROVIDE HIGH-LEVEL NONLINEAR RESPONSE DATA

DEVELOP IMPROVED ASME CODE DESIGN RULES

PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

EPRI	SAM TAGART, Y. K. TANG
NRC	DAN GUZY
GE (SAN JOSE)	BILL ENGLISH, HENRY HWANG, SAM RANGANATH, ED SWAIN
ANCO ENGINEERS	PAUL IBANEZ, KELLY MERZ
ETEC	RON JOHNSON, VINCE DEVITA
MCL	ROY WILLIAMS
CONSULTANTS	E. RODABAUGH, R. KENNEDY, D. LANDERS, R. L. CLOUD, D. MUNSON, S. MOORE, R. BOSNAK, L. SEVERUD

## PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

TASK 1: PROGRAM PLAN DEVELOPMENT (GE)

TASK 2: PIPE COMPONENT TESTING (ANCO)

- 41 FAILURE TESTS OF ELBOWS, TEES, ETC.

TASK 3: PIPE SYSTEM TESTING

- PFDRP "SYSTEMS 1 & 2" TESTS (ETEC)
- OTHER SYSTEM TESTS (ETEC)
- WATERHAMMER SYSTEM TESTS (ANCO)

TASK 4: SPECIMEN FATIGUE RATCHETING TESTS (MCL)

- 140 SPECIMENS, DIFFERENT MATERIALS & TEMPERATURE

TASK 5: - ANALYSIS OF TESTS AND DESIGN RULES (GE)

TASK 6: - IDENTIFICATION AND DEVELOPMENT OF ALTERNATIVE DESIGN RULES (GE)

TASK 7: - EVALUATION OF ALTERNATIVE DESIGN RULES (GE)

TASK 8: - PROJECT FINAL REPORTS (GE)

PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

STATUS AND SCHEDULE

PROGRAM INITIATED IN SPRING OF 1985

ALL TESTING COMPLETED (EXCEPT RETEST OF SYSTEM 1)

FINAL ANALYSES AND CRITERIA DEVELOPMENT UNDERWAY

PROGRAM ENDS JUNE 1988 WITH DRAFT FINAL REPORTS

INITIATION OF REVISIONS TO ASME CODE NB/ND/NC-3600 IN 1988

EPRI TO PUBLISH FINAL REPORTS



## PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

COOPERATIVE EPRI/RES RESEARCH AGREEMENT

FIVE REVIEW MEETINGS WITH PROJECT MANAGERS AND CONSULTANTS

INTERACTIONS WITH ASME AND PVRC STANDARDS GROUPS

- PRESENTATIONS AT MEETINGS
- MEMBERSHIP ON GROUPS BY PFDRP PARTICIPANTS
- ASME CODE CLASS N-451
- CLASS 2 & 3 DYNAMIC ALLOWABLE CODE CASE
- PVRC TASK GROUP ON PIPING FUNCTIONALITY

PUBLICATIONS

- PAPERS IN JOURNALS AND SMIRT
- FOUR SEMI-ANNUAL PROGRESS REPORTS
- FINAL REPORTS TO BE ISSUED BY EPRI

ARCHIVING OF TEST SPECIMENS AT NDE CENTER

## PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

### NRC PERSPECTIVE

#### PIPING REVIEW COMMITTEE

- RAISED CONCERNS ABOUT OVERCONSERVATISMS IN INERTIAL LOAD DESIGN
- REGULATORY CHANGES LIMITED TO RESPONSE CRITERIA (E.G., DAMPING)
- IDENTIFIED HIGH PRIORITY NEED FOR FAILURE TESTS (NUREG 1061 VOLS. 2 & 5)

#### PFDRP PRESENTATIONS TO NRC

- INFORMATION DISTRIBUTED, VIDEO TAPES SHOWN
- BACKGROUND PRESENTATIONS AT CODE CASE N-411 AND N-451 MEETINGS
- WATER REACTOR SAFETY INFORMATION MEETINGS
- 9/11/87 FORMAL BRIEFING TO STAFF
- 3/30/88 MEETING OF ACRS SUBCOMMITTEE ON STRUCTURAL ENGINEERING
- FUTURE MEETINGS WITH NRC STAFF

#### REGULATORY CHANGES

- R.G. 1.84 ENDORSES ASME CODE CASES
- 10 CFR 50.55A INCORPORATES SPECIFIC CODE ADDENDA & REVISIONS
- S.R.P. CRITERIA FOR FUNCTIONALITY CRITERIA, ETC.
- PFDRP RESULTS WILL PROVIDE "FAILURE MARGINS" DATA FOR OTHER REGULATORY ACTIONS

OTHER RES PIPING DESIGN RESEARCH

FORTHCOMING RES PIPING RESEARCH PROGRAM PLAN (NUREG-1222)

PIPING RESPONSE METHODS

- DAMPING
- INDEPENDENT SUPPORT MOTION (ISM) METHOD
- HIGH FREQUENCY, CLOSELY SPACED MODES
- NONLINEAR RESPONSE PREDICTION

NOZZLE FLEXIBILITY AND DESIGN

SUPPORT DESIGN

PIPING EXPERIENCE DATA

CUMULATIVE EFFECT OF PIPING CRITERIA CHANGES

IPIRG

PIPING RELIABILITY STUDIES

PIPING AND FITTING  
DYNAMIC RELIABILITY PROGRAM  
EPRI INTRODUCTION AND OVERVIEW

FOR

ACRS SUBCOMMITTEE ON  
STRUCTURAL ENGINEERING

PACIFICA HOTEL  
CULVER CITY, CALIFORNIA

MARCH 30, 1988

PRESENTED BY

SAM W. TAGART JR.  
EPRI

## TOPICS

- BRIEF HISTORY OF CODE RULES
- WHAT WE KNEW IN 1985
- SIMPLE ANALYSIS EXPLAINING NO STATIC COLLAPSE
- SUMMARY OF WHAT WE KNOW IN 1988
- THE OPPORTUNITIES AND THE CHALLENGES

## HISTORY OF PIPE DESIGN

- 1952 - MARKL FATIGUE TESTS FOR B31.1 (SEMI STATIC)
- 1963 - NUCLEAR P.V. RULES (STATIC AND FATIGUE LOADS)
- 1968 - NUCLEAR PIPING RULES (STATIC, DYNAMIC\* AND FATIGUE LOADS)
- 1975 - JAPANESE RESEARCH SHOWS LARGE DYNAMIC MARGINS AND FATIGUE RATCHET FAILURE MODE FOR PIPING (NO COLLAPSE)
- 1982 - PVRC PROGRAM TO IMPROVE PIPING
- 1985 - NUREG 1061 NRC PIPING RECOMMENDATIONS
- 1988 - EPRI/NRC PIPING DYNAMIC TESTS (BASIS FOR NEW RULES)

\* EFFECTS OF DYNAMIC LOADS WERE HANDLED BY STATIC FAILURE CRITERIA (CONFIRMED BY GREENSTREET TESTS)

## WHAT WE KNEW IN 1985

- PIPING DYNAMIC MARGIN WAS LARGE BUT UNCERTAIN
- PIPING FAILURE MODE FOR REVERSED DYNAMIC LOADING IS RATCHETING AND FATIGUE (NOT STATIC COLLAPSE)
- REDUCTION OF PIPING CODE MARGINS REQUIRED CONVINCING EXPERIMENTAL EVIDENCE PLUS ENGINEERING UNDERSTANDING
- MODERN NUCLEAR PLANTS HAD TOO MANY SNUBBERS

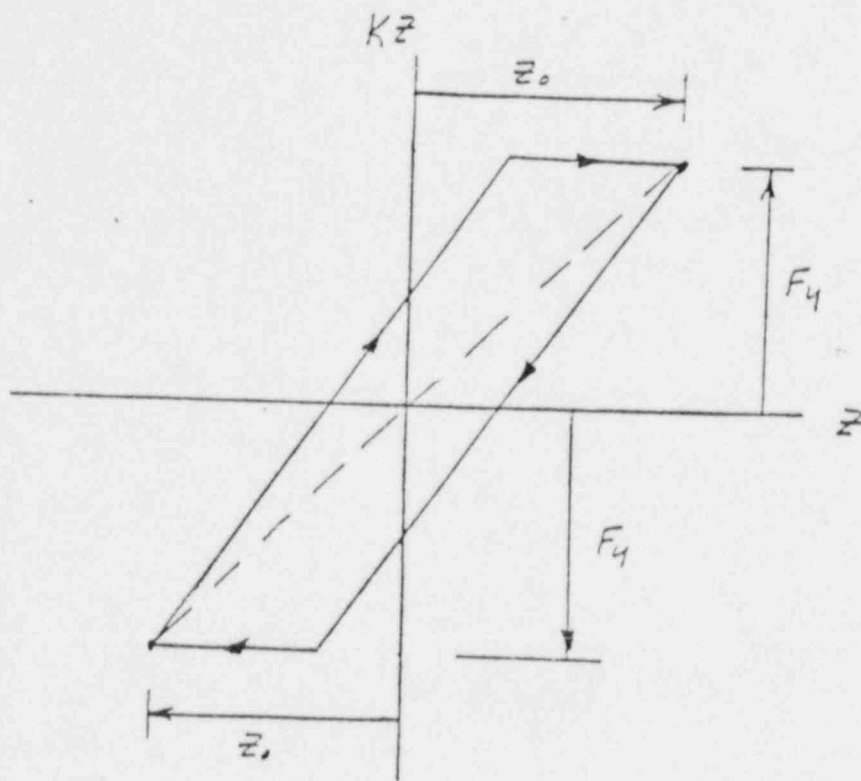


Figure 2  
Restoring Force In  
Spring During 1 Cycle



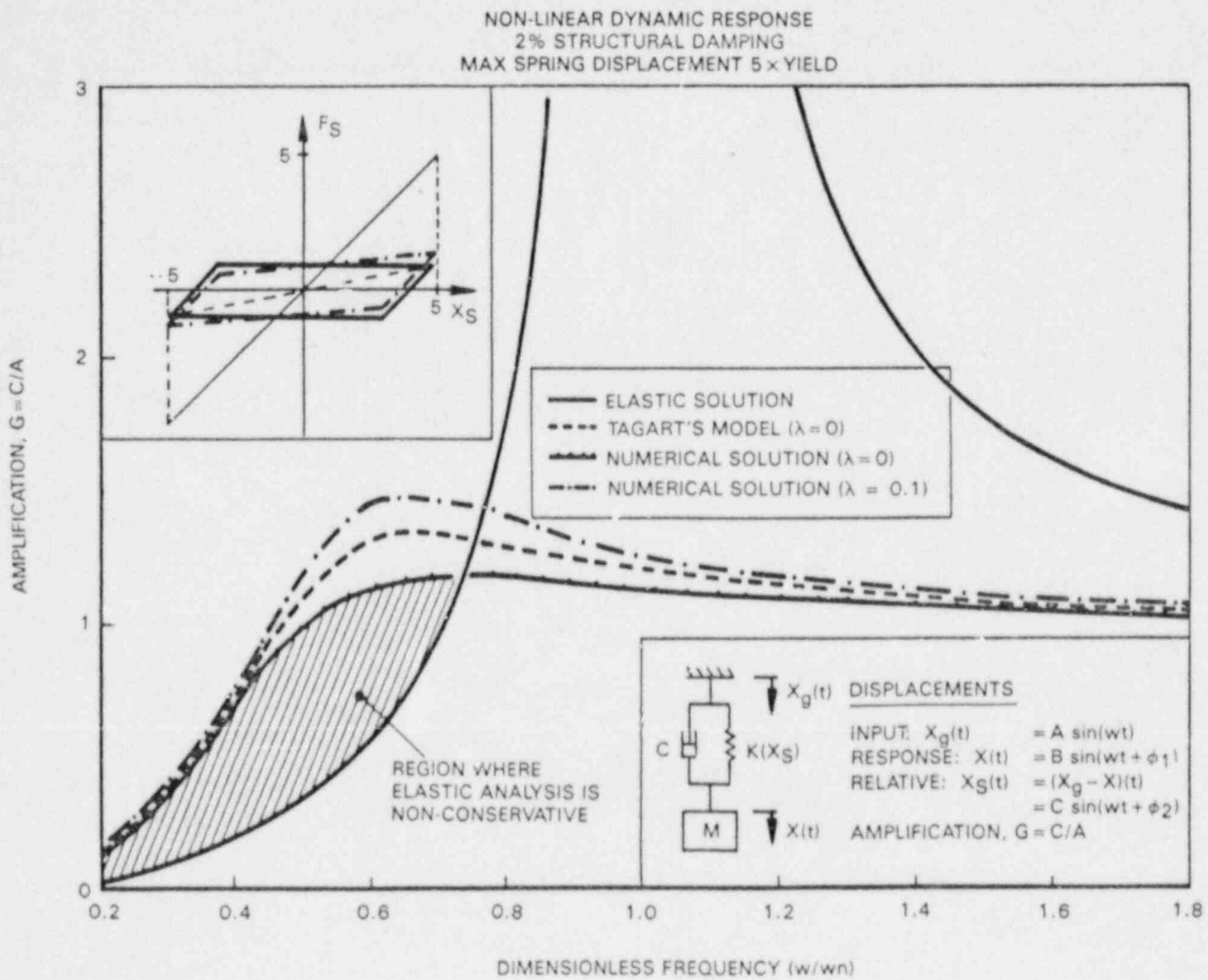


Figure 3.5-8. Dynamic Amplification for Elastic and Elastic-Plastic Systems

## WHAT WE KNOW IN 1988

- WHY STATIC COLLAPSE DOES NOT GENERALLY OCCUR
- WHAT TYPES OF DYNAMIC LOADS CAN COLLAPSE PIPING
- HOW TO APPROXIMATELY PREDICT COMPONENT TEST RESULTS FROM FIRST PRINCIPLES
- LIMITATIONS OF LINEAR DYNAMIC ANALYSIS
- CLARIFY CONCEPTS OF APPARENT DAMPING
- WHY SOUND PIPING SYSTEMS ARE SO FUNDAMENTALLY RESISTANT TO SEISMIC OR OTHER CYCLIC-TYPE DYNAMIC INPUTS ("TIME" DAMPING IS VERY HIGH AT MODERATE DYNAMIC DUCTILITY OF 3)
- HOW TO UNDERSTAND RATCHETING

## OPPORTUNITIES AND CHALLENGES

- SIGNIFICANT CODE MARGIN REDUCTION PROPOSAL (THIS PROGRAM)
- MANAGING PRIOR AND FUTURE OTHER CODE CHANGES

N-411

N-451

ISM WITH SRSS

SIMPLIFIED STATIC ANALYSIS

NON-LINEAR METHODS

SAM MODIFICATIONS

DESIGN BY RULES

- METHOD TO OPTIMIZE PIPING DESIGN FOR SAFETY AND COSTS



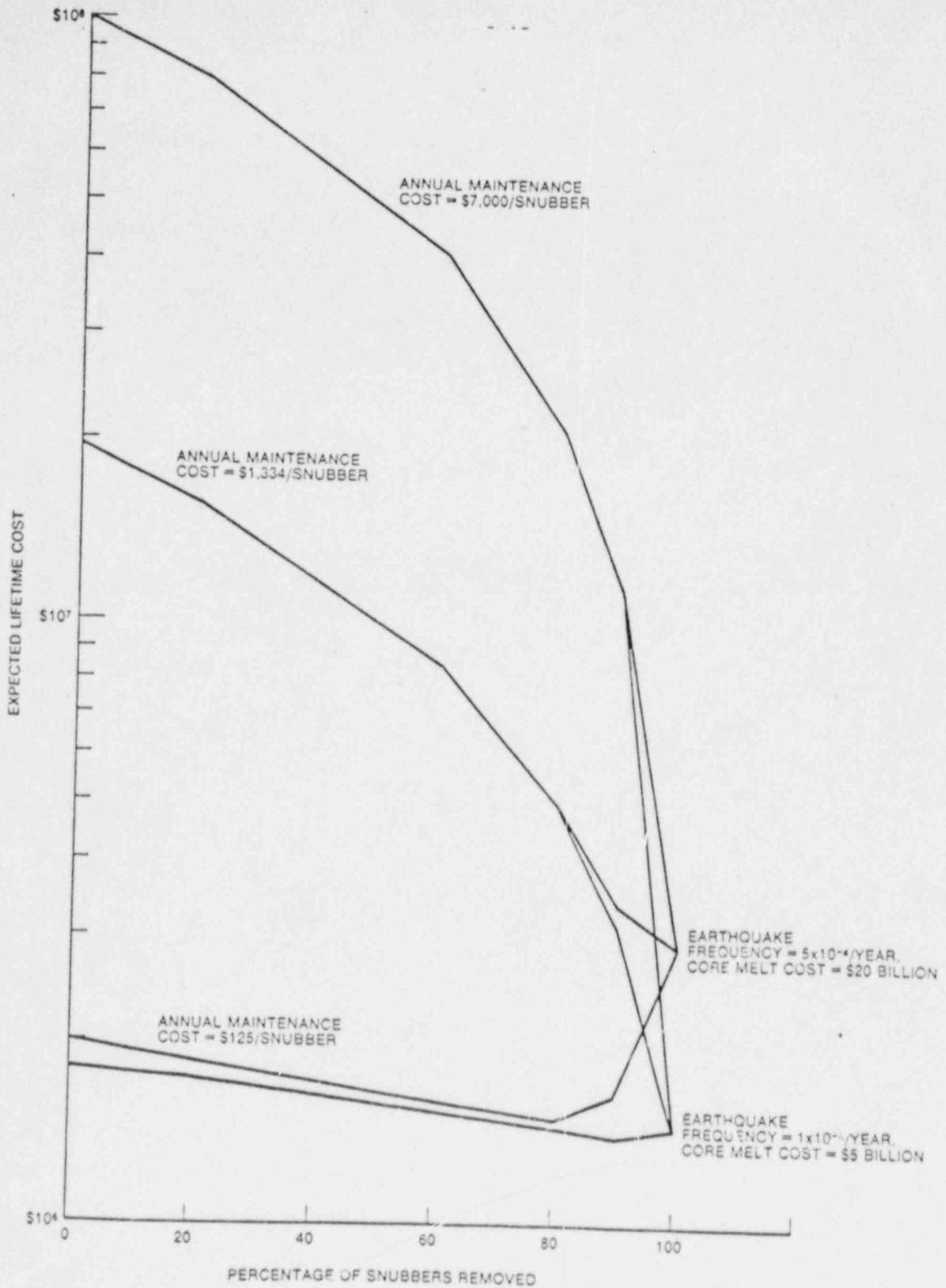


Figure 15. Expected Total Cost for an Entire Plant

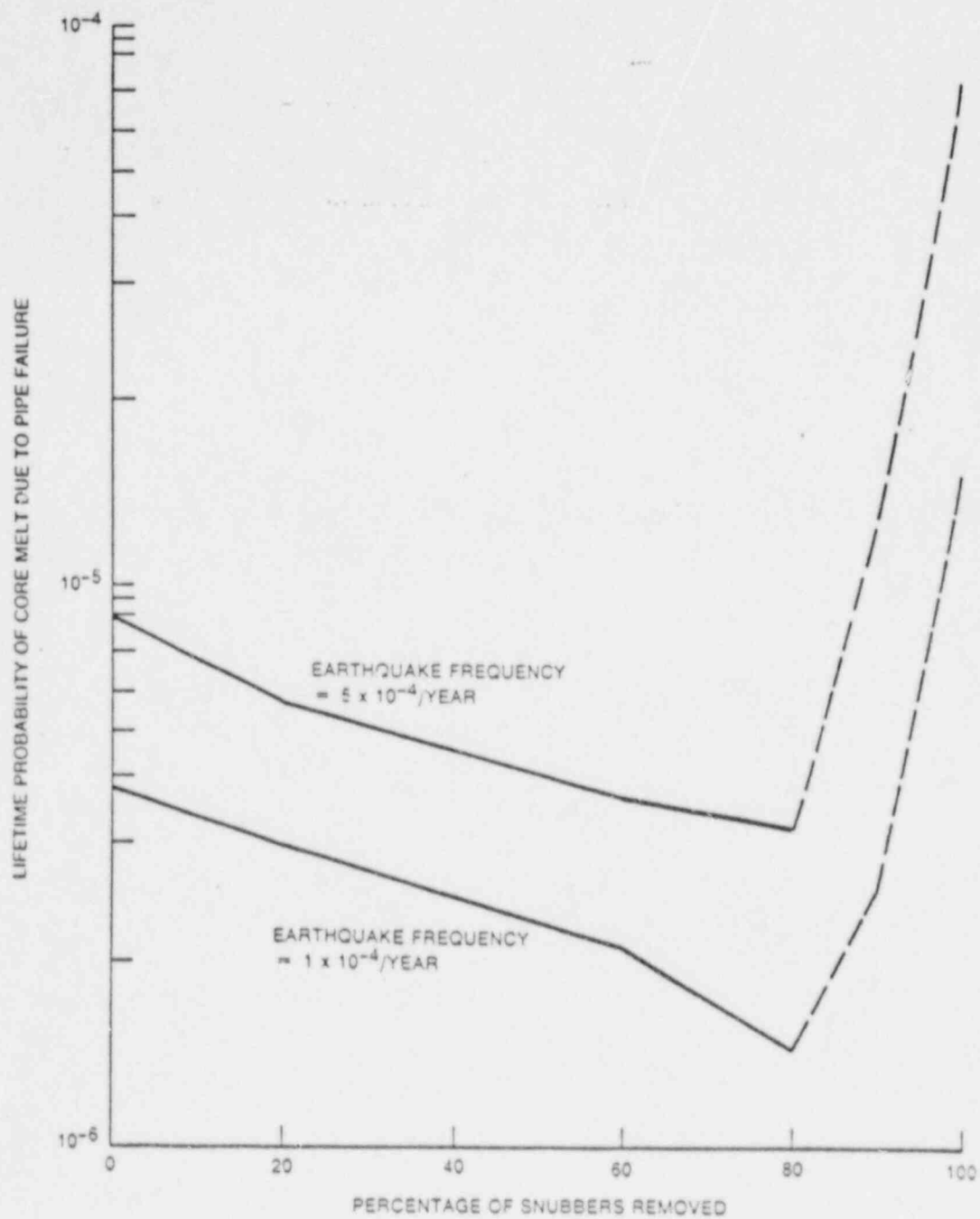


Figure 14. Core Melt Probability as a Function of Snubber Reduction  
(Results Extrapolated to an Entire Plant)

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POTENTIAL DESIGN RULE CHANGES

S. RANGANATH  
GE NUCLEAR ENERGY

## OUTLINE

### 0 REVIEW OF CONCLUSIONS FROM TEST PROGRAM

- COMPONENT AND SYSTEM TESTS
- SPECIMEN FATIGUE & RATCHETING TESTS
- RESULTS OF SDOF MODEL ANALYSIS

### 0 POTENTIAL DESIGN RULE CHANGES

- VALIDITY OF ELASTIC ANALYSIS
- PROPOSED RULES AND TECHNICAL BASIS
- STRATEGY FOR IMPLEMENTATION

### 0 LONG TERM GOALS



## CONCLUSIONS FROM COMPONENT AND SYSTEM DYNAMIC TESTS

- 0 COMPONENT AND SYSTEM TESTS SHOW THAT SEISMIC LOADS WELL IN EXCESS OF LEVEL D LIMITS CAN BE TOLERATED.
- 0 NO LIMIT LOAD FAILURES OCCURRED IN ANY OF THE COMPONENT AND SYSTEM TESTS. THIS CONFIRMS THAT CURRENT CODE STRESS LIMITS PROVIDING MARGINS ON LIMIT LOADS MAY BE OVERLY RESTRICTIVE.
- 0 TEST FAILURES INVOLVE A COMBINATION OF FATIGUE AND/OR RATCHETING SUGGESTING THAT CODE RULES SHOULD CONSIDER THIS. EVEN WHEN FAILURE DID OCCUR, THE NUMBER OF CYCLES WAS WELL IN EXCESS OF THAT IN TYPICAL SEISMIC LOADING EVENTS.
- 0 ANALYSIS OF TESTS SHOWS THAT ELASTIC PREDICTIONS ARE GENERALLY CONSERVATIVE FOR RESPONSE SPECTRUM ANALYSIS WITH PEAK BROADENING FOR UP TO 5 PERCENT DAMPING.

