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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

In the Matter of:

DIABLO CANYON LONG TERM SEISMIC PROGRAM

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UNITED STATES NUCLEAR REGULATORY COMMISSION'S
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

In the Matter of:)
)
DIABLO CANYON LONG TERM SEISMIC PROGRAM)
)

Tuesday,
February 23, 1988

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

BEFORE: DR. CHESTER P.SIESS
Chairman
Professor Emeritus of Civil Engineering
University of Illinois
Urbana, Illinois

ACRS MEMBERS PRESENT:

DR. WILLIAM KERR
Professor of Nuclear Engineering
Director, Office of Energy Research
University of Michigan
Ann Arbor, Michigan

MR. JESSE C. EBERSOLE
Retired Head Nuclear Engineer
Division of Engineering Design
Tennessee Valley Authority
Knoxville, Tennessee

DR. DADE W. MOELLER
Professor of Engineering in Environmental Health
Associate Dean for Continuing Education
School of Public Health
Harvard University
Boston, Massachusetts

ACRS COGNIZANT STAFF MEMBER:

Al Igne

NRC STAFF PRESENTERS:

Bob Rothman

PROCEEDINGS

DR. SIESS: This is a meeting will come to order. This is a meeting of the ACRS Subcommittee on the Diablo Canyon Power Plant. I am Chet Siess, Chairman of the subcommittee. And we have a lot of ACRS members and consultants in attendance today. Let's see if I can spot them.

At the far end, Consultants Seavuzzo, Davis, Page, Member Moeller, Kerr, Ebersole. Consultants Maxwell, Trifunac. Did I miss anybody? Okay. The cognizant NRC Staff member for today's meeting is Mr. Igne, who is sitting here.

The purpose of this meeting is to review the status of the Diablo Canyon long term seismic program. The rules for participation in the meeting has been announced as part of the notice published in the Federal Register on February 5. The meeting is being conducted in accordance with provisions of the Federal Advisory Committee Act and The Government and Sunshine Act. And it is requested that each speaker first identify himself or herself and speak with sufficient clarity and volume and/or use a microphone so that he or she can be readily heard and their remarks be properly transcribed.

I think one of the conditions when the long term seismic program was set up was that the ACRS would review it or that they would report to the ACRS annually. On that basis, this is our second annual meeting. We are running a little bit behind. But since the last progress report was No. 9, I guess we are only a quarter behind.

As I recall we reviewed the plans for the long term seismic program at a meeting in March '85. I looked over the list of people who were present at that meeting, at least members of the committee who were present, and I am the only one although some of our consultants certainly were present at that time. We met in Washington in July of '85 to review the Staff's evaluation of the proposed program and I believe that that was the point at which the program began in July of '85.

We met in November '86, which was our first annual review and at that meeting, Mr. Ebersole and Dr. Moeller were present. So, they're in on it for the second time. And I mention this simply because those that are making presentations should realize that several of the members that are present are hearing much of this for the first time. That, of course, is not true for our consultants, many of whom have been in on it from the very beginning.

And some of the geological-seismological consultants have been following this between meetings rather closely by attending work shops and going on field trips.

You have a copy of an agenda in front of you. It goes through noon tomorrow for the formal portion of the meeting. Tomorrow afternoon, some members of the subcommittee and some consultants are planning to make a trip to the Diablo Canyon Power Plant. I would suggest that during our first break this morning that those who plan to make the tour tomorrow get together with Mr. Cluff at some convenient corner of the room and give him some idea of what you want to see. They need to make some plans at the site for a tour and if different people want to see different things, I think it can be arranged to break it up into two or three groups or whatever, but not too many groups. So, I will remind you at the time of the first break, either at the beginning of the break or at the end of it, get together with Mr. Cluff.

Do any of the members of the subcommittee have any comments at this time or any questions about the agenda?

MR. EBERSOLE: Chet, I've got a comment to make.

DR. SIESS: Sure.

MR. EBERSOLE: Not long ago, I attended a meeting on the topic of thermal hydraulic neutronics in Los Alamos and as you must always know, I am a generalist. I am going to be listening to you in the hope of hearing from you -- not you walking around in your own particular area of expertise in churning up old data, regrinding what we already knew because nothing much has happened I think in the last few years, but I am going to be looking for what I could express, say, to some Member of Congress as to where you were and what you are going to do with what you have got and what you hope to get out of it in the context of practical changes, if any, to Diablo.

Now, I don't know whether I am going to hear that or not, but I am going to be listening for it. In short, I would like to have you walk out of your private world of expertise and make some statements to the ordinary practicing engineers who must do something to the plant or not do it.

DR. SIESS: I'll second that motion. I think most of us on this side of the table, not the consultants, the members certainly are generalists and we have some consultants who are probably at least as specialized as those that are sitting over there. And it is important that you try to either address your remarks to the generalists or be prepared to answer questions from the generalists.

I am not sure I agree with Jesse that it should be such that we could explain it to a Member of Congress --

MR. EBERSOLE: Maybe that was too much.

DR. SIESS: -- not too much of a standard, if I could pick the right Member of Congress, I guess.

The principal speaker for the Pacific Gas and Electric will be Lloyd Cluff, to my right. And the lead off from the Staff will be Harry Rood who is project manager for Diablo Canyon. I think we will let the Staff take over. I could make some background remarks, but I am sure they would end up repeated by either the Staff or PG&E. So, let Harry start. And you might introduce the people you have with you.

MR. ROOD: Thank you, Dr. Siess. On my left is Bob Rothman from the Staff. I am Harry Rood. On my immediate right is Mr. Bagchi and on the other side of him is Mr. Chokshi.

DR. SIESS: Are they generalists?

MR. ROOD: They are the specialists.

DR. SIESS: What is their specialty?

MR. ROOD: Well, Mr. Rothman is a geology --

MR. ROTHMAN: I am Bob Rothman. I am a geophysicist with the Staff and I am coordinating the technical review. And I am basically a seismologist by education and experience.

MR. BAGCHI: I am Bouton (ph) Bagchi. I am a Chief of the Structural and Geosciences Branch, but I am a generalist by any term.

MR. CHOKSHI: I am Ilis (ph) Chokshi with Probabilistic Risk Assessment Branch, Office of Research. By education, I am a structural engineer. And I also consider myself a generalist.

DR. SIESS: Thank you.

MR. ROOD: I would like to make a statement here on the status of a licensing related issue. As you know, the Diablo Canyon long term seismic program which we are here to discuss resulted from a license condition in the Unit 1 license. In the fall of last year, PG&E, the licensee, requested that we amend the license to extend the completion date for one year from July 1988 to July 1989. And the basis for that was the conflict of certain key personnel -- they were also needed to participate in a California Public Utility Commission hearing. This request for an extension was published in the Federal Register. Letters were received objecting to the extension. And, at present, a decision as to whether to hold a public hearing on this issue is pending.

With that, I would like to introduce Bob Rothman who will give a quick summary of the technical aspects at this point.

MR. ROTHMAN: Good morning. I'm Bob Rothman. I am a geophysicist, as I said, with the Staff. I am going to give you a summary of the Staff's program as it now stands. I will give you a brief background on the history of the Diablo Canyon Program.

(Slides shown.)

In the early 1970's the Hosgri fault was identified about 5.8 kilometers from Diablo Canyon and considered to have a potential for a magnitude of 7.5 earthquake. The Hosgri reanalysis was performed and it required modification of some of the structures and components. John Bloom performed the reanalysis for the PG&E, the utility, and Nathan Numark performed the reanalysis for the NRC Staff.

And a lot of Numark's conclusions were based on his experience and judgment. And following this reanalysis in 1978, the ACRS recommended that possibly a seismic reevaluation be performed in about 10 years following that day.

In the early 1980's new geologic information and differing interpretations of coastal California tectonics became available and in 1984, the NRC Staff proposed options for the reevaluation of the seismic design bases for Diablo Canyon. And the commissioners imposed a condition on the Diablo Canyon Unit 1 license requiring this reevaluation program.

This is a brief summary of the license condition. There are basically four parts to the condition. There was: evaluate relevant geologic and seismic data available since 1979, which was the date of the operating license hearings, and reevaluate early information, if necessary. Reevaluate the magnitude of the earthquake used as seismic basis. Reevaluate the ground motion as a result of this earthquake and assess the significance of the first three using PRA and deterministic studies to assure adequacy of seismic margins.

A three-year program plan was submitted in January 1985 and approved by the NRC in July 1985.

Under the direction of the Commissioners and the ACRS, the Staff was urged to have a strong review and an independent parallel program. And the NRC review and parallel program includes review of the tectonics and geology, also, independent work by NRC consultants in this area; evaluation of the earthquake magnitude, including independent work being done by NRC consultants, review of the seismology and ground motion and independent work in both of these area; soil structure interaction; deterministic assessment and probabilistic risk assessment.

And in all these areas, there is an independent if somewhat limited program being performed by the NRC consultants.

In the geologic, tectonics and geophysics area, the NRR Staff is responsible for review with RES Staff, Office of Research Staff providing support. And we have technical assistance from the U.S. Geological Survey and the University of Nevada at Reno.

In the seismology and ground motion, the NRR Staff is responsible for the review and we have technical assistance from the USGS, including an independent ground motion assessment. And we have a panel of experts which was put together by Lawrence Livermore National Laboratory for us who are reviewing the theoretical numerical modelling of the ground motion at the site.

Soil structure interaction, NRR is responsible for this with RES Staff support. And we have technical assistance from a panel of experts which was put together by the Brookhaven National Lab.

In the probabilistic risk assessment, the Office of Research has the lead responsibility with NRR Staff support and we have technical assistance from a Brookhaven National Lab review team.

DR. MOELLER: While you are changing, could I ask a question?

MR. ROTHMAN: Yes.

DR. MOELLER: For your NRC technical assistance, you called upon National Laboratories in three cases and in the first one, of course, USGS I understand. How was the selection of the University of Nevada at Reno made? Do they have unusual expertise?

MR. ROTHMAN: They have a neotectonics laboratory there which is headed by Bert Slemmons who is a world recognized expert in neotectonics. And he is leading a group there with several other faculty members and a number of graduate students. And he has worked on some issues like this in other areas for the Staff.

DR. MOELLER: Thank you.

MR. ROTHMAN: I might say that this whole review program is unique as far as the NRC Staff is concerned. Normally, when a utility is performing a study for a site, they do their study, they submit a report to the Staff which then reviews the report and asks questions. And we go through a process of meetings of questioning and reviewing. In this program, we had a very close interactive program with a large number of meetings in which the PG&E consultants and staff have made presentations to the NRC Staff. We have reviewed their reports and given them feedback. So, it has been an interactive, very close interactive program.

Here we have listed the number of workshops, meetings and field trips on each of the studies that we have had so far. And you can see this is quite a considerable number if you figure this has been over the past two years. We have had quite a number of meetings taking place.

MR. EBERSOLE: I wonder if you could clarify a point for me? In the final analysis, all we are trying to find out is in an earthquake can this plant TRIP and thus cease defission and then can we get the heat out. That is the TAP 45 picture, too. At what point does this program interface with, in essence, the final objective? Is it just with the structural aspects of the plant, not including the detailed equipment at the plant or not.

MR. ROTHMAN: Let me say that PG&E is going to present their part of the program, but they are going through a very detailed level 1 PRA study to try and look for weak points in the plant, for systems that are going -- that may cause problems and the consequences from that.

MR. EBERSOLE: I mention this partly in the context of remembering our old member, Glenn Reed who says these plants need a way to feed and bleed as the final way to get the heat out once you can get them TRIPPED. And I am curious as to how far PG&E is going to let the plant degrade and, yet, still make it safe.

MR. ROTHMAN: I think you will have to talk to -- that is a little bit out of my area.

MR. EBERSOLE: In the end, that's the route we are all going down, though, is how to do that.

MR. ROTHMAN: The idea of the program was to review the input to the plant and see if there was going to be a problem and then to evaluate this through deterministic and probabilistic studies.

Now, the probabilistic program started at the very beginning, although -- if it is shown that the design basis or the reanalysis basis of the plant, it was adequate, you wouldn't have to go into the plant. But because of the time lag, the program has started at the front end, also. And they are well along on this program.

DR. SIESS: Excuse me. You said something I am not sure is right. Isn't it conceivable that the geological seismological studies could show that the original seismic hazard was adequate and, yet, the PRA could show that the plant had some outlier or some local weakness?

MR. ROTHMAN: Yes, I think that's possible. That's right. But under the license condition as the license condition was written originally by the Commission, it was to perform deterministic and probabilistic studies as necessary. So, in reality, the program is going on, but it was not a direct requirement of the license condition that they started initially at the beginning of the program.

DR. SIESS: Now, looking at this with the PRA, is that significantly different than what would be done under the severe accident policy program of the IPEs?

MR. BAGCHI: No. This is independent from the IPEs. Some discussions are going on within the staff with respect to external ends for consideration within IPE. This is not the case for Diablo Canyon. We are addressing the long term seismic program license condition.

DR. SIESS: But wouldn't the PRA, wouldn't the seismic PRA they are doing here satisfy one condition of the IPE of looking for outliers?

MR. BAGCHI: More than likely it is going to reveal plant weaknesses because we are not going to stop at a particular earthquake level PRA. We are certainly going to look at all the hazards, the entire spectrum of the hazard.

MR. EBERSOLE: Would that appear in the form of what I will call the pinch points in the plants. I recall one mid-West plant found out its Achilles' heel was in the long stemmed dependent pumps that weren't properly braced and so they lost suction on critical cooling water. Is that going to come out of this particular program or out of some subsidiary program related to this?

MR. BAGCHI: The PRA is certainly going to look at component fragility and the Staff is going to do some plant walkdown along with the detailed review by the consultants. I feel something of that nature would certainly come out of the PRA.

DR. SIESS: But if a PRA were not being done, this would become a very compartmentalized, very specialized study unique to Diablo Canyon simply reviewing the seismic design basis without really reviewing the plant response to that.

MR. BAGCHI: I would have to agree with that, but there are some interesting questions on the specification of the ground motion in this particular area. And I am sure that a lot of you are quite familiar with that and we are all hoping that it would extend the state of the art, really.

DR. SIESS: There is no question we are going to extend the state of the art. I just wonder sometimes whether we are setting a new basis for siting nuclear power plants seismically.

Go on, please.

MR. ROTHMAN: I might point out now that the original intent of the license condition was just to reanalyze the seismic margins. The utility, itself, voluntarily decided to do a full scope level 1 PRA. That was not a requirement. Just a seismic PRA was a requirement of the Staff.

DR. SIESS: I think the original intent was to review the seismic design bases.

MR. ROTHMAN: Yes.

DR. SIESS: Which was more than just the margin of the hazard.

MR. ROTHMAN: To date, at the present time, the Staff has not seen anything in this program that would cause us concern about the plant. We have had this constant interactive review. We have made comments to the utilities both in writing and in meetings. Comments on the way they were doing the program, on some of the results that they were getting, they have incorporated some suggestions that the Staff has made. And the program is ongoing.

There was one thing, there was a broad notification last spring at a workshop and field trip in the San Louis Bay area, the PG&E notified us that they discovered a capable fault in the sea cliff approximately 10 kilometers from the plant and a possible extension closer to the site. And also that the active strand of the Hosgri fault was found to be about four kilometers from the site rather than the previously assumed 5.8 kilometers.

I would like to show you a little diagram just to show you: This is the plant in the center. These circles are one kilometer between circles. This is the 10 kilometers, end of sea cliff. In San Louis Bay there was this displacement in the sea cliff. There is a possible extension at Pecho Creek or Deer Creek. There was a possibility of downwarping in the beach terraces which might have been an extension of the fault. And PG&E had indicated that they had looked at some of the offshore work and there was a possibility of some disturbances in the sea floor.

If this was to extent it would have put that approximately two kilometers from the plant. And this is the active strand that is depicted by PG&E about four kilometers from the plant.

The Staff didn't feel that this offered a great safety significance to the -- safety concern to the plant. But we have an office letter that requires us to issue a board notification if there is any new information on a plant which might be of public interest, congressional interest or media interest. So, a board notification was issued to the Commissioners informing them of this. And that's about the stopping point as far as the Staff is concerned.

MR. EBERSOLE: Let me add one more thing. In our zeal to protect the plant from earthquakes, it is always true every time you do a good thing, you do a bad thing. And, [illegible], I would guess that Diablo Canyon probably is the richest source of the reverse effects of adding constraints and hydraulic and friction snubbers and so forth. And one might take a reverse look: to what extent have we increased the hazard of pipe faults and disruptions in mechanical constraints necessary to expansion due to pressure and temperature and so forth. Have we found it necessary to go back and clean up at Diablo than any other plant some of the constraints found not to be necessary with further analysis of the mechanics of structure.

DR. SIESS: It seems to me about four years ago a study on that was made, four or five years ago, of the effect -- the probability of snubber failure -- we asked: What happens if one snubber fails? And two assumptions were made: It failed locked up or it failed loose. It turned out you were a lot better off if it wasn't there.

Does anybody remember that?

MR. BAGCHI: Let me try just a part of that. N411 allows higher damping value than was considered in the design basis for Diablo Canyon. Diablo Canyon came in with two programs. One is trying to optimize the snubber population. And another one is to get approval of the staff to use N411 damping values which is higher damping values and supposedly would allow them to reduce these types of hard restraints, snubbers, what have you.

DR. SIESS: The snubber reduction program?

MR. BAGCHI: It has been approved, N411 and the snubber reduction program. It is ongoing. I am not aware fully of the status of that program.

MR. ROTHMAN: Aside from that, as far as I know, as a result of this program that we are undergoing now, the three-year program, there have not been any changes made at the plant. It has not resulted in any conclusions today.

DR. SIESS: This program?

MR. ROTHMAN: This program, the seismic reevaluation program.

DR. SIESS: Before you sit down, let me ask you a question that isn't really related to Diablo Canyon. Where we are right now, how far is that from an active fault?

MR. ROTHMAN: Well, the San Andreas fault is right over here. It runs along the west side of the peninsula.

DR. SIESS: How far?

MR. ROTHMAN: I would have to look at a map.

DR. SIESS: Less than four kilometers?

MR. ROTHMAN: No. Not less than four.

MR. EBERSOLE: The San Andreas fault from here? From this location here?

DR. SIESS: Yes.

MR. EBERSOLE: It's about 12 kilometers.

MR. ROTHMAN: It's closer than that.

MR. EBERSOLE: Closer than that? Four or five, I guess.

DR. SIESS: Anybody look for seismic margins with this building before?

(Laughter.)

MR. ROTHMAN: And in the past where the San Andreas fault has been characterized for nuclear power plants, we have usually considered earthquakes of a magnitude 8-plus on the San Andreas fault.

DR. SIESS: 8-plus a few kilometers is pretty close. Isn't it?

Any other questions for Mr. Rothman?

(No response.)

DR. SIESS: Thank you, Bob.

MR. ROTHMAN: Thank you.

DR. SIESS: That concludes the Staff's presentation at this stage?

MR. ROOD: Tht's correct.

DR. SIESS: Harry, I think I told you, as we go through this and take up the various items that are listed here on the agenda, I would like a staff status report at the conclusion of each one. That is geology, seismology, geophysics. Then you can tell us where the Staff stands on that. Ground motions, et cetera, right down the line.

We will try to dispose of these in order so that when we get through there is nothing hanging.

MR. ROTHMAN: I would like to point out, though, the Staff hasn't reached any conclusions.

DR. SIESS: That is an acceptable -- well, that is a status report, whether it is acceptable or not. But we just want to know where you stand on it.

Mr. Cluff?

MR. BRAND: Thank you, Dr. Siess. My name is Don Brand. I am the Senior Vice President of Engineering Construction for PG&E. I have spoken to you before. We are pleased to be back with you again today. We have had an ambitious and very expansive broad program underway for a good number of years. We believe we have made excellent progress with that program and we will be presenting that to you here in a moment.

Following the thrust of some of your earlier questions, I certainly am a generalist in terms of my contribution here today. At the same time, let me put this in some perspective with regard to the units at Diablo. Unit 1 was placed in commercial operation in May of 1985. Unit 2 placed in commercial operation in May of 1986. Since that time, both units have operated in our estimation and concurred with by several others have operated excellently. And let me cite a couple of capacity factor numbers just to put this in some context.

For the first cycle, first two cycles of Unit 1, capacity factors have been 85.5 percent and 86.6 percent respectively. With Unit 2, the first cycle was 83.9 percent. We are in the second cycle and its capacity factor thus far has been 90.2 percent.

We are very, very pleased with this operating record that we have achieved and it just denotes I think the design and the operation and the significant contributions of all of our people in managing a very ambitious but still a very important power generator for the western United States.

Let me then introduce our first specialist. This is Lloyd Cluff, our manager of geosciences and the program manager for the long term seismic program that will lead off with PG&E presentation for today.

Lloyd?

MR. CLUFF: Thank you, Don and Dr. Siess. My name is Lloyd Cluff and, as Don just mentioned, I am the program manager for the long term seismic program and manager of the geosciences department for PG&E. With regard to the question about generalists and specialists, I qualify as both in some of these areas. By academic training, I am a geologist having also been involved in seismological activities in my formal education. But by experience, however, for the last 25 years, I have worked on a number of critical facilities in the United States and around the world having to do with siting and review of existing facilities. And, so, in that sense, I am a generalist in knowing what the focus ought to be in terms of specialized results and how they impact on the general aspects of a facility like Diablo Canyon.

Let me start off with the first view graph which is the agenda. And just kind of give you a little road map on my presentations and the continuing PG&E presentations.

(Slides shown.)

I am going to be talking about quite a bit of background material as noted on the agenda as you already see. Others have already touched on some of these items. While there will be a little duplication, I think I will be complementary and kind of expand and emphasize certain points. And I will probably move through this fairly quickly, but don't hesitate if there are any points that if I am going to fast giving this background material to slow it down a little bit and we can look at aspects if needed.

My guess is that we will probably get through this quite a bit quicker than the time that we have allowed for this. And then I will introduce the various participants. I will begin the status of the various elements of the long term seismic program and then as we move into that, I will introduce the various PG&E and our consultant participants who will be making the presentations.

By way of the background and this has already been mentioned, but this letter of 1978 where the ACRS suggested that the seismic design for Diablo Canyon be reevaluated in about 10 years. And then in 1984, the ACRS subcommittee, this subcommittee in Los Angeles reviewed a proposed license condition on the operating license, and then the full ACRS meeting in Washington later that year also looked at that license condition.

The ACRS letter of 1984, we have abstracted materials out of that letter of 1984. It talks about the elements of the proposed license condition by the Staff stating that it will provide a suitable basis for seismic reevaluation. And it talked about the conduct of this program which later became known as the long term seismic program. PG&E would take the lead with the strong suggestion that NRC Staff independent evaluation be conducted as the work is being done and that the involvement of the USGS and others.

Also, there was some mention at that time of the performance of a PRA and the note is there about, useful to give insight in terms of -- also in terms of PG&E's people having an active role in this. And, as you will see later, a PG&E person will be presenting the PRA status that we have later on. So, we have had very active participation by a member of the PG&E professionals. And then the request to make sure that there was adequate review as the program was being conducted. And I will talk in more detail about that later. And then in '84, the operating license with the license condition which is --

MR. EBERSOLE: Let me ask a question.

MR. BRAND: Yes.

MR. EBERSOLE: It is interesting that the PRA is brought up in the context or background of the seismic problem. And one could almost infer that it was put up there to examine the seismic hazard. Do you happen to know whether it is a PRA that is in a general configuration that looks a probably the infinitely higher probability that the plant will get in trouble from some source of trouble other than earthquakes?

MR. CLUFF: We have, it's a full level 1 PRA that looks at all hazards --

MR. EBERSOLE: Would it be the kind of thing you would put in a ISEP?

MR. CLUFF: Let me show you the full license condition that Bob Rothman abstracted that. The four elements of the license condition. The first one being evaluating the seismic and geologic data in terms of existing data, new hypotheses that had been presented and also, if needed, to gather new data. And I will show you how we are following that license condition.

The second element is to take the information from this reevaluation of existing plus new information and to reevaluate the magnitude to be used in our evaluation of the seismic margins at Diablo Canyon and then in item 3, to take the data from 1 and 2 and to reevaluate the ground motion at tho site and considering other information that exists as well as information becoming available from additional recordings of earthquake or additional theory on earthquake ground motions.

So, the fourth element is to assess the significance of the results of the previous three parts of this program through reevaluation in a probabilistic sense and deterministic studies as necessary. And the focus on this program is to assess the adequacy of the seismic margin of the plant. So, we are looking at this as a seismic margin evaluation. And the program schedule was listed to complete this program within three years following approval and then program progress in terms of our quarterly reports and meetings with the Staff and their consultants and then, of course, these annual meetings with the ACRS.

Let me go back to the program plan as it was submitted on January 30, 1985. It was divided at that time into a number of elements of the plan in terms of geologic and earthquake magnitude, ground motions, both by empirical and numerical analysis, soil/structure interaction, seismic hazard, fragility and probabilistic risk assessment.

And, at that time, in the submittal, it was highly emphasized of the dynamic character of this program, that it must be flexible to achieve a successful completion and the elements of the program must not be viewed as absolute. We might find reasons to make some modifications in what was presented at that time. And we must structure the program to accommodate change if, in fact, we found things that required us to restructure things. And then, as the program evolves and progresses, within the framework of the approved plan. And we follow that very carefully and where we have made any changes in the program, we have fully informed the NRC and we haven't made any major changes, but we have restructured things to be more focused.

Continuing with the meetings in October of '84 with PG&E and NRC to review the proposed investigation. Then a series of meetings. I won't dwell on these. I just wanted you to see that there was a lot of interaction prior to PG&E's submittal of the program plan and then after the program plan was submitted and while the NRC Staff was reviewing it, there were a series of meetings leading to the meetings that we had with the ACRS in July of '85 and then, of course, on July 30th, based on those discussions and understandings, the NRC approved our program plan.

Throughout all of these activities, PG&E felt it important to establish a consulting board for the long term seismic program. Members of the consulting board and their specialty, but many of you know most of these individuals. And, as you know, while they are all specialists, they have general knowledge of things and would all be considered generalists with respect to the overall objective of reviewing Diablo Canyon.

Now, this consulting board has been an integral part of our ongoing activities. Their function is summarized here in terms of providing guidance and advice and review as we step through the various phases of the program. Phase I being the development of the program, several meetings with our consulting board to give us guidance and advice in that.

In the Phase II activities which we developed details of the scope of work to be done and then pairing out which is Phase III, what we are reporting on the status now and the conduct of the work and then they will be very much involved in a review capacity in completing the final report.

Let me just show you: There was some question from the NRC Staff that we had convened this prestigious group of people that were very prominent individuals and were very busy. They weren't so sure we would be able to capture very much of their time. Well, we had a meeting where those members met with us and the NRC Staff and reassured everyone that they were fully committed to work with us as needed.

Here is a list of the meetings we've had, formal meetings with our consulting board to review and advise and give us guidance and we have had regular meetings, the last ones being last October. And we have one that will be coming up shortly.

With respect to others, I will expand a bit on what Bob Rothman mentioned with regard to the advisors and consultants to the NRC. As mentioned, Dr. Slemmons of the University of Nevada is working not only as an individual, but several of his faculty and a number of his graduate students are not only participating in what we are doing in the field in gathering geologic data and reviewing the existing data, they are also carrying out independent studies on their own. They are doing some parallel work in terms of field work and so forth. And we get together every so often with the NRC and the U.S. Geological Survey to review that progress.

I notice that I meant to put on here as well the U.S. Geological Survey and for some reason that got left off. They are involved in a review capacity. Bob Brown, with the Survey is their key contact person, but from time to time, as many as five or six USGS seismologists, geologists and geophysicists have participated in our workshops that we have had.

There is a panel that was convened for ground motions that is shown here with these individuals. Also a panel on soil/structure interaction, and a fragility panel and then a panel on the probabilistic risk assessment group organized by the Brookhaven National Lab.

DR. SIESS: Excuse me, Lloyd.

MR. CLUFF: Yes.

DR. SIESS: I wouldn't even make a try at correcting the spelling of Rensselaer, but I would like to point out that Dr. Veletsos is not Andrew. It is Anestos, unless he has changed his name.

MR. CLUFF: Sorry for the typographical errors.

DR. SIESS: A former associate student of mine.

MR. ROTHMAN: I think this slide is a little bit dated. I might point out that the ground motion panel, except for Jean Savy who is a Lawrence Livermore employee, they are all university professors and they all hold doctorates, also. Steve Day is now with San Diego State University. He has left S-Cubed. And from the USGS we have Dr. Kenneth Campbell is performing independent empirical ground motion studies and is also reviewing the empirical ground motion work being done by PG&E.

MR. CLUFF: Yes. I had that on a former part of this slide. Apparently, in the final preparation, a few errors crept in as well as some names were left off.

MR. SEAVUZZO: Can you give a little more background on the fragility panel?

MR. CLUFF: The fragility group, no, I'm not the one to comment on that. Maybe the NRC --

MR. CHOKSHI: Dr. Fitzpatrick -- It might be Michael Bohen. He is with Sandia. He was at one time program manager for SSMIP. And has also extensive work done for A45 PRAs -- seismic external PRAs.

Jim Johnson was also involved in SSMIP work. He is a structural engineer and has done a lot of probabilistic structural analysis work. And Dr. Ravindra with Bob Kennedy is one of the earlier practitioner of the fragilitic type of analysis.

MR. SEAVUZZO: Are you doing some work with some of the new seismic analyses or tests that are being conducted by EPRI and so forth?

DR. SIESS: The seismic pipe.

MR. CHOKSHI: Yes. The experience data, yes.

MR. CLUFF: After the program approval and the comments that we had received from the Staff and their consultants, we felt that it was appropriate for us to go through in the initial phase of this, which we called Phase II, what we termed the scoping study. You all have received copies of the results of that.

Let me just review what the purpose of that was and it was to be more focused. While the plan that PG&E submitted included absolutely everything, it seemed like it included so much that it needed to be more accurately focused.

So, one of the commitments that we made to the Staff is that in the early part of our program we would do this study to focus on the scope of work to identify priorities and so forth and, so, we went through that analysis to look at a balanced program. It is well integrated. It is properly focused on the important topics and a clear sense of the priorities in a realistic schedule from a generalist point of view.

MR. EBERSOLE: On the focus on important topics, does that mean -- I think we are really interested in severe earthquakes. Not little ones. Is that a possible meaning of what that is?

MR. CLUFF: Well, that is certainly one example: To make sure that we are not worrying about interesting earthquakes but in the end don't make any difference.

MR. EBERSOLE: Well, it has always bothered me to hear some of the so-called experts tell me the worst earthquakes are those we are going to have where we have never had any. But the focus seems to be to try to figure out what earthquakes we are going to have from an existing place where we did have them. And that has always bothered me.

MR. CLUFF: This next view graph just shows the process that we used to conduct this study. This is our first restructuring. We organized the program into fewer elements. We called the first one, geology, seismology and geophysics. As I refer to this as we go along: GSG is the short form of that. And then ground motions and hazard analysis are really part of the same activity. Soil/structure interaction and fragility analysis and probabilistic risk assessment. So, we kind of grouped activities within these elements. And this is how we are carrying out the program.

So, for several months we took a look at various issues that had come up based on comments made by reviewers or outside critics, our own judgments about certain activities. And we focused information throughout the program in an interactive motion to help us develop a schedule and work plan that we felt was realistic and would address the issues that everyone was concerned with.

The scope of that, the result of that work resulted in a report which outlined the objectives of the whole program with the seismology, geology and geophysics giving the work tasks. Since this has been in a report, this is just a table of contents, but I just want to focus on the priorities. These are not necessarily listed in priority, but characterizing the Hosgri fault in terms of existing data, the onshore and offshore geologic and geophysical data and interpreted data. Quaternary studies in terms of the region and close to the site and as we moved -- I won't spend a lot of time on this. I just wanted to note that we had structured this to be source specific. The Hosgri, of course, was viewed by everyone as being the dominant contributor. But we had a task that addressed other nearby faults. And I will show you later the significance San Maguelito, Edna and some other structural features that, some of which lie closer to the plant than does the Hosgri. And, so, it was important to look at those in terms of whether or not they were capable of generating earthquakes that were important to consider.

DR. SIESS: Lloyd, in the original submittal for Diablo Canyon, what was the governing fault?

MR. CLUFF: In the 1976-80 time frame?

DR. SIESS: PSAR.

MR. CLUFF: Yes. That was the Hosgri. Oh, in the first PSAR. I thought you said FSAR.

DR. SIESS: PSAR.

MR. CLUFF: The governing earthquake was an assumed earthquake directly under the plant of magnitude of 6.75. That controlled the analysis and --

DR. SIESS: And San Andreas was far enough away that it didn't control, so, you had to assume something at the plant.

MR. CLUFF: Yes. There was an advice that was given by Dr. Benieoff in terms of a large earthquake on the San Andreas which is about more than 50 kilometers to the east. It was assumed that that large magnitude earthquake on the San Andreas could be associated with aftershocks. And that it was assumed that even though there was no known structures, that it would be a conservative assumption that there could be a 6.75 magnitude aftershock very close to the plant.

MR. EBERSOLE: At that time, was it true that you had to find something. So, you did. You put an earthquake under the plant. Was it true at that time wherever a plant existed at the edge of the water that the seismic investigation stopped at the water's edge and didn't go outward into the water? I'm talking about anywhere.

MR. CLUFF: The answer to that is: It depends.

Maybe I could address that --

MR. EBERSOLE: I'm talking about even the East Coast.

MR. CLUFF: In this case, there was consideration given to offshore information. Due to the irregular nature of this coastline and often other coastlines, having personally being involved in looking at a lot of siting facilities on coastlines often from a geologic and seismic point of view, you learn so much more from information on land when you have an irregular coastline that you cannot --

MR. EBERSOLE: I know. But tht is like looking for your watch you lost under the street light. I am trying to get a general picture. Were we at that time not properly considering plants, other plants on coastlines when we should have unless the oil companies are out there digging around.

MR. CLUFF: I was not involved this project until just three years ago. Let me ask someone who was involved that might more accurately respond to that.

Bill White, is your voice available to --

MR. WHITE: Let me point out that at the time of the Hosgri reanalysis in '76, the actual work for this plant had been done in the late Sixties and early Seventies. See, you are talking about plants of tht era rather than plants that were being investigated --

MR. EBERSOLE: That was my question.

DR. SIESS: At the PSAR stage.

MR. WHITE: Which was the late Sixties.

DR. SIESS: Which was the late Sixties. What was the safe shutdown earthquake and what was it based on?

MR. WHITE: During the PSAR stage, there were actually two earthquakes that controlled. Four were considered. In the PSAR they were called A, B, C, D. The one that was directly under the plant controlled over some frequency range. That was Earthquake D, as I recall. Earthquake B, which was another earthquake, that was from a real fault controlled over the lower frequency range. So, we overlapped those two spectra and that is what really controlled the overall seismic criteria.

DR. SIESS: And San Andreas at 50 kilometers 8 point something didn't control anything?

MR. WHITE: It did not control. It got worn out before it ever got to the site.

DR. SIESS: And how much offsite information did you have at that time? Offshore, excuse me.

MR. WHITE: I think there was a limited amount. And the reason they hypothesized the Earthquake D, the one that was directly under the site, was to compensate for tht information.

DR. SIESS: Now, the Hosgri -- what was the original SSE zero period acceleration? DDE?

MR. WHITE: DDE, they called it in those days, it was point 4.

DR. SIESS: Okay. You had a point 2 design earthquake and then the double earthquake was point 4.

MR. WHITE: That's correct.

DR. SIESS: The Hosgri reevaluation then involved the Hosgri fault at about what? 5 kilometers?

MR. WHITE: 5.8.

DR. SIESS: What magnitude?

MR. WHITE: 7.5.

DR. SIESS: 7.5. And that ups it to

MR. WHITE: .75.

DR. SIESS: .75.

MR. EBERSOLE: Well, you know, what I am looking for is we are indebted to the petroleum industry to have found the Hosgri fault and extended our inquiry out beyond the waters' edge. It would be embarrassing, indeed, if I found a bunch of East Coast plants that didn't have any interest in oil and, yet, there were faults out there.

MR. ROTHMAN: Yes. There have been studies done for some East Coast plants. I personally know that for St. Lucy, we had the utility go out and do some specific work.

MR. EBERSOLE: We are not about to have another Diablo Canyon finding made, then, on the East Coast?

MR. ROTHMAN: One of the problems we have had on the East Coast is that even the faults that we have identified have not been capable faults to date. But we have done offshore work on the East Coast where onshore or other information has indicated there might be faults.

MR. EBERSOLE: Triggered by the Hosgri finding, I guess.

MR. ROTHMAN: I have only been with the NRC for the last eight years.

DR. SIESS: The USGS studies on Charleston have involved offshore.

MR. ROTHMAN: Involved offshore, but not for any specific plant site. A lot of offshore work was done under the NRC Charleston program.

MR. CLUFF: Let me just focus on a general question. In terms of utilizing scientific data bases to assess the seismic potential of a region, one certainly wants to look at the geologic and particularly the geologic aspects that relate to seismic activity, look for any evidence of paleoseismicity as well as geophysical data tht might be useful and the historical earthquake record that is recorded either in historic reports or instrumentally.

And, so, when you look at those data bases, one has to be very careful in just taking one of them like geophysics, offshore geophysics and just because you see a fault or a fold or a structure, making the judgment that: Aha, that is a fault that is capable of releasing a large earthquake. One needs to combine all the data to make that final assessment. And why my observation in coming into this program, there has been a lot of speculation based on using a limited data base that doesn't integrate all the data to allow you to say what is the answer you get out of combining everything. And tht is what this program is doing. It is integrating all the data.

MR. CLUFF: Let me move on to the ground motion. This is strictly, again, a continuation of -- it is a listing of the activities, work tasks and so forth in terms of attenuation, developing a response spectra, the time histories and looking if we have any side effects. And then taking a look using numerical modeling techniques to see what we could learn out of that and particularly in terms of calibrated numerical modeling.

In the seismic hazard analysis activity, it is a matter of looking at probabilistic ground motion estimates and peak acceleration plus duration and then I want to make sure to alert you and further speakers later today, perhaps even tomorrow, we have adopted a spectral acceleration. We find much more useful in this projects. I will let others talk about that later on.

DR. SIESS: What you are calling seismic hazards is simply probabilistic basis for describing the ground motion?

MR. CLUFF: Yes. This is the input, the hazard's curves that would go into the PRA.

MR. EBERSOLE: Well, this is all in the context of translating an earthquake at some distance to the point of interest. Isn't it?

MR. CLUFF: Well, it is looking at all of the aspects in terms of the size of the earthquake, what we think the realistic probabilistic earthquake magnitude would be. And then the frequency of occurrence or the return period of that.

MR. EBERSOLE: But I mean it is all based on the idea that you are going to translate the effects.

MR. CLUFF: That's right.

MR. EBERSOLE: From some other point of origin other than the plant proper.

MR. CLUFF: That's right. We look at the travel path from the origin to the site and then take into account the site condition.

DR. KERR: You referred to numerical models. What other kind is there?

MR. CLUFF: Well --

DR. KERR: That seemed to be in contrast to something else.

MR. CLUFF: Well, it is just the term that's been used in terms of using mathematical models based on computer driven aspects to be able to look at hypothetical cases.

DR. KERR: Okay. I understand.

MR. CLUFF: That's used in a lot of other activities. It is the numerical modeling of ground motions.

DR. KERR: That is versus empirical?

MR. CLUFF: Yes, that's right.

MR. EBERSOLE: You speak of the San Andreas fault being worn out before it gets to this plant site. To me, that brings up the interesting question of how -- what is the distance through an unbroken plate you have to go before you said, "This is where we are going to have a new break."

MR. CLUFF: That is a question that has been raised on many projects that I have been involved in. And we can, I think, demonstrate that when you are in an environment like the coast of California that is influenced by the San Andreas and its related fault, that what it takes to break new crust of material is so much more difficult to accomplish when you have got already developed planes or zones of weakness that that is not a consideration that we worry about.

If you are in a stable continental block where you have some small earthquakes going off, you are not so sure in those environments.

MR. EBERSOLE: That is because this is the limited range or expansive unbroken -- in California, that is rather limited, whereas, in the East, it is not. Is that right?

MR. CLUFF: Well, we have in the area of the coast ranges of California, we have well developed faults like the San Andreas and a number of others that I'll be showing you.

MR. EBERSOLE: I think what you are telling me: You have had your big breaks. Now, you are just worried about further movement on them.

MR. CLUFF: Well, it is not necessarily you get a big bang when it initially breaks. It is a matter of evolution as it develops. And it takes, often, several million years for a big fault like the San Andreas to develop. And then it continues to localize earthquakes and it is interesting in that context to share with you that we used to think of the San Andreas as a fault that would produce magnitude 8 earthquakes or greater all along its entire length.

Now, we are finding in new studies that have been completed in the last few years, that there are segments of the San Andreas fault that are slipping at the same rate as other segments that produce magnitude 8 plus earthquakes and the consensus of the scientific community that those other segments may only result in what we call characteristic earthquakes of magnitude 6, just more often.

And we are now finding that in only a couple of places on the San Andreas fault is capable of 8 plus earthquakes, most of the Andreas fault is around magnitude 7. And that is a new realization that has just come about and really focusing on how to segment how faults behave and how they behave on different segments. And we are taking advantage of looking at tht new information to apply it to other faults in the region. It is a very important concept.

MR. EBERSOLE: Thank you.

MR. ROTHMAN: Were you asking this for pertaining to East Coast earthquakes, also?

MR. EBERSOLE: Yes. I am really trying to get something of a feel about how big an unbroken plate has to be.

MR. ROTHMAN: Well, the East Coast of the United States is not a plate boundary. That plate boundary is out at the mid-Atlantic ridge

MR. EBERSOLE: But in California, these are.

MR. ROTHMAN: Yes.

MR. EBERSOLE: And at what point do you begin to get nervous that apart from the distant earthquake, you can generate new faults?

MR. ROTHMAN: I was just worried that you may have thought that the East Coast was a plate boundary.

MR. EBERSOLE: I know the East Coast -- at least I think I do.

(Continued on next page.)

MR. ROOD: What I think you are hearing is something to the effect that everything that can happen has already happened.

MR. CLUFF: That's true. And we know enough about the past history from a theoretical look in terms of seismic source characteristics as well as what we call paleoseismicity, evidence from the geologic record of past earthquakes, and the instrumental seismicity that we can characterize where and how big and how often.

DR. SIESS: Within the past 100 years, have there been any surprises?

MR. CLUFF: I guess it depends on how you define a surprise. Surprise, let's say differences. The point that I just mentioned on the San Andreas, that is not necessarily a surprise, but it is a change in thinking about this big plate boundary fault that in many places it may not produce any bigger than magnitude 6 earthquakes. Five years ago I don't think you would find many people that would subscribe to that conclusion.

DR. SIESS: That last earthquake at the end of the Whittier, was that a surprise to anybody? It was obviously a surprise to some of the people that built there.

MR. CLUFF: It was a surprise to the people on that early morning, as many of you watched them on television, ducking under tables in the aftershocks.

Yes, and no. That earthquake occurred along a northwesterly extension of a known zone of faulting -- the Elsignor-Whittier fault -- but it did occur in an area where the actual fault that slipped had not been represented on a geologic map. But that trend corresponded to a zone of very young geologic deformation. From that perspective, it was not a surprise in the magnitude 6, about, earthquake. We know from that event a Coalinga event, when you have intense, when you have a geologic deformation that you can quantify, that you should be worried about moderate or earthquakes of say around magnitude 5 to 6.

DR. SIESS: If I looked at a hazard map, would that have indicated that?

MR. CLUFF: A hazard map in California I think would have included that as a zone because all of that part of the Los Angeles Basin is Zone 4. And the basis for mapping source for hazards I think included that general trend.

MR. MAXWELL: Lloyd, was it the San Fernando earthquake, the very destructive one, somewhat of a surprise?

MR. CLUFF: Yes. In some ways it was a surprise. That's a good example, John, to look at that. That was a magnitude 6.5 earthquake that occurred in an area where no published active faults had been identified.

I personally, and many members of the Geological Survey, and other universities, said well, let's take a look at that. Had we done studies like we do for large dam projects, nuclear power plants, would we have recognized that fault that slipped? And the answer is yes. There was abundant geologic, geomorphic, paleoseismic evidence of repeated slips on that San Fernando fault. No one had really looked. There was no need to. There was no emphasis to look in that area.

So in a sense it was a surprise. But when we looked at it terms of nuclear power plant siting, it was not a surprise.

Just going on very quickly, this outlines the various tasks in the other elements of the program. The following speakers will be talking about our progress and some of the tentative results that we have achieved in terms of looking at the site conditions. And some of this we have already presented to you at the last meeting a year ago November.

The free field input motions; then, looking at the two methods of modeling the soil structure interaction to the CLASSI and SASSI programs, and the 3-D structural dynamic models, and then correlation with that reported data and then some parametric studies, and the following activities in that element.