## CONCLUSIONS FROM FATIGUE-RATCHET SPECIMEN TESTS

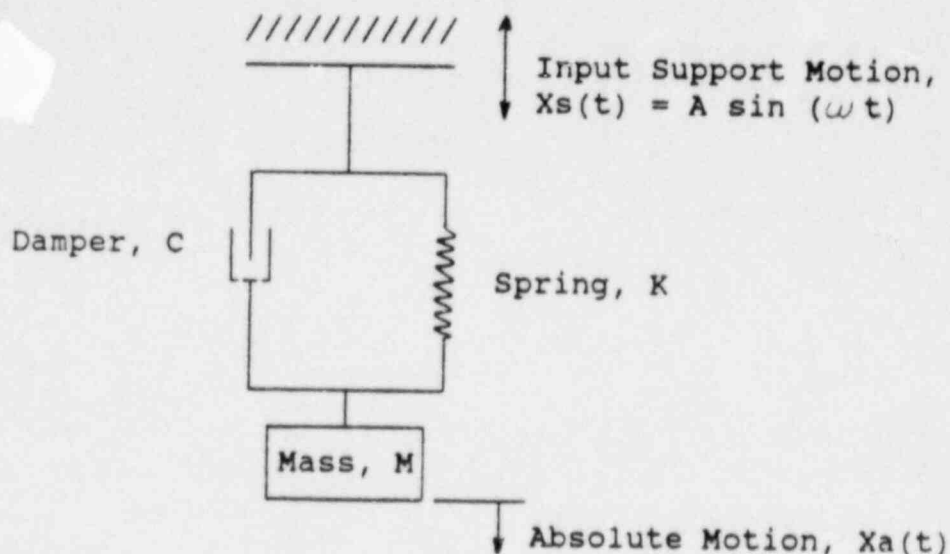
- 0 RATCHETING OCCURS WHEN THE COMBINATION OF PRIMARY MEAN STRESS AND CYCLIC DYNAMIC STRESS EXCEEDS THE YIELD STRENGTH FOR POSITIVE MEAN STRESS.
  - TIME INDEPENDENT RATCHET STRAIN DETERMINED FROM MILLER MODEL
  - $E_R = S_{\text{MEAN}} / E_p$  FOR BILINEAR STRESS - STRAIN CURVE WITH KINEMATIC HARDENING
- 0 TWO BAR AND BEND TESTS SHOW TIME DEPENDENT RATCHET STRAIN FOR THE LOW FREQUENCY (0.5 cpm) TESTS.
  - RATCHET STRAIN PER CYCLE DEPENDS ON MEAN STRESS, CYCLIC STRESS, AND TEMPERATURE
- 0 PRELIMINARY DATA SUGGEST THAT TIME DEPENDENT RATCHET IS LESS SIGNIFICANT AT HIGHER FREQUENCIES.

## FATIGUE-RATCHET RESULTS (CONTINUED)

- 0 FAILURE IS EITHER BY FATIGUE OR BY EXCESSIVE RATCHET STRAIN LEADING TO NECKING AND SUBSEQUENT RUPTURE.
- 0 WHERE FAILURE WAS BY FATIGUE, THE DATA POINTS FALL ON THE MEAN FATIGUE DATA CURVE REGARDLESS OF THE RATCHET STRAIN.
- 0 THUS, AS LONG AS THE CUMULATIVE RATCHET STRAIN IS NOT EXCESSIVE (SAY 5% - 10%) THERE IS NO SIGNIFICANT EFFECT ON CYCLIC FATIGUE LIFE.

**SINGLE DEGREE OF FREEDOM (SDOF)  
MODEL ANALYSIS**

# THE ELASTIC SDOF SYSTEM WITH INPUT SUPPORT MOTION



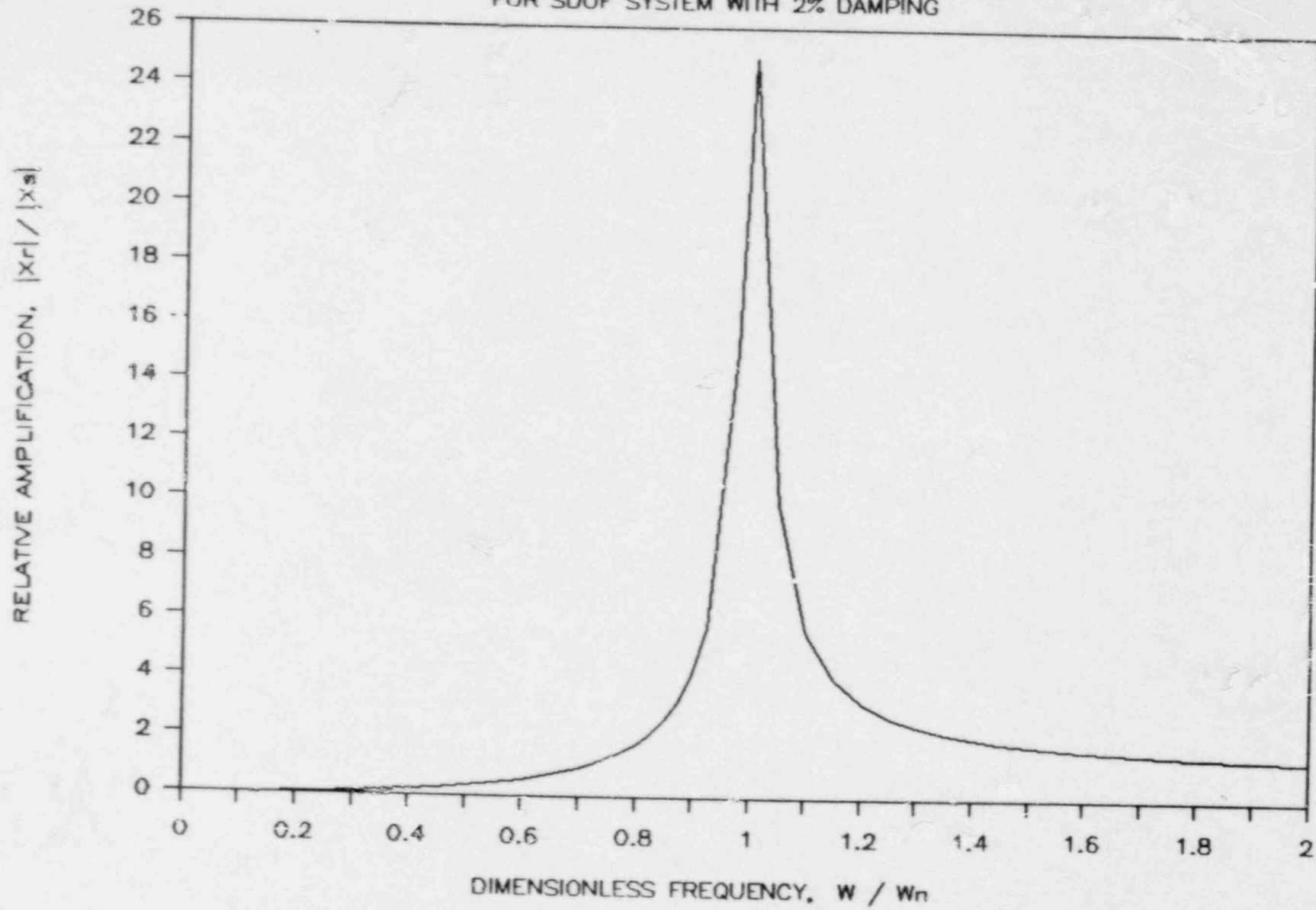
$$\text{Relative Motion, } X_r(t) = X_a(t) - X_s(t)$$

Two types of Displacement to be studied:

- 1) **Absolute Displacement of Mass** - Analogous to the motion of piping system components. Important in determining accelerations and velocities for loads on pipe mounted equipment.
- 2) **Relative Displacement between Mass and Support** - Analogous to relative displacements or deflections of piping components. Important for determining strain in piping components.

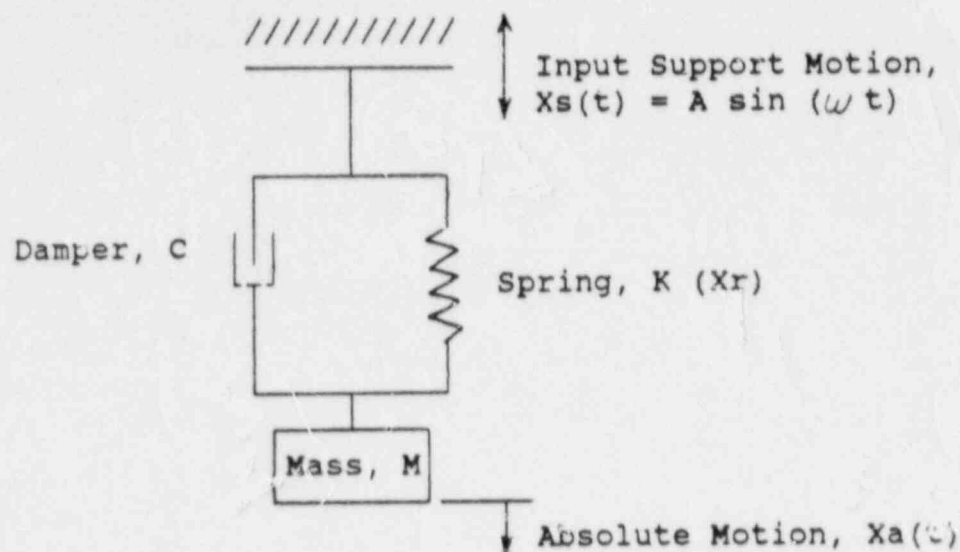
# RELATIVE ELASTIC DYNAMIC RESPONSE

FOR SDOF SYSTEM WITH 2% DAMPING



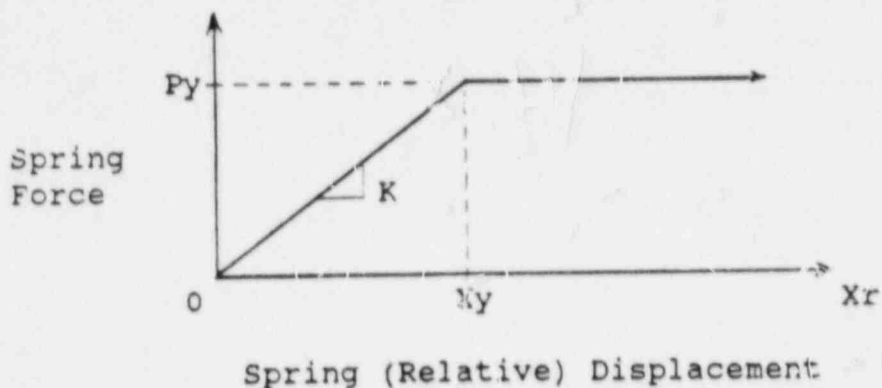
# ELASTIC-PLASTIC SDOF MODELS

Modified Elastic Model - Developed by Sam Tagart



$$\text{Relative Motion, } X_r(t) = X_a(t) - X_s(t)$$

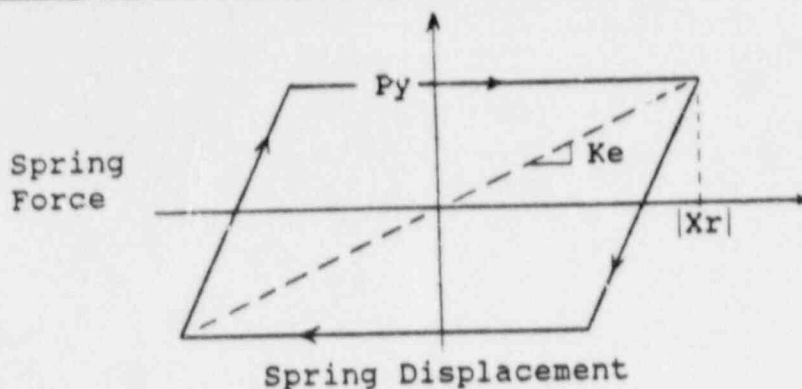
Assume Elastic - Perfectly Plastic Spring



- o Model Elastic-Plastic system as elastic system with reduced stiffness and increased damping as shown on following page.

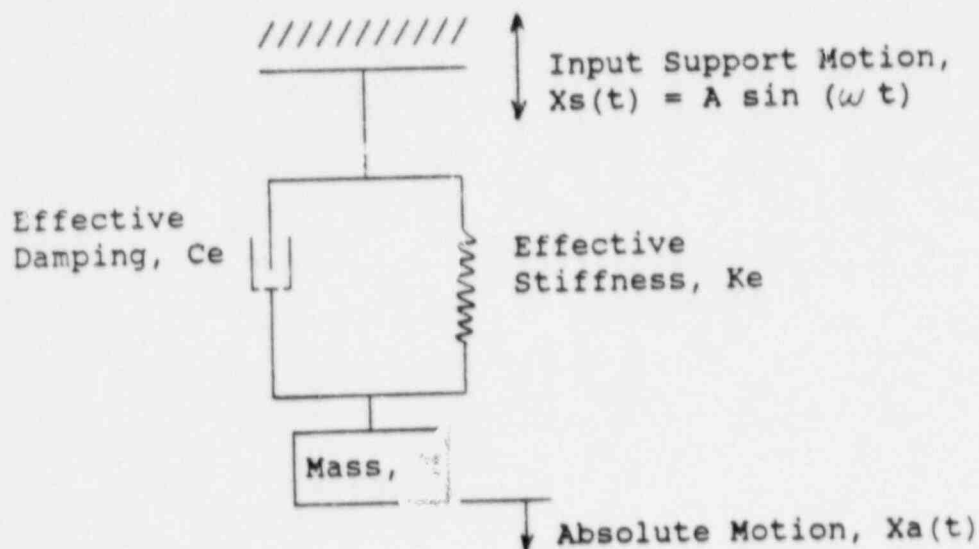
## MODIFIED ELASTIC SYSTEM

### Spring Force-Displacement Hysteresis



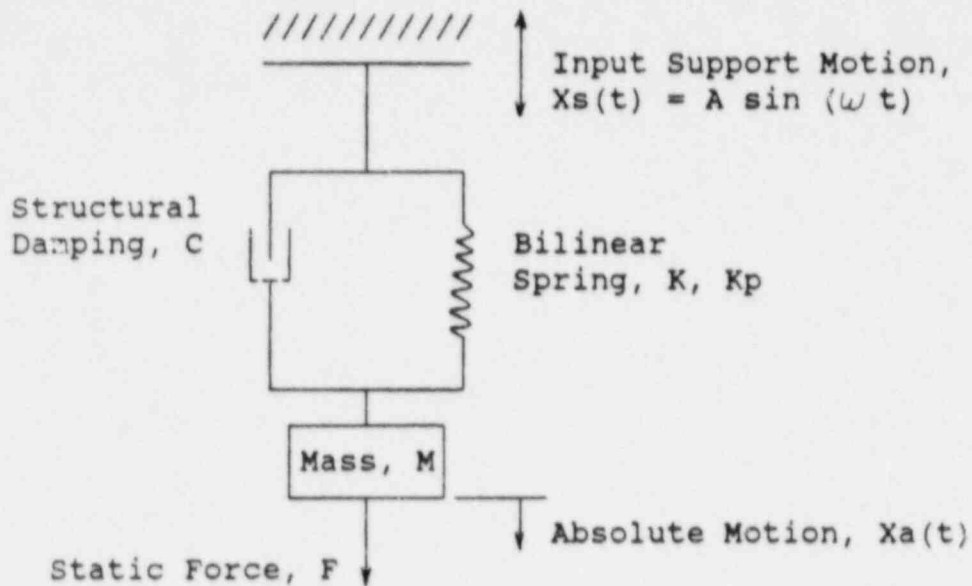
- o Stiffness reduced to account for plasticity. Effective stiffness calculated to give yield force at maximum relative displacement.
- o Damping increased to account for irreversible work. Effective damping calculated to give same irreversible work per cycle as elastic-plastic system.

### Modified Elastic Model

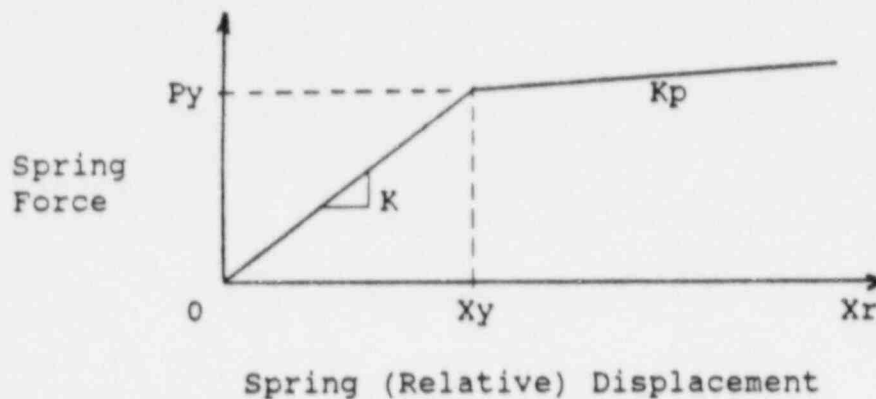




## ELASTIC-PLASTIC SDOF MODELS

'Exact' Numerical Elastic-Plastic Model

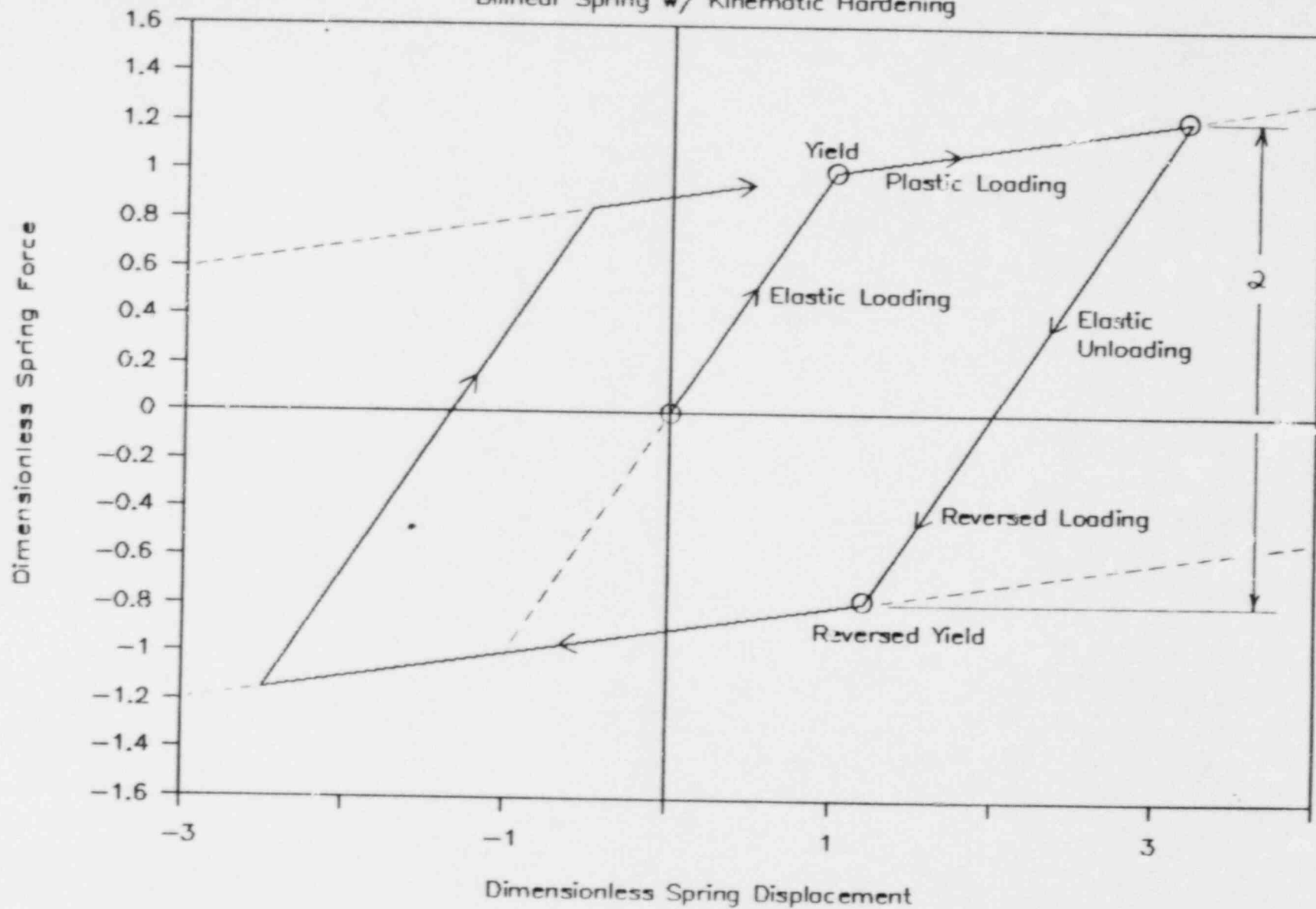
Assume Bilinear Spring - Includes strain hardening



- o Assumed Kinematic Hardening as shown on following page.
- o Static force is included such that ratchetting may be simulated.
- o 'Exact' time history solution using numerical solution.