In the fragilities area, the work tasks for simply stated at that time as shown here. In terms of looking at the dominant contributors to seismic risk, this may respond to some of the questions earlier. And to incorporate the soil structure interaction results and to look at improving our ability to focus on important contributors, and then the median in-structure response spectra and looking at the lower tails of the fragility curves, and looking at the balance of the plant piping and other aspects of the fragility assessment. And then of course look at items that were not considered in the Phase II fragility analysis.

From the standpoint of the program and its schedule as it is now constituted, we have the beginning of the program that started back in 1985, July of 1985, after a program approval, and here is where we had major kinds of whatever information we had, in a tentative fashion, we would have input into the various elements of this long term seismic program. Because of the need to finish this program in a reasonable amount of time, while ideally you would like to do these sequentially the programs are all going on at the same time so we have a continual flow of updating of information and using tentative results and then modifying them as we get more accurate results as the time goes on.

So what we see here is the flow where we are right now in early 1988. We are about to get another update from the GSG end of the ground motions. And then that will flow into the probabilistic risk assessment and the soil structure interaction aspects. Actually, these two areas down here connect up to this flow down here and this is just an update of these two aspects here to look at what we had tentatively concluded over here.

The final input we show here is in late 1988 or early 1989 in terms of our final conclusions that we believe we will have reached in the GSG part of the program, will flow into the ground motions and then once we know from this what we've concluded about the seismic sources that need to be considered, the size of the earthquakes that we have concluded that we will use, and then taking that into the ground motions into the SSI and then the fragility and the PRA, to allow the final rungs on the PRA to be done in the last few months of the program.

That means that these programs all this time are continually doing work and looking at various aspects, sensitivity studies and so forth. But we won't have reached conclusions that we will be presenting to the staff and so forth in workshops prior to these input times. We have workshops scheduled here late in 1988 and we will have subsequent workshops in ground motions and so forth to review with the staff what conclusions we have reached, what will appear in our final report that will be produced when we complete the program.

Now, you notice here that I'm showing the completion of a program assuming that the requested license amendment will be granted.

MR. DAVIS: Question on that?

MR. CLUFF: Yes.

MR. DAVIS: Is the PRA that is referred to on the bottom line here the Level 1 PRA that you talked about earlier?

MR. CLUFF: Yes, that is correct.

MR. DAVIS: I'm not sure what your definition of Level 1 is but the conventional definition excludes consideration of the containment response and its safety systems.

In other words, a Level I PRA looks only at the probability of core melt. So I am a little concerned that you are using the same definition. Will this exclude any consideration of containment response and containment safety systems?

MR. CLUFF: I'm not the one to answer that question, and Bruce Smith, the PG&E engineer that's in charge of the PRA aspect, Bruce, could you comment? You need to speak up so that they can hear you.

MR. SMITH: Sure. The PRA is an official Level 1 PRA. However, in coming up with our plant damage dates, we do take some consideration of the state of the containment, whether or not the containment is intact or not, as part of our plant damage statement.

So yes, we do, in some form.

MR. DAVIS: Okay. Maybe you are going to talk about this in a little more detail. But in the past, there have been occasions where there are interactions between the containment safety systems and for example the emergency core cooling systems.

And when you exclude any consideration of the containment safety systems, you may be missing some important sequences that could be generated by a seismic input event.

Also, there have been vulnerabilities found in containment structures in other plants. And I'm just concerned that you may be cutting things off a little bit early on the PRA.

Do you intend ever to extend the Level 1 into a Level 2 and 3 PRA?

MR. SMITH: We have not made that decision yet. The PRA is set up to go to those higher levels if we deem that necessary.

MR. DAVIS: You may have to do it for the IPE, but that is another subject.

MR. CLUFF: Let me just say that it is not our intention to go beyond the PRA that we have envisioned here based on what we have right now.

As mentioned before, there's been a lot of involvement of reviewers and so forth. Let me just show you very quickly not only we're going to make sure that we're not working in a vacuum with the PG&E and their consultants and the NRC and their consultants, but it was expressed early on that we want to make sure that we have a chance to review this in a peer reviewed aspect in professional society meetings and journals and so forth.

So let me just briefly show you --

MR. EBERSOLE: Before you get to that, let me ask you, in quick passing, you mentioned you were going to look at the balance of the plant. And I wonder if you are looking at the possibility of absolute, or rather of sudden and gross intrusion of salt water into the secondary system as a result of condenser tube failure or some such thing as that?

MR. CLUFF: Again, I'm not the one to answer that question.

DR. SIESS: Why don't we save that?

MR. CLUFF: Yes. I think we'll have an opportunity, and please ask that later on.

We have had a number of symposia held that have been conducted through the Seismological Society of America, the Geological Society of America and the American Geophysical Union, at least two meetings of all of these societies where we haven't had symposia that focus on the Diablo Canyon but symposia that includes the geographic area of Diablo Canyon.

Let me just show you as just examples -- here is one of the titles of papers for the Cordilleran Section of the Geological Society of America held last year. It was in May of 1987. We had three sessions. Session 1 was on seismotectonics of the Central California Coast Ranges. And the presiding individuals here, Ina Alterman at that time was with the staff of the NRC. Bob Brown was the representative for the U.S. Geological Survey, and myself, and then Dick McMullen is on staff at the NRC and Burt Slemmons with the University of Nevada. So the presiders of this conference were all individuals. But we sent out a notification that we were having these special symposia and we invited others to participate. And so we had, as you notice here, these two authors were not members of the review of working group on this project, and all of these papers were made with respect or presented with respect to this area in Central California Coast Ranges.

So we have had an opportunity through that. Let me just quickly show you other parts of that same meeting. This was 2, the Session 2 of that again showing the various aspects in terms of geology, seismology and geophysics and so forth. These were all organized with respect to various aspects of addressing the tectonics of the coast ranges.

And then Session 3 of that symposium was to address the issue of the relationship between folds in faults and slip rate on various seismic sources and again, a list of participants there, many of which are part of this program but also a number of them being outside people who have done work in the area and were eager to present some of their results.

This was a very useful mechanism to understand work that was in the process of being conducted at the time.

And then the last part of that Phase 3 was two more papers and then I gave a general summary of that entire session.

This, by the way, these series of papers, all the authors of those papers have been invited to contribute either an expanded abstract or a full paper to a peer review journal. This will probably be a Geological Society of America journal where all of this information will be out in the literature and it should come out during this year.

Just quickly to show you some other examples. I don't want to spend too much time on this.

But this was the American Geophysical Union meeting called the edge. This is a consortium of universities doing work on the edge of the continents trying to understand offshore/onshore relationships in Central California. And again you will notice, Dr. Pen Page was a participant and presented some of the work in that. And again, a lot of the people working on this project, both from the PG&E perspective as well as reviewers, and other interested researchers at universities and the U.S. Geological Survey, were involved.

At the Seismological Society meeting again, special sessions on strong ground motion. Most of these were on other aspects. But we had a number of people, this paper down here by Sommerville and Helmberger, and I think there may be -- I guess that was the only one in that session. But we've had an active participation in looking. I won't spend any more time on this. Just to show that we've got a lot of -- these are all in the handouts that you've received. And a number of symposia and meetings where we've had an opportunity to talk about, without it being focused on Diablo Canyon, to look at the aspects of understanding the regional geology and seismicity and so forth and geophysics as it might pertain to this geographic area.

This fall the most recent meeting in December of 1987 was a special session that had to do with -- and a number of the reviewers and so forth and participants in our program, these two papers down here as well as Professor Bolt who was on our consulting board, participated in that meeting. And we are watching when important earthquakes occur, and of course the Whittier Narrows, there was a special session there. And some of our workers were involved in looking at that, particularly Professor Bolt, on our consulting board. And then some of our work on one of our consultants in simulation of accelograms and so forth, in looking at the importance of that earthquake and incorporating that data into our analysis.

Let me go on to just a recap then of the involvement from the beginning or from the beginning, which was May 1984, in the draft discussions of the license condition through the point where the program plan was approved, and then a listing of the various workshops that we have had in giving some tentative results or status reports on our Phase 3 efforts.

Here is a workshop in soil/structure interaction and ground motions. We had a coordination meeting, and then some more ground motion workshops. We've had a lot of activities where the NRC staff and PG&E professionals with their consultants meet for sometimes a full day, sometimes three days, to conduct not only workshop sessions but field trips. You see a number of places where we've had several field trips. And we've had the opportunity of some of your consultants participating in these workshops and field trips.

I know that Dr. Page and Dr. George Thompson have I think been present at almost all of our workshops on geology, seismology and geophysics, and field trips that we have had. And so they have been able to participate and keep track of where we're going. This brings us up to date to the ones that we most recently had in 1987, in looking at all aspects of our program. And the most recent meeting we had was in January of this year to discuss where we are in the PRA program.

DR. SIESS: Excuse me. As I recall, the last time we met, the staff was complaining that they weren't getting enough paper to review. Could the staff tell us whether that situation has improved? By improve, I mean you are getting more paper.

MR. ROTHMAN: Yes. I would say yes. I was -- there was a hiatus of my involvement in the program due to NRC reorganization, at the time of the last meeting, so I wasn't involved with that. But I think we are happy with the number of reports and the quality of reports we are receiving now.

DR. SIESS: Thank you.

MR. CLUFF: Thank you. I would like to emphasize that not only the amount of paper but we have tried to focus on the significance and importance. And I'm glad to hear Bob say he is pleased with the quality.

This is the last viewgraph I have that kind of leads us into the next part of the program where we'll get into the results of various elements of the program. This kind of summarizes where we are in terms of the various elements in being complete.

In the parts of the program where we're collecting a lot of data in terms of existing data or data that we didn't know about that existed but just discovered it or data that we are generating by conducting our own field work or analysis. And in the geology, seismology, geophysics, at the present time that is about 75 percent complete. And then we're in our analysis and interpretation phase, which is about 65 percent complete.

The ground motion again has both data acquisition analysis. And until we get more earthquakes, I think we have about got all we need in that. But as you know, earthquakes are always occurring and we are always conscious of incorporating the data. As many of you may be aware, the Whittier Narrows earthquake by itself generated probably many more times the ground motion records that totally existed from a lot of other earthquakes in the past.

So we are carefully looking at the results of what is coming out of various interpretations and doing some analysis and interpretation of our own, of not only that earthquake but the Mexican and the Chilean earthquake and others that have happened since this time. And we're incorporating that information into our data base and interpretations.

And soil/structure interaction, again, we're about 75 percent complete. Fragility analysis about 80. And the PRA is about 85.

You have to understand that all these programs are going forward and they are driven by the results that will finally come out of here. And that will be essentially complete later this year. We expect that that part, of course, in terms of all the data acquisition and analysis and interpretation, will be complete by late this fall, early winter. And then from then on in that part of the program we will be finalizing our final report and we will be treating the final information down in here, and these other people will then be adjusting the analysis and interpretations they have made based on that final input.

So this is kind of the last and the lead-in to the next section. It might be appropriate even though we're kind of ahead to take a break now. I'm the next speaker for a while in the next part. And if it's all right, I'd like to take a quick break.

DR. SIESS: Does this conclude your discussion under the heading "Background"

MR. CLUFF: That's correct.

DR. SIESS: We are really a little ahead. But in any case, it's time for a break. We'll take a 15-minute break. Be back at 10:20. And I'd like to remind, about what I said earlier, those that are planning to take the plant tour tomorrow, I would suggest that if you are going to get coffee get it, and come back in here and meet with Mr. Cluff or whoever he designates to talk about what you want to see at the plant.

MR. CLUFF: Could we just meet right up here in front by this viewgraph machine?

(Whereupon, a brief recess was taken.)

DR. SIESS: I was just looking at the agenda and for some reason it says 4:00 p.m. today. Is there a good reason for setting 4:00 p.m? That is flexible unless somebody notifies me that they have got to go somewhere at 4:00. Five would be a little more reasonable, I think.

Okay proceed.

MR. CLUFF: Thank you, Dr. Siess.

As a matter of fact, with regard to the schedule, based on the discussions that we had up here of the people going on the field trip, we found an interest in a number of things that we can certainly accommodate and do. But to do that in the short period of time that we have, as the schedule shows, leaving here afternoon, and there are people who are on that trip that need to be back to San Francisco at 6:00.

I would propose that we do the best we can to achieve, like we are ahead of schedule right now, to continue that so that we could leave earlier if that is agreeable in the morning rather than at noontime.

DR. SIESS: We will certainly aim for that. I don't, however, intend to repeat the performance at the last meeting where we finished up the night before after dinner. Wasn't that the Diablo meeting? Yes. And disappointed a reporter who showed up the next morning and so forth.

But if it looks like working a little later tonight, and we will certainly try to finish up tomorrow. What would be a good time to aim for tomorrow?

MR. CLUFF: Okay, I have checked with our plane that we will be using, and we can leave as early as 10:00 from here, and if we could do that, I would like to try to do that.

DR. SIESS: Okay, we will watch the agenda. And if 10:00 looks reasonable, about 5:00 we will review the situation and decide whether we want to go to six. I don't think we want to go much later than 6:00 though, although ACRS members are used 6:00, 6:30. Hadn't been much later than 6:30 since Bill Kerr has been chairman, but he's not chairing this session. Okay.

MR. CLUFF: Fine.

(Slide.)

MR. CLUFF: We are going to move now into the status of the various elements of the program. And the first one being Geology/Seismology/Geophysics.

This first slide strictly emphasizes that this program is focused on important issues based on studies that we did early on, develop the scope of work, and we are data-driven. We haven't come to preconceived conclusions about models, tectonic or geologic models, but we are looking at data. And once we get totally incorporated and integrated and interpreted those data bases, then we will be giving the results in terms of the outcome of this work. So that is where we are right now is in gathering, or analyzing and interpreted data.

And we are going through four steps in this activity. Is the acquisition of data existing, or new, or what others are doing, analysis of all of those data bases and then interpretation and integration of all the data bases focused on characterizing seismic sources.

And so that last step is only done after we have integrated all the important information. And one has to be careful about coming to conclusions or judgments based on a limited data base, or without integrating the appropriate data.

(Slide.)

In terms of data acquisition, we of course have an extensive data base in the literature that was developed on the Diablo Canyon project prior to this program going ahead, but we augment that and have been in contact with researchers and people that have been working in this geographic part of California, and looking at particularly some new information in terms of marine and fluvial terraces, and the dating of those terraces, and I will talk about the significance of those in a moment.

And then we have conducted in specific locations where we targeted areas, we get some new information and actually going out in the field and exposing some of those materials through trenching techniques that have been very helpful.

Then in the offshore, combining the offshore and onshore geophysics, Dr. Savage with PG&E will be talking about this in detail a little bit later on in what we call the COMAPS high resolution, a nearshore study that PG&E conducted a little more than a year ago and then a deep crustal survey that PG&E conducted using Diglcon. These are the contractors that we had conduct that work for us under our direction.

And also in that onshore/offshore geophysical program, there was an integrated interest in this HARC group. Stanford University and Rice University and the U.S. Geological Survey and others had a great interest in this. And when the discovered that we are going to be doing some more work, they concentrated their efforts in coordination with ours.

So everyone benefits in getting access and getting more data than what one individual group might have gotten. And Dr. Savage will talk about that in more detail a little bit later.

Then some geophysical surveys that have been done by the petroleum industry that Western and Nekton, and these are just acronyms on the type of data that it is, and Woody will talk about that later.

In acquiring data that was developed for the petroleum industry, again the petroleum industry generally is not interested in seismic sources. They are interested in looking at faults or folds or structures that trap petroleum.

And so they tend to be fault happy in terms of the more faults, the more trapped petroleum you can find, the more people will pay attention and go out and drill holes. And so you tend to encourage a lot of fault interpretations that may or may not be realistic.

So we wanted to get the basic data that they developed. Then process it from the perspective that we were interested in looking at the stratigraphic and geologic relationships that would lend itself to integrating that with our other data bases to interpret the importance of seismic sources, so that the objectives in that. So that's what this reprocessing is all about.

And then the State of California has been conducting nearshore, shallow, high resolution work that is aimed at seismic hazards assessment, so offshore exploration and petroleum production. And we have been working together with the people that have been involved in that to share and help collect data of common interest. And this is in the 3-mile limit area.

And then the Central Coast Seismic Network, this is a network that PG&E has installed. It is operating, fully operational now specifically for the Diablo Canyon project. And Woody Savage will be giving you progress report on how that system is operating and what value the information that we are receiving is in our analysis.

(Slide.)

Let me show you now a map that kind of shows in map form where we were when we started this program. This is a representation of the State of California, Division of Mines and Geology map of this area. Plant. Here, the blue line, represents the coast line. And one sees a lot of lines on this map, and the question is, well, which ones are important in terms of Diablo Canyon.

Of course, we have always known that this zone that is represented out here, named here the Hosgri fault, is one that is important to us.

But nevertheless, there are some smaller lines, smaller faults, at least in terms of this pictorial representation here, the San Miguelito fault here that if in fact that's an important fault and if it is accurately mapped, or maybe it extends, we ought to know more about that, and so that's an obvious choice.

The Edna fault and there has been some other faults. I am going to end up at the end of my presentation here in a few moment with a map that shows the faults that we have -- where we are in the program now that are important, and I will put two on the two viewgraphs so you can see the difference in where we have come, and the progress that we are making and focusing on, the structures, faults and folds that we think are most important to us.

As you know, there have been a number of different hypotheses presented in terms of the tectonic style of the deformation. In other words, there has been great debate on the geometry of a lot of these faults, and namely, the Hosgri. Is it a near vertical fault? Or does it incline at some angle with the horizontal? If so, at what angle, and how does that relate to the other faults that are shown on this?

And as we are gathering the data and going through this analysis, we are now unfolding, I think, a very realistic picture of really how these faults, and the ones that are important to us are interrelated. And, of course, that's the aim of this project when it is completed.

Now there are a number of studies that came out of our scoping of Phase III that specifically focused on the important structures, and for the next little while I am going to focus strictly the onshore information. And so there were some specific studies aimed at some of these faults here, San Miguelito and Edna. And then because of the suspected relationship or connection between the Hosgri and the San Simeon faults, the San Simeon fault, this fault right up here. And on some maps they are shown as the same fault. Other interpretations, they may be separate and so forth.

And so since that fault comes on land up at San Simeon, it was a good opportunity to look at those relationships. So I am going to show you a series of slides now that --

MR. EBERSOLE: Before you throw that down.

MR. CLUFF: Yes.

MR. EBERSOLE: There are two large areas up there, one out in the water and one in the upper center in which there is a sparsity of faults.

MR. CLUFF: Yes.

MR. EBERSOLE: How would you characterize the subsurface that leads to that degree of absence of faults?

MR. CLUFF: Yes, let me defer that until you show -- this represents the state of understanding at the time that this map was published back in mid-'70s. And we will be showing some viewgraphs later on that Dr. Savage will be showing that will show -- we have looked at data bases that go offshore to a great extent, and we now know whether or not this large blank area is truly free from faults, or whether or not --

MR. EBERSOLE: Well, it merely was because you hadn't looked there.

MR. CLUFF: Well, sometimes that's the case, and Dr. Savage will address that as he shows that offshore. He will be addressing the offshore and the seismicalogical studies a little bit later.

(Slide.)

So let me now use the same base map as the basis for illustrating the studies that we have been conducting. This one in the stickel pattern outlined in yellow represents the extent of Quaternary Terrace deposits.

Now let me explain to you why these are important, and I will have some slides I will show you in a moment that illustrates that.

We find that these Quaternary Terrace deposits exist all along the coast of California, but particularly for application to understanding the tectonic environment surrounding Diablo Canyon, the area that I have noted here from the edge of the Santa Maria Basin, northward along the coast, to the San Simeon region. This is a unique opportunity to look these deposits and it's a mechanism from which we can gain an understanding of the rate of deformation and faulting, of any faults that intersect or folds that are nearby that might influence these features, and I will tell you why as I show some things from slides that follow.

Let me move this over to this, and then through some chotochrome slide. Now maybe we could -- yes, let's turn this one off.

(Slide.)

This is a view, an oblique view looking along the coastline. The plane was about here where San Luis Bay comes out. And the Diablo Canyon Power Plant, you can barely see part of the structures right up here in the background. This white area up here is the offshore sea stacks, those rock outcroppings are out in the ocean just offshore from the power plant.

But the point I want to stress here is that you have this topographic, almost flat there, an inclined near flat plane that you can see here well represented, that follows around the coast, and I am going to quickly take you along the coastline, this being the most southerly part, although these extend even farther to the south.

And what these features are is that this represents both a time line and a physical line in terms of a reference plane that is a platform that was cut by a former stand of the sea. In other words, these areas were at a lower elèvation at one time, and due to regional uplift where the most of the coast of California is, generally speaking, uplifting at various rates.

And so as the surf planes off these surfaces, it creates what we call a wave cup platform, and then on top of that platform are deposited materials of the terrace deposit, which were termed Quaternary Terrace deposits. This was all accomplished in the last couple of million years.

And so what we have are a whole sequence of wave cup platforms, terrace materials on top of those. The ages of which we know, or in a study we have determined.

And so we know when those were formed, and since they are plane surfaces, the ocean being the reference base, then we can look at the amount of deformation or faulting and come to a lot of very important conclusions about which faults to worry about, which faults not to worry about, and which folds might be causing fold deformation that might reflect faults at depth that don't expose themselves at the surface.

So it is a very valuable strain gauge, as I like to look at it,, and the youngest terrace, the modern one that's being planed just offshore right now. The next one is about 83,000 years old. And we actually have 12 terraces. You can only -- the trained eye can see two terraces in here. I won't take the time to go into that now, but we have identified as we go along the coast 12 terraces going back to more than 1 million years.

The older ones aren't as well preserved, so that the strain gauge data are only limited for some of those that may be 700 to a million years old. But, nevertheless, their relative position with the younger ones that are essentially continuance, the 83,000 year and 240,000-year terrace are almost continuously preserved and are an excellent opportunity to allow us to look at the faulting, the rate of faulting and the rate of deformation in this entire region.

(Slide.)

The next slide is continuing along, and now you can see how well developed these are. And in these areas not only did we do detailed mapping and surveying of a zillion points along these surfaces and drilled down to look at the character and the depth, and geometry of what we call the shoreline angle to be able to assess the continuity and any deformation that are related to these features in the plant.

(Slide.)

The next slide just moves on to show the plant. The plant is located on those Quaternary deposits and wave-cut terraces, the younger ones. And as you can see, they continue.

(Slide.)

The next slide continues on northward around the point here. These white rocks that we can see from down south. Continuing on to the north then.

(Slide.)

And the next slide shows very plain our representation of these two younger terraces that are here.

(Slide.)

And the next slide shows as we are up at San Simeon. Now this is the -- these terraces continue on up the coast of California. And in a general sense have been very helpful in understanding the deformation and fault behavior in other places. But for the benefit of this project, this is as far as we need to go in terms of understanding.

And the San Simeon fault comes right through here. At this angle it traverses off and goes offshore again here.

And so this is a rare opportunity to look at the interplay of the San Simeon fault and the number of terraces that we have identified here, and to be able to date the rate of faulting and so forth on the San Simeon fault and the style of faulting and the character in terms of the fault behavior. And even we have identified evidence for some past earthquake activity in terms of looking at the amount of slip and relate it to the size of past earthquake.

(Slide.)

So the next slide then looks back -- or, no, it is continued on. This is over the top of this area where the San Simeon fault comes on land here or offshore. And you notice here that at this point we get quite a high topographic relief and I will just make mention of this right now, and Woody Savage will talk more about this when he shows the results of some of our instrumental seisimity interpretation where we have essentially division between strike slip fault that is coming through here and some vertical dip slip, or reverse slip faulting that goes inland along another fault trend at this location, and this bifurcation. Not only is it represented topographically and geomorphically, but in the seismic history that other slides will illustrate.

(Slide.)

The next slide I think is the last slide that looks back then. We just turned around, looked back. The power plant is out on the -- this area here of the Irish Hills, and this is looking down, the erosional trench cut by this steam canyon. The stream is following that because of a crushed zone along the fault. And then one can see the features out there that represent a series of these wave cup platforms and terrace deposits.

And we have done a lot of detailed studies up here to characterize that relationship and assess the behavior and characteristics of the San Simeon fault.

So that is the last slide. Let me turn this viewgraph back on over here.

(Slide.)

What I just showed you was a sequence of aerial shots from about right here, all along across the plant, and then all the way up to this place in San Simeon. So this is a unique data set that is very important to us in assessing the amount of deformation that has occurred in the past approximately million years.

Let me go back since this is a little more convenient on this side with my right-handedness.

(Slide.)

Show you where we have gathered some additional data to supplement that information. This is bore hole water well data that have been very important to us with respect to the plant site. We did a lot of boring here, not having anything to do with water well, but to help us identify and characterize the ages and the geometry of those wave cup platforms and terrace deposits. So that was an area of intense concentration to examine that area.

Then in the area where the San Miguelito fault is, we had some additional detailed subsurface information that we felt would be helpful. And then in this area some water well data and other information were gained from some bore holes. That existed in some that we in addition drilled ourselves.

And also up in this area near San Simeon, the same kind of information was acquired there, and also an area here near Morrow Bay where I will talk about a little bit later, Woody Savage and I, about the importance of the disappearance of these strain gauges as they come up here. They just end. And what we found out is there is another fault that is not shown on this map that actually terminates those terraces. They are not there, and this area is actually subsiding, and we have been able to quantify the rate of that subsidence due to water well data and the stratigraphy that we have gotten out of those existing well data sets.

Now some other information that we have been gathering and evaluating is from trenching. Here is places where we have come in, and this has focused our understanding whether or not this San Miguelito fault has evidence of disrupting these strain gauges, these wave cut terrace platform and as well as up on the hillside here, any information from the younger deposits to see if there had been any deformation in the last few hundred thousand years. So that's what these locations were aimed at.

These were aimed at the Edna fault, and then these out here where there is not a fault shown there because of the state of knowledge of this map, this other fault that we have discovered through completing this stage of this program, is the Los Osos fault, and that's what these trenches, to try to understand behavior of that fault.

And then the detailed studies that we conducted up here at San Simeon to understand the behavior of the San Simeon fault on shore.

(Slide.)

The next is -- let's see, you are going to do the geophysics after this?

MR. SAVAGE: Yes.

MR. CLUFF: Yes, and then I am going to summarize the importance of integrating both the wave cut marine terrace data with the geophysical data that Woody will present. So Woody will show mostly the offshore geophysics and seismity, and then I will come back and pull this material together to show you the results of some of the tentative conclusions that we reached so far.

DR. SAVAGE: My name is Woody Savage. I am a seismologist with Pacific Gas and Electric. And I am a specialist seismologist. I have spent the last 15 years or so working both with the U.S. Geological Survey as well as in an industrial capacity studying earthquake activity. But I am also a generalist. I think it's important to be a generalist in proceedings like this, because one of our objectives is to integrate multiple data sets. And again, that's been part of my professional activity for the last decade and a half.

Well, Lloyd's development of the program as we have been carrying it out left off with part of the discussion of our data acquisition efforts. And what I will do is briefly give you the location, primarily the location information of the data sets that we have been acquiring most recently.

Now, in November of 1986, we met with you and presented quite a bit of information about the locations and some of the results from processing and interpreting offshore geophysical data, and certainly offshore geophysical data has been very important in understanding the Hosgri fault zone and its relationship to onshore geologic and tectonic structures.

Well, following the interval of -- following the time of that meeting last year, we have collected some additional data sets, and just for the sake of completeness I would like to make sure that the geography and significance of those data sets is fairly clear.

(Slide.)

I don't have a figure that shows where we had data up until this time, but it was basically along the entire stretch of the Hosgri, with a lot of emphasis in the southern portion of the Hosgri, because this is the area where, as Lloyd mentioned earlier, there has been longstanding oil exploration interest, and much of the data that have been collected offshore have been specifically for oil exploration purposes.

The first data set I will describe is called the COMAPS data set. It was collected by PG&E by the contractor COMAPS, and is what's called a high-resolution study. The high resolution means that the emphasis is on studying the shallow set of entry structure from the sea floor surface down to as deep as a few kilometers.

The energy sources that are used are high frequency and they range from side-scan sonar which collects a fairly realistic image of what the ocean floor looks like in a side-looking sense. Those soundings were collected, and then two very high frequency geophysical sources were used. 3.5 kilohertz device and what's called a boomer which image the sallow set of entry structure down to a depth of about between 10 meters and perhaps as deep as 50 meters. So, again, it is very shallow penetration data acquisition.

The remaining geophysical technique used is called CDP, common depth point reflection surveying, and this reflection profiling was done with a relatively high-frequency source, not the same sort of seismic source as is used by the deeper penetration oil company explorations.

So within this region extending from the middle of San Luis Obispo Bay, across the Hosgri, extending into the interior of the Estero Bay and on up past where the San Simeon fault comes on shore, we collected a number of lines of data. Most of the lines have the orientation, as how shown schematically in this figure here, cross both the trend of the Hosgri as well as the trend of some of the other geophysical structures that we have seen offshore.

But there were also northwest going lines which serve to tie these data together.

We will see the application of this COMAPS data set later on this morning in a high resolution geophysics look at the Hosgri fault zone.

(Slide.)

The next geophysical topic as seen on your right here is the Diglcon survey. I am going to put the microphone down here to align this slide.

As Lloyd mentioned, we had an opportunity -- well, first of all, we had a need to develop a better understanding of the deeper crustal structure within the region. The plant site being right here southwest at San Luis Obispo.

The oil company data and in general other geophysical techniques that have been used have penetrated with good returns only a few kilometers, 2, 3, 4, 5 kilometers at best. And there are questions about what's happening in a deeper crustal sense and in a regional sense that we felt merited a true depenetration geophysical survey, and that survey was discussed very briefly with you at the last meeting in November, because we had just come back form the field having collected those data a that point.

So these were the lines that we shot using a very large airgun source, and we shot one cross line here. We also recorded airgun shooting onshore, so we ended up having the ability to image the crustal structure across the coastline. It's certainly been commented that lots of time geology seems to end at the coastline.

Well, obviously it doesn't, and this is one of the techniques to develop a clearer understanding of the onshore/offshore relationships.

And these lines crossed not only the offshore St. Lucia Bank, an elevated basement platform in the offshore, but went across what's called the Santa Lucia escarpment, which is a relic of the subducting process, plate tectonic subduction that was occurring some 25 to 30 million years ago that terminated at that time period.

MR. MAXWELL: Could I ask you a question?

Do you really get subsurface data across that coastline?

MR. SAVAGE: Yes, and we will have a chance to look at the product of that.

It's like all geophysical techniques applied in the arena of studying faults. What one gets are geophysical data which are then processed using very sophisticated computer processing techniques, which are then interpreted by geophysical specialists.

And what comes out of that are lines on a cross-section or contoured surfaces. The relationship between those products and questions that are of significance to this kind of a proceeding takes another step of interpretation. Simply seeing an image on a geophysical section doesn't mean that that's an active fault. It doesn't mean that it is a fault that is capable of a particular size earthquake.

That relates to the integrated effort that Lloyd referred to earlier.

But to directly address your question of what we get across this boundary, yes, we will see some examples shortly.

For those of you who are interested in the specifics of this kind of a survey, the refraction survey used a 10,000 cubic inch tuned airgun array. It was tuned to long periods, because these airgun sources look like small earthquakes occurring offshore. In fact, our seismet network last for the last several weeks been going crazy detecting an airgun survey offshore.

We shot once a minute, and extended about 120 kilometers offshore, and we were able to see this airgun source off on the far side of the San Lucia escarpment.

The reflection survey, these are the parameters associated with recording the 6,000 cubic inch gun. This gave us penetration down to depths of several tens of kilometers. And you will see a bit later what at least one of the images looks like coming from the depenetration study.

(Slide.)

Another data set that we have acquired and incorporated recently consists of some selected more recently shot lines from oil company files, Western and Nekton, and those are again kind of schematically represented here. We felt that we would like to have a better, deeper control on geophysical imagery, particularly in San Luis Obispo Bay and the Estero Bay area, looking at some of the structures that come from the onshore and extend offshore. The Los Osos fault being one in particular that we have looked at in detail.

These data are traditional oil company two to five second data. They are not high resolution data. So they do not give a clear representation of young deformation as that deformation may be expressed within the upper sediments in the ocean.

MR. EBERSOLE: Tell me your generalized theory as to why these lines run northwest-southeast rather than some other direction

MR. SAVAGE: Why the --

MR. EBERSOLE: Yes, all of them, the whole family of them.

MR. SAVAGE: That's right. Well, that's actually a quite fundamental observation, and has to do with the long-term history of not only the San Andreas fault but the evolution of this entire plate margin.

It has been a margin of lateral transport tectonically for tens of millions of years. And this structural grain, the northwest-oriented structural grain has been established for a long time. It relates to the comment Lloyd made earlier about these -- these northwest-oriented structures being the preferred vehicles for allowing motion to be accommodated.

MR. EBERSOLE: YOu used the word "grain". To me that suggested slumping into the south.

MR. SAVAGE: No, I'm sorry. Grain was in a very large-scale sense.

MR. EBERSOLE: I know.

MR. SAVAGE: It's a preferred trend orientation.

The reprocessing -- Lloyd mentioned this briefly earlier -- was done on records such as these Western and Nekton records, as well as many of the older, the previously acquired data sets that PG&E has been using and interpreting, to see if by using modern processing techniques on data that were acquired 10 and 15 years ago, whether we might improve the resolution.

And that resolution has to do with reducing noise on the record, reducing processing artifacts, defractions that may obscure our ability to see structure within those geophysical profiles, and also to enhance penetration with depth.

We would really like to be able to see images that may be related to geologic structure, particularly faults within the basement rocks. In a nutshell, our reprocessing was very effective in reducing noise within the upper kilometer or kilometer and a half of these records. And those data have been -- those enhanced images have been incorporated in our interpretative effort.

However, the ability to image in the basement was not enhanced by the reprocessing. That was an objective that we very seriously tried to achieve, and it in general was not very successful.

(Slide.)

The last data set I would like to mention is one that we have very recently acquired through cooperation with the California State Lands Commission.

The state is acquiring data to be used for geohazards assessments in the event that there is a leasing of oil leases in the nearshore region, within the 3-mile limit. And so this shows the location of that State Lands data set.

And, again, it is a high resolution data set which we will using to look in detail at the way these faults extend offshore, onshore and offshore area it's called the Casmalia fault. You will see that term later on today also, the Lions Head fault. But also the Hosgri fault zone comes within the State Lands limit near its southern termination. And so these data will be very useful in further understanding the southern end of the Hosgri zone itself.

Let me make sure I don't get out of place here.

(Slide.)

I would like to move on to a discussion of another relative -- for PG&E's operation framework anyway, a new data acquisition, an that's the Central Coast Seismic Network.

To put the seismicity data into a more regional context, here is a map of the California - Nevada area showing earthquake activity located and presented by the U.S. Geological Survey for the years 1980 through 1984. And we can see represented in both the lines plotted on the map, which are some of the major faults within California, as well as seismicity. That in some cases the seismicity, the micro earthquakes, these are earthquakes greater than magnitude one and a half, and generally most of the events here are in the magnitude of one and a half to about two and a half with relatively few larger ones.

Well, these little earthquakes certainly show us where the San Andreas and the Kalaveras Hayward fault systems are in central California, and the San Yosento fault, the San Andreas would be up here, the southern portion of the Whittier Elson fault system. Those are expressed by the location patterns of smaller earthquakes.

But there are areas that are not so clearly defined by the -- at least the mapping of little earthquakes.

Also, there are certainly large differences in the level of earthquake activity. We see here in the -- along the San Andreas portion of southern California a very dense pattern of earthquakes representing a very high level of earthquake activity.

Within the coastal region we are looking at here, we see a high level of activity along the San Andreas, a few hot spots of activity here that we will be looking at in more detail, and then a low level of activity in other portions onshore. And when we get offshore, there is an apparent hiatus in earthquake activity.

MR. PAGE. Woody, would you point out the site

MR. SAVAGE: Yes, I'm sorry. It is hard to see here. That is the Diablo Canyon site is right at that location.

MR. PAGE: I wondered if it was where that little cluster is to the north.

MR. SAVAGE: No, that's up at San Simeon and we will see this.

(Slide.)

Okay, the site again sits right here, and these are earthquakes that we have plotted up for the same time period taken from both Cal Tech and U.S. Geological Survey. And so, roughly speaking, it's the same data set shown in more detail.

And one of the important observations here has to do with the apparent lack of earthquake activity extending in the far offshore area, and a lack of earthquake activity seen in the nearshore area.

A very pertinent question was raised earlier about whether these white areas on the fault maps represent places where there just hasn't been work done to identify faults, or whether there is a real absence of faulting.

In this area here in the offshore Santa Maria Basin, the situation is there, there is an absence of recent geologic activity. We see that in terms of an absence of micro earthquake activity.

DR. SIESS: Excuse me. When a geologist says recent, I have to ask for a transaction.

MR. SAVAGE: Okay, that is in the context of seismic sources that are concerned to us from say a strictly speaking --

DR. SIESS: Is recently 1986?

MR. SAVAGE: Pardon me?

DR. SIESS: Does recent mean 1980 to 1986

MR. SAVAGE: Well, for a seismologist, that's very recent, but I was referring to the relationship between seismicity in a historic or very recent human lifetime sense as well as geologically recent meaning late Quaternary deformation.

DR. SIESS: Years?

MR. SAVAGE: And that would be in the 500,000 to 10,000 year time frame.

DR. SIESS: I need to get calibrated --

MR. SAVAGE: Okay, I appreciate that.

MR. EBERSOLE: To what do you attribute all the blank space out there to the left?

MR. SAVAGE: We will see a geophysical cross-section here using the Digicon lines. We will look at a cross-section going through this area here. And we will see that in the offshore Santa Maria Basin, there is an undeformed, and this again in the recent geologic sense the last million years or two million years, an undeformed basin. That basin is bounded on one side by the San Lucia Bank and on the other side by the Hosgri fault zone, and uplifted basement to the east.

So this is a real quiet area both seismically speaking in terms of the last -- here seen the last six years and as far back as we have seismic instrumentation to the early 1900s, as well as geologically. This is a very quiet area.

(Slide.)

Just to address the other quiet areas seen on the fault map, that was in this region here. This is both geologically in a million year time frame as well as in terms of seismicity, a quiet area. There is very little deformation going on internal to this region. This is a block of granite that has been moved along the San Andreas fault. And while there is a lot of deformation occurring on its eastern margin and a bit of deformation occurring on its western margin, the interior of the block is very quiet.

Yes, sir.

MR. DAVIS: It looked like you had a five southeast of the site, right on the coast

MR. SAVAGE: Yes. Yes, that's a magnitude 5.1 earthquake, and we will see in a few minutes a very detailed look at this area.

MR. DAVIS: What as the ground acceleration associated with that event? Do you have any feel for that?

MR. SAVAGE: Let's see, that event was -- it occurred in 1980, and it was recorded at the Diablo Canyon Plant site with a few thousandths G. The peak acceleration was a few thousandths G.

MR. DAVIS: So you don't know what it was right at the 5 --

MR. SAVAGE: No, there were no ground motion measuring instruments there. This is just slightly offshore.

DR. SIESS: Do you remember where the site was for the Sun Desert plant

MR. SAVAGE: No.

DR. SIESS: It was over in there.

MR. SAVAGE: Yes, out in here.

Okay. Well, we were talking about this figure, not only to set the background of seismicity data that are used in the project, but also with respect to PG&E Central Coast Seismic Network. And that seismic network covers the coastal region from up here near and north of San Simeon, where there is a dense concentration of activity. This is the area where, as Lloyd mentioned, there is the strike slip San Simeon fault appears, and yet there is obvious evidence of uplift on closely related fault systems.

This is a complicated structure geologically, and what we see is a lot of complexity in terms of small earthquake activity as well.

The seismic network covers down the coastline, past the plant site to the area of Point Sal, and the instrumentation extends a bit inland as well, and we can see that in this figure here.

(Slide.)

When we planned the installation and long-term operation of the Central Coast Network, it was with the realization that this seismic network was operating within an area that the U.S. Geological Survey already had a seismic network, although a rather sparsely distributed network.

And so these two, the Central Coast Network highlighted in green, as well as the USGS stations, seismic graphic stations operating is shown by the uncolored symbols.

So you can see that along the coastline here from the San Simeon area down to Point Sal we have provided fairly dense coverage, station spacing of 10 to 15 kilometers.

Just as a point of interest, the area up here along the San Andreas fault is Parkfield where the U.S. Geological Survey has a major research project going to augment their capabilities to predict earthquakes. There is an active earthquake prediction for a magnitude 6 earthquake there now. And it's entirely possible, in fact, that the amount of instrumentation installed in Parkfield has permanently turned off the possibility of that magnitude 6 earthquake occurring.

(Laughter.)

People at the survey don't talk about it that way though.

In outline, the seismic network is a very modern and fairly automated design. The data in the field are collected using continuously operating systems which both high-gain and low-gain, which the data are transmitted continuously via low-power radio telemetry to a couple of locations at PG&E's

microwave system. And there the data are multiplexed together, entered on the microwave system and transmitted up to our offices in San Francisco.

There the data are digitized and processed by an on-line computer system to identify the occurrence of earthquakes, and distinguish the occurrence of earthquakes from noise events. We are not able to distinguish earthquakes for airgun shots, it turns out.

And then those data are analyzed using a seismic work station. So we can call up the data on the screen, do our location and magnitude determination analyses in --

MR. EBERSOLE: Tell me something. We are picking up dynamic events. Isn't there some correlation of these events with some static measurements of displacements, extremely accurate ones that are being made now? And do you interrelate the two

MR. SAVAGE: Yes, that is another good point.

In recent years, well, say in the last several decades, the U.S. Geological Survey in particular has performed a lot of triangulation studies, geodetic measurements which are the static deformation -- of the static deformation sort.

Within the last few years, the accuracy of satellite location systems has become so great that it's now possible to in essentially a real time sense measure plate motions using what's called very long base line interfermotery.

And in fact these data sets have been influential in how -- in both the very regional tectonic understanding of crustal deformation within California, but also in particular with respect to understanding the nature of movement along the Hosgri fault sound.

In fact, part of the literature review that Lloyd referred to earlier has to do with our keeping track of what people are finding with these VLBI data sets, and geodetic analyses. And those -- many of those VLBI analyses are keyed to Vandenberg down here, and using the satellite geodesy it's possible to essentially watch this piece of earth on with Vandenberg located, move to the northwest with respect to the continental period.

MR. EBERSOLE: Do you anticipate that being related when something is going to be released?

MR. SAVAGE: In terms of a possible earthquake.

Well, that's definitely a speculative research area that the USGS is addressing now. To my knowledge, there is no definitive ability to make those sorts of measurements in a predictive fashion. It's really a case of doing the research to understand the phenomena.

DR. SIESS: What's the rate of movement between the plates?

MR. SAVAGE: The current estimate for the rate of movement along the San Andreas fault here -- sorry. For the rate of movement across the San Andreas fault from the interior of the continent to somewhere way offshore here is about 5 centimeter per year.

So that's the Pacific plate moving northwest past the continental plate.

Lloyd, in his presentation, will talk in more detail about rates of deformation, slip rates on faults that have been developed to more accurately define the distribution of that deformation, certainly to the west of the San Andreas. And that's where our keeping track of those VLBI and other geodetic results are certainly important to understand tectonic relationships.

DR. KERR: Five centimeters is a relative motion.

MR. SAVAGE: Yes, it's relative between the interior of the continent and way offshore.

Along the San Andreas fault, the rate is about 37 millimeters a year, 3.77 centimeters per year. So there is some other motion taken up both to the east of the San Andreas and to the west.

(Slide.)

Well, the Central Coast Seismic Network has operated for more than a year now, and here is a figure showing in a comparative sense what we see using this network compared to what we have been seeing using data coming from the Geological Survey.

I think one very important feature here is that this is a general pattern of seismicity that we see, and this is activity recorded from September 1987 to I guess the last event shown on this map is -- it's a week old.

The pattern of seismicity here is very similar. We see no activity occurring in the near offshore area until we get down to the latitude of Point Sal, and then the activity is distributed off to the southwest just as we see in this figure here.

We see a scattered pattern of very small earthquakes occurring in the onshore area. The most concentrated area of activity is up in the region north of San Simeon. So many of the same features that we see here, using what, seven years of data, we see in a nine-month period using a much more sensitive, more high resolution seismic network.

DR. SIESS: How did you pick that time element?

MR. SAVAGE: Well, the network actually began operation, we first began reporting data in July of '76. And one can take the view that these things are somehow controlled. But from about that time until September of '87, the level of micro earthquake activity within, particularly within this region here essentially was absent.

So we had -- in fact, I was beginning to think that we had another Parkfield problem where --

MR. ROOD: Excuse me. Did you mean July of '86?

MR. SAVAGE: Yes.

MR. ROOD: As opposed to '86?

MR. SAVAGE: Yes, '86.