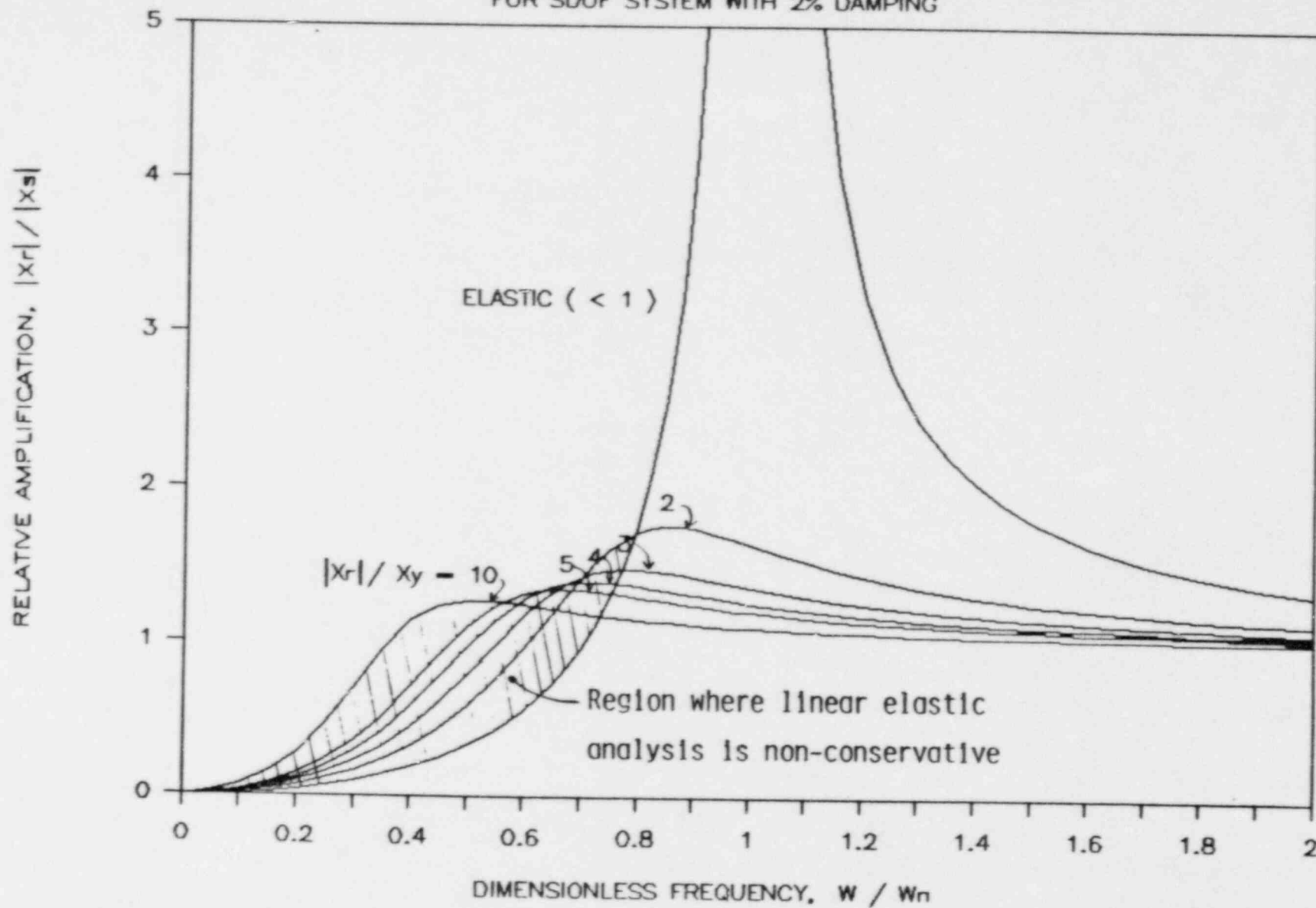
# Spring Force-Displacement Cycle

Bilinear Spring w/ Kinematic Hardening



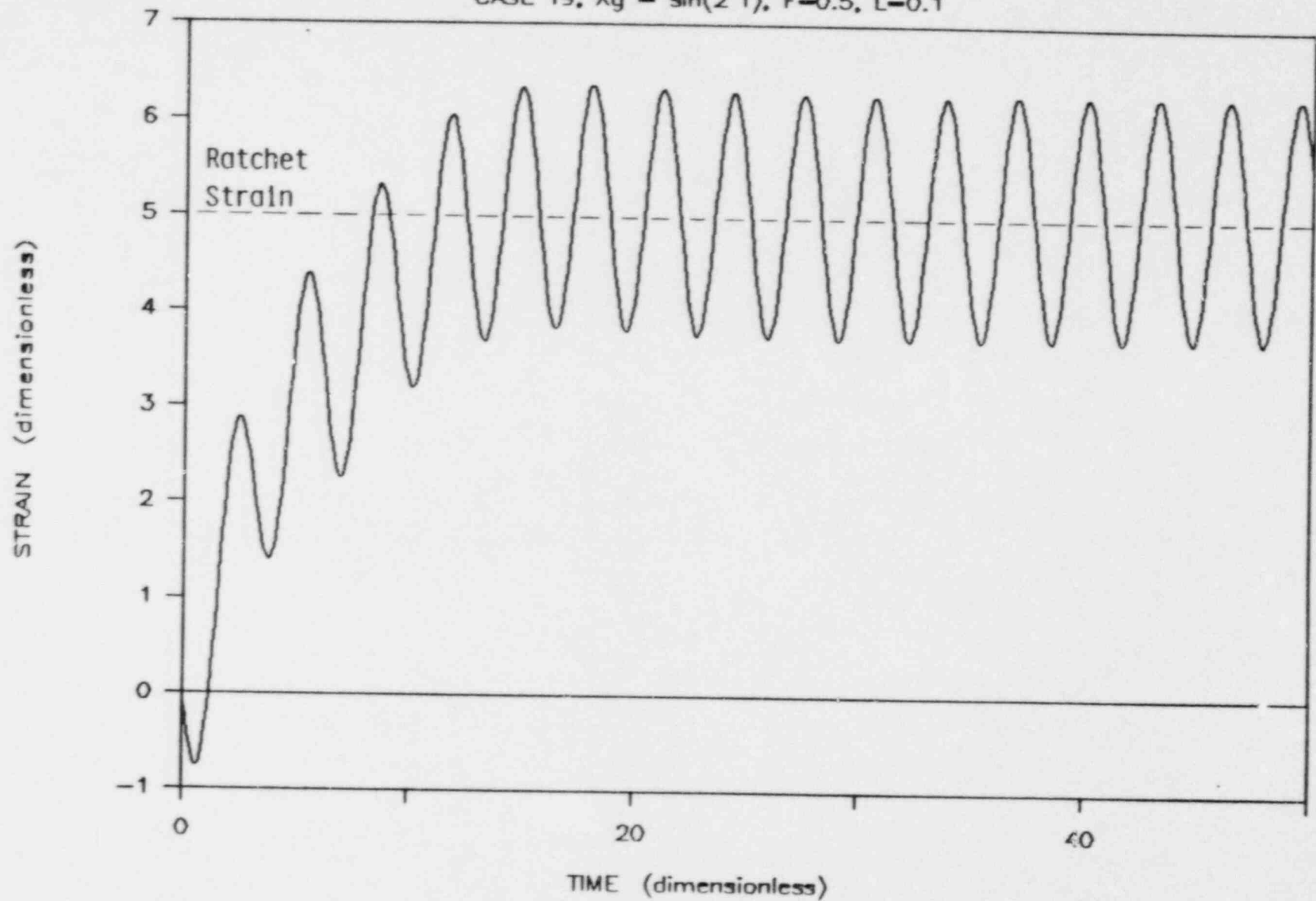
# RELATIVE EL-PL DYNAMIC RESPONSE

FOR SDOF SYSTEM WITH 2% DAMPING



# SPRING STRAIN vs TIME

CASE 19,  $X_g = \sin(2T)$ ,  $F=0.5$ ,  $L=0.1$



CASE 19.  $X_g = \sin(2T)$ ,  $F=0.5$ ,  $L=0.1$

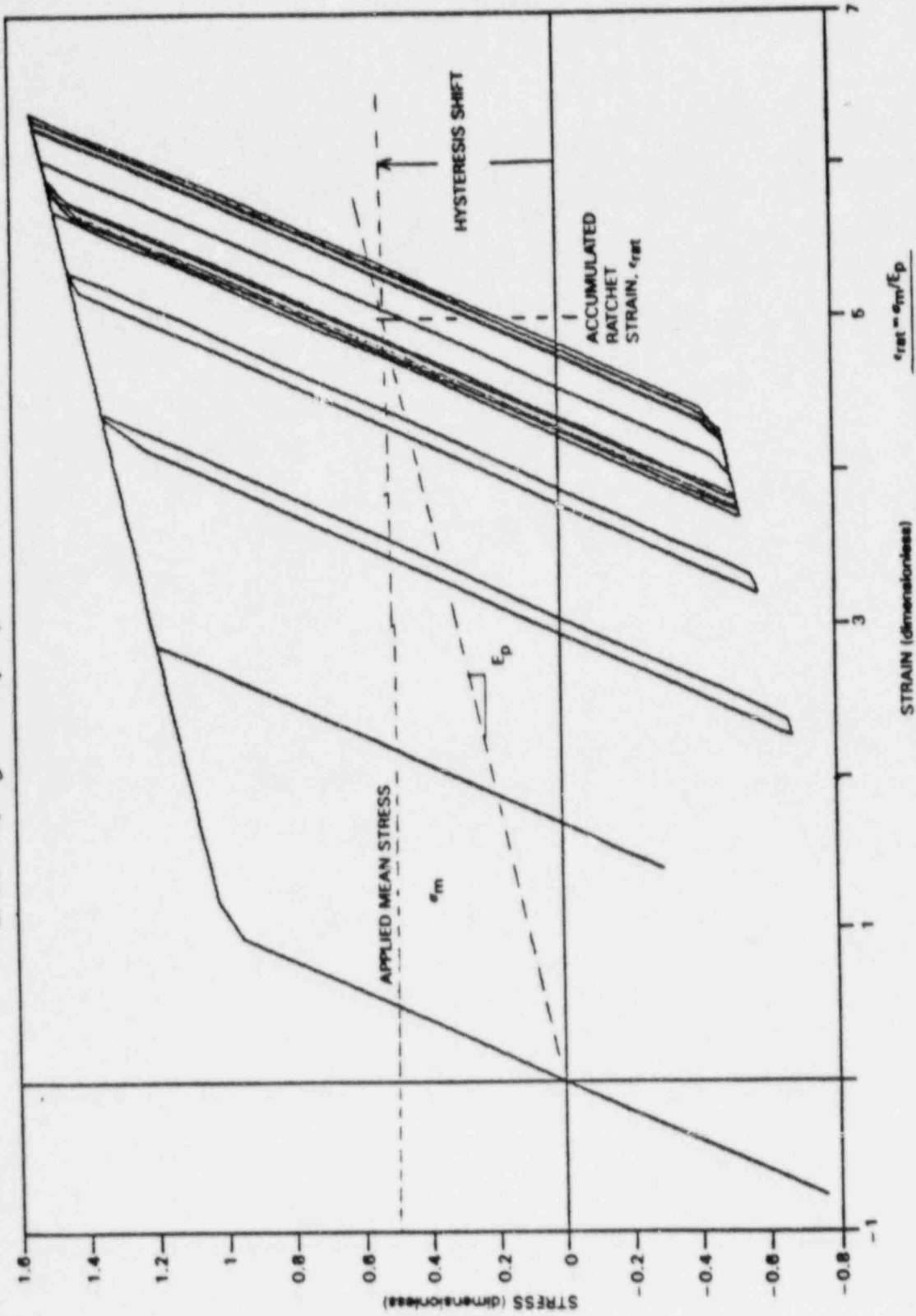


Figure 3.5-9. Arrest of Ratcheting Due to Stress-Strain Hysteresis Shift, Case 19

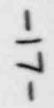
## CONCLUSIONS FROM SINGLE DEGREE OF FREEDOM (SDOF) SYSTEM ANALYSIS

- 0 SDOF EVALUATIONS SHOW THAT ELASTIC ANALYSIS MAY NOT BE CONSERVATIVE FOR APPLIED FREQUENCIES BELOW THE NATURAL FREQUENCY.
- 0 PEAK BROADENING MAY BE NECESSARY TO ASSURE THAT ELASTIC ANALYSIS IS CONSERVATIVE. THIS ACCOUNTS FOR THE SHIFT IN NATURAL FREQUENCY WITH PLASTICITY.
- 0 RATCHETING OCCURS WHEN  $S_{\text{MEAN}} + S_{\text{DYN}} \geq S_Y$
- 0 CUMULATIVE RATCHET STRAIN  $E_R = S_{\text{MEAN}} / E_p$
- 0 SDOF ANALYSIS INDEPENDENTLY PREDICTS THE SAME CUMULATIVE RATCHET STRAIN AS THE MILLER MODEL FOR BILINEAR KINEMATIC HARDENING.
- 0 SDOF MODEL MAY BE OVER CONSERVATIVE COMPARED TO RESULTS OF COMPONENT AND SYSTEM TESTS:
  - GROSS SECTION YIELDING ASSUMED INSTEAD OF LOCAL YIELDING IN BENDING
  - VARYING  $E_p$  IN THE ACTUAL STRESS STRAIN CURVE INSTEAD OF LOWER CONSTANT  $E_p$  IN THE BILINEAR MODEL
  - HIGHER MATERIAL YIELD STRENGTH DUE TO STRAIN HARDENING

## RATCHET CRITERION BASED ON RESULTS OF COMPONENT & SYSTEM TESTS

- 0 WHERE GOOD DATA ARE AVAILABLE, THE MEASURED STRAINS CAN BE USED TO DETERMINE THE STRESS LEVEL BELOW WHICH THERE IS NO RATCHETING.
- 0 FOR TYPICAL MEAN STRESS VALUES (  $0.5 S_M$  ) SIGNIFICANT RATCHETING WAS NOT OBSERVED FOR STRESS AMPLITUDES BELOW APPROXIMATELY  $6 S_M$  FOR BOTH CARBON STEEL AND STAINLESS STEEL AT ROOM TEMPERATURE.
- 0 THIS STRESS VALUE MAY BE USED AS THE STRESS LEVEL BELOW WHICH SPECIAL FATIGUE OR RATCHETING ANALYSIS IS NOT NECESSARY.

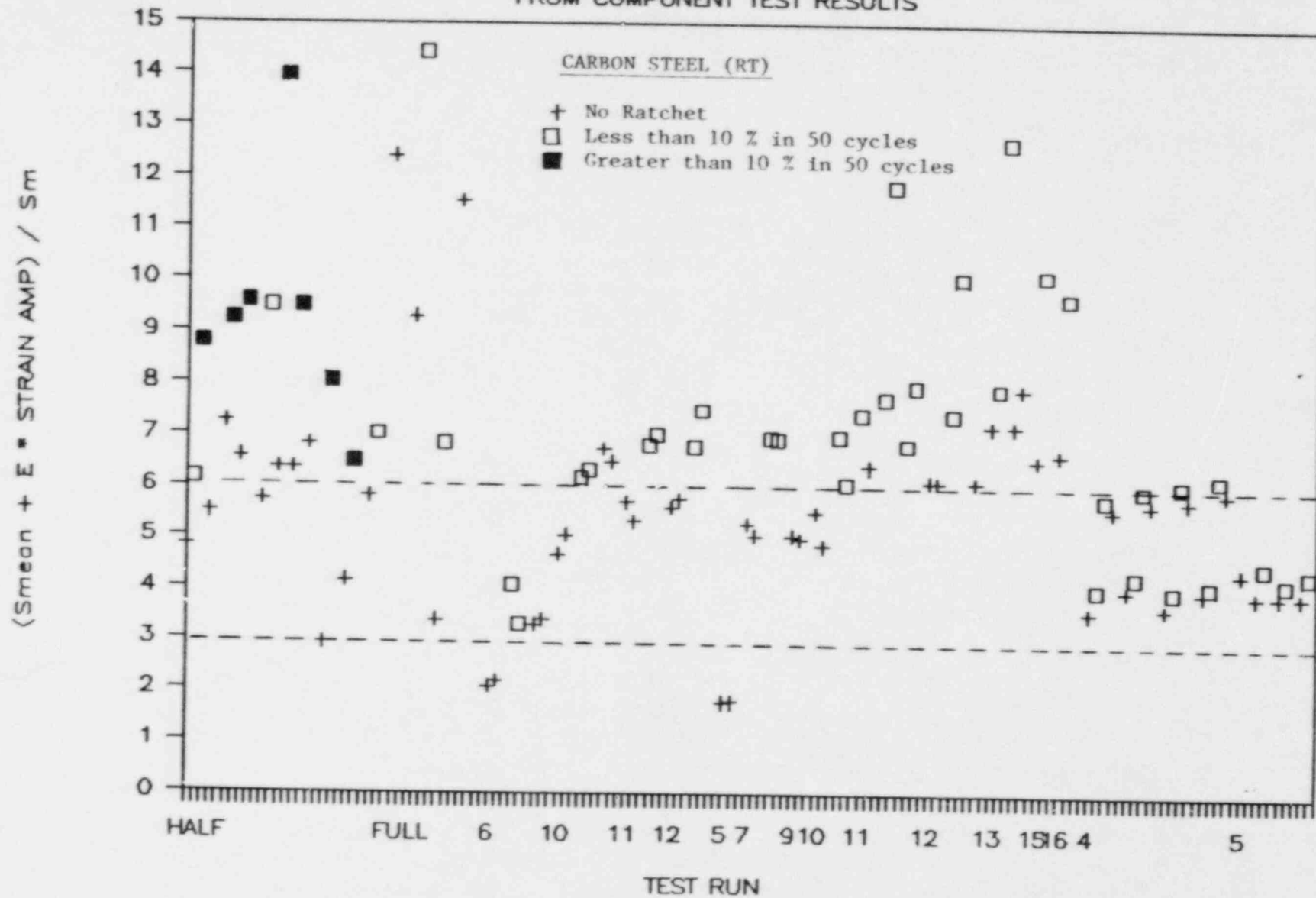
FROM COMPONENT TEST RESULTS





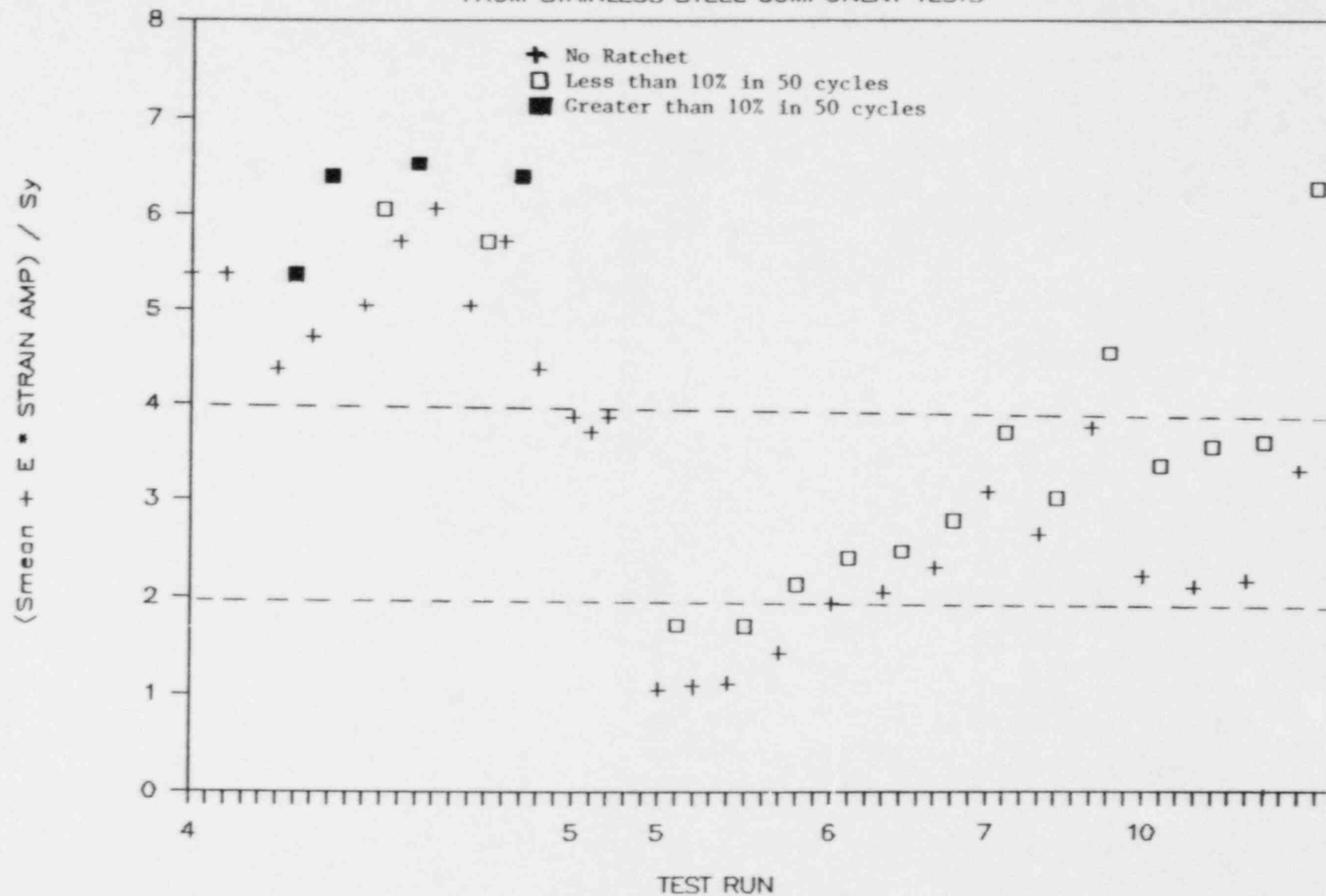
# RATCHET THRESHOLD

FROM COMPONENT TEST RESULTS



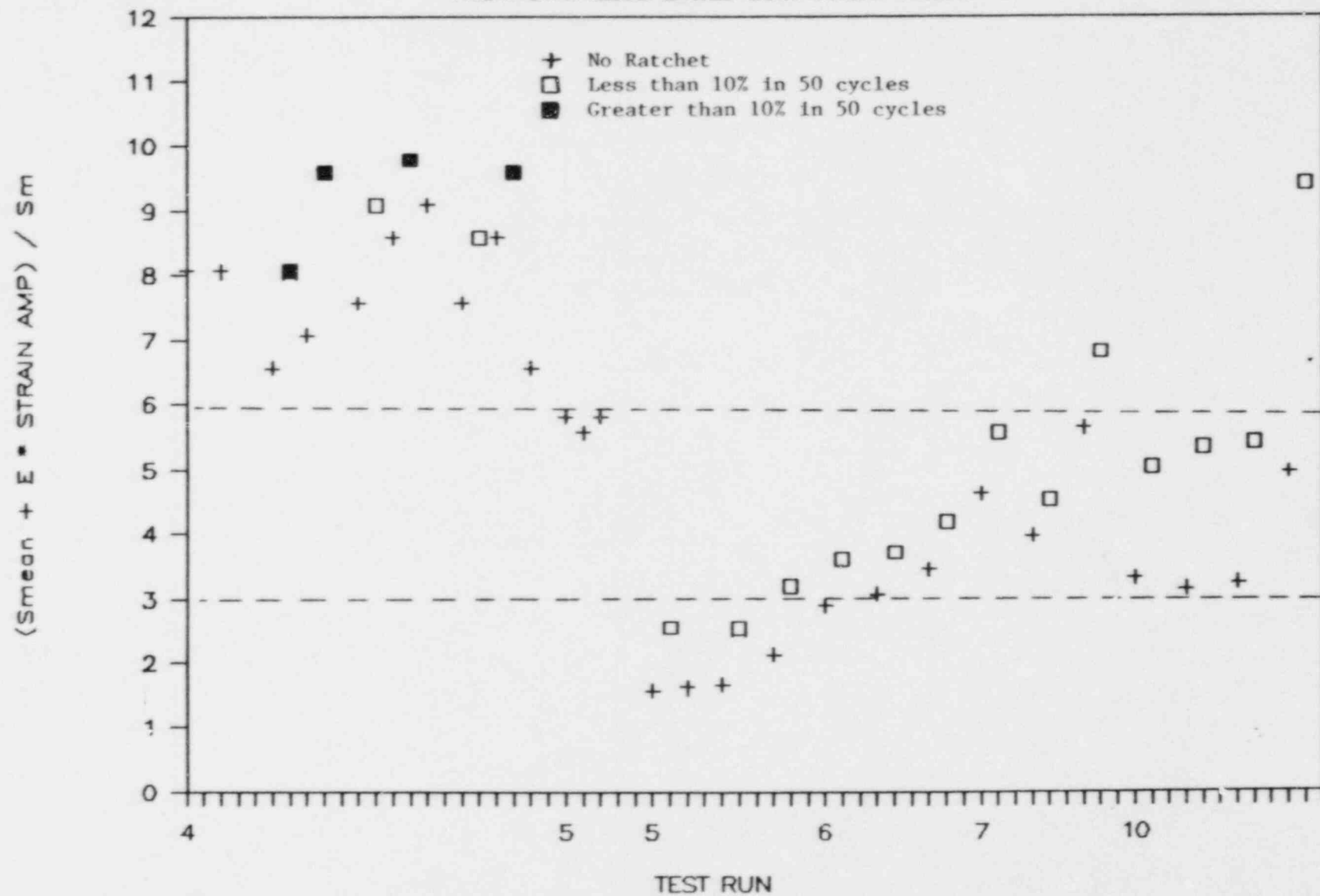
# RATCHET THRESHOLD

FROM STAINLESS STEEL COMPONENT TESTS



# RATCHET THRESHOLD

FROM STAINLESS STEEL COMPONENT TESTS



## POTENTIAL DESIGN RULE CHANGES

### o PRESENT CODE LIMITS

PRESSURE + EARTHQUAKE STRESS (Eq. 9) LIMITS

LESSER OF

LEVEL B	$1.8 S_M$	OR	$1.5 S_Y$
LEVEL C	$2.25 S_M$	OR	$1.8 S_Y$
LEVEL D	$3.0 S_M$	OR	$2.0 S_Y$

FATIGUE ANALYSIS FOR LEVEL B; NO SPECIFIC RATCHETING CONTROLS.

### o PROPOSED NEW CODE LIMITS

PRESSURE + EARTHQUAKE STRESS (Eq. 9) LIMITS

LESSER OF

LEVEL B	$3.0 S_M$	OR	$2.0 S_Y$
LEVEL C	$4.5 S_M$	OR	$3.6 S_Y$
LEVEL D	$6.0 S_M$	OR	$4.0 S_Y$

FATIGUE ANALYSIS FOR LEVEL B; NO SPECIFIC RATCHETING CONTROLS.

## STRATEGY FOR CODE IMPLEMENTATION

### SHORT TERM GOALS

- 0 PROPOSE FOR INCLUSION IN CURRENT NB - 3000 REQUIREMENTS. WITH THIS APPROACH IT MAY BE DIFFICULT TO IMPOSE RESTRICTIONS ON ANALYSIS APPROACH.
  
- 0 INCLUDE NEW RULES IN A CODE CASE; IMPOSE SPECIFIC RESTRICTIONS ON HOW IT IS USED:
  - RESPONSE SPECTRUM ANALYSIS
  - PEAK BROADENING TO BE INCLUDED
  - DAMPING NOT IN EXCESS OF 5 PERCENT
  
- 0 USE NON-MANDATORY APPENDIX APPROACH

## LONG TERM GOALS

- 0 TEST DATA SHOW THAT PIPING COMPONENTS CAN TOLERATE LOADS WELL BEYOND CURRENT CODE LIMITS
- 0 THE CURRENT DESIGN CRITERIA MAY BE ADDING TO COSTS SIGNIFICANTLY WITHOUT COMMENSURATE SAFETY BENEFITS
  - + SUBSTANTIAL DESIGN/ANALYSIS COSTS
  - + INCREASED HARDWARE COSTS, E.G., SNUBBERS, PIPE SUPPORTS
  - + INCREASED MAINTENANCE COSTS
  - + POTENTIAL FOR INCREASED STEADY STATE STRESSES IF SNUBBERS 'LOCK UP'
- 0 STATIC ANALYSIS MAY IN FACT BE ACCEPTABLE IN MOST CASES RESULTING IN SIGNIFICANT SIMPLIFICATION
- 0 LONG TERM DESIGN ANALYSIS GOAL SHOULD BE TO IMPLEMENT REALISTIC STRESS LIMITS WITH SIMPLER ANALYSIS METHODS

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## PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM

- OVERALL PROGRAM STRUCTURE
- OBJECTIVES OF PROGRAM
- PFDR TEST PROGRAMS
  - COMPONENT TESTS
  - SYSTEM TESTS
  - SPECIMEN TESTS

OVERALL PROGRAM STRUCTURE  
EPRI/NRC PIPING AND FITTING  
DYNAMIC RELIABILITY PROGRAM (PFDR)

- TASK 1: PROGRAM PLAN DEVELOPMENT - GE-SJ
- ▷ ● TASK 2: PIPE COMPONENT TESTING - ANCO
- ▷ ● TASK 3: PIPE SYSTEM TESTING - ETEC, ANCO
- ▷ ● TASK 4: SPECIMEN FATIGUE RATCHETING TESTS-MCL
- ▷ ● TASK 5: ANALYSIS OF TESTS AND DESIGN RULES -  
GE-SJ
- TASK 6: IDENTIFICATION AND DEVELOPMENT OF  
ALTERNATIVE DESIGN RULES AND  
REGULATIONS - GE-SJ
- TASK 7: EVALUATION OF ALTERNATIVE DESIGN RULES  
- GE-SJ
- TASK 8: PROJECT FINAL REPORTS - GE-SJ



## OBJECTIVES OF PROGRAM

MAJOR OBJECTIVE: DEVELOP AN IMPROVED, REALISTIC  
AND DEFENSIBLE SET OF PIPING  
DESIGN RULES FOR INCLUSION IN  
ASME CODE

1. DETERMINE ACTUAL FAILURE MECHANISM FOR PIPING  
SYSTEMS AND COMPONENTS
  - A) LOW FREQUENCY LOADS
  - B) MID FREQUENCY LOADS
  - C) HIGH FREQUENCY IMPULSIVE LOADS
2. MEASURE PIPING SYSTEM DAMPING FOR VARIOUS STRAIN  
LEVELS OVER A LARGE RANGE OF FREQUENCIES
3. DETERMINE INFLUENCE OF SUPPORT FAILURE ON  
PIPING SYSTEM RESPONSE
4. SHOW EFFECT OF LOW FREQUENCY INPUT TO PIPING  
FROM BUILDINGS SUBJECTED TO LARGE AMPLITUDE  
EARTHQUAKES
5. DEMONSTRATE THAT PIPING COMPONENTS AND SYSTEMS  
CAN TOLERATE EARTHQUAKES MUCH LARGER THAN SSE  
WITHOUT PIPE FAILURE

OBJECTIVES OF PROGRAM (CONTINUED)

6. DEVELOP LABORATORY PROCEDURE FOR QUANTITATIVE EVALUATION OF FATIGUE-RATCHETING
7. QUANTIFY ECONOMIC BENEFITS OF NEW DESIGN RULES TO UTILITIES BY APPLICATION TO TYPICAL NUCLEAR PIPING SYSTEM
8. SUGGEST CHANGES TO SRP AND RG WHICH REFLECT INHERENT DYNAMIC MARGINS IN PIPING
9. DEVISE SIMPLIFIED METHODS FOR ACCOUNTING FOR PLASTIC DEFORMATION, AND FATIGUE RATCHETING
10. SIMPLIFY PIPING SYSTEM DYNAMIC ANALYSIS

## PFDR TEST PROGRAMS

FOCUS

### COMPONENT TESTS

- MOST SEVERE LOADING
- MOST INSTRUMENTATION
- DEMONSTRATES COMPONENT BEHAVIOR
- DETERMINES FAILURE MODES
- PROVES FUNCTIONALITY
- HELPS PREDICT SYSTEM TESTS
- CALIBRATES DESIGN RULES

### SPECIMEN TESTS

- DEMONSTRATES RATCHETING
- EVALUATES MANY MATERIALS
- DETERMINES TEMPERATURE EFFECTS

### SYSTEM TESTS

- CONFIRMS REDISTRIBUTION OF LOADS
- CONFIRMS MODE OF FAILURE
- CONFIRMS FUNCTIONALITY
- CONFIRMS DESIGN RULES AND MARGINS
- PROVIDES BENCHMARK ANALYSIS DATA

## COMPONENT TESTS

### OBJECTIVES

- DETERMINE FAILURE MODE (S) UNDER DYNAMIC LOADING
- MEASURE RATCHETING AND CYCLES TO FAILURE
- DEVELOP ENGINEERING UNDERSTANDING OF COMPONENT BEHAVIOR

### COMPONENTS TO BE TESTED (6 IN. DIA., SCH 10, 40, 80)

ELBOWS, TEES, REDUCERS, NOZZLES, SUPPORT CONNECTIONS

### PLAN FOR COMPONENT TESTS

- INPUT PEAK AT 0.5 HZ BELOW COMPONENT NAT. FREQ.
- ANCO SLEDS OPERATED AT MAXIMUM EXCITATION

### DESIRED RESULTS

- FATIGUE RATCHET CRACK IN 2 - 3 SEISMIC INPUTS

### ACTUAL RESULTS

- SCH. 10: CRACKED IN 1/2 TO 3-1/2 SEISMIC INPUTS
  - SCH. 40: CRACKED IN 1-1/2 TO 3-1/2 SEISMIC INPUTS - OPTIMUM
  - SCH. 80: CRACKED IN 5 TO 9 SEISMIC INPUTS
- INVESTIGATING BEHAVIOR AT INTERMEDIATE LOAD LEVELS

PIPING AND FITTINGS DYNAMIC RELIABILITY PROGRAM  
COMPLEMENT TEST SUMMARY

NO	TYPE	MAT SCH	RES STR % (1)	PRESS	LOAD DIR /SIZE	DYN MOM LIN MOM	LOAD TYPE	P-P CYC STRAIN OO	INPUT X LEVEL D	NO TH	FAIL MODE
1	Elbow	CS 80		1500	I-P	1.21	SSE	2.5%(1)	15	5	WF
	(Retest)	80		2600	I-P	1.21	SSE	1.5%(1)	15	0.5	FR
2	Elbow	CS 80		1500	O-P	1.04	SSE	1.4%(1)	15	5	WF
	(Retest)	80		2600	O-P	1.04	SSE	1.4%(1)	15	4.5	FR
3	Elbow	SS 10	3.5	400	I-P	2.36	SSE	2.4%(1)	21	3.5	FR
4	Elbow	CS 40		1000	I-P	1.66	SSE	2.0%(1)	18	2.5	FR
5	Elbow	CS 40	13.8	1700	I-P	2.06	SSE	2.0%(1)	21	3.5	FR
6	Elbow	SS 40	16	1700	I-P	2.00	SSE	2.0%(1)	19	3.5	FR
7	Elbow	SS 40	9	1000	I-P	1.80	SSE	2.0%(1)	23	4.5	FR
8	Elbow	SS 40	1.5	0	I-P	1.80	SSE	2.0%(1)	24	5	WF
9	Tee Fix-2	SS 40	8	1700	O-P	2.50	SSE	2.2%	21	1.5	FR
10	Tee Fix-2	SS 40	6.5	1000	O-P	2.40	SSE	2.2%	21	2.5	FR
11	Tee Fix-2	SS 10	3	400	O-P	1.00	SSE	1.9%	16	0.5	FR
12	Tee Fix-2	SS 40	11	1700	I-P	2.30	SSE	2.2%	27	2.5	FR
13	Short Elb.	CS 40	6	1000	I-P	2.30	SSE	1.9%(1)	22	2.5	FR
14	Tee Fix-2	CS 40	10	1700	O-P	2.46	SSE	2.2%(2)	18	1.5	FR
15	Reducer	SS 40	18	1700	8x4	1.18	SSE	13%(3)	13	5	FR
16	Reducer	SS 40	2.5	1700	8x4	1.72	SSE	3.3	30	0.5	FR

PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM  
COMPONENT TEST SUMMARY

NO	TYPE	MAT SCH	RES STR % (1)	PRESS	LOAD DIR /SIZE	<u>DYN MOM</u> LIM MOM	LOAD TYPE	P-P CYC STRAIN OO	INPUT X LEVEL D	NO TH	FAIL MODE
17	Short Elbow	CS 40	2.5	1000	TOR	N/A	SSE	2.5X(1)	20	3	FR
18	Reinforced Fab. Tee	CS 40		1000	8x4		SSE			0.3	FR
19	Elbow	CS 40		2300	I-P		SSE				
20	Nozzle	SS 40		1000	12x4		SSE				
21	Guide Lug	CS 40	5	1700	8x6 Circ. Mom.		SSE			0.4	FR
22	Guide Lug	SS 40		1700	8x6 Circ. Mom.		SSE			0.4	FR
23	Strut	CS 40	1.5	1000	I-P	2.3	SSE	2.1	N/A	5	WF
24	Elbow	CS 40		1000	I-P	1.0	Static Closing	2			Collapse
25	Elbow-Mid	SS 10	4	800	Mix	6.0	RV2 Mid	1.4	27	7	WF
26	Elbow	CS 40		1700	I-P		Sineswp			8	FR
27	Tee Fix-1	SS 40	8	1700	O-P		Mid + Sine			9	WF
28	Waterhammer	CS 40		1700 1000	I-P I-P	2.7 3.1	Solid Wh 2.2 Water Slug			3 3	WF Collapse

PIPING AND FITTING DYNAMIC RELIABILITY PROGRAM  
COMPONENT TEST SUMMARY

NO	TYPE	MAT SCH	RES STR X (1)	PRESS	LOAD DIR /SIZE	DYN MOM LIM MOM	LOAD TYPE	P-P CYC STRAIN DO	INPUT X LEVEL D	NO TH	FAIL MODE
29	Waterhammer	CS 40		1700	I-P/ Strut	2.7	Solid Wh	0.55		3	WF
				1000	I-P/ Strut	2.8	Water Slug	0.40		3	WF
30	Elbow 1.4 Hz	SS 10		0 410	I-P 4 Hz I-P 1.3 Hz		SSE	1.36 2.0		3	FR
31	Elbow 4.1 Hz	SS 10		410	I-P		Sineswp + SSE			3.5	FR
32	Elbow	SS 40		1700	I-P	3	Static Opening	0.5		3	WF
33	Pipe 15 Hz	CS 40		1000	M/A	1.1	Sineswp	1.1		10	WF
34	Pipe 6 Hz	CS 40		1000	M/A	1.8	Sineswp	2.16		4	FR
35	Elb High Wt	CS 40		1700	I-P	1.65	SSE	3.4%(1)	18	5	FR
36	Tee Fix-1	CS 40		1700	Thru-run		SSE			0.5	FR
37	Elb 1.4 Hz	SS 10	4	0	I-P	1.03(4)	SSE	2.0%(1)	10	2	RB
38	Tee Fix-1	CS 40	20	1700	O-P	1.92	SSE	2.7%(3)	20	3.6	FR
39	Tee Fix-1	SS 40	10	0	O-P	1.84	SSE	3.4%(3)	11	4	WF
40	Reducer	SS 40	9	0	8x6	1.2	SSE	3.3	2	2	RB
41	Elbow	CS 40		1000	I-P		SSE & SINE				

#### SYMBOLS:

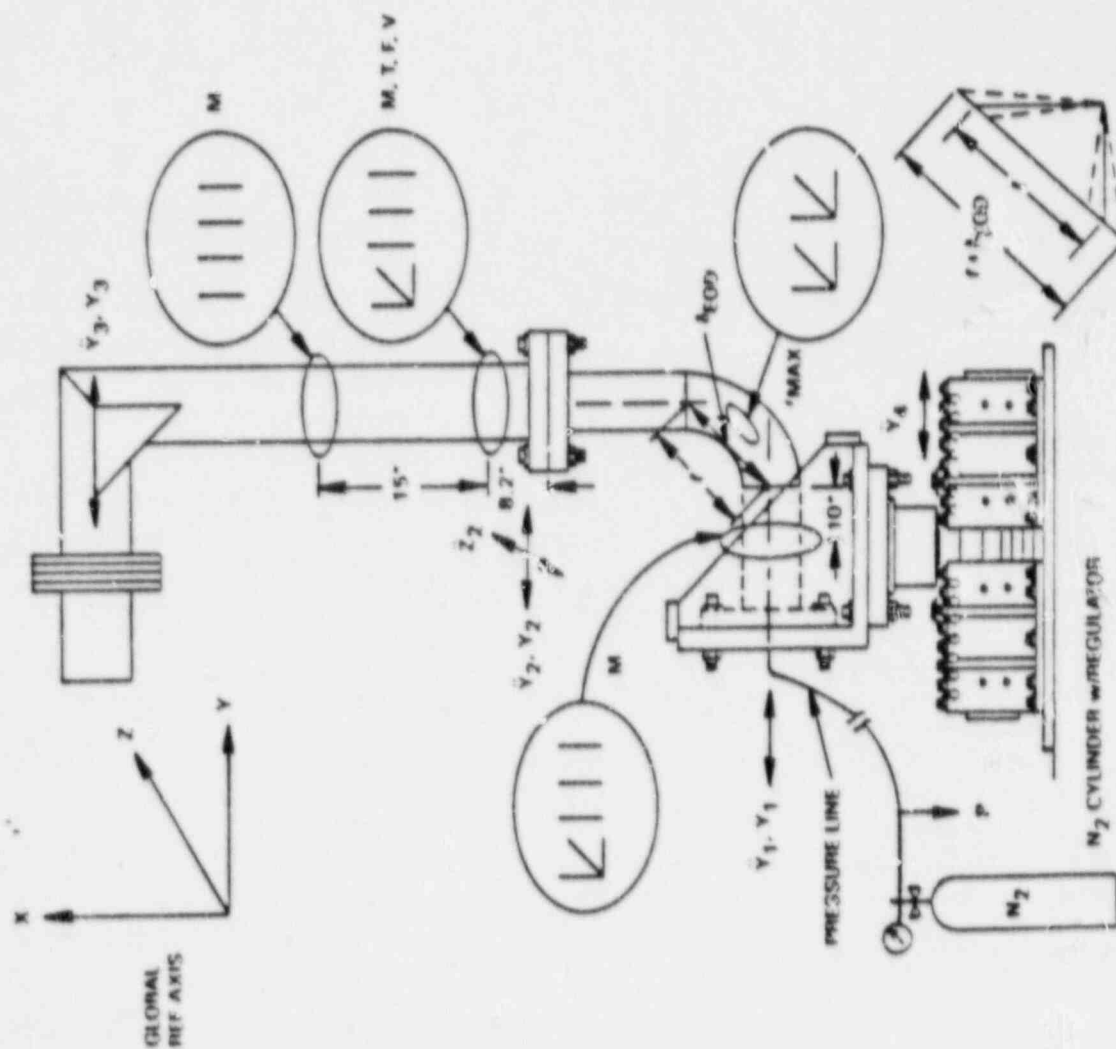
WH	*	Water Hammer
I-P	*	In-Plane
O-P	*	Out of Plane
Fix-1	*	Single End Fixed
Fix-2	*	Both Ends Fixed
NO TH	*	Number of high level input test runs to cause failure
FR	*	Fatigue ratcheting failure
MF	*	No failure
RB	*	Ratchet Buckling
FR1	*	Fatigue ratcheting failure and followed by ductile tearing
Residual Strain	*	Measured by 2 inch scratch marks
Input X		
Level D	*	Calculated stress using linear response spectrum analysis, 2% Damping, $\pm 15\%$ broadening and actual sled input. Use the calculated stress, $(\sigma_2 \text{ M/Z})$ , divided by Level D allowable, $35 \frac{\text{ksi}}{\text{in.}}$ to determine multiple of Level D allowable.

#### NOTES:

- (1) For all the elbows, the measured strains are on the outside surface. For strain on inside surface, multiply the values by 1.5:  
The inside surface is 1.388 times of the outside, principal strain is 1.072 time of circumferential strain and the circumferential strain is 1.01 time of average strain over gage length 1/16".  
 $1.388 \times 1.072 \times 1.01 = 1.50$ . For 2" scratch mark, the factor 1.01 is increased to 1.52 and the multiplication is  $1.388 \times 1.072 \times 1.52 = 2.26$ .  
For ratchet strain on the inside surface, a factor of 2.0 over the tabulated values.
- (2) Gage failed too early, there is almost no data, w/ previous similar test run data.
- (3) Gage failed too early, it is not known if peak values have been obtained.
- (4) Weight stress over 1000 psi.

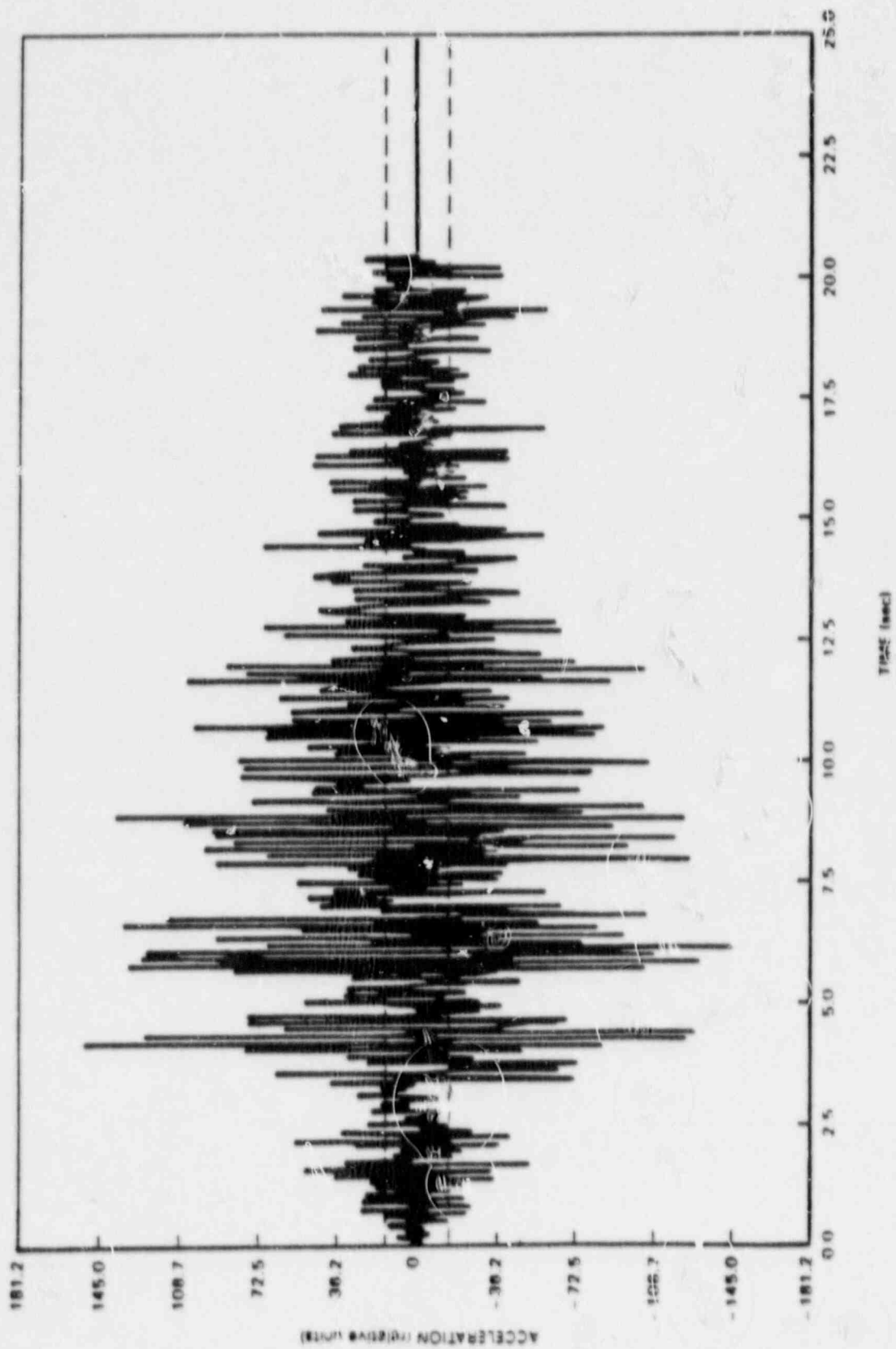


SYMBOL	STRAIN GAGE ORIENTATION
	ROSETTE ORIENTATION
	AXIAL ORIENTATION

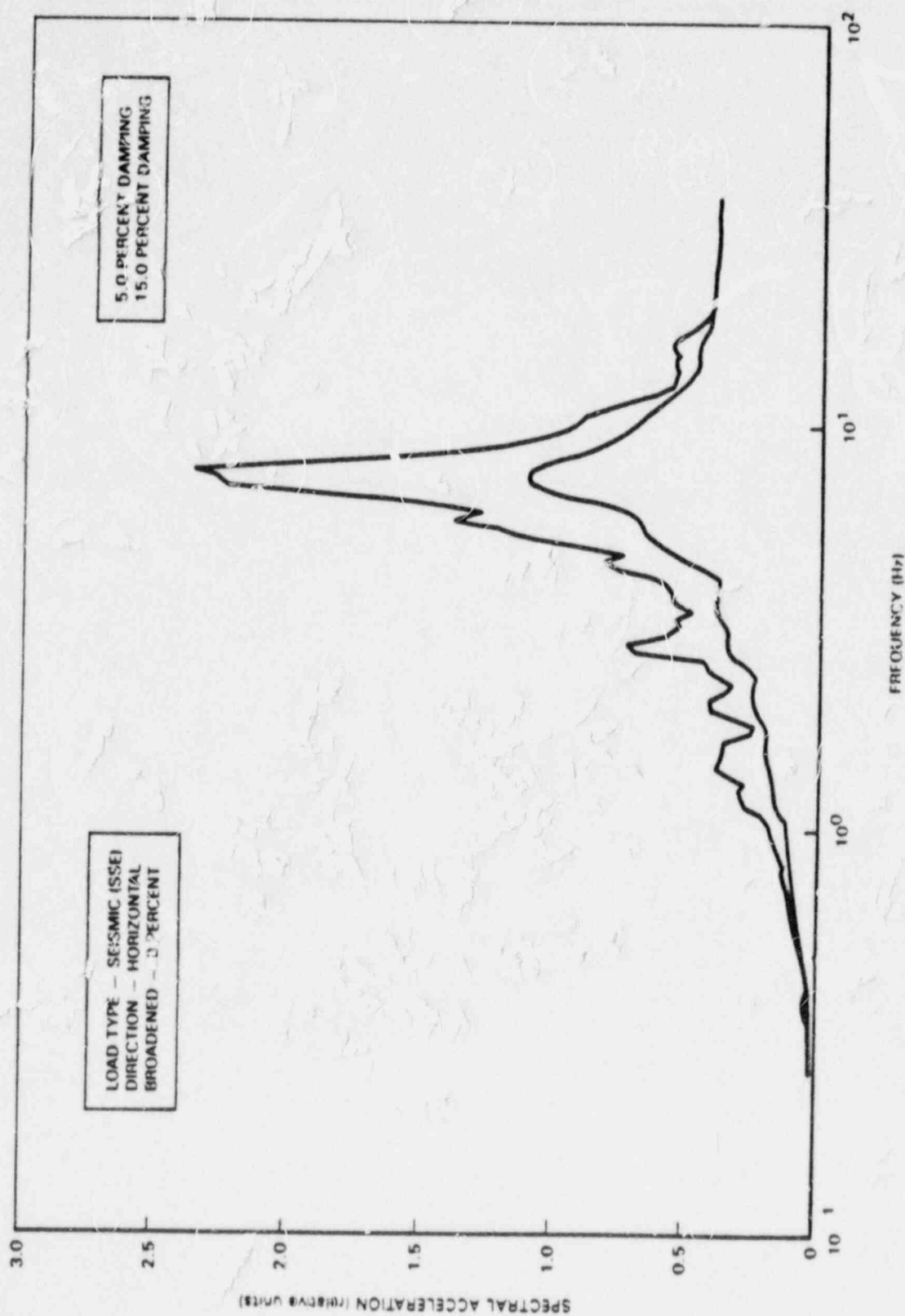


SYMBOL	DESCRIPTION	DATA CHANNELS
$\dot{Y}_1$	ACCELERATION	1
$\dot{Y}_2, \dot{Z}_2$	ACCELERATION	2
$\dot{Y}_3$	ACCELERATION	1
$\dot{Y}_4$	ACCELERATION	1
$Y_1$	HORIZONTAL DISPLACEMENT	1
$Y_2$	HORIZONTAL DISPLACEMENT	1
$Y_3$	HORIZONTAL DISPLACEMENT	1
$\delta_{EOD}$	ELBOW OPENING/CLOSING DISPL.	1
$P$	PRESSURE	1
$M$	MOMENT FORCE RESULTANT	10
'MAX	PEAK STR	2
	TOTAL	28

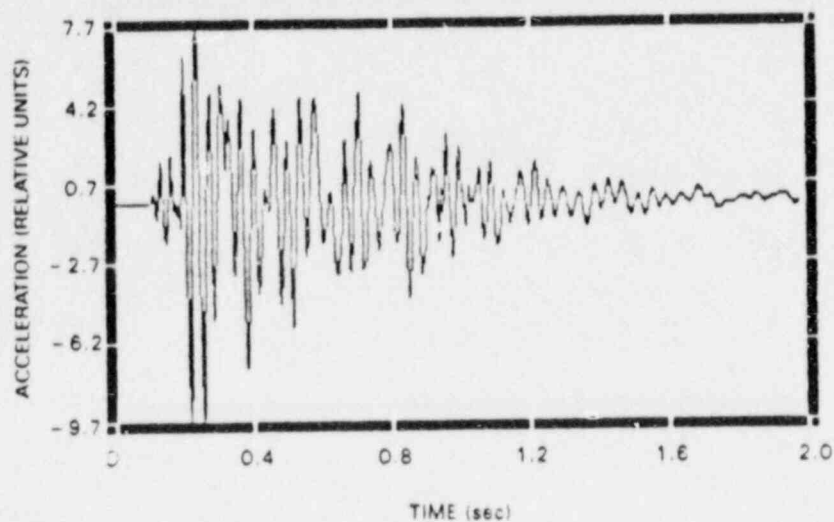
Location of Transducers for In-Place Elbow Component



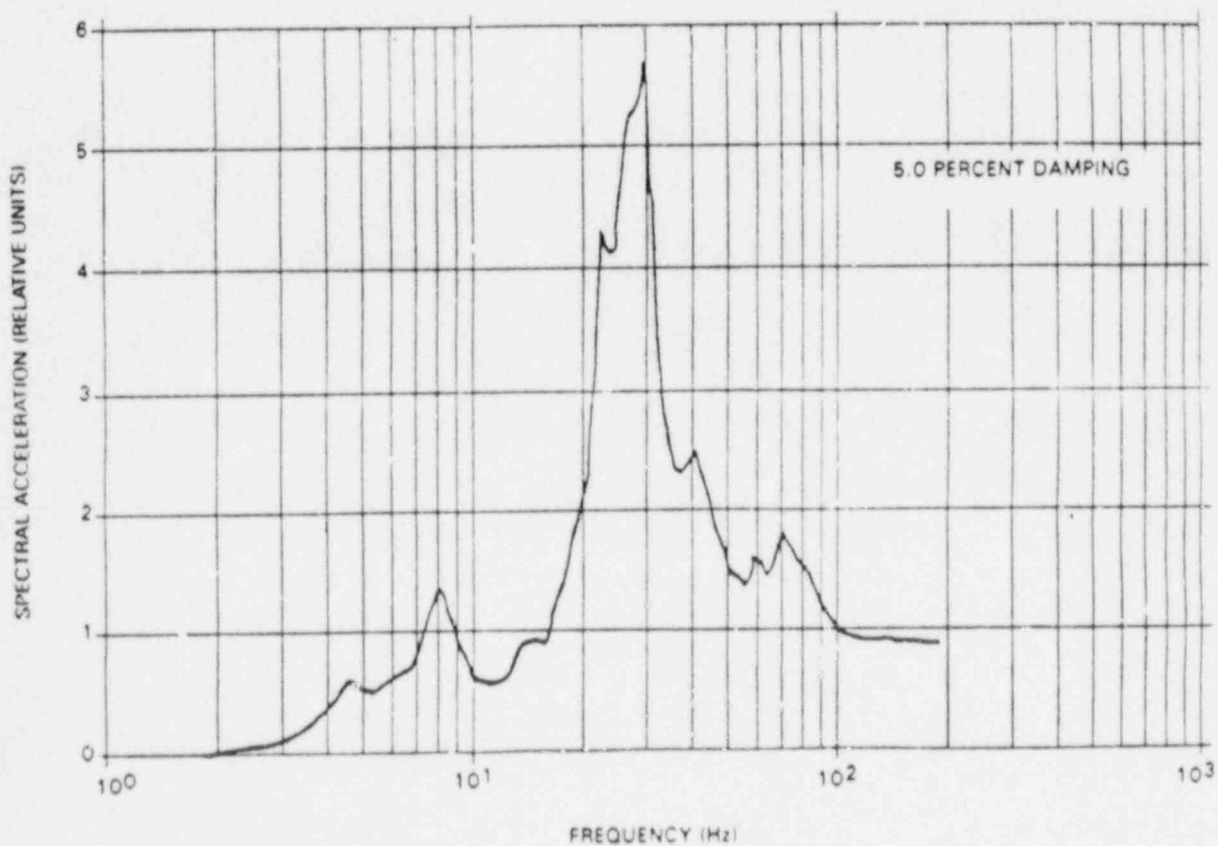
Input Motion Time History



Input Motion Response Spectra



Mid-Frequency Input Motion Time History (SRV)