Another Parkfield situation where we had -- as soon as we put the instrumentation in, the earthquake activity stopped. It turns out, unfortunately, I guess that didn't actually happen.

MR. DAVIS: Where is the plant on this?

MR. SAVAGE: I'm sorry. It's right here, just about at the center of the network.

Well, just as a quick example of what an earthquake looks like on this network, here is an earthquake that occurred, in fact, this is the most recent event shown on the figure. This is an earthquake that occurred near Piedras Blancas in the San Simeon area right up in here. And it is an earthquake of magnitude 0.7.

This is not as small an event as we can routinely detect with a network. We are still learning how small the earthquake activity can be that we will be able to see with the network. But it's about a half magnitude unit or more below the threshold of detectability that the U.S. Geological Survey has in the same region.

MR. SEAVUZZO: What are the axes on that?

MR. SAVAGE: So what we are seeing here, and we are seeing in the other figure is a time trace of that earthquake.

The figure I showed before -- I'm sorry, I was getting a little fast here. We will just put that on as well.

(Slide.)

This is an image taken off of the computer system of what the earthquake looked like on multiple stations. And we are seeing out here, that's the closest station at the top and we are moving out in distance away from the hypocenter of the earthquake. And this fourth station here, the event is entering the noise. We are starting to lose the detection of the event, and this is about 20 kilometers away from the epicenter of the earth.

DR. SIESS: What's plotted there?

MR. SAVAGE: What's plotted is time going horizontally, and just an arbitrary time of initiation here. And this is moving. In time, this is the arrival time of the signal.

DR. SIESS: What's the vertical coordinate?

MR. SAVAGE: The vertical scale is in digital counts. It is not converted to ground motion. These are velocity sensors.

DR. SIESS: Oh, these are velocities.

MR. SAVAGE: Yes, these are velocities.

VOICE: What is the magnitude that we are looking at? Inches per second or something.

MR. SAVAGE: Oh, I don't know. It's very small.

These are --

MR. ROTHMAN: It's probably on the order of milimicrons or something like that.

MR. SAVAGE: Yes.

MR. ROTHMAN: It's ground motion.

MR. SAVAGE: It's extremely small.

MR. DAVIS: How can you be sure this was a seismic event versus some man-caused motion?

MR. SAVAGE: Well, there are two quick bases for identify that.

One is that when we locate this earthquake, we have a pretty good velocity model now and can triangulate the location. When the location comes out to being -- in this case, it was a depth of about 5 kilometers. So that's probably the single most useful diagnostic feature.

Also, as seen in this reporting down here, we have a vertical component. It's this station right here. We have a vertical component record which shows the key wave very clearly. We also have horizontal components which show a very strong S wave, which is another diagnostic feature of earthquakes as opposed to explosions.

MR. DAVIS: Thank you.

MR. SAVAGE: That's a summary of the seismic network operations.

And I would like to move on now to a discussion of the data analysis elements of the long-term seismic program.

(Slide.)

As Lloyd indicated earlier, we are doing many things simultaneously. The organization of our presentation here was to give you an overview of the data acquisition activities that are occurring, and then to describe the ways in which we are analyzing those data.

That will be followed by a discussion of some of the interpretations that we are drawing from these analyzed data.

As I mentioned kind of briefly before, when we collect offshore geophysical data in terms of say these high resolution geophysical surveys, or the more deeper penetration reflection profiling studies, what we get is something that only a computer can deal with in terms of data analysis. I'm sorry, in terms of data processing.

That processing is done using parameters and using decisions in parameter selection that are guided by what we would like to be able to image. And, thus, the image that comes out, the features that are seeing on these records that we then interpret using all of the geophysical and geological skill and information we have, those images are in a sense controlled by what we tell the computer to produce.

So we have to be very careful to not only make good decisions about how the processing is done, but keep in mind that what we are looking at when we see say a record section profile isn't necessarily an exact representation of the truth.

What we have to do is interpret that record using multiple data sets, using correlations with geological information derived say from wells, using regional geological structure information to arrive at a best interpretation of those particular data.

Well, when we start off with an analysis of a geophysical data set, what we have been doing in the project is developing a series of representations of interpretation of those data. Those include trend maps which is a surface map representation of the orientation of faults. That is a particular interpretive feature we are after.

What we have seen with the Hosgri is just in this older map that Lloyd showed.

(Slide.)

This is a picking and a correlating of images seen on multiple lines that seem to fit together in a pattern as represented here.

Well, to help understand and interpret the reality of that pattern, we also construct contour and isopack maps. These are derived by taking a lithologic or a stratigraphic interpretation from these vertical reflection profiles, use well data to help us identify which particular lithologic unit or stratigraphic unit we are looking at, and then correlate those from line to line to form both contour maps of the surface of that particular stratigraphic unit, or a map that shows the thickness of that unit.

And the analysis of these maps then will help tell us about the history of tectonic activity as represented by the geophysical data, as well as then looking specifically at fault behavior to evaluate the history of movement along particular faults.

Structural sections are these vertical profiles that come from the geophysical data acquisition with the stratigraphic structure inserted, and then depth corrected.

So in order to develop these structural sections, we have to have a very clear idea about the function of -- sorry -- the relationship of seismic velocity within rocks versus depth.

Then we can also interpret these multiple data sets, geophysical data sets to identify fault surfaces to try and map in three dimensions the orientation and lateral extent of fault surfaces. This is an activity that we are just in the process of doing now, and certainly with respect to understanding the behavior of the Hosgri fault is a very important activity.

And, finally, we can use the very high resolution shallow data, both ocean depth soundings corroborated by the very shallow high frequently geophysical data to develop maps of ocean floor topography.

MR. EBERSOLE: May I ask a question.

MR. SAVAGE: Sure.

MR. EBERSOLE: It may be buried in your terminology and I can't hear it.

But you seem to be talking about influence propagation at 90 degrees to the fault itself. Is that the predominant worry, or what about prolongation of the fault in the linear direction?

I see lots of faults, so to speak, aimed at Diablo but they never -- you never talk about the ever getting there. I guess I am crack conscious.

MR. SAVAGE: Well, I think we all are.

(Laughter.)

We will see some -- a high resolution image of these particular features. It turns out, just to respond to your comment here, that while there are geophysically identified features in the subsurface offshore that have this trend, the trend that's parallel to the imaging of the Los Osos fault. Our onshore geologic work that Lloyd described has precluded the recent geologic activity of those features.

So it really brings up I think an important point here. With the geophysical data, we look back in time hundreds of thousands to tens of millions of years. And yet what we are interested in is not what happened 10 or 20 million years ago. We are interested in what may be capable of happening during the lifetime of a critical facility like Diablo Canyon.

So to just see an image of a fault offshore and corroborate that, yes, that is a true fault image doesn't meant that it is of seismogenic significance.

And with respect to these particular features here, they do not extend onshore, or they don't disrupt the marine terrace surface that Lloyd described, and in fact haven't disrupted that surface for approximately the last 750,000 years.

MR. EBERSOLE: There has been some sort of crack breaker occurrence.

MR. SAVAGE: At some point during the history of this coastal region, that's true. And an important thing for us is that isn't occurring now in terms of -- in terms of these structures being --

MR. EBERSOLE: Is that a different kind of rock that the cracking counters

MR. SAVAGE: You mean in terms of --

MR. EBERSOLE: Stops along that curious line.

MR. SAVAGE: I don't know. That's a question that we are certainly trying to better understand right now.

MR. ROTHMAN: Excuse me.

MR. SAVAGE: Yes.

MR. ROTHMAN: What you are imaging there is not the sea floor surface, but some depth like the top of the maya seam or something like that.

MR. SAVAGE: In this figure

MR. ROTHMAN: In that figure, yes.

MR. SAVAGE: That is correct.

MR. ROTHMAN: So those are not faults that are at the sea floor surface.

MR. SAVAGE: Yes.

MR. ROTHMAN: I think that's important.

MR. SAVAGE: Yes. We will see in just a little bit this region imaged at very shallow depths using the high resolution data. So we are looking down maybe a half kilometer or so.

MR. EBERSOLE: What sort of depth am I looking at there, in general?

MR. SAVAGE: Well, it ranges from near ground surface -- sorry -- near ocean floor surface, in this area here say, within a few hundred meters to depths of maybe a half kilometer or so down in the southern region here where we are looking through a rather thick sedimentary cover.

MR. EBERSOLE: Okay.

MR. SAVAGE: Let me just briefly show a couple of example of the analyses that have been done on several of our geophysical data sets.

(Slide.)

The first example, it's a bit hard to see this just seen in a brief viewgraph presentation so I brought the physical record section here for anyone to look at who is interested, and I'll perhaps just tape it up on this board during lunch.

(Continued on next page.)

DR. SAVAGE: What we have done to adopt as a mode of preparation and presentation of these profiles is to provide on a single sheet of paper all of the acquisition and processing information. And this will be for a line that extends with its eastern end just crossing the Hosgri in San Luis Obisbo Bay and then extending well off to the Southwest.

We also present on that same figure an uninterpreted section. This is just one end of that line. The line starts here and goes off to the Southwest. And this is an uninterpreted section. And two-way travel time is shown in the vertical scale here going down to five seconds. So we would in theory be able to see structures down around eight to ten kilometers deep.

Well, in parallel with that figure, we present an interpreted section. This is the eastern end of the line. Here are relatively shallow picks going down to the two and a half seconds which corresponds to about three kilometers depth for the Hosgri fault itself. We see the Hosgri in many, many areas as an expression of the old basin boundary.

Here is elevated bedrock on the east. And this is the offshore Santa Maria Basin extending well to the west. And the basis for assessing the lack of deformation within that basin is the thick stack of undisturbed quaternary and later tertiary sediments with that basin. So this has been a passive basin for literally millions of years.

Well, the final representation of this interpreted section is shown here. This is a depth corrected section. So we have converted from two-way travel time to kilometers in depth. And again it is important to realize that there is a lot of interpretation associated with that. This is not something, this conversion to an apparent geologic cross-section is not done casually or quickly.

We have used well data such as the wells shown here and a well shown here to enable us to identify which geologic units these are. And we know their ages, and we know their extent. So we can correlate the seismic stratigraphy, the geophysically identified stratigraphy, with the real ithologic stratigraphy in the offshore area, and come up with this kind of geologic structural representation. So again, this is a typical product of the data analysis that would be one of the structural sections here.

I would like to go back at this point to the offshore Digicon survey and show where we are at this point with respect to the analysis of those data. Again this data analysis process is certain an active one within some of the elements of the long-term seismic program.

With respect to this deep crustal data set, it is also a very active program in the academic community. It is too bad that George Thompson is not here today, because he has been certainly one of the active participants along with students at Stanford University, Rice University, and the Houston Area Research Council, UC Santa Cruz, and people at the U.S. Geological Survey in analyzing data that all of those organizations acquired at the same time that PG&E was conducting the deep data acquisition effort.

A little bit ago, we saw the base map here, the Diablo Canyon plant site. This area, Point Arguello and the San Simeon region up here. We saw in this figure the location of the PG&E lines which we collected specifically for utilization in this project.

Well, the convenience of having the Digicon mobilization all done allowed HARC and Rice Universities to collect some additional lines. And.those lines are shown by the dotted green symbols here.

The survey also collected a line of refraction data onshore using the explosions that we set off. And both the USGS and PG&E had seismic stations, earthquake recording stations, operating during this time period. And so the data acquisition effort combining what PG&E did with all of these other groups is really quite monumental. And it was the reason for the Edge symposium as it was called, the program for reviewing current results from the analysis of these data sets by all of the various participants at the American Geophysical Union last December.

There is a figure here in your packet that simply enumerates the various activities, the data acquisition activities, carried out by the various participants. And I think that at this point that we will go to slides to show some of the results.

(Slides shown.)

DR. SAVAGE: This slides shows a migrated section that ran along what we are calling PG&E 3 or FLEC-3. You will see that terminology used on these figures.

DR. SIESS: What does migrated mean?

DR. SAVAGE: Migrated is a data processing term. And it has to do with an attempt by the computer to take events seen within the data. An event would be a packet of energy. And to geometrically move that packet of energy to where the computer thinks that it came from in a reflection sense. So it is a step in processing these sorts of data to extract an image of a meaningful geological structure at depth.

This representation here is not something that is easily interpreted, particularly seen in this scale and from across the road. But it does represent some of the major features of this data set.

We crossed the Hosgri fault zone which is seen in here. And we crossed this flat lying, certainly in the last few million years, undeformed offshore Santa Maria Basin. We crossed an old fold called the Queenie structure which is an unusual feature this far north within the Santa Maria Basin.

Further south, there are more such folds that are active at the present time.

We see within this section old basement structures. Here is an east dipping structural block. It is down dipped to the east. Out here we see the east margin of the Santa Lucia Bank, which is not an exposed basement but an uplifted basement block. And then further to the west, we enter the region that is presumed to be an ancient accretionary wedge associated with subduction within the trench, the ancient trench seen offshore. On this figure, you just see a little corner of the sediment filled trench that has been sitting out at the slope, at the bottom of this slope for thirty million years or so.

MR. EBERSOLE: How deep is that vertically?

DR. SAVAGE: This is --

MR. EBERSOLE: No, the whole picture.

DR. SAVAGE: Oh, the whole picture?

MR. EBERSOLE: Yes.

DR. SAVAGE: We are seeing down 16 seconds. Which if you can do the velocity conversion is about 30 kilometers.

MR. EBERSOLE: IF there were oil there, would you have seen it?

DR. SAVAGE: Well, I would not have. I am not a petroleum explorer. But the oil exploration interests is up in there set of entry deposits here. So this sort of data is not collected for petroleum purposes.

MR. EBERSOLE: But it might produce it nevertheless.

DR. SAVAGE: Well, I am sure that there will be some interest in these very far offshore structures from the petroleum industry.

MR. CLUFF: Well, you might want to reference where earthquakes are occurring in depth.

DR. SAVAGE: Let me just go on to the next one. These are a few further steps in both the processing and interpretation of that particular image that we saw previously. These figures are still represented in terms of not and not distance. We will get to a distance section in a few minutes.

But there are some important features to look at here. This is called a stick diagram. And what is done is depict images that may have some geological significance. We see a lot of topography expressed in the upper section going down two to three kilometers. We see some images that appear to be dipping to the east. We see some flat lying images. And we see some images that appear to be dipping to the west. What these features are, we at least have not gone far enough in our analysis to really understand in detail.

Further to the west, we see another packet of slightly east dipping sub-horizontal images. We see a much more complicated shallow structural environment. And then in the far offshore off the Santa Lucia escarpment, we see another sedimentary basin.

And this is an interpretation of this figure actually using the migrated version of this section combined with the identification of some deeper structure to focus in particular on the distribution and character of the sedimentary structures overlying the basement structures.

And Lloyd, the next slide, please. This shows now a depth section going from sea level at the top down to a depth of 24 kilometers. So this has been converting using in fact some assumed velocity functions. We do not have good velocity data at this point going down as deep as 24 kilometers.

And what we see here is that now the Santa Lucia escarpment assumes its real shape. It is not a 45 degree angle cliff in the offshore. It is actually a rather substantial slope for an oceanic environment, but it is certainly more gentle than one sees in the unconverted time section. And we see this complicated sort of structure in here and complicated structure out here.

The question, Lloyd, that you mentioned about earthquake depths. Within both the offshore and the onshore area, we see earthquake activity basically no deeper than 12 to 14 kilometers. And most of that activity is concentrated say in the 4 to 10 kilometer range. So we are looking below the seismogenic portion of the crust.

The figure at the top here shows a presentation of gravity and magnetic field data as far offshore as those data have been acquired. The basic features are that we see in the gravity curve, which is the bottom one here, we see these basement highs represented in the gravity. The regional gravity trend is consistent with a thickening continental crust in the east. So this would tell us that we would probably have some dipping, some structure dipping, to the east on which the crust is thickening.

And the magnetic field data is not really clear. We do not know at this point what geological structure that the magnetic field data may be associated with. It is pretty long wave-length and fairly deep, certainly down in the basement.

The advantage that we have with the kind of survey that we did with Digicon is that we not only have the offshore reflection profiles, but we shot with air guns offshore and reported those data onshore. So this gives us a vehicle for crossing the coast line in a fairly detailed fashion.

What is shown here, and you cannot quite see the bottom legend here, but these are individual air gun shots lined up in a reflecting profiling sense extending from 150 kilometers offset which is out at the Santa Lucia escarpment, the edge of the continental plate, and into near the coastline. The station itself is further inland, about 35 kilometers inland.

So this is the sort of data that we collected with our refraction program. And on the viewgraphs now, I will show the interpretation of those.

So here is that same long distance profile. We looked at the recordings from the air guns seen at this station. It happened to be called No. 1166. And this is a rate tracing model that was used to interpret those refraction data.

The procedure here is an iterative one. You make a preliminary interpretation, test your rate tracing model, revise velocities, revise geometries, and work to get both a geologically consistent model as well as a model that fits the travel time data for this particular data set recorded at that station.

We certainly took advantage of the far offshore reflection images. We not only looked at our records, but we also looked at the records that Rice University and HARC had collected.

And I should say that this particular rate tracing model fit very well provided that we accurately took out the near surface geologic structure, again another use of the combined interpretation of reflection and refraction geophysical data.

And that let to what our current working model is here, which again is consistent with what other scientists at the Edge symposium presented.

We have an oceanic plate underlying the coastline that dips gently to the east in this region. And those reflections that we looked at appeared to be associated with the top of that oceanic plate.

To the east, the plate appears to flatten or dip much less steeply than it does up here. The actual data that we have go back about to this region here. So we are not sure that the oceanic plate extends this far east.

DR. SIESS: Where is the subduction zone now, or is there one?

DR. SAVAGE: There was a subduction zone. There was an active subduction zone.

DR. SIESS: But none now?

DR. SAVAGE: But it has ceased. And this for all intents and purposes essentially a static situation.

DR. SIESS: So subduction on this part of the coast?

DR. SAVAGE: Not for thirty million years.

MR. EBERSOLE: What is below the plate?

DR. SAVAGE: This would be upper mantle material. I am not sure just where one enters the transition from what would be called continental estenosphere to oceanic estenosphere. But it is certainly upper mantle material below this.

So we see here the thickening of the continental crust to the east. The seismogenic zone goes down to about in here. The granitic basement rocks velocities as shown lie to the east of the Nacimiento fault in this area. And we have pretty solid evidence for the presence of a Franciscan basement, certainly by its geologic exposure on land, but also to a substantial distance offshore based on both limited drilling data in this area as well as the excellent fit of the rate tracing model to this particular velocity structure.

MR. EBERSOLE: What is the units of the large numbers?

DR. SAVAGE: These are in kilometers per second.

MR. EBERSOLE: Velocities.

DR. SAVAGE: They are velocities, yes. Velocities of wave propagation within these various geological materials.

MR. EBERSOLE: Is that what characterized the material?

DR. SAVAGE: That is essentially the large scale seismological characterization, right. So this is the geological characterization put on top of that.

MR. SEAVUZZO: And these are the P wave velocities?

DR. SAVAGE: These are P wave velocities, that is correct.

So we see in fact below the oceanic plate velocities typical of upper mantle material in other parts of the world. So I think that one of the important results of this sort of analysis right now is that we see that we are not dealing with a very complicated multiple element basement structure. This

Franciscan basement is the material that exists beneath much of coastal California.

There do not appear to be, at least in this region here, any anomalous basement blocks or any major changes in velocity structure that would be of influence in our interpretations of earthquake causes in this region here.

From the standpoint of some of the other groups that collected data during this November 1986 project, there is a lot of interest in understanding the tectonic relationships out here, in unraveling the history of tectonism and the plate tectonics aspects of this region.

MR. EBERSOLE: Do you have any feel for the variation vertically in that picture?

DR. SAVAGE: Well, there are some general kind of rules of thumb for the temperature variation. In the onshore area, there have been temperature gradient measurements. And the onshore area appears to be sort of normal continental temperatures, not elevated temperatures. And I just do not know about the offshore area. One would expect not to have any unusual temperature regimen there.

DR. SIESS: There are two different basement materials on either side of the Nacimiento fault?

DR. SAVAGE: That is correct. This is a very simple block model.

DR. SIESS: How did that come about?

DR. SAVAGE: It came about by the long-term behavior of the San Andreas fault system.

DR. SIESS: The strike slip?

DR. SAVAGE: Yes.

DR. SIESS: Just moved up from the south?

DR. SAVAGE: That is correct. These are basement pieces that have been slid along the San Andreas off this figure. Actually, San Andreas would be right in here, just east of point six.

MR. ROTHMAN: About a year or so ago, some people at the USGS were postulating a low velocity wedge on the coastal side.

What has happened to that?

DR. SAVAGE: Let me point out where that is. Just a second.

(Pause.)

DR. SAVAGE: That was an analysis and interpretation done by Ann Trahue and her colleagues at the USGS. And that was based on their interpretation of some earlier work along this line here. And I guess that what we are looking at in this figure is an interpretation along this line here. If we were to, for the purposes of comparison, just move to the north, what we see, and again according to Trahue's model, is that this granitic basement in part is underlain by a low velocity zone.

Her data did not go out very much further than this. So we were left at that time with an apparent wedge. I am sorry, I am drawing that too high up. It was down in here. A low velocity wedge in this region that had no known westward extent. That was certainly one of the issues that we were interested in looking at with these lines.

And what we found is that Trahue's low velocity interpretation may well be correct, but that low velocity zone on this line is very localized. It does not extend to the coast, and in fact may not be properly interpreted as a package of low velocity sediments.

That same feature that could be interpreted as a low velocity zone does not exist on the southern line. So what we discussed in fact at the Edge meeting was that this appears to be, that her interpretation appears to be some local phenomenon that does not have regional extend.

DR. SIESS: Would you help me. If that section is on that lower line, would you identify the Nacimiento on that?

DR. SAVAGE: Yes, sir. It is this fault.

DR. SIESS: That piece there. It is only labeled up north.

DR. SAVAGE: The faults do get very complex in here. So this is the granitic basement and the Fransican extends out here. Okay. Just kind of noting what time it is here.

DR. SIESS: We are planning on breaking for lunch about 12:30 wherever you are.

DR. SAVAGE: Okay. A third geophysical data analysis that I would like to present to you has to do with the use of the bathymetry data, the ocean floor topography data. And what we have prepared is seen in part in this figure here. And this is a topographic map of the ocean floor. Here is Point Buchon. The Diablo Canyon plant site is right in here.

The area that Lloyd described in terms of marine terrace studies is this onshore region here in part extending. The onshore work extended well to the south and well to the north. So this is a rather large scale map where one kilometer is a pretty sizable portion of the figure.