Mid-Frequency Input Motion Response Spectra (SRV)

# TEST 4 - ELBOW

CARBON STEEL

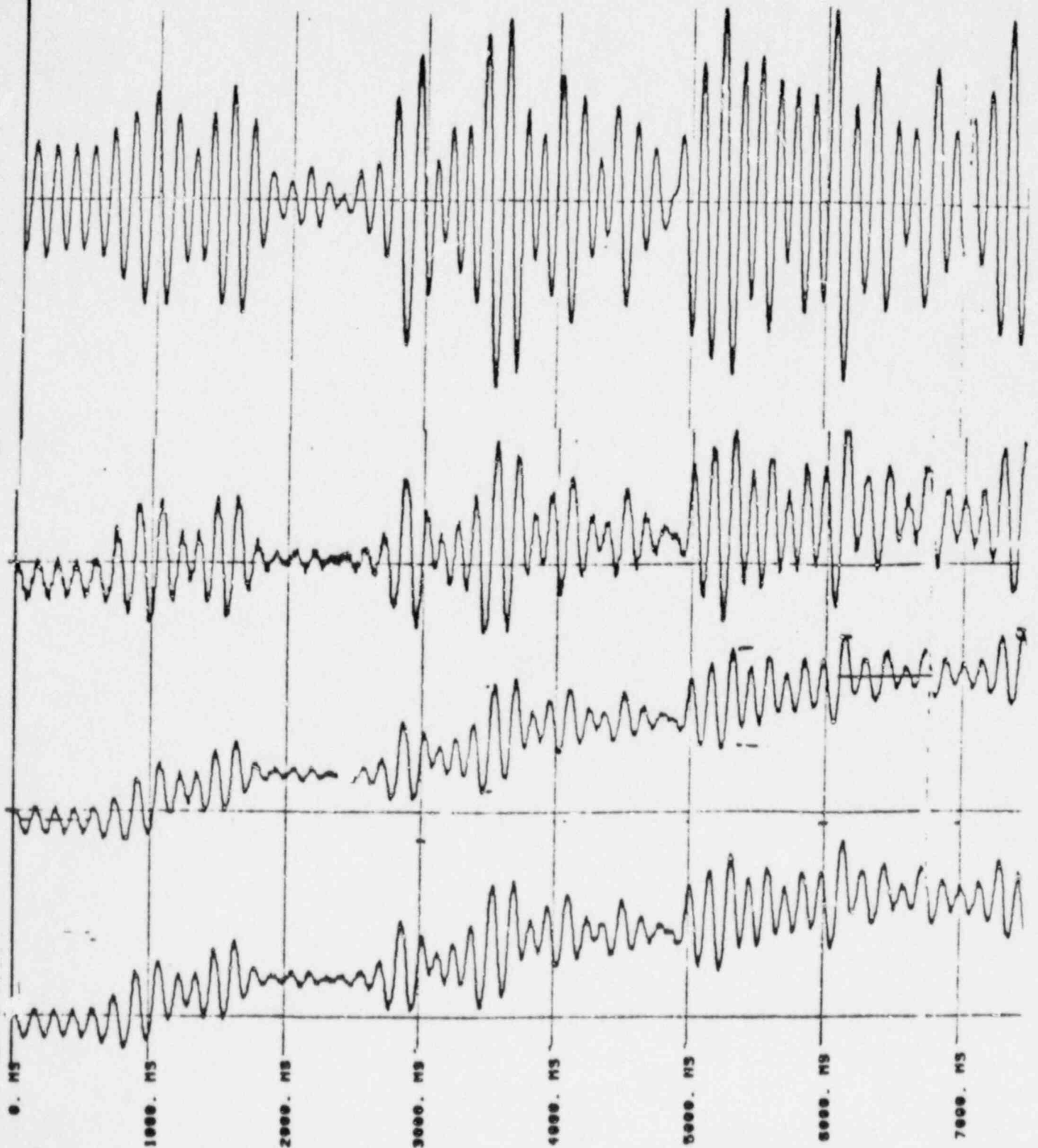
IN-PLANE SEISMIC LOADING

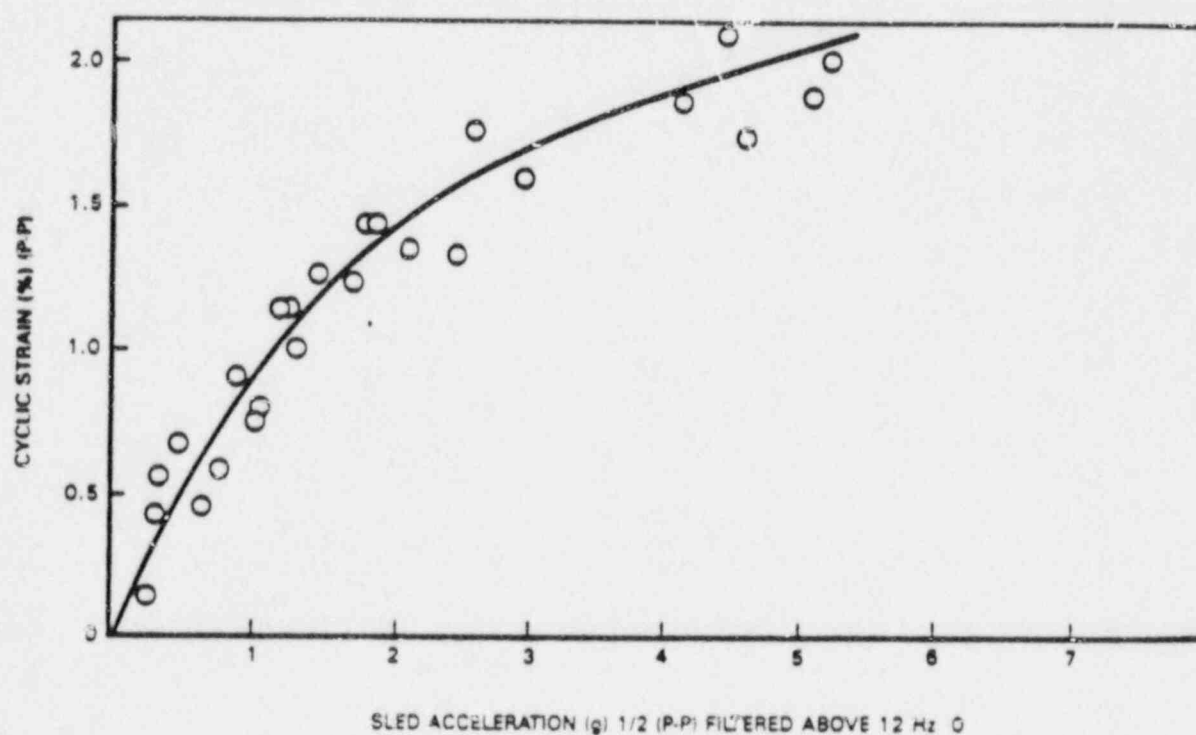
INTERNAL PRESSURE = 1000 PSI

RELATIVE DISPLACEMENT, TOP TO SLED

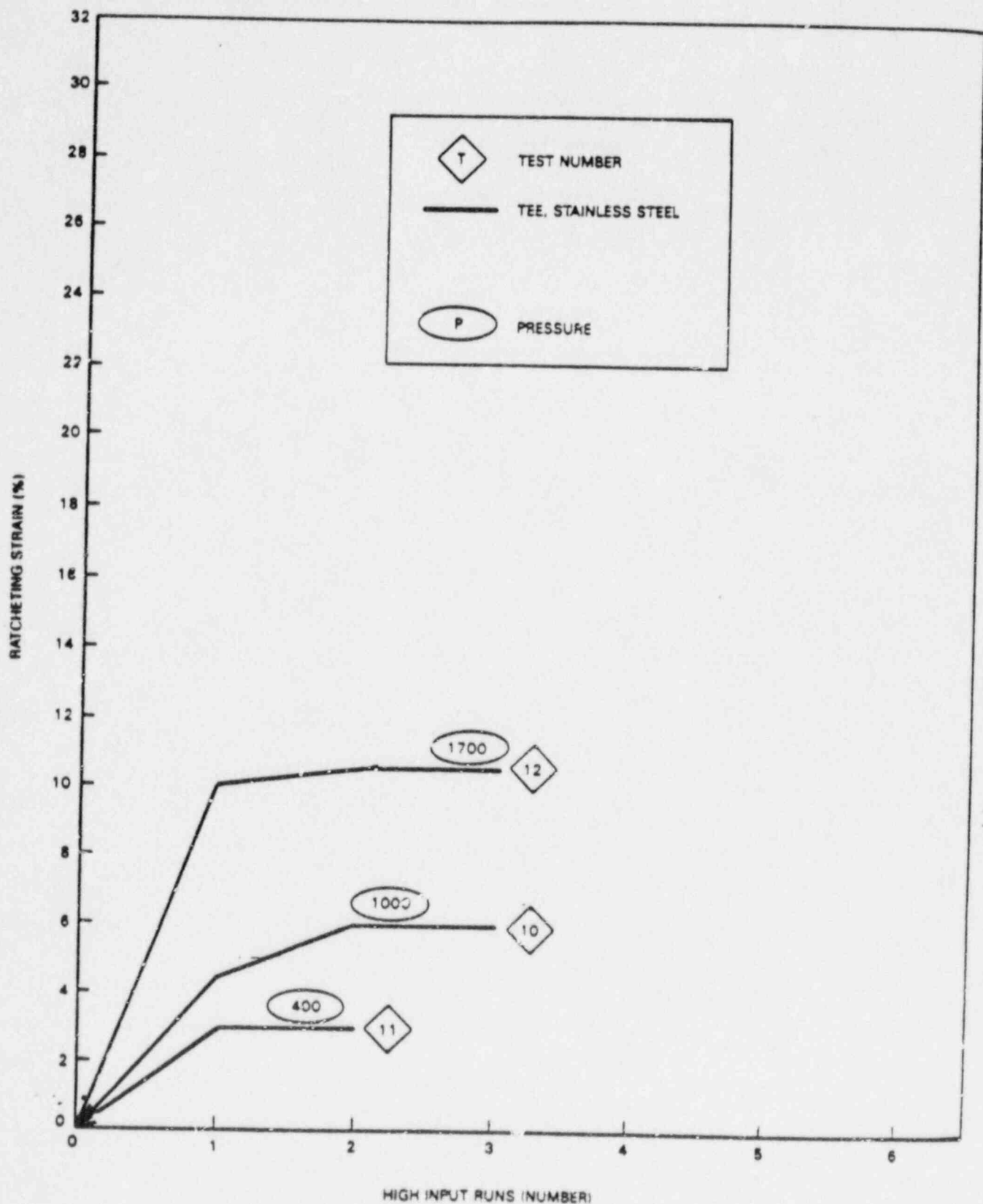
STRAIN AT ELBOW BEND CENTER

BASELINE

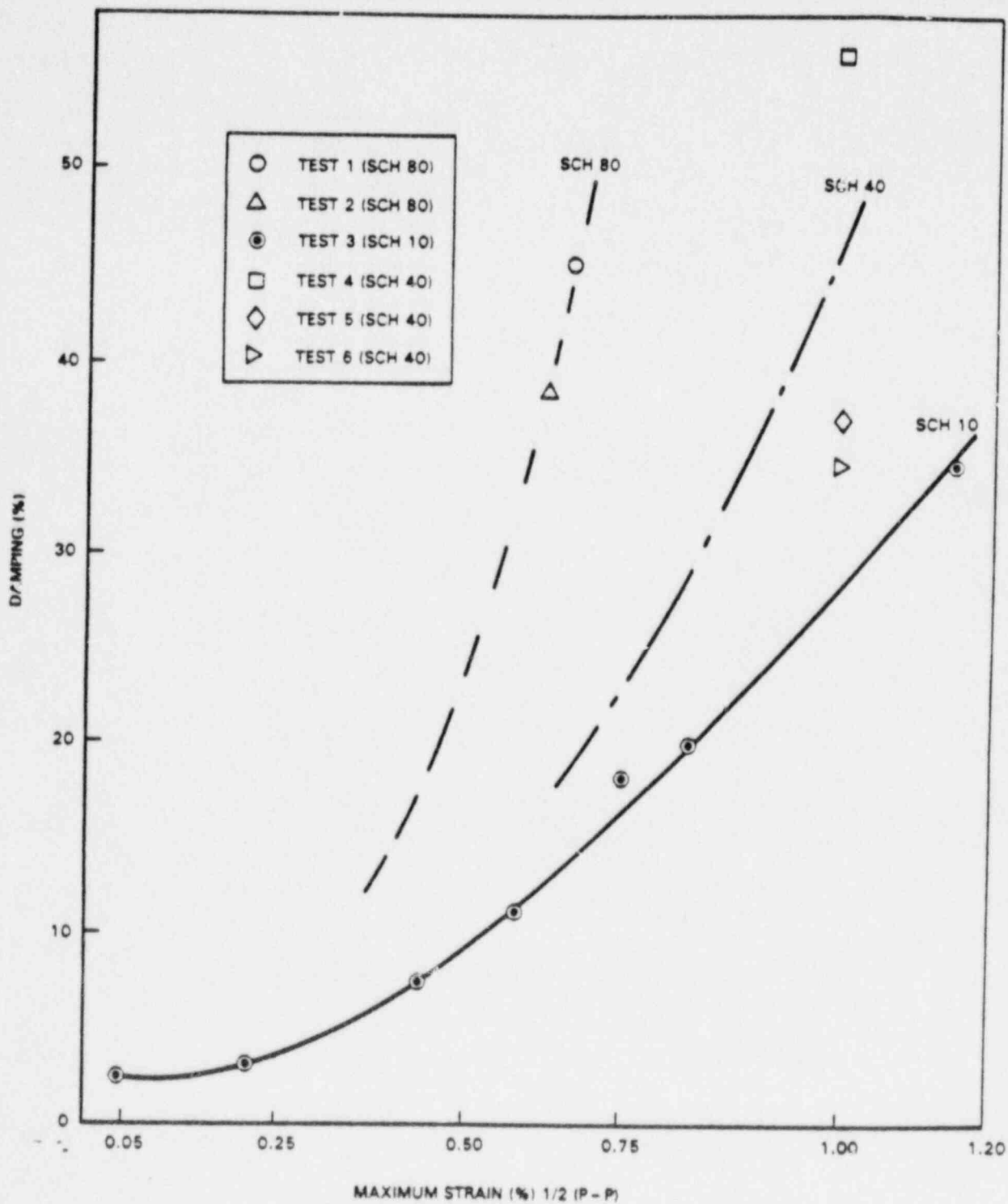




Measured Elbow Strain Versus Input Acceleration  
(Test 3 Schedule 10 Elbow)

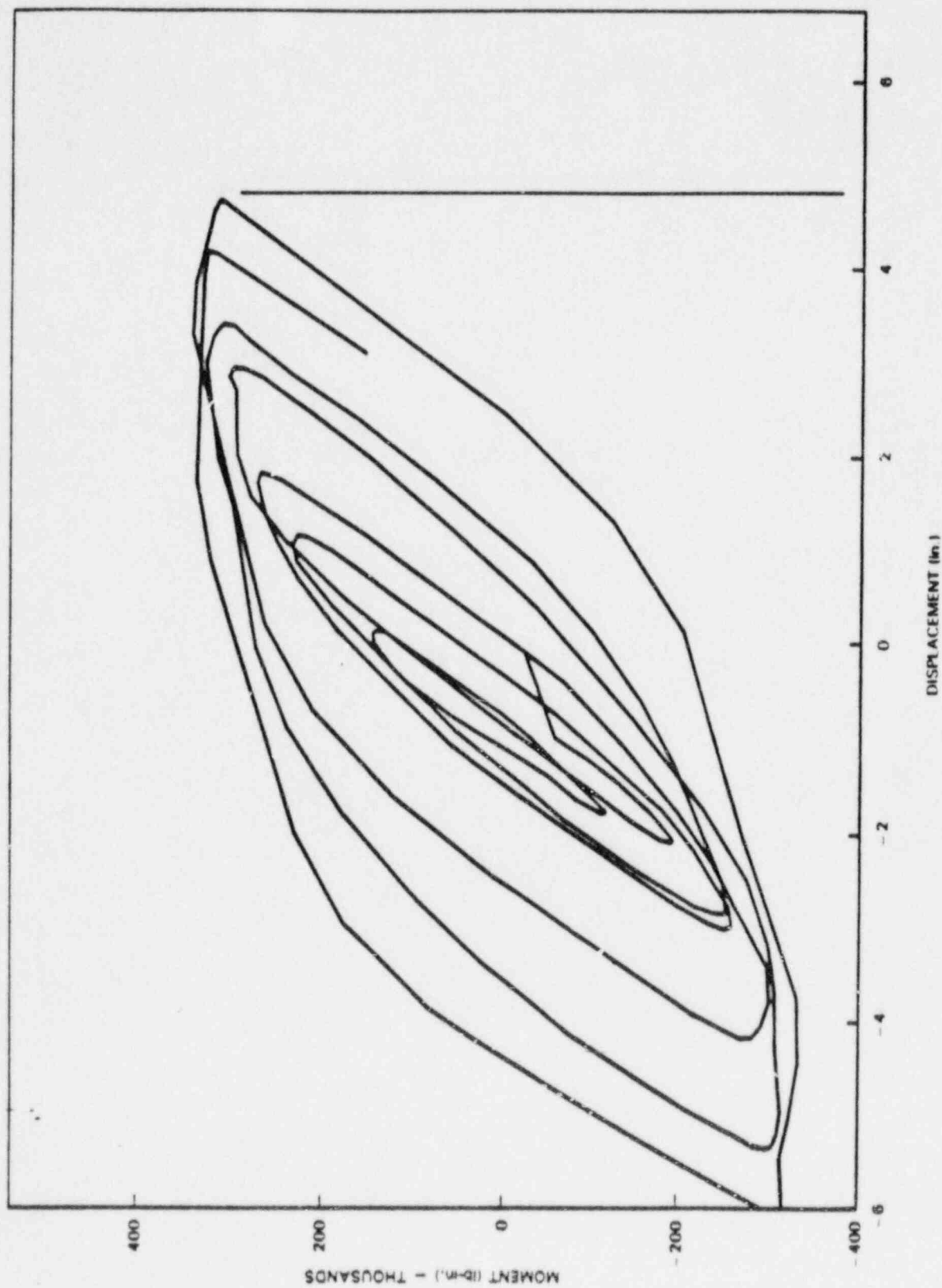


Fatigue Ratcheting Strain Based on 2-in. Wide Marks



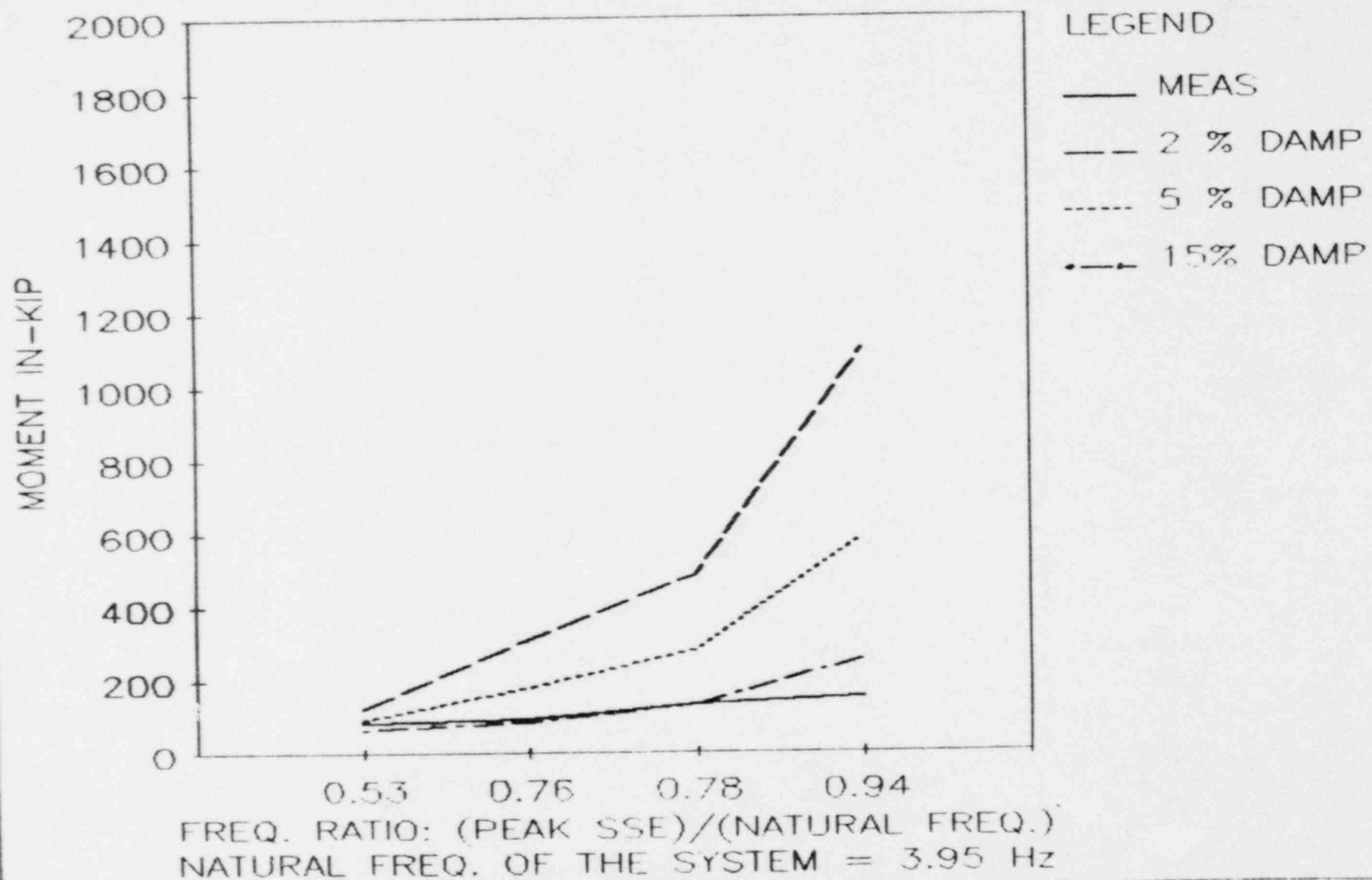
Equivalent Damping Versus Maximum Strain