And what we are looking at is, our purpose was to acquire and process the available bathymetric data which is provided in great part by NOAAH, but we augmented that data set with ship track bathymetry data, depth soundings.

And so our current ocean floor topographic map as shown here is a contour interval of two meters. So that gives a sense of the resolution of this particular map.

Well, just as one can use a topographic map onshore to assess the geologic history of the region and look at the possible fairly recent behavior of faults based on the presence of scarps or other geomorphic features associated with faulting, we can do the same thing using this map looking at the sea floor.

I should point out that on this map that there are a number of areas of rather sharp topography that are of just a couple of meters height to as much as several tens of meters. And those are emphasized by a bit of shading here. So you can see that there is a scattered pattern of what we are calling sea floor scarps.

The origin of those scarps and their potential significance or relationship to faulting are what we are interested in evaluating.

Well again, just as was the case with the onshore marine terrace studies, it is very important to know where the shoreline was and what its lateral extent has been.

Lloyd talked about ancient shorelines onshore. What we see here are old shorelines extending offshore, the oldest of which was a longstanding sea floor feature that existed about 20,000 years ago, and developed a very well-established seashore.

There are younger coastlines shown in the highlight as indicated here. And it is important to recall that some of these scarps them that we see may well be associated with these shorelines. In fact, there is a coincidence between some of the scarp-like features and shorelines. You can just see the spatial relationships here.

Well, the next comparison to make is with the location of faults as mapped geophysically. And again this is using the high resolution geophysical data. We are not looking very deep. We want to see the correspondence between fault strands and the presence of these scarp-like features, these topographic features on the sea floor.

And what we see again is some apparent correspondences. Let me make sure that it is clear which lines are faults are here. So they are these orangy lines here that are high resolution trend map fault traces. And we do see a few correspondences. This curved feature here, up here. This locality here and down in here. There are some correspondences between the sea floor scarps and the locations of faults.

MR. EBERSOLE: Are you saying in essence that sudden events caused a shoreline change?

DR. SAVAGE: No. I am saying that we see expressed today as a sea floor scarp could either have been produced by an earlier coastline, as an earlier coastline, or it could have been created by a recent fault.

MR. EBERSOLE: That is what I meant.

DR. SAVAGE: Or it could have been created by erosion along an older preexisting fault.

MR. EBERSOLE: Well, for the slow moving shoreline, how much is that due to earth movement versus the movement of the sea itself, do you attempt to differentiate?

DR. SAVAGE: I am sorry, I am not sure that I understand your question.

MR. EBERSOLE: Well, the shoreline can change by the water coming up or down, or the earth coming up or down, or both.

DR. SAVAGE: Correct.

MR. EBERSOLE: Do you differentiate?

DR. SAVAGE: Not in terms of this figure. The sea stands indicated here, the still stands, are derived from sea level taken from other areas and brought into this area to identify at what bathymetric level that we should be seeing that still stand. So that is where the coast would have been eroding.

This is again another data analysis product that can be used to help understand in this case a variety of different erosional processes as well as the possibility of there being active faulting occurring in the offshore area here. Just as we look onshore for the presence of scarps as one of a number of diagnostic techniques to identify the location of faulting and help evaluate its activity, so we use the correspondences between the sea floor scarps and the presence of shallow faulting as one of the tools to help us assess the presence and level of activity of faulting.

We will come back to this figure later on in the discussion, and talk about some of the implications of these sea floor scarps. Well, let me see here, in our data analysis discussion. I think that I am about to be covered with viewgraphs here.

The next section of the data analysis discussion, let's see, will probably take fifteen minutes or so.

DR. SIESS: I think that this is a good time to stop then.

DR. SAVAGE: Okay.

DR. SIESS: And come back in an hour. We will recess for lunch.

(Whereupon, at 12:30 p.m., the subcommittee recessed, to reconvene at 1:30 p.m., this same day.

AFTERNOON SESSION

(1:00 p.m.)

DR. SIESS: We are ready to continue. I do not know if anybody looked at your artwork up there during the break.

DR. SAVAGE: Well, it is there for anyone who is interested.

Well, just to get back into the flow here. We have been covering a variety of data analysis topics, and so far have been concentrating on some examples from the geophysical data analysis. I will not describe in any detail these items of analyzing the data collected during the geologic studies. Lloyd will be covering a lot of these analyses as applied to the area of the San Luis Obisbo.

So he will be talking about how we have used the stratigraphic information. And the correlation of certainly marine terraces constitutes one of those correlations. Studies of geological materials to establish timing and rate of fault and fold development, and in looking at recency of faulting. And along with timing, the deformation rate of both the behavior of faults as well as fold structures.

So I would like to do a brief review of a couple of seismicity data analyses that we have performed, and then move on into the first of two of our data integration topics. And that will finish my presentation, and then we will go back to Lloyd.

We talked at our last get-together in November of 1986 about some work that we had completed on the 1927 Lompoc earthquake. This event was an offshore event that occurred in November of 1927, and is certainly influential in a lot of the decisions and judgments made during the course of the Diablo Canyon project.

What we did at that time as of November was to look at long period seismograms at a particularly high quality long-term station that is operated in the Netherlands. Since then we have also looked at the regional seismogram data recorded in California and Arizona.

We compared recordings of not only the 1927 Lompoc earthquake, but other more recent and more well understood earthquakes using a seismograph modeling basis for the comparison. And the figure that you saw last time that represents this technique of developing a dynamic model for the rupture associated with the earthquake for the fault plane movement generating synthetic seismograms as those seismograms would be recorded at either a nearby or distant point, and then comparing the synthetic seismograms with the observed data to either modify the model, the source model that is being considered, or to finalize that model.

And based on both the long period data which you saw before, long period analysis, as well as a confirmation using regional data, this is the source picture that we come up with for the 1927 earthquake.

It had a focal depth of about 10 kilometers. So it was not an unusually deep nor unusually shallow earthquake. It was a reasonable, a reasonable crustal earthquake. The focal mechanism is essentially pure dip slip. There may be an unresolvable small strike slip component in the mechanism. But it is basically pure dip slip. One plane dips fairly steeply to the northeast, and the other plane dips at a shallow angle to the southwest.

The seismic moment is 1 times 10 to the 26th, nine centimeters, which can be converted to a moment magnitude of 6.6. We went back to examine Gutenberg's notepad data at Cal Tech to take another look at what had been reported. Subsequently to the development of a magnitude scale in the 1930s, what had been noted by Gutenberg and his coworkers as they reviewed historical earthquakes.

And what we found there was that he had noted the surface wave magnitude of the 1927 earthquake at 7.0. We compared the long period recordings, some of which you saw in the previous figure, with the Coalinga earthquake in particular to assess the accuracy of this number using a modern recorded earthquake and came up with the same value of 7.0 as the appropriate surface wave magnitude.

MR. EBERSOLE: Can I bring up a translational problem. Those last four parameters are a case in point where you are talking as far as I am concerned to a closed society. I would like you to put those into other geometric terms.

DR. SAVAGE: Okay. The seismic moment is a relatively modern parameter that is used to characterize the large scale dimensions of an earthquake. Just as moment is a moment arm times the surface, that is the same kind of static quantity that is represented by this measurement here. It is the amount of fault displacement times the fault area with some elastic constants in there.

DR. SIESS: If I were a nuclear power plant, what would it mean to me?

DR. SAVAGE: That is where these numbers come in. The magnitude values are values that are used in the ground motion analysis.

DR. SIESS: Well, you told me that you were looking for something like foot pounds or whatever. The seismic moment, I think.

DR. SAVAGE: I think that the important parameter here to pay attention to I guess at this point is the surface wave magnitude. This is one of the key magnitude values that is used in developing comparisons with recent recordings of strong motion data, and it is the measure that we use to establish ground motion estimates.

MR. EBERSOLE: Is it non-dimensional?

DR. SAVAGE: The magnitude?

MR. EBERSOLE: Yes.

DR. SAVAGE: Yes, it is non-dimensional. It is simply a number. It is a ratio actually.

MR. SEAVUZZO: How high would that number go for a large earthquake?

DR. SIESS: It is open-ended.

MR. SEAVUZZO: I realize open-ended, but what would be typically?

DR. SAVAGE: Well, the surface wave magnitude scale is generally considered to saturate. In other words, no matter how great the rupture extent for an earthquake might be, the surface wave magnitude appears to become limited at about a magnitude of 8.5. But that surface wave magnitude is a measurement made at 20 seconds period.

Now the moment magnitude is not so limited in its dynamic measurement in the sense that this is intended to be a very, very long period measurement. In this particular case, we are using data that are of periods in the ten to twenty second range. So it is a fairly long period value.

For instance, the basic definition of moment being the static displacement on a fault rupture times that area of the fault, this is an unbounded magnitude measure, moment magnitude.

MR. EBERSOLE: Does seismic moment have something like an energy release concept?

DR. SAVAGE: Only generally. One has to make some assumptions to convert the energy density along the fault into an energy radiated measurement. But it really is not normally or typically used in that regard.

DR. SIESS: I recall hearing Clarence Allen say once that a Richter magnitude had to level off somewhere around 11 or 12, because that would correspond to a fault 24,000 miles long which would divide the earth into two parts.

DR. SAVAGE: Yes, I think that is pretty reasonable, a safe maximum magnitude.

And the other magnitude value that was indicated on the Gutenberg notepad was what is referred to as a long period body wave magnitude, which was given a value of 7.3.

Now one of the other very interesting issues associated with the 1927 earthquake is where it occurred. And as I think all of us are aware, this has been a question that has received a lot of attention using a variety of data sets for the last fifteen or twenty years. And what I have represented here as superposed on our last seven years of seismicity data is a box here of magnitude 7 size that sits on or is in the vicinity of what is called the Lompoc structure, the Lompoc fold.

This is the area within which there is evidence for geologically recent sea floor deformation. There is a large fold, and some faulting that is very young apparent on the sea floor and just beneath the sea floor.

As we have talked before, this area is very different than the area west of the Hosgri fault in the offshore Santa Maria Basin. South here, we begin to pick up the presence of young anticlines. And in some cases, the presence of faulting at shallow depths in the young sediments.

This region here is also the area in which several scientists have located after shocks for this earthquake using some relative measures of data taken at seismographic stations in the area, in the Southern California area following the 1927 main shock.

Another important factor is that this earthquake did generate a sonomy, a local sonomy, which was reported with wave heights of four to six feet along this area here, and in fact was being recorded in Helo, Hawaii on the water level meter, the title meter in Helo.

So the situation with this earthquake is that although at this point that we do not have, and I do not know of anyone who has any more definitive location of where the earthquake occurred, that this is the most likely candidate area. There is the presence of deformation of the sea floor. That deformation combined with this sort of focal mechanism, a vertical fault movement mechanism, would be capable of generating the sonomy that was observed.

So at least as a working hypothesis, this is the area that we are considering to be a likely epicentral area for the 1927 earthquake. And this is the mechanism of that earthquake represented in what we call the beach ball representation.

Again the mechanism strikes. In this direction, a strike that is parallel to the strike of the Lompoc structure. It is also worth noting that that is a strike parallel to the Hosgri fault zone in this region. One of the differences being though that the Lompoc fold shows evidence of geologic deformation, vertical deformation, where that is not the case along the Hosgri.

DR. SIESS: Why do you not know the location of the Lompoc?

DR. SAVAGE: This earthquake occurred just before th operation of seismograph stations in California with good timing to be able to use modern location techniques to locate that main shock. We have used a number of inferential means t locate the event that basically all fit together. But there is not what one would call at this point an absolutely known location.

DR. SIESS: It was enough to get a magnitude, but not enough to get a location?

DR. SAVAGE: That is in fact correct.

Another aspect of looking at the seismicity data in the area is to assess how well located these modern events are. And apart from the 1927 earthquake in this area, one of the largest events offshore and along the coast here occurred in 1980 in the magnitude of 5.1 earthquake.

And so we used the data, the seismicity data in this area, in a procedure to evaluate the accuracy of earthquake locations. And that procedure is called a master event technique, where we take a very recently occurring and very well recorded earthquake and calculate residuals in terms of that particular recent location at seismograph stations on the on-shore area within fifty to a hundred kilometers, and then go back with the station corrections and relocate the earthquake activity in that vicinity.

We have done that process here for the earthquake activity seen in this little region here near the Casmalia fault along the Hosgri fault on the offshore. And what we find is that the center of the locations of these earthquakes occurring just west of Point Sal move by about two kilometers compared to the routine USGS earthquake locations which are shown in this figure. In fact, at essentially the scale of this figure, you cannot see that the locations have changed.

In particular, we have relocated the main shock which moved it from sitting out here to being right in the middle of this pocket of earthquake activity. The focal mechanism we rechecked with the mechanism that had been determined by the USGS, and it seemed to be just fine, and suggested an occurrence of faulting along the slip planes oriented parallel to the Casmalia fault, not oriented along the Hosgri fault.

We particularly tested how stable the orientation of those planes were to see if in fact this event really represented movement along the Hosgri, and the orientation of the mechanism seems to indicate that it does not.

When we look at these data in cross-section, looking in this case along a direction or view parallel to the Hosgri fault zone, so the Hosgri sits on the plane perpendicular to the plane of view here, we see the distribution of activity. Most of the earthquakes occur in the depth range of about 4 to 9 kilometers. The largest event in the 1980 earthquake is at a depth of about 8 kilometers.

One of the hypotheses that we are looking at in terms of regional tectonic activity in the coastal area and particularly with respect to the Hosgri is to see if there is evidence for the presence of and the seismogenic capability of possiblistic faulting. And that would be seen in this figure as it has been suggested, that maybe there is a fault that is expressed near the surface here, but that flattens with depth.

If that model were appropriate for this particular situation, the flattening would occur at about this depth. And what we see is that these earthquakes appear to be occurring below the level of that possibilistic faulting. This is one locality along the Hosgri fault zone where we have the ability to combine both focal mechanism studies and relocations to gain another piece of evidence useful to evaluate alternative tectonic hypotheses as well as fault orientation and fault behavior hypotheses.

I would like to move on now to a brief discussion of some of the data interpretation activities, and I will do a brief high resolution tour along the Hosgri fault zone moving from the northern termination through the area. I will start with the northern end up here to look at the hear here opposite the San Luis Obisobo incline here, and look at the portion of the Hosgri down in this reach south of the Pecho fault here, and extending down the Casmalia fault which is this offshore extension here.

And then we have not completed out high resolution look down here, but I will make a few comments on the southern extension.

At the previous ACRS meeting in November of 1986, we discussed in quite a bit of detail the work that had been done in the onshore area along the San Simeon fault. Lloyd referred to this briefly this morning. And some of the key products of that work was to identify the San Simeon fault as a predominantly strike slip fault as it exists here in the onshore area near the south end of its onshore expression with a rate of slip of a few millimeters per year, and evidence for activity in the holocene.

So this is a geologically active fault, predominantly strike slip moving it up at not a very high rate, but certainly a rate that is adequate to provide geologic evidence for ongoing deformation.

Well, earlier today, we saw several different kinds of geophysical data that were collected in this portion of the offshore area. It is one of the products of our analysis of those data that is represented by the major trends seen in this figure here, and in somewhat less detail the trends along the northern and central portions of the Hosgri fault zone seen in this figure.

So what I will mention first, here we see just the very southern tip almost out of reach of San Simeon. The Hosgri fault zone, as we are considering it, characterized by high resolution geophysical data ends at its northern end right here. This is the northern most element of that fault. And let me see, I am sorry. This is the northern most element of the Hosgri.

North of this point not shown on this figure but seen again in the high resolution data passing to the north, the faulting turns to the west and becomes very, very broken up, very disconnected. And we lose the association, the clear association, between the Hosgri fault zone as seen in this reach with the edge of the basin, the offshore Santa Maria Basin.

To move back to this figure, and what we are seeing is the northern end of the relatively youthful Hosgri fault. When we try to trace the San Simeon fault to the south, we see clear geophysical evidence. We have lines that cross the Hosgri right in the interior San Simeon Bay. And lose the ability to see the fault along the coast here, because the fault is too close to the coast. But we do see a long linear element of coastline up on the east, which is consistent with the character of the San Simeon fault to the northwest.

We have a lot of detailed high resolution geophysical data within the interior of the Estero Bay, and we do not see the San Simeon fault extending beyond this region into Estero Bay.

What we do see in the high resolution data are two very key features in the offshore which I think tell us just what is going on with this fault. Here we have a strike slip fault entering the offshore and ending somewhere in this region here. What occurs in this region are a series of late quaternary basins that are filled with up to a few tens of meters of sediment. The locations of the basins are indicated by these hatched symbols.

We also see within the basin or this basinal area few tens of meters deep a series of small normal faults along which these basins appear to have formed. The mapping as represented in this figure is not very detailed. It does not show all of the normal faults that have been identified as margins for these internal basins.

What appears to be going on, and this is based not on just looking at these particular data here, but in comparison with the identification of these kinds of features in many faults in other areas of the world, what is going on is that there is strike slip movement that is being transferred from the San Simeon fault to apparently the Hosgri fault offshore. That is the reason for the presence of this set of quaternary basins and the normal faults in between.

So we have some very important information about deformation that is entering into this fault system at its northern termination.

Looking further down the Hosgri zone then, superimposed on this trend map, this is the high resolution data trend map, we see some of the topographic scarps that have been identified in the bathymetry analysis. And as we discussed before, some of these do lie along traces of the Hosgri fault, and those faults are shown represented here.

As we look along the Hosgri fault zone from north to south, we see that the Hosgri becomes more complex. From essentially a single trace, we see two and in a few three traces weaving along. Some of these fault elements and fault traces appear to end, and new fault traces begin. One case of that is here.

Where there is an impingement of faults coming from onshore to the offshore, we also see in some cases some identifiable features. In one case, the Los Osos fault extends through this area here coming from onshore into the offshore. And we see a small elevated block that is represented by these fault scarp symbols here called 59 meter ridge. 59 meters is the term used. And when we talk about mountain ranges, we often talk about mountain 2733, which is the elevation at the top. Well, 59 meters below sea level is the elevation at the top of that block. So that is the origin of this 59 meter ridge term.

And this appears to be a little block that is being squeezed in between the Los Osos fault and the Hosgri. And it may well represent some good evidence for current recent geologic tectonism along the fault in this area here.

The high resolution data as used to identify these individual traces does show evidence of late quaternary and holocene deformation. Not at every crossing of every line, but in enough of a pattern to allow us to consider that this is a zone that has been moving in a fashion to reveal itself geophysically.

As we go past the site here, we see a little scarp associated geographically with the trend of the Pacho fault. The Pacho fault, as it extends to the east, appears to dive beneath undeformed late quaternary sediments, although there is faulting that comes up within those sediments to a relatively youthful level.

South of about this point here, the Hosgri fault zone is seen in high resolution, and dives beneath undeformed late quaternary sediments. So what we see is a pattern of youthfulness and possible sea floor expression in this area that ends as we move to the south. The traces are still evident and seen further down in the section, but the evidence for youthfulness and for recency of movement has diminished.

DR. SIESS: Excuse me. That slide on your left, what are the green lines?

DR. SAVAGE: I am sorry. The green lines represent a couple of the normal faults, the small normal faults that exist between the inferred extension of the San Simeon fault as it is postulated to come down here and end and the Hosgri.

DR. SIESS: I guess that you are trying to convince me that the Hosgri does not connect up with the San Simeon?

DR. SAVAGE: Yes, that is certainly our interpretation.

DR. SIESS: And I guess that I did not hear what is supposed to convince me or conversely, the fact that they jog, that there would have to be a jog to make them connect up?

DR. SAVAGE: Well, this is a five kilometer wide step-over.

DR. SIESS: But why could I not draw the red line where you have got the green line?

DR. SAVAGE: Because the sense of movement seen along this fault here is not the same as seen here. The geophysical expression of these two faults is simply not the same.

DR. SIESS: Could you translate sense of movement to something that I could understand a little better?

MR. CLUFF: Maybe I could address that very quickly.

DR. SIESS: Sure.

MR. CLUFF: This is a classic textbook of a right lateral step-over that we see in the faults in New Zealand, and in other parts of California, and in other strike slip environments, where you get a slip coming in this direction here, and a slip coming in this direction here. And when you get two segments of a fault system or a zone of weakness that is deforming in a strike slip sense, you get what we call a pull-apart or a graven develop. And that pull-apart results from this shift, and it just forms this down drop block that is being represented here by normal faults and depressions in between.

And that is a classic textbook pull-apart characterizing the ending of one fault and the motion transferring from one to the other. So we are using this to say that it looks like there is a significant component of strike slip which we feel that we have concluded up here with a great deal of confidence that is being transferred along this part of the Hosgri fault here.

DR. SIESS: And the green fault is moving out?

MR. CLUFF: This green fault would be faults dipping at an angle. In other words, the hanging block is down with respect to the other side.

DR. SIESS: A vertical movement?

MR. CLUFF: Yes, a pure dip slip.

DR. SIESS: Okay.

MR. CLUFF: In a normal sense.

DR. SIESS: And that is due to the graven effect?

MR. CLUFF: Yes. It is a localized graven effect that we found in other similar environments develop at the ends of these kinds of segmented faults.

DR. SIESS: And when they offset like that, that means that the energy is not likely to be combined in some way?

MR. CLUFF: Well, we have not finished our analysis and interpretation of this, but this is a good reason for being able to characterize the end of a slip on a segment of this fault. The Hosgri, as you have seen on this, is segmented into even more finer segments. And this would say that this is unlikely to slip in a major earthquake any farther than this. It is very rare that you get them to jump over that at a great distance.

(Continued on next page.)

MR. SEAVUZZO: Don't you have some north-south motion there? I looked at this -- something's got to be straining in between. What's happening in between?

MR. CLUFF: Yes, this block is moving in this direction and this block is moving in this direction. Something strange that's in between is what's happening here.

MR. SEAVUZZO: So you're talking about -- there's a strain in there, is that what you're saying?

MR. CLUFF: Well, it's being relieved by this pull-apart base in terms of the geometry here. It's a classic example of that.

MR. SEAVUZZO: I'm looking on to the last scission. I don't know whether those damn -- what's happened in the middle? Something -- is either straining, and building up strain, or it's relative motion.

MR. ROTHMAN: Well, you get vertical displacement, which accommodates some of the horizontal displacement, beginning that quadrant is in the third dimension.

MR. SEAVUZZO: Well, wouldn't there be a crack some place?

MR. ROTHMAN: He's showing those two green lines of vertical falls.

MR. SEAVUZZO: What's the spot between? It doesn't at the end of the San Simeon and the end of the Hosgri are connected.

MR. SAVAGE: That's right. You don't -- this figure doesn't show all of the details of how this deformation is accommodated. These north-south faults do turn a bit to the north and serve to accommodate that, basically, that strain that you're mentioning.

Just as a last comment here -- with respect to the south end of the Hosgri, we'll be looking at the state land state we're expecting in the near future here, which would help identify the behavior of the southern end of the Hosgri down in this region. There are several hypotheses for just where the Hosgri goes. Some would carry the fault down towards Point Arguello; some would carry it in to connect with onshore faults. and that's the reason we want to look at the high resolution data, to better establish or to evaluate how this deformation is being accommodated at its southern end.

It's worth noting that, in a relative sense, it appears that the youthfulness of deformation seen up here does not persist into the more southerly portion of the Hosgri. So there's some evidence for a decrease in the rate of deformation along the Hosgri heading towards the southern end of the fault.

Well, Lloyd I think I'll pass the time back to you.

MR. CLUFF: I'm going to very briefly now summarize the integration of a lot of the data, the interpretations that Woody has just presented, and leave you with a comparison of that first map, that we showed early on. And then the result.

Here is one that I showed earlier this morning that shows the areas where we did detailed trenching studies, and if you recall, I mentioned that we were aiming at evaluating the importance of the San Miguelito fault, saying that if we could find where that intersected various geological centers, it would allow us to characterize that fault and as well as the Edna fault, and as well, the Los Osos fault here that's not shown on this map, but I will show it a little bit later.

On the other screen I'll show what we have found now, and I want to be careful in that the last major workshop that we had with the NRC staff and their consultants and reviewers was last May, and that the story that I will tell here is consistent with the results of that workshop; and we've done quite a lot more data; hasn't changed our tentative conclusions yet. It strengthened some of them; and caused us to look in greater detail in some of the others.

But I don't want to go beyond what they have reviewed.

But this map here shows the extent and the importance of these strain gauges that I talked about before, and these numbers that are represented here from Montana De Oro to the north down around the Plante, and then into San Luis Bay, and then into San Luis Bay and then down past Pismo Beach.

We have found very useful horizons and things that we can use to characterize the deformation throughout the time interval that may have existed. And the ones represented here go back as far as in excess of 700,000 years.

Well, to make a long story short, what we have found is that the projection of the San Miguelito fault into the area on this map here shows that that fault has not disrupted or deformed those wave cut terraces for that period of time, and based on that, and other trenching studies and so forth, we have come to the conclusion that the San Miguelito fault is not a potential source or a source -- it's not capable of generating earthquakes.

We have come to the same conclusion for slightly different reasons, but on the same basis, along the Edna fault, and in that detailed look, we found another fault that you haven't heard much about, other than Woody and I giving kind of general reference to it, and that's the Los Osos fault, and in studying the region and in looking at some not only marine but non-marine terrace deposits inland, we found the existence of this feature here, that is, the Los Osos fault, and that does show evidence of some multiple displacements in the late quaternary time in the last few tens through hundreds of thousands of years.

So we've classified two faults that were previously thought that they might be seismic generators as not; and then we found another one that we didn't even know was there that is a source of seismic activity based on its geologic evidence.

And we're in the process of characterizing that.

As you can see from this map, it's a zone, a highly distributed zone of surface displacements, and it seems to be highly segmented, at least one or more segments in here; another one in here; and another one in here. And this is getting beyond where we have reviewed this with the NRC staff and their consultants. But we have characterized that as a reverse slip fault dipping to the southwest, and what we found in lookin at these marine terraces, is these numbers: .2, .2, and we've got a lot more observations. There's a consistent trend down to right here, where there is a disruption in the wave cut terrace at that location; and there had been no deformation in the period of time that is represented by those terrace, wave cut terrace and terrace deposits;

This led us to looking at the two disruptions here, the discovery of a fault we've named the San Luis Bay fault. And this asterisk here shows where that was first recognized.

A very minor feature and very difficult to see, and has without going into a lot of detail, has a very low slip rate. I'll show you the results of our slip-rate analysis, and it is just barely deformed compared to other faults, like Los Osos and others.

And so we see some minor faults here. One at this projection of this, connects we think to a disruption in the wave cut platform there. There's another disruption at this location; and then some off-shore profiling that we've done and interpretation of some of the geophysical data, it seems like if that fault does continue -- it could just stop. These are minor faults that come and go, but it might continue out here and in some form either be terminated or be related in some way to the more through-going Hosgri.

So, based on the compilation of these data, both the geophysical data, the seismic geology data, the geomorphic analysis and detailed geological mapping, we have concluded that the strain gauges allow us to show that the northwesterly trending San Luis Pismo syncline, has not been deforming in the period of time that are represented by those quaternary terrace deposits, up to as much as 700,000 years.

So the young folding that is represented in other parts of the area seems to have ceased some million or so years ago, and this area is being deformed as a kind of a rigid block. You recall Woody talked about some rigid blocks over in here; another one out in there; we seem to have found another one here that's bounded on this side by well-defined, and we're characterizing that fault now and there is even some sub-boundaries that seem to be bounding that are represented by these drainage patterns that would be very minor faults that tend to bound this block behavior, and then the southwestern side of that block, we're still trying to understand, but it seems to be clearly represented by the Hosgri on this one side.

And then between the Hosgri and then as we approach the coastline here, there seems to be some zones of weakness that are experiencing some very minor rates of deformation compared to the other more active faults in the region.

Let me go to characterizing the seismic sources. This is, I think Woody probably showed that earlier. We're looking at using source parameters -- develop source parameters using the integration of all of the data sets that we're talking about, characterizing the geometry and then the magnitude of future events that we think might occur based on what we see and the pattern that we can see based on the past, and estimating the size of the earthquake and the frequency of occurrence with those earthquakes; and then while we're doing this being able to quantify the uncertainty about these assessments and look at alternative tectonic models.

Now, the comparison that I want to leave you with in terms of the result, is two maps here. The map on the right is the one that we started the program with, showing faults that we weren't certain of which ones that were most important for the project, and the representation here in a relative sense, shows the faults that right now based on the data that we've gathered, have some -- show evidence of young displacement in geologic time; and the comparative rate of slip, with the largest being the San Andreas being the dislocation about 33 millimeters per year, so it's the biggest contributor to regional seismicity and future events.

The next would be the range and order of magnitude less one to ten millimeters per year as Woody Savage mentioned, we've been able to quantify the rate of slip at least at this location. We believe it's appropriate to extrapolate that onto the Hosgri and that's somewhere between one and let's day four millimeters per year.

Then, we have the next rate, which would be the Los Osos fault here, and then the hundredths of millimeters per hear which would be these small features here, the San Luis Bay fault and one called the Wilmar fault and the Pecho fault and some others.

This represents the current tentative interpretations that we haven't fully reviewed with the NRC staff, but I don't think that's much different from what we presented to them last May, although we've developed a lot more geophysical and on-shore data to help us focus on the important points.

Let me conclude by leaving, showing you the conclusions we reached at the last November meeting in November 1986. The upper three bullets there show the conclusion that I took off the viewgraphs of that time, and if you just go through those, the on-shore near-shore geologic studies in San Simeon are of value to us in characterizing the type of slip on the Hosgri, sense of slip, near-surface geometry, the rate of slip, and being able to characterize earthquake recurrence and displacement. And we're going to use that in our final analysis.

And then the on-shore view physics is helping us clarify the lateral continuity and segmentation of the various faults and structural elements, their slip history; we believe that they'll help us understand the down-dip expression and test the other crustal hypotheses or crustal models that have been presented, and at that time, we said that, based on our scope of work, that we have not found any surprises in -- identified what we had not included in our early seismic source characterization.

Here is where we are today based on the work we've done since that time. And we're emphasizing data interpretation, leaving to the source characterization, and we want to emphasize integration of multi-databases, and analyses that allow us to look at various hypotheses to address alternative characterization of the area.

We haven't concluded which model seems to fit, or whether one model will be the final answer. And we have reached the conclusion that both the San Miguelito and Edna faults are not capable, according to the NRC criterion, and that the Pismo synchinorium, or syncline trend, has not been subjected to active faults for at least and probably longer than, 100,000 years.

And that that block behaving as a block type motion, and that that block is bounded by the Los Osos on one side and a zone of faulting, the largest of which is the Hosgri over on the southwest in Wilmar, Oceana, and San Luis Bay faults are minor rates and points of deformation along a distributed boundary.

And then the Lompoc earthquake we've come to what we believe to be a competent conclusion about its magnitude, and its mechanism, and with a little more work we will be coming up before too long about where we believe the earthquake occurred.

So that in a thumbnail kind of brings you up to date on where we are on the GSG part of this whole program, and the next part of this is then to go into the ground motion aspects.

DR. SEISS: I thought there was still a question last time as to whether the Hosgri was vertical or curved?

MR. CLUFF: We're still analyzing and looking at that. Let me say that, as we analyze and interpret the data, we see a lot of reflectors that are both vertically inclined and just off vertical,and some that are very shallow.

The important thing that we're trying to learn is which one of those reflectors represent faults, and which ones of them are tied to the deeper seismicity in the region. The Listric model seems to be in the ones that have hypothesized these, are so shallow that those Listric faults are not down to the seismogenic depths that we're seeing in the seismicity.

DR. SEISS: Does your ground motion studies take into account that uncertainty?

MR. CLUFF: Yes. As Wen Tsai will show, the ground motion studies have been operated with an assumption that we haven't told them which model to use, and so they've been looking at both sides of that, and his data will show, he's incorporated both reverse slip faults and strike slip faults.

DR. SEISS: Okay. Are there any questions for Mr. Cluff and Mr. Savage?

Do the consultants have any questions, especially the geologists? Go ahead, Mike.

MR. TRIFUNAC: I just wanted to ask, how did you get the slip rates?

MR. CLUFF: Oh, okay, the slip rates are based on being able to date these quaternary terraces, particularly, or other deposits and finding both multiple and indicuvual long term slip rates and shorter term slip rates on a different ages, and then just calculating on what the rates of deformation have been in those younger geologic deposits.

DR. TRIFUNAC: But how did you get the slip rates for the areas that don't have the terraces?

MR. CLUFF: Okay, the slip rate that we've determined on the San Simeon, we're assuming is representative on slip on the Hosgri. That's an assumption right now that we're still working on the mechanics of how you do that, and we have young terraces and deposits on along this fault, and here and along the Wilmar fault, and the Rinconada, Bert Clemons has just finished some studies up there where he has been able to characterize the slip on Rinconada.

So all of these are based on hard field data, with the exception of not having exactly the information offshore because of the resolution of both the deposits and the amount of slip offshore?

DR. TRIFUNAC: These should be consistent with Seismicity, shouldn't they?

MR. CLUFF: Pardon me?

DR. TRIFUNAC: These slip rates should be consistent with seismicity, shouldn't they?

MR CLUFF: Yes.

DR. TRIFUNAC: What did you find, are they consistent?

MR. CLUFF: Woody, that's a question to you.

MR. SAVAGE: There are different kinds of consistency to look for here. Many of the faults shown in this figure are not very fast-moving faults, and we wouldn't necessarily expect that a short, historical record would accurately represent the rate of earthquake productive of each of those faults.

That's particularly true -- well, it's essentially true of all the faults that move at rates less than a centimeter or so per year.

I think our experience in California where there are a number of faults that move very quickly, on the order of a centimeter or more per year, we do see a pretty close association between the good-size historical earthquakes, and those faults.

But there are many faults in California that move at rates in these ranges, over several orders of magnitude, some of which have evidence of historical activity, and others of which do not.

So broadly speaking, the pattern we see of slip rates representing deformation in the region is consistent with both the historical seismicity pattern and even the microearthquake pattern, where we have faults or with reasonable amounts of deformation we tend to get more of a small earthquake -- greater density of earthquake activity, but it's going to take a longer period of time than we have now to really clearly establish that seismicity slip rate correlation.

DR. TRIFUNAC: I don't understand why -- I don't understand why you need more time. You have shown today a whole bunch of micro-earthquake events that you have --

MR. SAVAGE: Those are micro-earthquakes and they accommodate on the scale of things very, very little deformation. They serve to indicate where strain is being released -- where stress is being released due to finer fracturing. They help us understand the pattern of stresses within say this larger region, but the recurrence of a magnitude one or magnitude two earthquake, doesn't necessarily represent the behavior of an earthquake -- behavior of a fault in a large earthquake, that may have an earthquake as large as magnitude six or seven.

There are many faults that are quiescent for a long period of time before they exhibit seismic activity.

In fact, the San Andreas, just in the southern corner of this figure, in terms of seismicity, has been very quiet since 1857. We couldn't locate the San Andreas fault using micro-earthquake activity.

DR. TRIFUNAC: I'm not suggesting that -- I think you didn't quite understand me. I'm asking for consistency -- something can be inconsistent and still not disprove a hypothesis.

MR. SAVAGE: So you are saying for how consistent are the rates of --

DR. TRIFUNAC: You have seismicity data in your hand -- it's a short one, but that's all you've got. Then you have here slip rates. Now those are either consistent or not with respect to whether this is a unique and complete estimation. That's what I'm getting at.

MR. SAVAGE: Well, I guess I would view that generally speaking, this kind of scale, yes, the seismicity is consistent with where we see lots of slip being released.

DR. TRIFUNAC: I was thinking about the diagram which had much more details?

MR. SAVAGE: Okay?

DR. TRIFUNAC: Yes, right.

MR. SAVAGE: Well, what we see, for instance, here is a strong lineation of seismicity, but the lination is consistent with a big fault, but the amount of stress being released by this seismicity is nowhere accounts for or doesn't account for, the kind of slip rate we see here.

But we also know that there is an historical record of earthquakes including magnitude sixes in the Parkfield area and magnitude eight earthquakes to the north and south -- that do tell us that, yes, that fault is behaving in a fashion consistent with historical record.

For the faults in this region here, I believe we don't have enough data to argue the consistency that I think you're looking for, to be able to say, well, these faults, when they have larger earthquakes, will accommodate the slip that we see on these features here. If one adds up the rate of slip in the little earthquakes shown on this figure, it isn't enough to represent the slip rate seen on that figure.

DR. TRIFUNAC: Excuse me, your problem is understanding it: I'm trying to understand the seismicity curve, log normal, for this magnitude, for a given source region, and I'm not suggesting that we read off the small events and match up this -- not at all.

But if there is some kind of a linear log on some kid of log-log scale, it is either consistent or not, do you follow what I'm saying?

MR. SAVAGE: Okay, now I understand. In terms of earthquake recurrence within a large region.

DR. TRIFUNAC: Is it consistent or not?

MR. SAVAGE: Yes, it is consistent. But it is only consistent when one takes a very large area. To take a particular fault and look at the log-N versus M data, no, it does not work. It does not work.

DR. TRIFUNAC: It does not work for individual faults?

MR. SAVAGE: It doesn't work well for individual faults. And that, there are some good examples of that, for instance, in Southern California, the San Jacinto fault works very well --

DR. TRIFUNAC: Keep the picture -- don't go off away -- stay here. I'm looking at this picture.

MR. SAVAGE: Okay, no. Take that fault by fault, the seismicity data do not tell you what the frequency magnitude relationship would be that one might derive from slip rates. Which is why, generally speaking, we would prefer to use slip rates as a basis for estimating the occurrence of large earthquakes, rather than taking the occurrence of magnitude two and three earthquakes and extrapolating that up to magnitude five or six or seven.

DR. TRIFUNAC: So how are you going to use this?

DR. SEISS: Next presentation.

DR. TRIFUNAC: Oh, okay.

DR. SEISS: I think you read the ground motion.

DR. TRIFUNAC: You see, this is the basic input into this calculation, and it is not consistent. I mean, how can you --

MR. SAVAGE: We're planning to look at two different recurrence models, what's been called the "characteristic" earthquake model, which is a larger quake, with, again the linear frequency magnitude relationship doesn't apply very well where there are repeats of larger earthquakes and a paucity of smaller earthquakes.

Or we will try where we feel that we have an appropriate amount of data to compare this sort of pattern of earthquakes along a fault with the longer-term historical pattern to look for the general consistency.

By and large that approach doesn't work very well. It doesn't provide a very good predictor. Slip rates appear to be a much better predictor for the occurrence of large earthquakes, because large earthquakes carry most of the slip along the given fault.

MR. MAXWELL: My question could sort of lead in to what you're coming into now. Everything we've heard and seen and talked about concerns the geometry of faulting and the time of faulting and so on, and the assumption seems to be that it doesn't make any difference what's being cut by the faults.

You have three very distinct kinds of rocks in this area, the big, Franciscan melange; the selenium block -- crystalline rock; and locally, the very thick-bedded mainly tertiary rocks.

And it seems to me that each of these sequences must have very different elastic properties that, somehow or other, they're directly on the energy and perhaps even on the slip mode of earthquakes.

I just wondered if you'd taken this -- or will you take this into account; then you've taken it into account and maybe you can't take it into account, but as a geologist, I would like to know.

MR. SAVAGE: Well, certainly, in bulk terms, the Franciscan melange is very different than an unfractured granite. But when we look at fault zones through either of those two materials, to my knowledge, there may not be very -- they're both -- the fault zones themselves, are gouge zones filled with altered minerals with complicated fractured materials, such that the mechanical properties of the gouge may not be very different from Franciscan to granite.

MR. MAXWELL: Well, we're talking about earthquakes, though, and there would be other factors on attenuation here too that are very important.

Had you attempted specifically to analyze earthquake problems with respect to these very large bodies of different kinds of rock?

MR. SAVAGE: Not in any detail Not in the detailed sense that you're suggesting, to look at, say, the propagation properties of granite right here compared to the Franciscan formation here.

Our sources -- the seismic sources that we will be considering in the analyses, are pretty local, and they're all within the Franciscan baseman. So the impact of granitic terrain i n a ground motion sense is probably not so great.

MR. MAXWELL: When you feed this information into what I assume you must, in this soil/structure interaction, fragilities, and so on, is it cricket to use the data from all kinds of faults in that as compared to -- and then say that's what is going to happen in this mainly Franciscan sequence, I guess that's --

MR SAVAGE: Yes, that's a point that does need to be argued. The case needs to be made for justifying that.

DR. SEISS: Yes, Ben.

MR. PAGE: I'd like to mention something that Woody alluded to earlier, and that is the revised estimate of relative plate motions which is relevant, I think, to the activity of fault along the coastal strip. About a year ago the relative plate motion was revised or at least postulated to be revised by Mitz, Gordon, and one other person, and as Woody said, I think he said that the relevant motion now seems to be on the order of 4.8 centimeters a year.

Whereas, say three or four years ago, the common wisdom was, the Ocean was about 5.7. So it stopped by nearly a centimeter a year. That is to say, in all the faults to the east of the San Andreas, and all the faults to the west of the San Andreas, collectively only have to account for one centimeter a year, if the recent calculations are valid.

So that, I think, lends plausibility to the rates shown here on this map. For instance, the green being one to ten millimeters a year. According to these recent figures, it couldn't be greater than that, because the relative plate motion doesn't permit that.

Of course this is assuming that all the latest research is accurate.

MR. CLUFF: Thank you, Ben.

DR. SEISS: I have some recollection that you said that several years ago, Ben?

MR. PAGE: I said something qualitatively like that, but at that time the plate motions were much higher. I think at that time they were six centimeters a year. Luckily, they've been diminishing instead of increasing.

DR. SEISS: Other questions? Okay, Lloyd, go on to the next part.

MR. CLUFF: The next part of our program is the next element, the ground motions. I'm up here with Ben Tsai of PG&E. We'll make that presentation. Ben?

MR. TSAI: My name is Ben Tsai. I'm a seismologist on the PG&E staff working on the mountain seismic program ground motion element. As I reported -- well, my job today is to report to you the progress we have made since last meeting on the ground motion area.

As I reported to you in the last meeting, the ground motion studies within the mountain seismic program has two main objectives. The first is to update the ground motion assessment of the site; and the second is to provide specific ground motion data for engineering analysis; and to achieve this objective, we need to make use of three sources of data.

One is an updated slow motion data base corrected worldwide. The second is to use the information and data derived from the geology, seismology, and geophysics element of the program as you have heard earlier to date.

The third source of data to be used is the existing ground motion recordings acquired at the site through the years, and for this program.

To make use of this data we use both empirical and numerical modeling methods.

Now, my main presentation is to give you a report on the current status of the ground motion studies, which include empirical studies, numerical modeling studies, and the assessment of special incoherence at the site, and the last one i the --

DR. KERR: Excuse me. This morning I asked about the distances that go in or numerical modeling method and something else, and mention was made of "numerical" and "empirical."

Now, I gather that the difference is that an empirical study is empirical and a numerical study is semi-empirical? Is that -- an appropriate characterization?

MR. TSAI: Well, in this program, "empirical" can be translated as real records, actual records. And "numerical" meant to say that the ground motion estimate is based on modeling -- numerical modeling, which has some empirical bases, but also uses currently acceptable theoretical understanding.

DR. KERR: That makes it more clear.

MR. TSAI: Thank you. The fourth area I would like to you is a summary of the ground motion data provided up to date for engineering -- that is, this second objective of the ground motion studies, and I will come back to this later on, on each of these. I will start with the empirical studies.

For this presentation, I will show our compilation of an updated slow motion data base, and I will also show you some examples of the environment in terms of peak ground oscillation and spectra oscillation attenuation relationships, and also we have done some progress to make site-specific ground motion characterization to achieve the first objective.

This chart will summarize what we have compiled in that data base. It is that corrected records from 47 shallow-focused earthquake sites worldwide ranged from 4.6 to 7.4, and the closest distance to the Pohl-Roger surveys range from very close to the board or 300 kilometers for peak values, and up to about 50 kilometers for the spectrum values.

Those ratios are mainly recorded on rock or rock-like site. And the total record available at this moment is 154 bore peak values, and 65 for special oscillation.

This is a list of the earthquakes, corrected, and it is in the high mount of -- by the way, all the materials I am reporting are contained in the written progress reports mailed to you before the meeting, and the three separate progress reports.

This is what we call a scatter diagram to show what data are available for peak values. The horizontal axis is the [ ] and the vertical axis is the [ ]. So both of those data reside in this area, between say 10 Km to about 100 Km and mostly with [ ] of 6.5, whereas our main interest is in this area and relatively few data or recordings are available, and therefore, this is one of the main modifications that we need to use empirical modeling on to make up this lack of recordings.

MR. MAXWELL: You plotted that as a graph. Is there any relationship that theory would say these two factors should exhibit? I mean, should this be a straight line or a curve, or is it just a map?

MR. TSAI: Yes. There are some relationships. For example, for a magnitude lower than five, it is simply too weak of a ground motion to be recorded.

Now, for say, a distance between what would be 100 Km, smaller earthquake would not be recorded. Now, for lack of recording in this area, where there are not so many large earthquakes, and also there are often not instrumented, in the case of those.