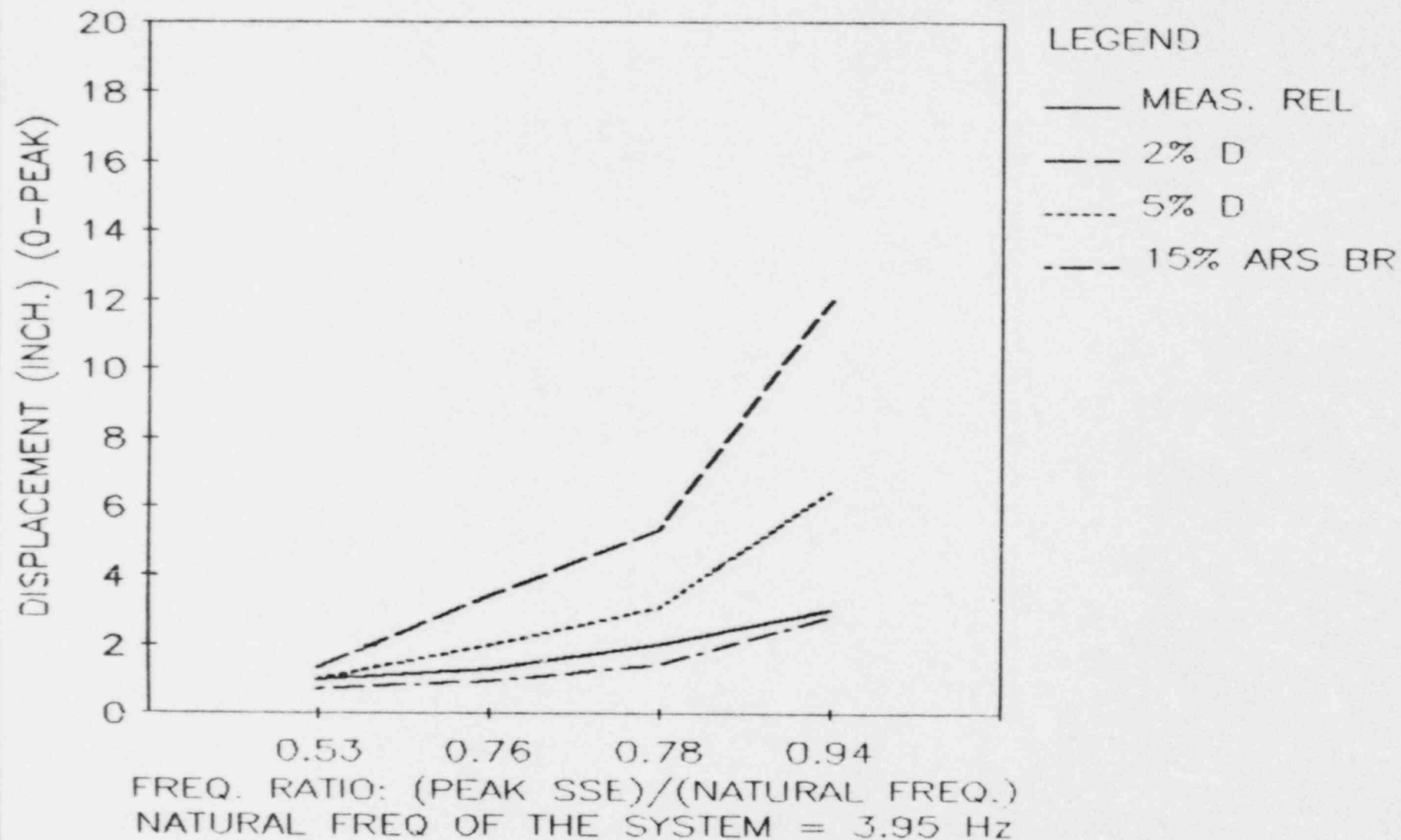


Test 39, Run 4 Moment vs Displacement

# T31 6 IN. ELBOW SCH 10 IN-PLANE 410 PSI CALC MOMENT VERSUS MEASUREMENTS



# T31 6 IN ELBOW SCH 10 I-P 410 PSI DISPLACEMENT VERSUS MEASUREMENT



## OBSERVATIONS FROM COMPONENT TESTS

- DYNAMIC LOAD REVERSAL PREVENTS COLLAPSE
- SEISMIC LOADS BEHAVE LIKE SECONDARY NOT PRIMARY
- RATCHET FAILURE LOADS > SSE
- RATCHETING DOES NOT IMPAIR FUNCTIONALITY
- DAMPING FOR LARGE DYNAMIC LOADS > R.G. 1.61
- AMPLIFIED HIGHER FREQUENCY SRV INERTIA LOADS CAUSE SMALL RESPONSE

### BOTTOM LINE

FAILURES ARE CHARACTERIZED BY

FATIGUE AND/OR RATCHETING

\*NOT STATIC COLLAPSE\*

## OBJECTIVES OF SYSTEM TESTS

CONFIRM FAILURE MODE (3 OR 4 SLED INPUTS)

CONFIRM EFFECTS OF LOW AND MID FREQUENCY LOADS

DETERMINE SYSTEM DAMPING

- BALANCED SYSTEM STRESS
- UNBALANCED SYSTEM STRESS
- DIFFERENT TIME HISTORIES
- W & W/O SNUBBER AND STRUT

CONFIRM FUNCTIONALITY

CONFIRM DESIGN RULES AND MARGINS

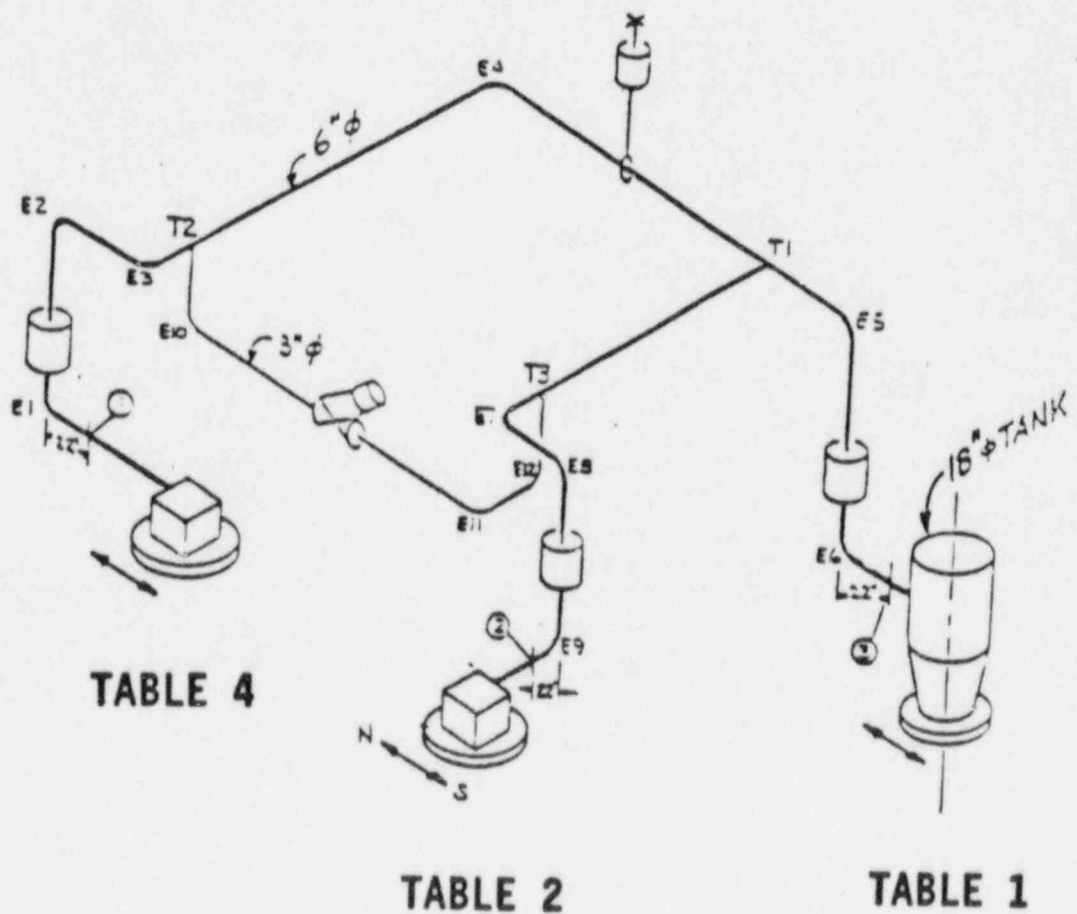
## SYSTEM TEST 1

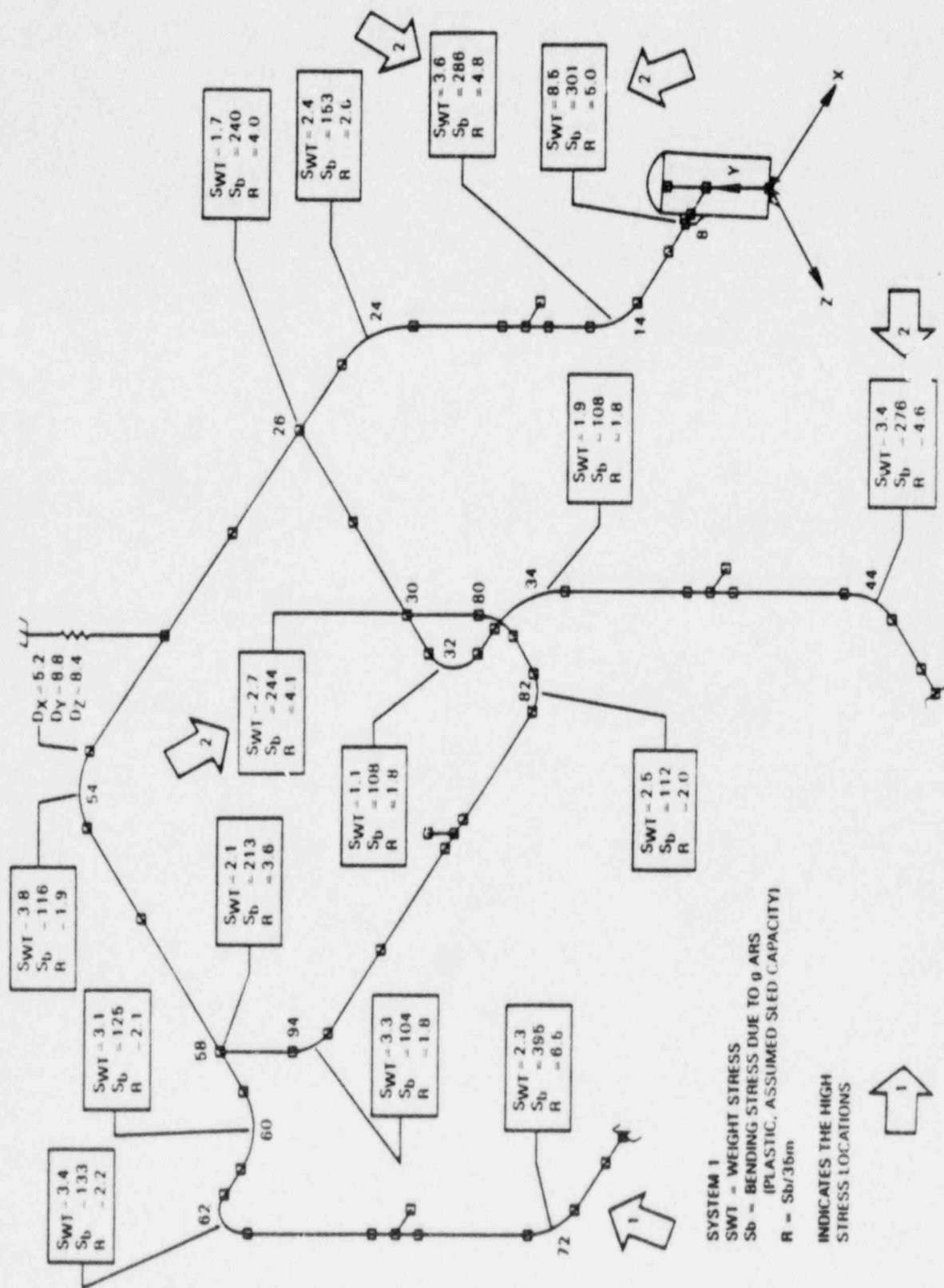
PWR COMPONENT COOLING WATER

THREE SLEDS

CARBON STEEL A106B

INTERNAL PRESSURE = 1000 PSI





Stress Summary for System 1

## PIPE SYSTEM TESTING

### PERFORMED TEST RUNS FOR SYSTEM TEST 1

- OBE } .. UNIFORM
- SSE } .. ISM
- 5XSSE }
  
- 1/2 TABLE CAPACITY (33 SSE) } ..UNIFORM
- FULL TABLE CAPACITY (52 SSE) }
  
- MID FREQUENCY . UNIFORM, FULL TABLE





Side View of Cracked Elbow Near Table 4



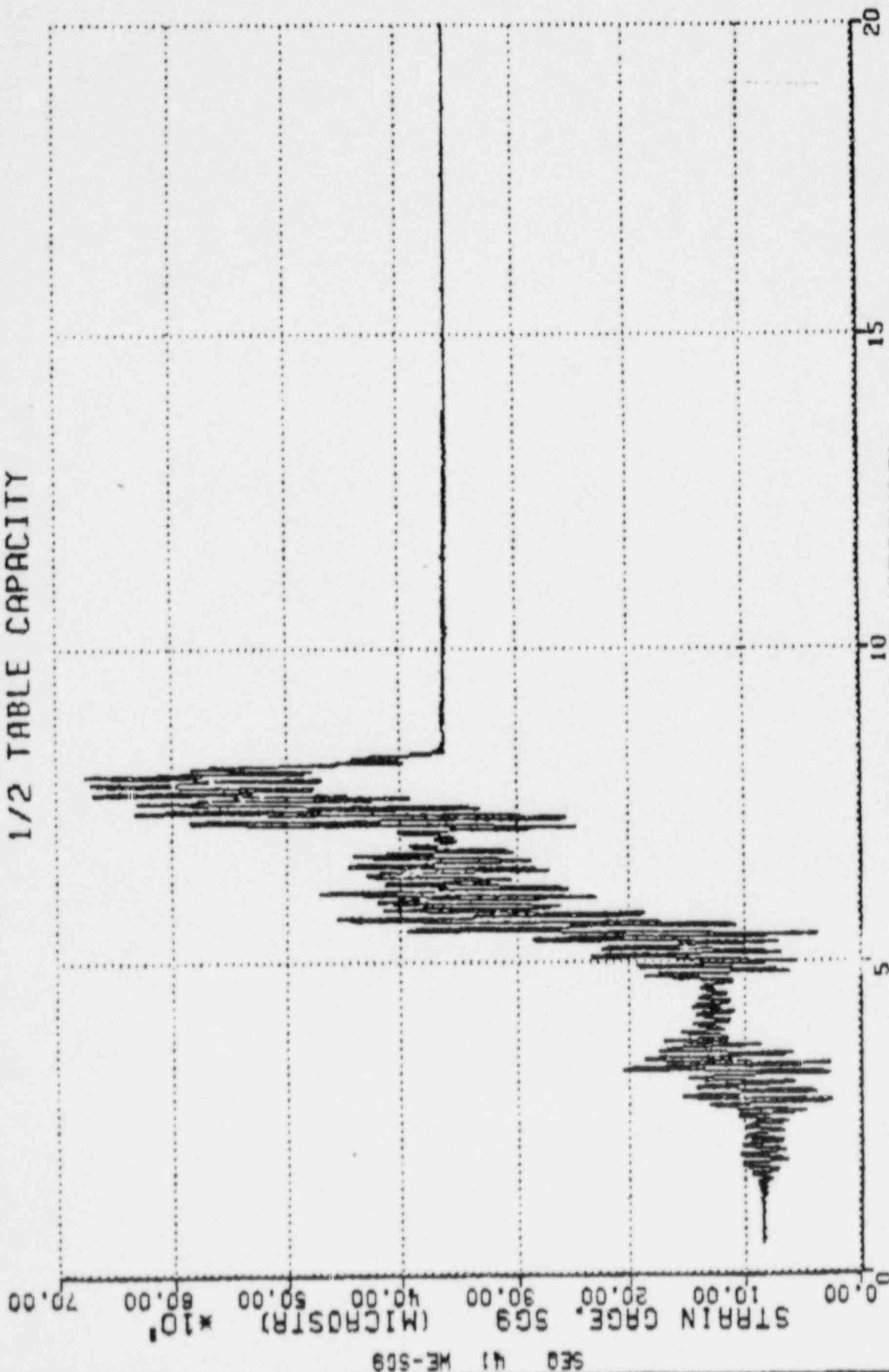
Side View of Cracked Elbow Near Table 4

# SYSTEM TEST 1 - TEST RESULTS AT FAILURE LOCATION

<u>PARAMETER</u>	SSE —	5SSE (7SSE)	HALF (33SSE)	FULL (52SSE)
INPUT X LEVEL D				
2% DAMPING	0.8	5.3	27.0	42.0
5% DAMPING (BROAD, SLED ARS)	0.5	3.1	16.0	24.0
MEASURED MOMENT, IN-KIP	66	330	725	717
CYCLIC STRAIN, P-P, %	0.09	1.2	3.7	4.4
RATCHET STRAIN, DURING RUN, %	0	0.44	8.5	2.4
RATCHET DISPLACE, IN. FOR 20 SEC RUN	0	0	1.0	4.5
DAMPING, %	4.2	6.4	23	-

EIEC DATA PL 5/21/87

TTF REAL-TIME PLOT  
1/2 TABLE CAPACITY



DAY 5/21/87  
H:M 16:03  
SEC 40.000

5/21/87  
16:03  
45.000

ELAPSED TIME (SECONDS)

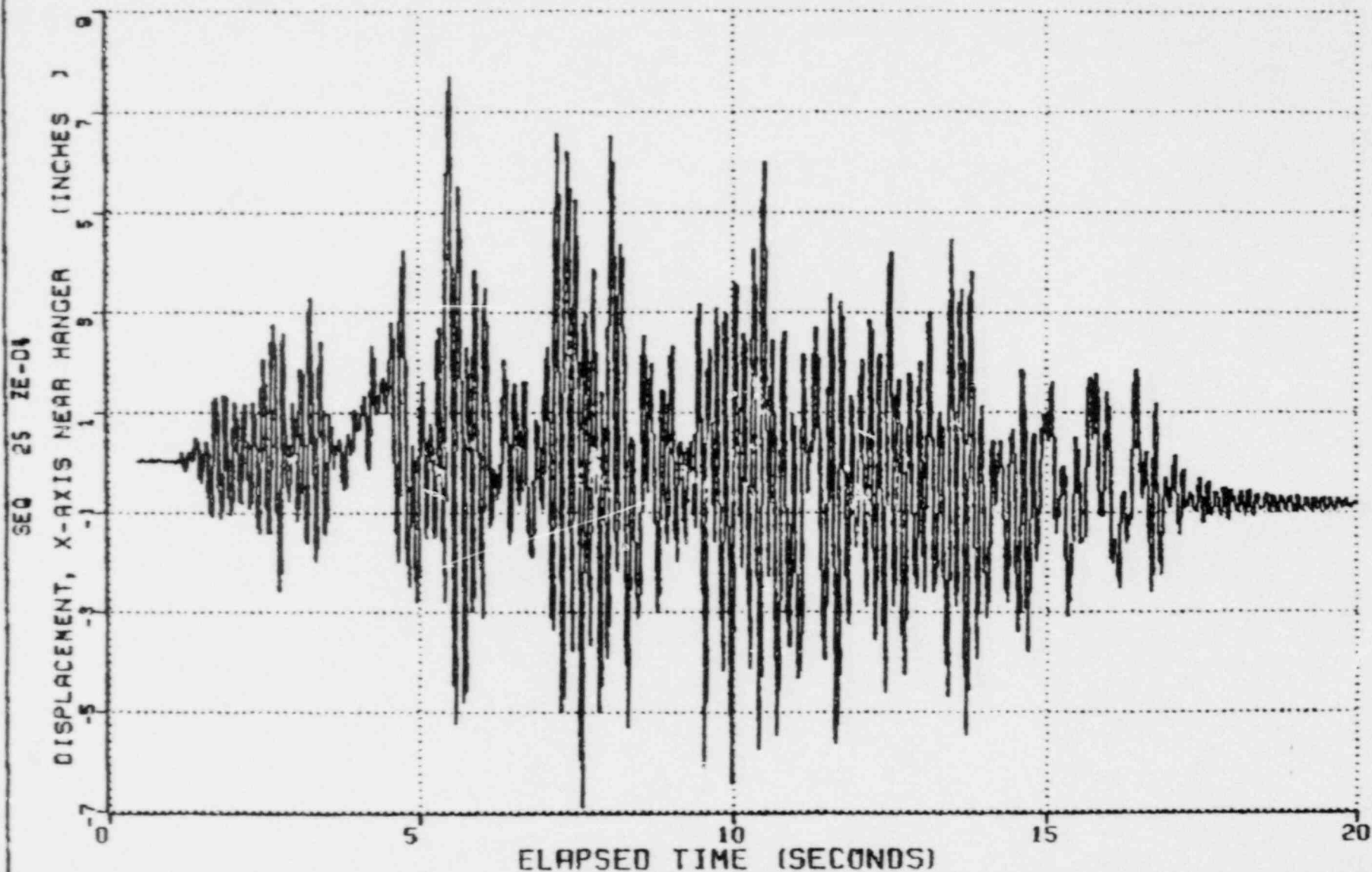
5/21/87  
16:03  
50.000

5/21/87  
16:03  
55.000

5/21/87 DAY  
16:04 H:M  
0.000 SEC

ETEC DATA PL 5/21/87

TTF REAL-TIME PLOT  
1/2 TABLE CAPACITY



DAY 5/21/87  
H:M 16:03  
SEC 40.000

5/21/87  
16:03  
45.000

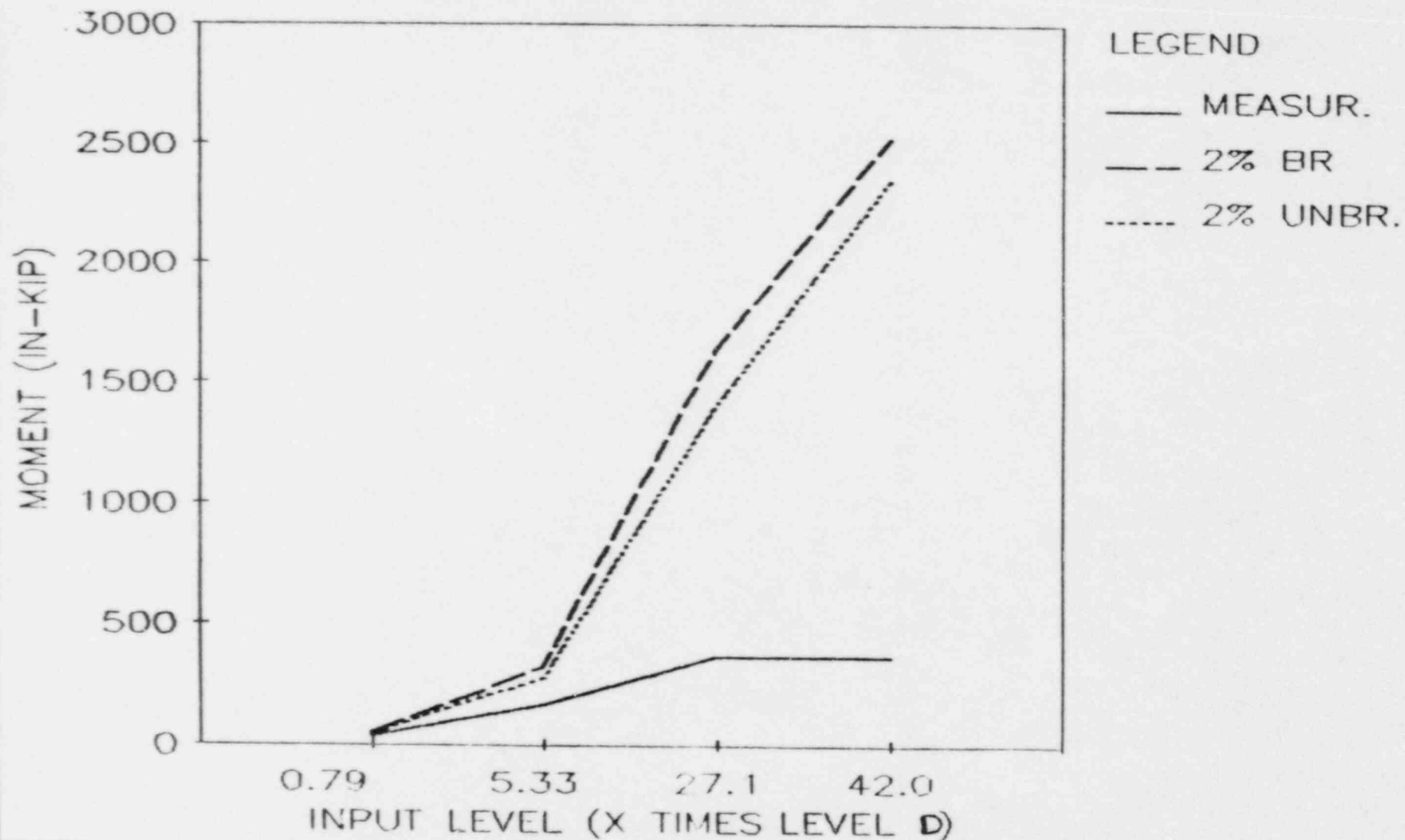
5/21/87  
16:03  
50.000

5/21/87  
16:03  
55.000

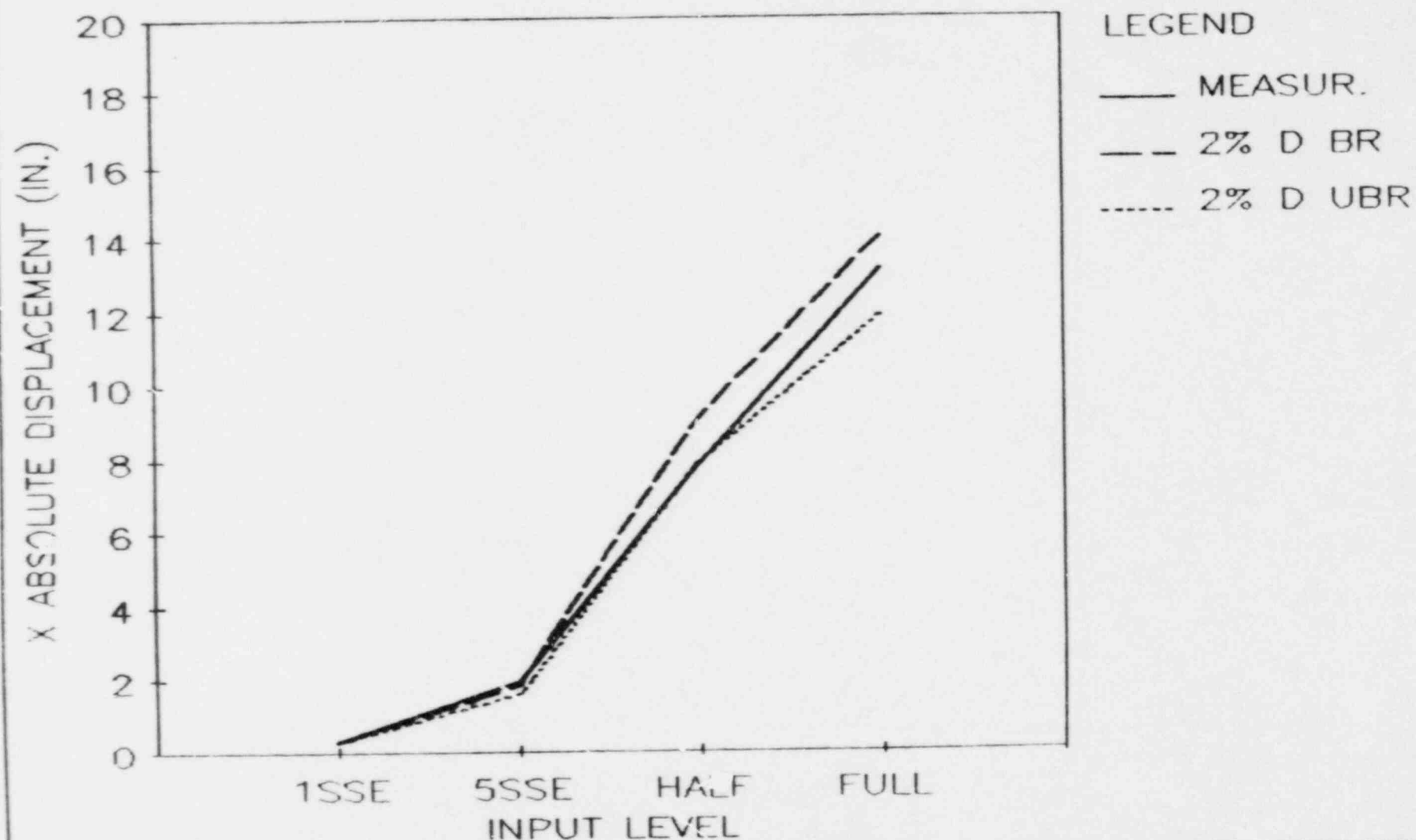
5/21/87 DAY  
16:04 H:M  
0.000 SEC



# SYSTEM 1 TEST DATA CORRELATION MOMENT VERSUS INPUT LEVEL 2% DAMPING SLED INPUT ARS



SYSTEM 1 TEST DATA CORRELATION  
ABS X DISPLACEMENT VERSUS INPUT  
2 % DAMPING SLED INPUT ARS



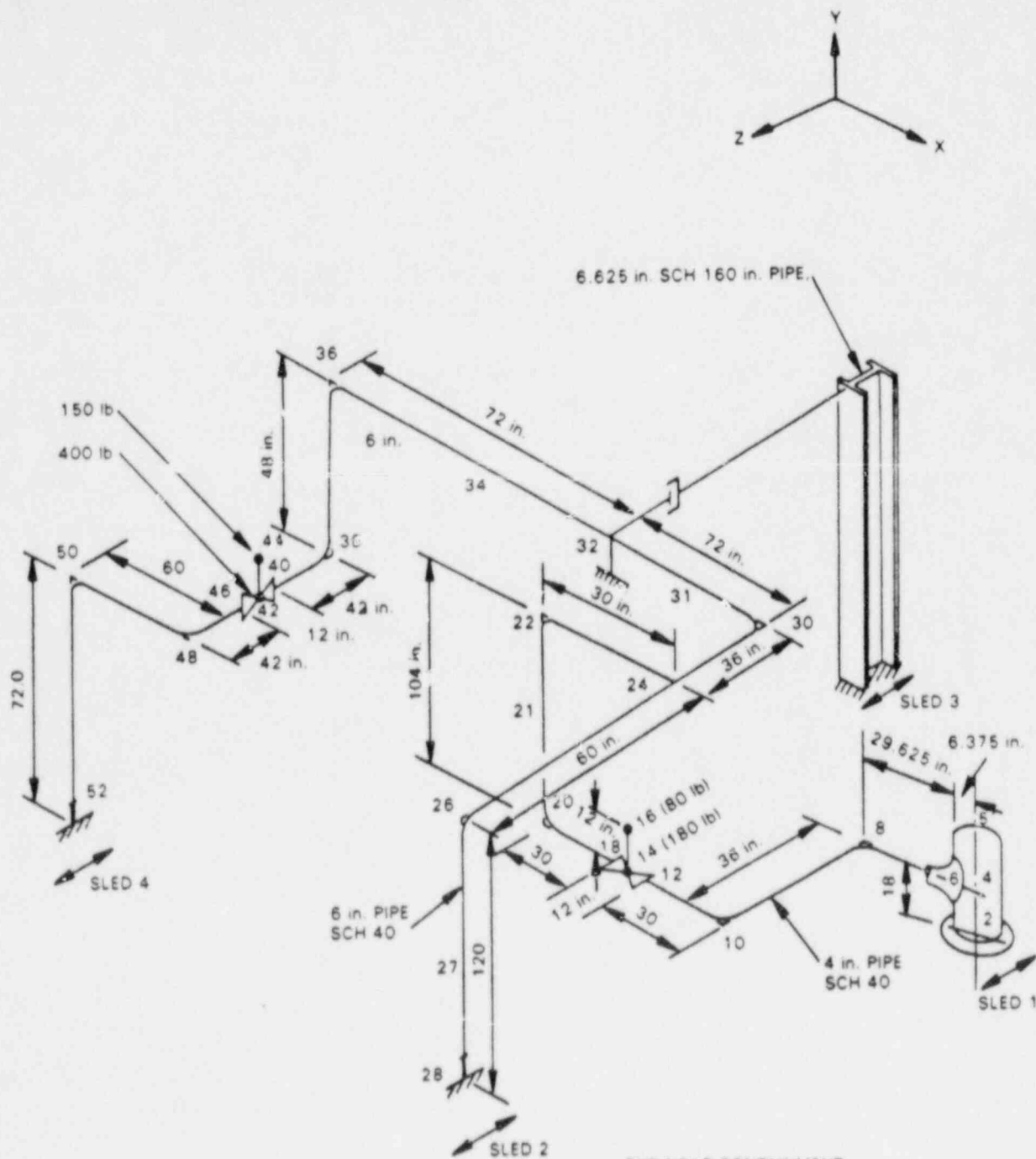
## SYSTEM TEST 2

BWR RHR SYSTEM

FOUR SLEDs

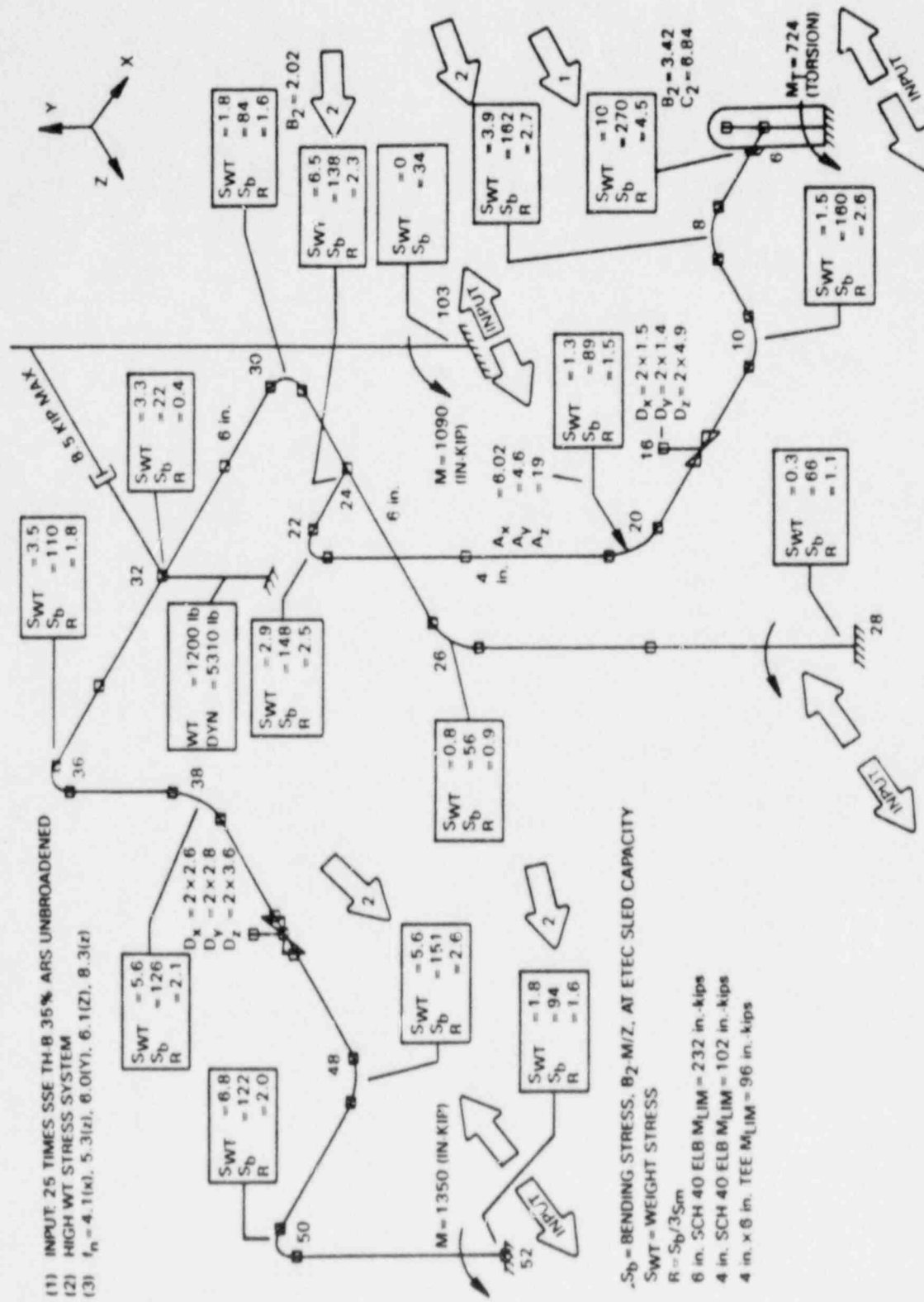
STAINLESS STEEL 316L

INTERNAL PRESSURE = 1000 PSI



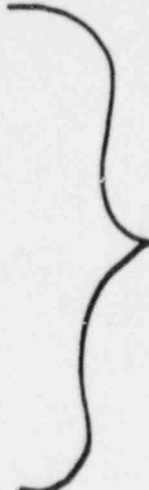

RHR NEAR CONTAINMENT

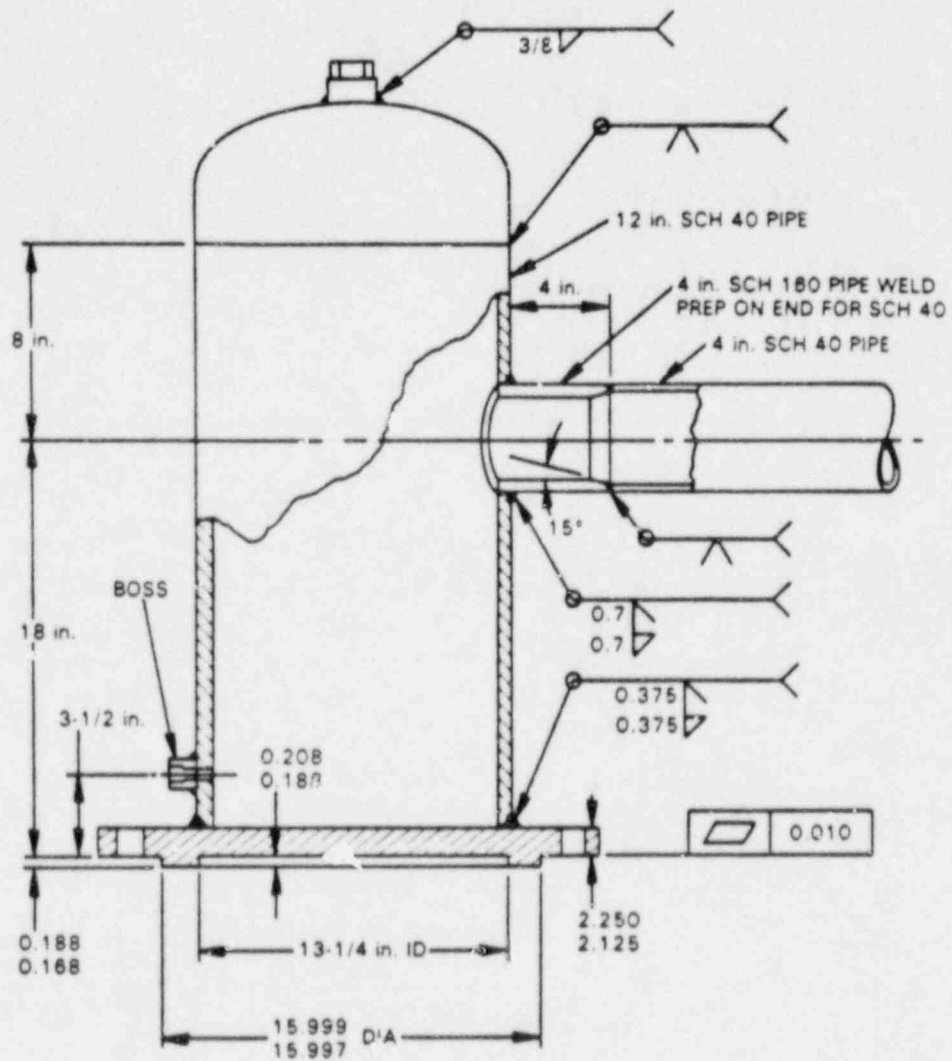




System 2 Stress Diagram

## TEST RUNS FOR SYSTEM TEST 2

- SSE
  - 2 x SSE
  - 5 x SSE
  - SINE SWEEP
  - HALF TABLE
  - FULL TABLE
  - MID-FREQUENCY
- .. UNIFORM
- .. ISM-CORRELATED
- .. ISM-UNCORRELATED
- .. UNIFORM
- 
- 



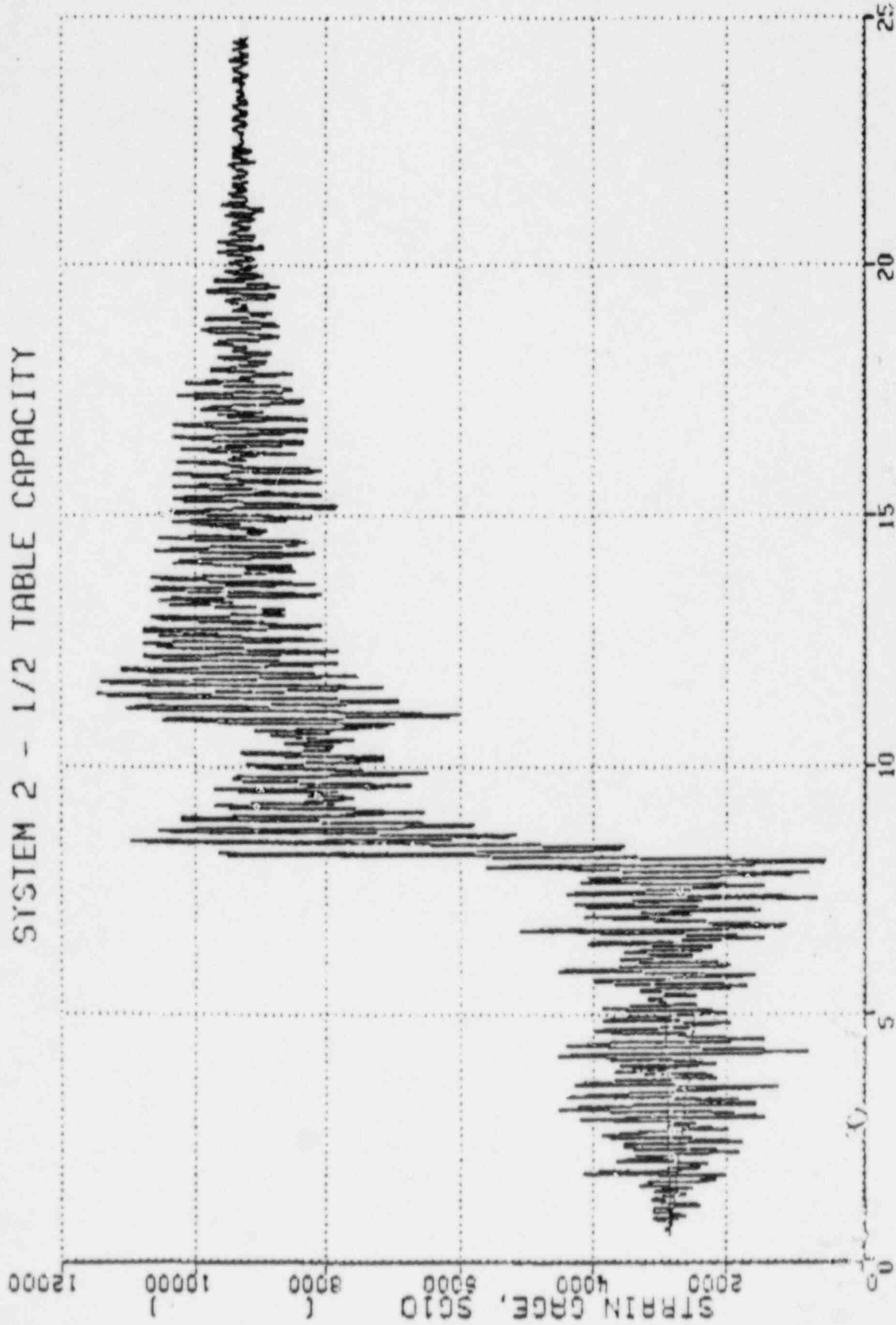
Fabricated Nozzle Test Detail

## SYSTEM TEST 2 - TEST RESULTS AT FAILURE LOCATION

PARAMETER	SSE —	5SSE —	HALF (9 SSE)	FULL (18 SSE)
INPUT X LEVEL D				
2% DAMPING	1.0	6.3	11.0	21.0
5% DAMPING (BROAD, SLED ARS)	0.8	4.9	8.0	15.0
MEASURED MOMENT, IN-KIP	39	119	156	235
CYCLIC STRAIN, P-P, %	0.21	0.77	0.96	2.8
RATCHET STRAIN, DURING RUN, %	0.07	0.18	0.65	2.1
RATCHET DISPLACE, IN. FOR 20 SEC RUN	0	0	0	2.1
DAMPING, %	5.0	5.0	22	-

FILED DATA PLOT 1/87

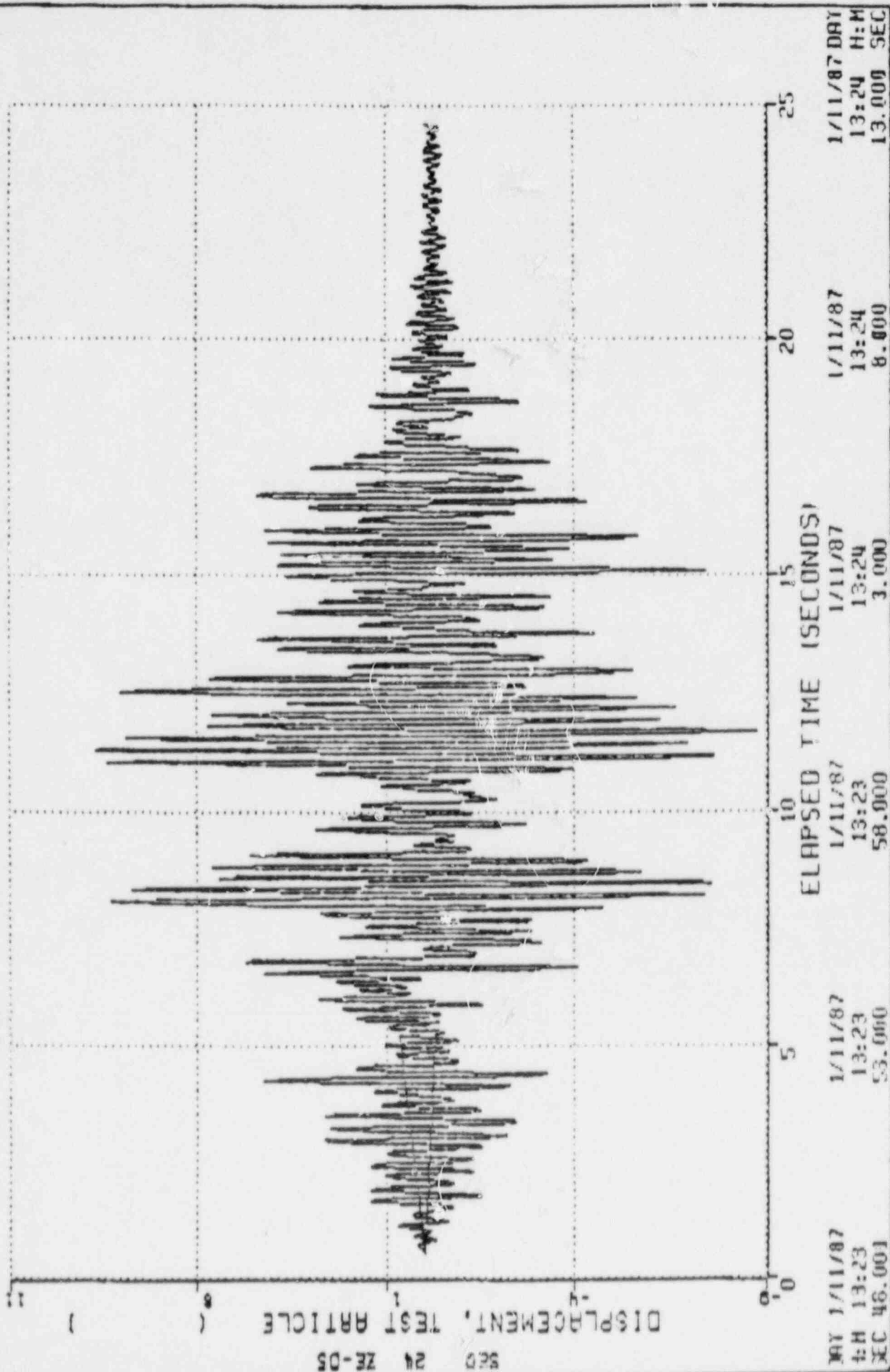
# TTF REAL-TIME PLOT SYSTEM 2 - 1/2 TABLE CAPACITY



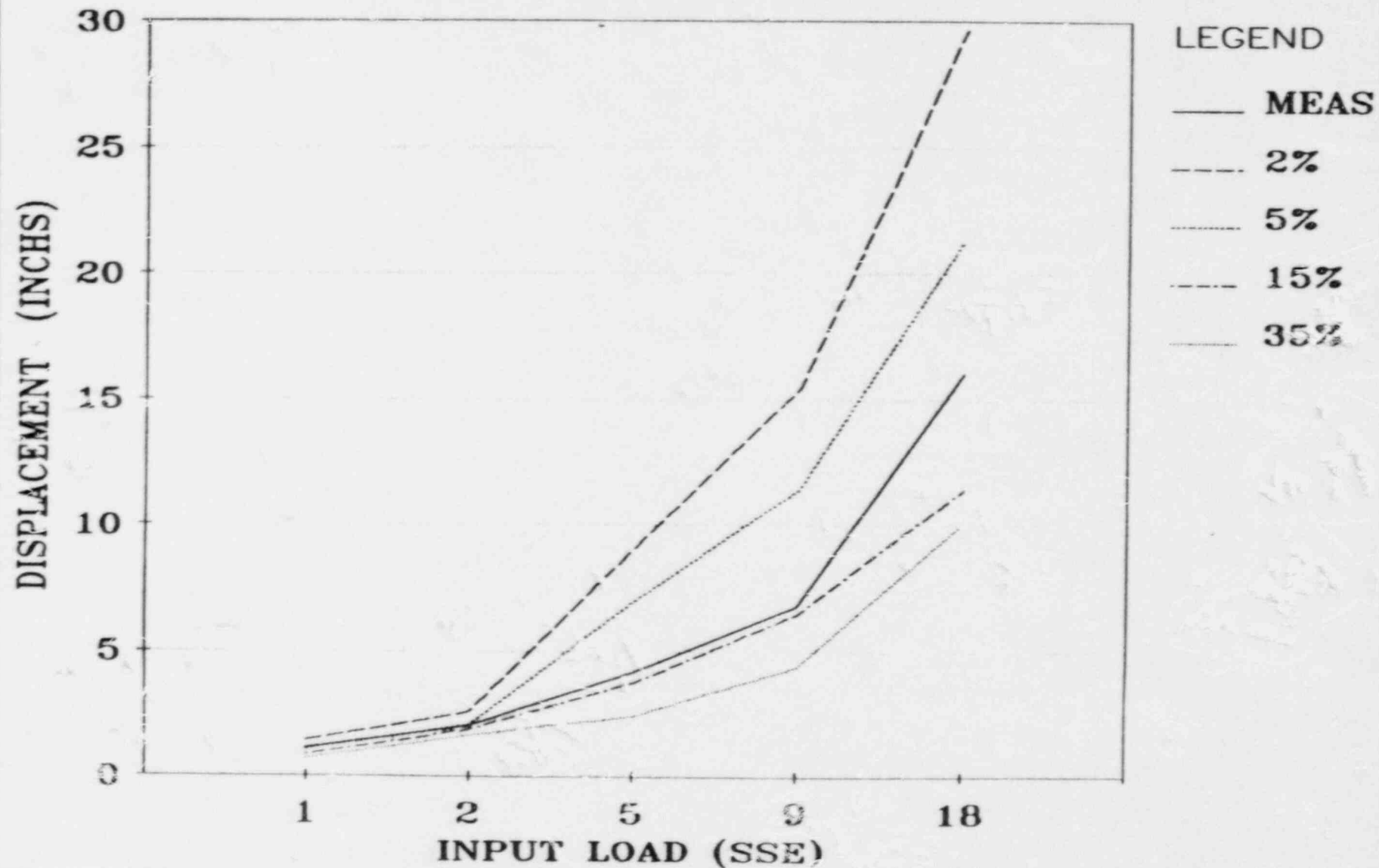
BY 1/11/87	1/11/87	1/11/87	1/11/87
LM 13:23	13:23	13:24	13:24
EC 48.000	58.000	8.000	13.000
			SEC

ETEC DATA PLOT 11/87

# TTF REAL-TIME PLOT SYSTEM 2 - 1/2 TABLE CAPACITY

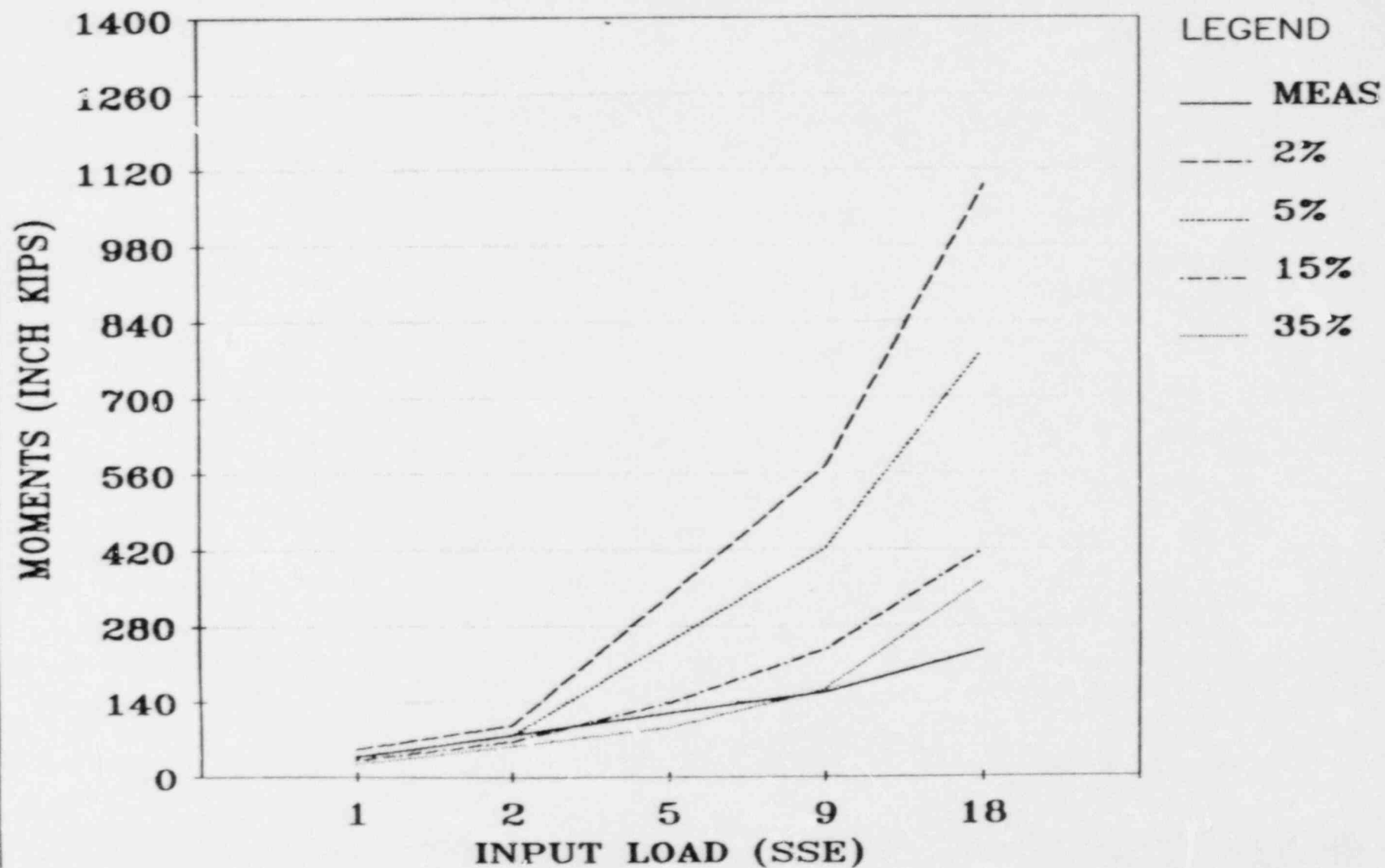


DISPLACEMENT MEASUREMENTS VS CALCULATIONS  
EPRI SYSTEM TEST #2  
NODE 20W (BROADENED ARS)





**MOMENT MEASUREMENTS VS CALCULATIONS**  
**EPRI SYSTEM TEST #2**  
**NODE 6 (BROADENED ARS)**





### OBSERVATIONS FROM SYSTEM TESTS

- FATIGUE RATCHET FAILURE MODE - CONFIRMED
- FAILURE LOADS  $>$  SSE - CONFIRMED
- FUNCTIONALITY UNIMPAIRED - CONFIRMED
- DAMPING  $>$  R. G. 1.61 - CONFIRMED
- AMPLIFIED SRV LOADS SMALL - CONFIRMED

#### BOTTOM LINE

EXTREMELY DIFFICULT TO FAIL PIPING WITH DYNAMIC LOADS

## WATER HAMMER TESTING

### COMPONENT TESTING

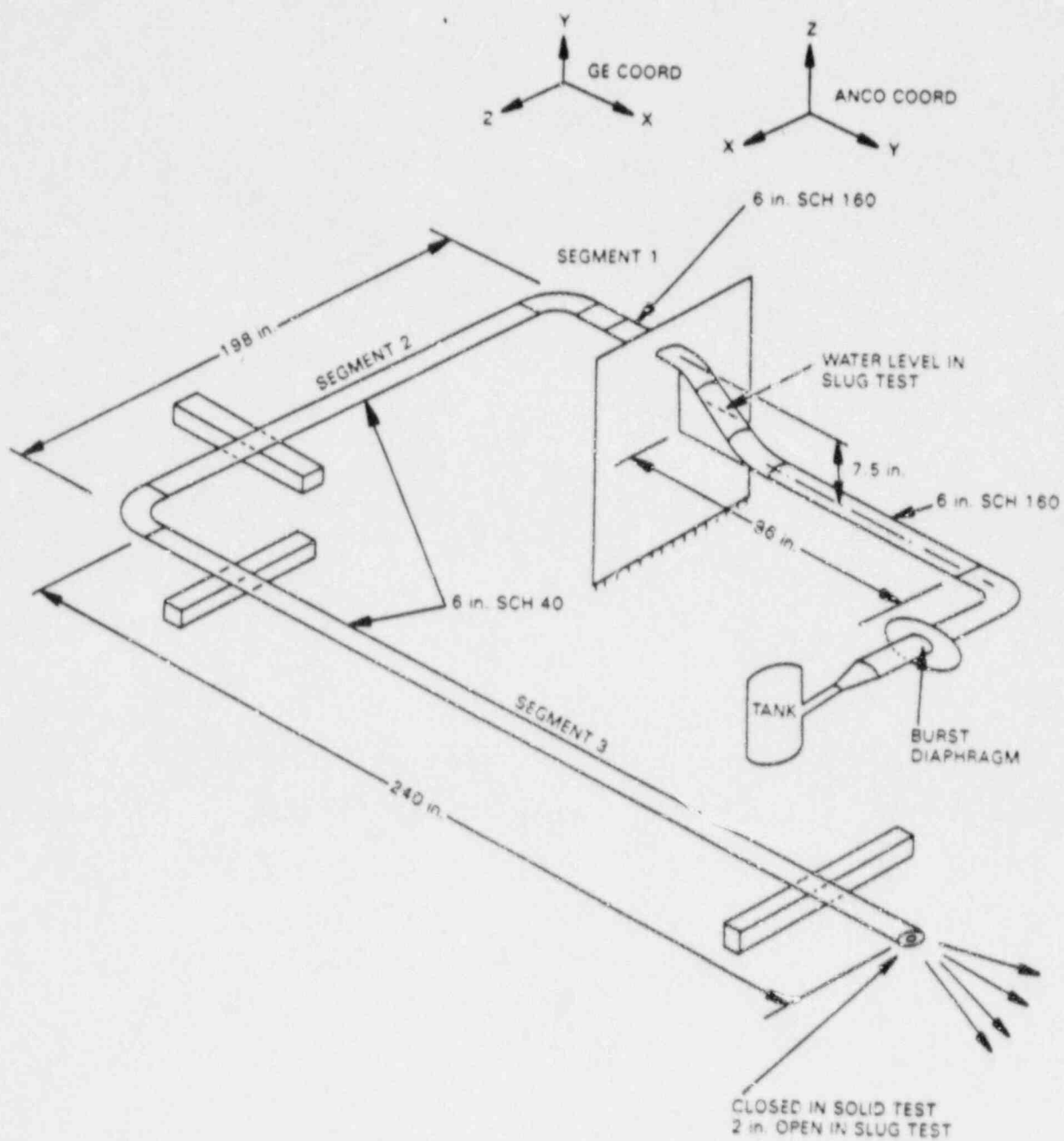
- TWO SMALL LOOPS, TESTS 28 AND 29
- 6-IN PIPING SYSTEMS
- CARBON STEEL, SCH. 40
- WITH AND WITHOUT SUPPORTS

### SYSTEM TESTING

- TWO LONGER LOOPS, MINI-SYSTEMS 1 AND 2
- 3-IN PIPING SYSTEMS
- CARBON STEEL, SCH. 40
- SUPPORTS, BRANCHES, SIMULATED VESSEL,  
THIN PIPE

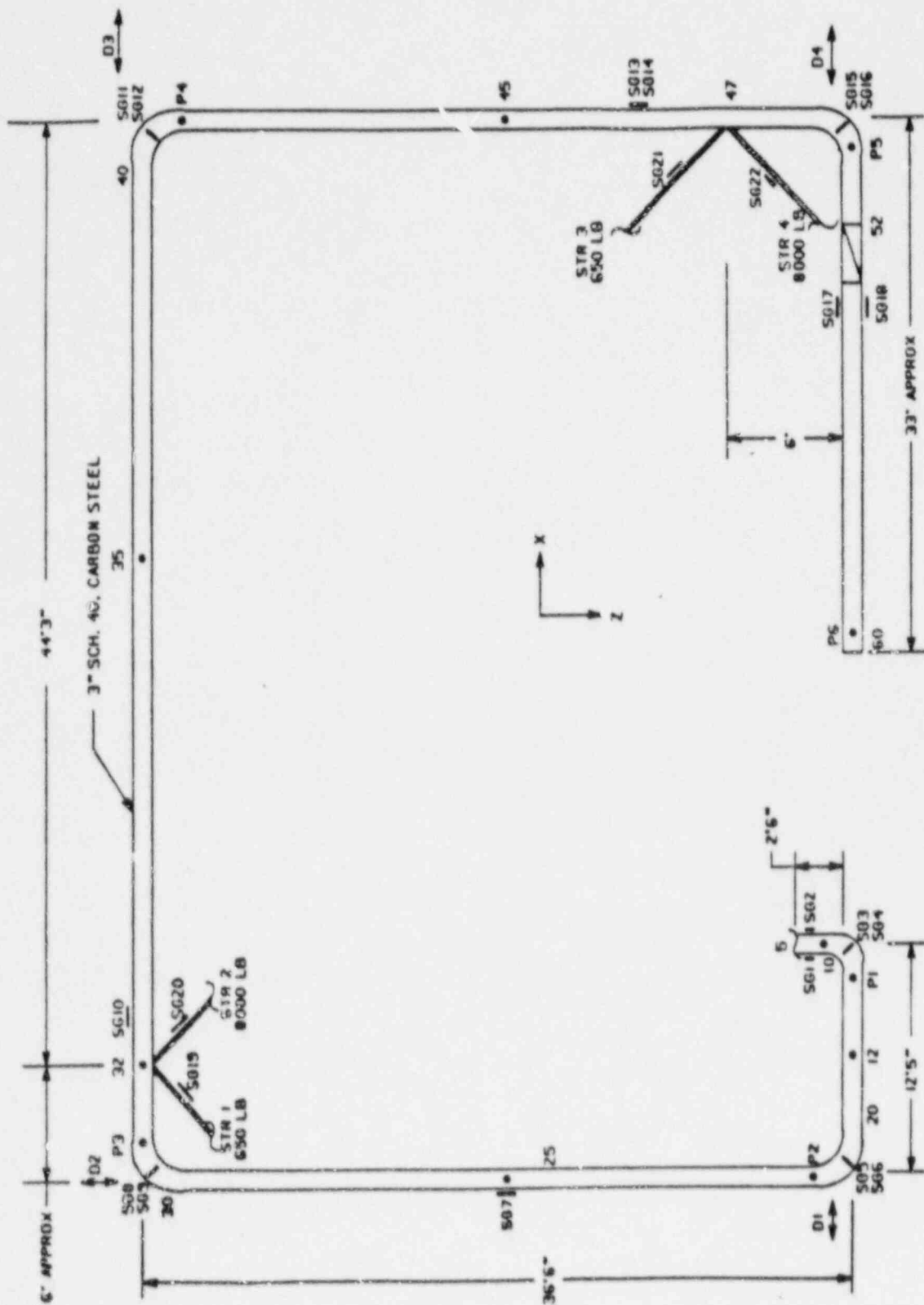
## LOADING CONDITIONS FOR WATER HAMMER TESTS

- SIMULATED STEAM HAMMER TEST
- HARD SYSTEM ACOUSTIC TEST
- WATER SLUG TEST
- VARIOUS PRESSURES FROM 150 TO 2000 PSI



Test 28 Water Hammer Test Configuration

# MINI SYSTEM 1 WATER HAMMER



INSTRUMENT	CHANNEL
P1 - P5	6
SG1 - SG 24	22
D1 - D4	4
TOTAL	32

TMP. 17E.HAMMER

PRELIMINARY OBSERVATIONS FROM WATER HAMMER TESTS

- WATER SLUG CAUSES PRIMARY LOADING - CAN COLLAPSE PIPING
- STEAM HAMMER AND HARD TESTS MORE LIKE SECONDARY LOADING - DID NOT COLLAPSE PIPING
- SUPPORTS CAN TOLERATE LOADS 10 X RATED LOAD W/O FAILURE
- PIPE CAN TOLERATE TRANSIENT PRESSURES 2 X BURST PRESSURE W/O FAILURE

BASIC RULE: DESIGN TO AVOID WATER HAMMER

### OBJECTIVES OF SPECIMEN TESTS

- DEVELOP LAB SPECIMEN TO EVALUATE FATIGUE RATCHETING WITH MEAN STRESS
- CORRELATE SPECIMEN BEHAVIOR WITH COMPONENT BEHAVIOR
- EXTRAPOLATE CONCLUSIONS FROM 4 TEST MATERIALS TO OTHER PIPING MATERIALS
- INVESTIGATE FATIGUE RATCHETING EFFECTS AT TEMPERATURE (550 DEGREES F)

Modified Test Matrix

Test Type	Temp F	No. of Mat'ls	No. of Tests	Purpose
Baseline	RT	4	5	Same as original program
Baseline	550	4	4	Find high temp properties
Two Bar Low Mean	RT	4	5	Find effect of low mean stress on all materials
Two Bar High Mean	RT	4	5	Duplicate tests with high mean stress
Two Bar Low Mean	550	4	4	Determine effect of temp on low mean stress test
Two Bar High Mean	550	4	4	Duplicate temp tests for high mean stress
Two Bar Rate Effects	RT	2	8	Investigate strain rate effects on the amount of ratchetting
Ten/Bend smooth	RT	2	4	Verify Ratchetting on 2 materials
Ten/Bend notched	RT	2	2	Test same 2 material for notch effects
Press Pipe	RT	2	2	perform four point bend tests on pressured pipe

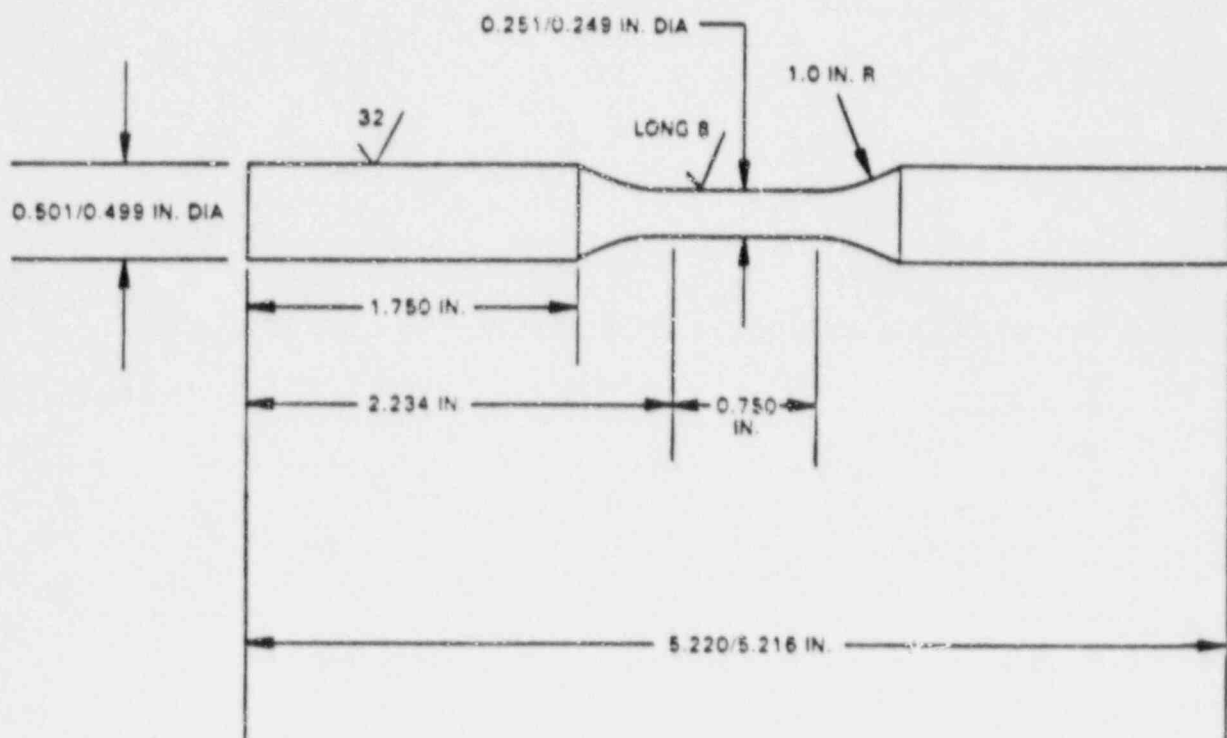
Materials Tested

Material 1	A333	Grade 6 Carbon Steel
Material 2	A358	Type 304 Stainless Steel
Material 3	A387	Grade 22 Class 2 Steel
Material 4	A503	Grade B Class 3 Steel

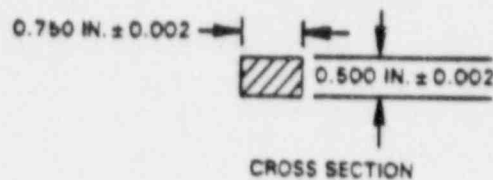
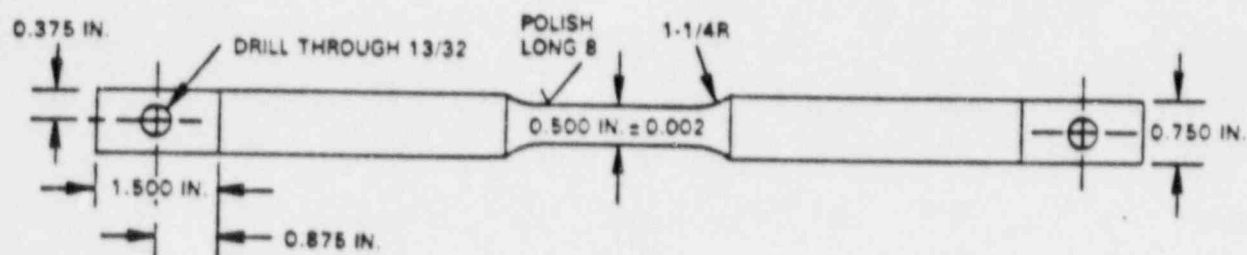
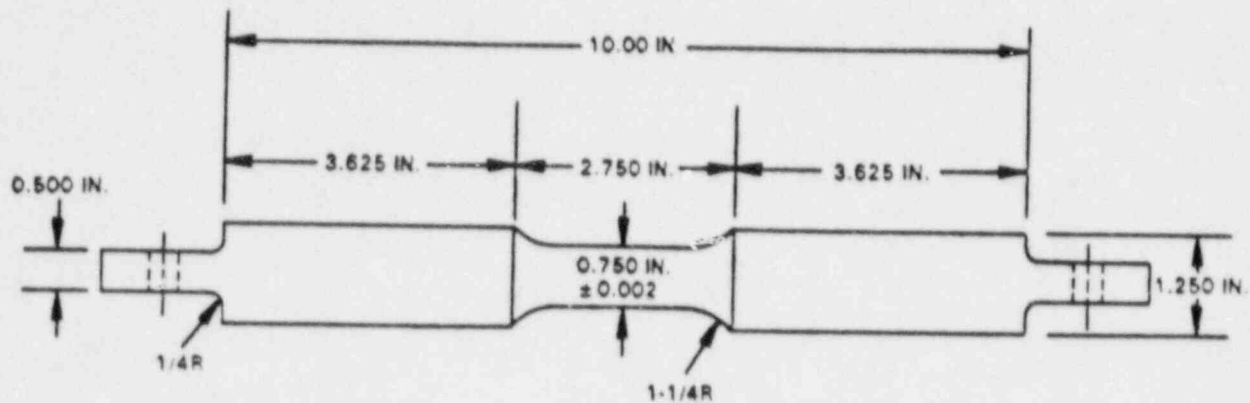
Notes:

1. When two materials are to be tested they are A333 Carbon Steel and A358 Type 304 Stainless Steel.
2. Number of tests are for each material to be tested.

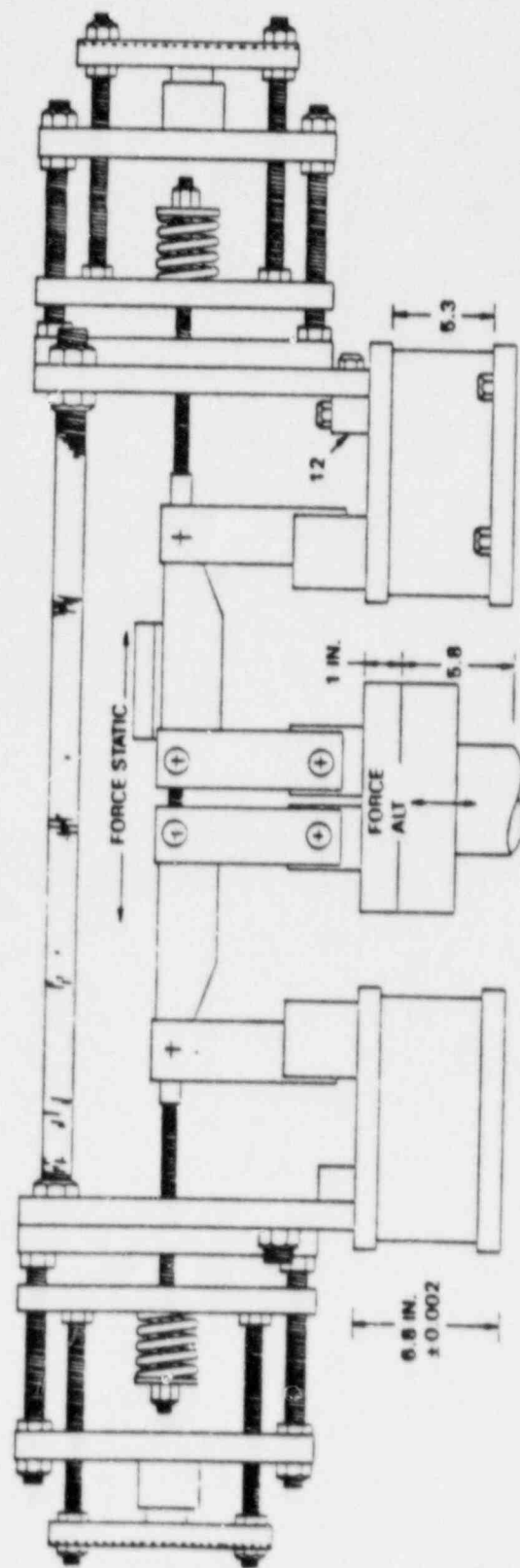




Uniaxial Test Specimen



Verification Specimen



Test Fixture

90

## OBSERVATIONS FROM SPECIMEN TESTS

- 2-BAR TEST CONSERVATIVELY ESTIMATES EFFECTS OF RATCHETING ON CYCLIC LIFE
- BEAM AND PIPE SPECIMENS CONFIRMED 2-BAR TEST RESULTS
- WITH CONTROLS ON CUMULATIVE RATCHET STRAIN, MEAN STRESS AND TEMPERATURE DID NOT AFFECT CYCLIC FATIGUE LIFE
- CYCLIC CREEP OBSERVED IN LOW FREQUENCY SPECIMEN TESTING MAY NOT BE PRESENT IN HIGH FREQUENCY SEISMIC LOADING