MR. MAXWELL: Excuse me. I think you missed the question: the question was, was this simply a map, or should we try to draw a line through these?

MR. TSAI: Yes, this is simply a map. A diagram showing the availability of the records.

MR. MAXWELL: Thank you. The range?

MR. TSAI: The range, yes. Thank you. And to a related amount or quantity is this spectral data available in our data base.

We then use this data base to look into the peak value and spectrooscillation regression, or activation relationship. And we use standard regression function of 4, and take two states to determine the co-axes. First we do single regression for a narrow band of [ ], in other words, fix this M, and the vibration, then, with regard to distance, when this question is determined, then we go to the second state, use the whole set of data, and let the parameters be determined by the exact situation.

DR. KERR: You mean, after plotting the graph, which shows that there really isn't any fixed relationship between magnitude and distance, you now set up -- you ask the computer to find one?

DR. SEISS: No, no. This is PGA. Magnitude and distance are on the right.

DR. KERR: Okay.

MR. TSAI: Yes, This is the distance, R, and this is the magnitude, and on the left is the PGA.

DR. KERR: Okay, there should be.

MR. TSAI: And this is one example over how that configuration compare with the data points. On the horizontal axis is the distance measure from this recording side to the closest point of the ruptured fault studies; here the vertical axis is the peak oscillation in [ ].

In this particular example it [ ] to 615. In the data, points went from 6.3 to 6.6, and for the relationship is meant to represent the reverse or stress poles. You can see the southern curve is median whereas the hatched lines are plus-minus one standard deviation and two standard deviation.

DR. SEISS: If E is taken as 0 in your equation, do you give them a solid line? Or is this --

MR. TSAI: Yes, that would be the mean, yes. Operative.

MR. SEISS: Okay.

MR. TSAI: And so the estimate in proving the best estimate and dispersion about the best estimate,. We use quite similar function of form for the SA -- spectral-acceleration attenuation relationship regression.

Whereas here, we used three state procedure. First as mentioned earlier, we first find out the PGA attenuation relationship, and then for spectro-acceleration, we use the normalized parameter SA over PGA for our dependent regression parameter. And then we combined these two to get the absolute spectro-acceleration.

Again, the regression result also shows this discretion.

This is one example for magnitude 6.5, and for a period .18 second, that's about 8 hertz, for 5 percent bend gain, and again, you can see the data points compare with the regression without a median plus-minus standard deviation whereas the data point is out to 50 kilometers.

This is for another period of frequency of 4 hertz, around 4 hertz, a similar amount, and this is then for 6 frequencies.

Now, I'm moving to this element, progress in site-specific ground motion spectral estimate. The final result will comprise the median and dispersion about the median.

Beside specific criteria, we have been referred to as the earthquake magnitude to source to site distance; site condition and style of reporting.

Among these four criteria, three of them will be determined by the GSGS studies. The Geology and Geophysical seismologist study in terms of magnitude distance, this is related to the location and extent of the seismogenic source, and also the style of reporting.

The fourth element is related to the site conditioning, and in our case, we classify it as a rock site. These are geology, site geology, and shear wave, but I will save that for the final.

Now, then we divide out a procedure, or actually use two approaches, to make the estimate and for one of the procedures we use a working model with regard to this full criteria to complete the development of the procedure.

MR. TRIFUNAC: Going back to the specs on two or three. I'm not sure I understand -- does the direction come in only for PGA? Or is the configuration basically different in different period ranges in SA?

MR. TSAI: In this one?

MR. TRIFUNAC: Do you understand what I mean? I don't see from what you're saying there whether you have different attenuation or the same attenuation equation at different periods from the assay?

MR. TSAI: Well, this is then for different periods.

MR. TRIFUNAC: Yes, yes. That is only a factor saying how much bigger or smaller SA is relative to PGA. So the whole spectrum has the same attenuation equation.

MR. TSAI: Now,this allows for different amplification for different periods.

MR. TRIFUNAC: Is CN upstairs different for different periods or not? You see up on the top?

MR. TSAI: No, this is fixed.

MR. TRIFUNAC: But there is only one attenuation equation.

MR. TSAI: We allow for this one, let's see, this one and this one, to be determined. And that is based on we have devalued the most rock-site and soil-site data to see that within about 50 kilometers, the spectra shape is relatively constant. It's not sensitive to the distance and magnitude. In particular for magnitude higher than six.

DR. TRIFUNAC: There is only one C for every -- everythinr right?

MR. TSAI: Right. And for this particular work, we nearly have two approaches. Traditionally, you derive site-specific response spectrum or ground motion of peak values from regression without. But in our case, we have a site which is relatively crossed to an extended source and where a relatively small amount of data is available.

Now, if we soley rely on this, we essentially will rely on observations made at a distance smaller magnitude to project for our side in terms of closer distance, higher magnitude. And so then, I think that there may be an alternative approach, and that is, we go direct through the recordings. Whole recordings of the magnitude and the distance range which are of most interest to us, and in this case, we limit our magnitude to about 6.3; distance within 20 Km and with slag or rock site and used a smaller member of soil site outer adjustment for this particular purpose, and at the moment, we make the assumption that the style report will be equally likely between strike state and reverse.

Now, I will talk about this part, and this is direct result from the graduated relationship I just had shown you a few examples earlier.

Okay so, since we need to determine the median and dispersion, we need to have relatively large example of records. And here is a diagram showing what our variable recordings at rock site within a hundred Km and at about 6.3. And after looking at this diagram, we found 13 records. And that means we have 26 compliments.

And from that we heard that it's not quite large enough of an example, so in addition those records were dominated by the stress or reverse earthquake.

Therefore, we go to the soil site and found out that within that similar constraint, we have a number of records which may be used but in this particular case, these are records from the 1979 Imperial Valley earthquake recorded between 5 Km and 9 Km, which is on terms of distance is many inches to us.

And this is a summary of what has been selected, a quota of 18 records mainly ranges from 6.3 to 7.4; distance from 3 to 20 Km and total of 18 records under the survey. Of six components, five of them are from soil records.

You recall that for site-specific spectra estimate, one uses a single magnitude, single distance and designated style brought in, whereas the records range from different distance and deferent magnitudes, and in some cases as soil-site condition, therefore, we need to adjust them to approximately a uniform or single criteria, a single, single set of criteria and so we have accomplished this, and we need to make a magnitude adjustment; distance adjustment; and site condition style brought in.

And those adjustments are documented in the written report. I would just show you one example of the magnitude and distance adjustment. This is normalized for a distance of 4.5. That's the distance for the present exercise. We pix a distance as 4.5 kilometers and for magnitude 7, this would be the adjustment factor in individual records. In other words, if the record was obtained at 10 kilometers, we would adjust an upward to get an equivalent motion of 4.5 Km for magnitude, if the record was from a 7.5 in actual case 7.4 earthquake, we were reduced that to this point for the 7.0 magnitude, and so forth.

So there is three adjustment. One is magnitude; distance; style of reporting; and then for a smaller number of five records, we adjust for site conditions.

MR. MAXWELL: But that means that the shape of the spectrum is not deemed to be definable?

MR. TSAI: Yes. For adjusting from soil to rock site, both the peak value and spectral shape, are adjusted. We use that frequency dependent upon spectrum adjustment.

MR. TRIFUNAC: I thought you just showed that diagramming to be the previous viewgraph which has a coefficient which you opted by or diminished the record, by a constant number?

MR. TSAI: Yes.

MR. TRIFUNAC: So that would mean that you are making a correction which is assuming then that the spectra do not depend on magnitude -- the shape of the spectra?

MR. TSAI: Yes, on rock site or magnitude.

MR. TRIFUNAC: Rock site to soil site doesn't matter.

Magnitude alone?

MR. TSAI: Yes. For a magnitude of about 6 or 6.5. For smaller magnitude or low frequency part is dependent -- apparently dependent on the magnitude.

MR TRIFUNAC: So you develop like an average factor?

MR. TSAI: Is this -- for the site adjustment I have a table here. Yes, this is the adjustment we made for between rock site and soil site. The ratio of rock site and soil site, you can see umbrification at a high frequency range, and the umbrification and low-frequency range.

MR. TRIFUNAC: I'm thinking just about five inches no facilities sites.

MR. TSAI: Okay, the main view --

MR. TRIFUNAC: Just one adjustment?

MR. TSAI: Yes, peak. With peak, adjustment for peak value, and then constant shape for magnitude.

MR. ROTHMAN: Ben, you've been showing studies that you've been doing for horizontal components of ground motion. Are you doing equivalents for the vertical component to ground motion?

MR. TSAI: Yes. I will not be showing you as much in terms of ground -- vertical component as horizontal component.

MR. ROTHMAN: You're doing equivalents?

MR. TSAI: I'm doing a concurrent study, yes.

And then, for the current exercise we make two estimates on this, the spectrum one is the peak value; the other one is for a band, a frequency band, which has the highest umbrification, and in our case, for the present case, we pick an average between 3 and 8.5 hertz, and that compared to other practices it's relatively close to what has been done.

MR. SEISS: Excuse me, I looked at that, and I did look at it before I came here, and I wanted to say, thank PG&E for sending me all that good reading material. But I could easily see how you picked 8.5, since it fell between 8 and 9, but I couldn't figure out why you picked 3, except that it was a nice round number, and everybody else had picked numbers like 2, 2.3 and 2.5.

MR. TSAI: This, at the beginning was more or less prescribed by our engineering part of the program. Maybe Bob would want to respond to that?

DR. SEISS: It didn't have any relation to what people did before? Mr. Kennedy told you to take three and you took three?

MR. KENNEDY: Basically, what records that were associated with close-in recordings; higher magnitudes, on rock-like sites, looked at the spectrum case from those recordings and found that some of these high amplitude recordings tended to start knocking off, to start deceleration at around 3 hertz.

So this was an average shave based on a few recordings, early in the project. I think the shape has changed subsequently.

DR. SEISS: Bob, will you come up a little farther here? They can't hear you down there.

MR. KENNEDY: This was an average shape based on a few recordings that were selected early in the program by Professor Seed and myself, primarily. The recordings that we looked at were primarily for Clamberdown, Toboz, and a couple others. This shape here is -- subsequently we have developed a phenomenal shell more site-specific, spectra shapes for these high-ground motions, both these shapes do start to drop off pretty much like this one does, at about 3 hertz and tend to have their highest amplitude in the 3 to something in the 8 to 9 hertz range, and frankly, the 8.5 is just half-way between 8 and 9 hertz?

DR. SEISS: Don't say it drops off like that, because that one doesn't drop off until 2.5.

MR. KENNEDY: Well, it's supposed to drop off about three hertz, is where we have that drop off.

DR. SEISS: Thank you.

MR. TSAI: So this is schematic shaving ratio and how it is then in the visual spectrum where you pick the PGA value, and then average over this frequency band for each spectrum and then come in the medium and 84 percent high, 16 percentile, and so forth.

And this is the result of that exercise showing for slightly earthquake medium spectrum, that frequency band is 1.07G, .55G for PGA and 84 percent and 60 percent nigher with respective shown in the picture, and for equal probability of strike slip and reverse fault-ins, we adjust 10 percent of upward and that will give us 1.85 G for the 84th percentile and 1.18 G. for the median at .75 G for the 16th percentile.

And compare those numbers with direct regression of the same conditions; that is, the same criteria of 97, 4.5 Km rock and a mixture of side slip and reverse, one can see for median 1.18 and one averages over this distance-frequency band, one will get 1.33 G, and so forth.

So after this exercise, we felt that the approach that we were taking is reasonable, and we believe that it is more direct.

MR. TRIFUNAC: Excuse me, at the expense of confusing myself many, many times, you are relying on these numbers that you're talking about log-Normal distribution functions?

MR.TSAI: Yes.

MR. TRIFUNAC: Have you tested whether the data you have admits using log-Normal distribution?

MR. TSAI: It's not that -- we do not have enough data to test that particular dispersion.

However, recently, Everett Humpsett of Municipal Creek, and now in the industry, used a small one irradiator, where you have repeated recordings at one single station with repeated earthquakes, and he and others that show that log-Normal distribution is a reasonable approach.

MR. TRIFUNAC: For what, for spectra, or for --

MR. TSAI: In his case, it's for PGA.

MR. TRIFUNAC: Yes, but that's a different thing.

MR. TSAI: And of course spectrum --

MR. TRIFUNAC: You are not looking at spectra here.

MR. TSAI: For spectra, at the moment, I am not aware of any independent study for that particular aspect, but from the data we have in terms of this spectra shape, we feel that log-Normal for the moment is a reasonable approach. Of course the dispersion are different between PGA and Spectra value. Different frequencies.

MR. TRIFUNAC: Would you use some other than log-Normal distribution if you were convinced that the log-Normal does not fit the data? I mean, the log-Normal does not feed the data when you take a large data sample. Wouldn't it be reasonable to suppose that it might not be the best thing to have a small data sample?

MR. TSAI: If the data size shows that trend, then of course, we need to consider that possibility.

DR. SEISS: If you didn't use normal, what would you use? What choices do yon have? Do you have enough data to get the actual distribution?

MR. TSAI: No. And we haven't tried that because
we're using state of the art approach, and up to this point, most work is done based on a normal approach.

DR. SEISS: Excuse me, before you take that down, I thought the last thing you said before we started asking questions was, if you chose the statistics, the lower value, there were two choices there.

MR. TSAI: Yes.

MR. SEISS: What was the basis for choosing the lower of the two values?

MR. TSAI: This one?

MR. SEISS: I thought yon said that, on the basis of what you'd done, you had decided to go ahead using the statistical basis rather than the regression curves?

MR. TSAI: That was our purpose, yes. At this point of the time. Of course, the final choice they will be based on the result from GSG in terms of magnitude, distance, and style of reporting.

MR. SEISS: I'm sorry, you have two methods and they give different answers by about ten percent. Why did you choose one?

MR. TSAI: Our preference -- I must say, our preference is not based on the number we got, but on the approach itself. We believe that the direct analysis of near-figure slow motion recordings give better representation than say you use regression results, which are weighted more for more distance, smaller earthquakes. And it's this great spectral points, they're based on that ground, not on the numbers. It just so happened that the numbers came out lower.

Now, I would then move to the numerical modeling studies, first where it explains the development of a method we call "semi-empirical simulation" method. And then I will show you how this method was calibrated, and then I will show you some of the preliminary accumulations.

Now, the purpose of the numerical simulations for this program are two-fold. First is to generate realistic oscillation time histories, for engineering analysis, basically to supplement the empirical records.

The second purpose is to perform sensitivity studies on ground motion characteristics at the side with respect to those characteristics, propagation and site properties, which may have some range of uncertainty and we need to perform the sensitivity, the various sensitivity studies.

Now, the result developed for this particular so far are actually three methods. We have first used an empirical green's function summation method, and the result of that was reported to you during the last meeting in terms of developing a sweep of time histories for earlier fragility analysis.

Since then, we have developed a semi-empirical simulation based on single source function and we found that there are some deficiencies in this method; therefore, we then moved to the current method, which uses multiple empirical source functions. And I will explain to you the reasons for this and some of the calibration without.

respect to different assumptions.

The last part is the Green's function, which sets forth the propagation effects between source and recording side. We used the so-called generalized ray method, which some of the samples were shown earlier by Dr. Savage.

Then, in this calculation, we need to have a crustal model, which is constrained by the site recordings, and after this we also compare the result with some more complete method, called frequency wave member integration method.

DR. KERR: What does it mean to say the crustal model is constrained by a site recording? Does it means depends upon?

MR. TSAI: Basically, checked with the site recordings. That's what I mean.

DR. KERR: Thank you.

MR. TSAI: Now, the need for using empirical source function is several fold. One is, as I mentioned earlier, the frequency dependent radiation pattern. And also there are scattering near the source which we cannot account for in a reasonably deterministic manner. And there are propagation complexities due to multi-pattern or reverberations.

In the case of our simulation, we used a simplified layer model. And there are irregularities within those layers which cannot deterministically be accounted for. And so we thought that one way of accounting for that would be just to use the rear records. And there are accumulations in between and near site scattering.

So those are the needs we consider justified to use our empirical source functions.

As for the segment size, I mentioned it to you earlier that it has to be small enough to meet the Fraunhoffer approximation.

On the other hand, they have to be large enough so that the rear record has enough signal to noise ratio. It is significantly above the noise level. And they allow for reliable estimate of the seismic moment, then use this moment to steer upward to our target moment. That translates into the number of segments we need to sum up.

And then that is the next one. And so we then check that estimate with some observational data and that is shown in the next one.

Typically, say, we are looking at this group and the size is a few kilometers. So that is the sub-element size we use in our simulation.

And the recordings we used which produced those recordings, that earthquake needs to be accurately located, and there are multiple recordings. And also they need to be distributed around the area so that they can be used to represent radiation at different areas.

And after this consideration, going to the available records, two sets of records were selected.

The first set consisted of 16 recordings from the 1979 Imperial Valley aftershock. The second set is 12 recordings of the 1983 Coalinga aftershock.

It so happened that this is a strike slip earthquake and this is a reverse of thrust earthquake.

DR. KERR: Is a barrier interval an interval over which the fault is expected to behave in the same way?

MR. TSAI: Yes. That referred to a specific model. This is called a barrier model, for the fault, and it hypothesizes that the fault, when it ruptures, it ruptures with certain spots, not uniformly across the fault or fault surveys. This is one of the models.

DR. KERR: For this model a barrier interval represents a sub-element?

MR. TSAI: We will get to that. It is reasonably equivalent to our sub-element size.

So after this selection we then compare with the, I think it is in the earlier slide, but I will just show the comparison.

This is the full amplitude spectrum, an average of 12 Coalinga aftershock records, 16 in solid lines, average of 16 Imperial Valley aftershock records in dotted lines. And down here are an average of three local earthquakes. Three earthquakes around the Diablo Canyon site. And what we are comparing is the slope of this spectrum which we are mainly concerned about the frequency range starting from roughly here to about here. In some cases it extends to 25 hertz. And one can see that the relative frequency content is quite comparable between what we selected and what actually observed although the ground motion level is one order of magnitude lower at the site than what we selected for our simulation.

DR. KERR: Excuse me. What you concluded was that the shape of this curve ought to be independent of acceleration based on these two sets of data?

MR. TSAI: The slope. Basically, the slope. The basis of frequency --

DR. KERR: I understand. From these data you concluded that the shape ought to be independent of acceleration or independent of acceleration over some range or what?

MR. TSAI: This two sets of records were used to represent our projection of ground motion at the site. But they are recorded somewhere else. And our concern is that if for some reason the frequency content here is deficient in high frequency --

DR. SIESS: Just a minute, please. It might help I think if you explain what your vertical scale is. That's not acceleration, is it?

DR. KERR: This is a spectra acceleration. At full amplitude.

DR. SIESS: Transform, not acceleration. It's a spectral content of acceleration?

MR. TSAI: Yes, that's right. Full year amplitude of the acceleration record.

DR. KERR: So that the attenuation is independent of frequency?

MR. TSAI: No.

DR. KERR: If you get a recording that is done away from the site, and therefore there has been a transmission over some distance, --

MR. TSAI: These are all very close recordings.

DR. KERR: Okay. I misunderstood you.

MR. TSAI: And what this means to show is that we are, we do want to have our simulation to produce a record whose frequency content can reproduce what is observed at the site.

DR. KERR: Isn't there in this the assumption that the frequency content is independent of the magnitude of the earthquake?

MR. TSAI: Yes. It is over here.

MR. TRIFUNAC: The problem I am referring to is that if you use the Imperial Valley aftershocks. I would suggest that they have a lot of surface wave image.

So even though the spectra shapes are consistent, the arrival times and the nature of the motion are simply quite inconsistent.

DR. TSAI: These aftershock records we checked, they contain relatively low surface waves, not like main shock. Second, surface waves normally are in the lower frequency part instead of at high frequencies.

MR. TRIFUNAC: I disagree totally with that.

MR. TSAI: This is an empirical way to show that observation method. This has been not modified in any fashion but just to show the whole records. If you do the full year transform, you have the amplitude versus the same manner to the site recordings.

MR. TRIFUNAC: That's fine. It's just unique.

DR. TSAI: That's true. I agree with that statement, yes.

DR. KERR: Aside from being unique, is it representative of what one expects it to eventually be used to represent? I mean, that's the important thing, it seems to me, not whether it's unique or not.

MR. TSAI: This is to show that we, the set of recordings we selected, the consistency with the site recordings in terms of relative frequency content.

MR. TRIFUNAC: But that's all.

DR. TSAI: Yes, that's all. And that is the nature of the empirical representation.

DR. SIESS: Is this the only measure of how good it is?

MR. TSAI: We then compare with the end result.

MR. TRIFUNAC: You won't be using this simulation?

MR. TSAI: I will show you without using those sets of simulations.

MR. TRIFUNAC: They just are the aspects which are sensitive to other aspects that you have not matched. Particularly, I think, you will be invoking coherence, and you will be using the consequences of this simulation as an input into structure interaction.

MR. TSAI: Yes. Yes that is addressed over here.

MR. TRIFUNAC: And those are very sensitive to the other aspects that are not constrained by the full amplitude.

MR. TSAI: Yes. The comparison of full amplitude is just one way of showing their consistency. There are, of course, many other ways to show their consistencies.

DR. SIESS: Are you going to tell us what they are?

MR. TSAI: For example, I show you the comparison between the simulated wave form and the theoretical prediction. Those are in terms of the amplitude.

MR. TRIFUNAC: But that is in the period range which is outside our interest here. Those are displacements in the long period range. And I think you agreed just a few moments ago we are talking about high frequencies.

MR. TSAI: No. The comparison is acceleration.

DR. SIESS: Why don't we go ahead and we'll see when we get to the end if you've covered it. If not, we'll come back to it.

MR. TSAI: I will show you what has been done. Of course, this has been discussed with the ground motion panel, NRC ground motion panel, and there are comments of different aspects of the approach.

MR. ROTHMAN: Could I add something to this? I think the reason that comparison was made was that after the last ground motion meeting which was early in the fall, some of our consultants questioned the fact that they were using aftershocks of the Imperial Valley earthquake, which is a thick, sedimentary site, to simulate motion at a rock site. And the question was whether the high frequencies would be attenuated due to the soft sediments in the Imperial Valley. I think what they are trying to demonstrate here is that the high frequency content is similar for those Imperial Valley earthquakes as it is for those recorded on the site. I believe that is all they are trying to show here, that they are not abnormally attenuating the high frequencies in the Imperial Valley.

DR. SIESS: Let's go on and get the whole story.

MR. TSAI: The treatment of fault heterogeneity we have used a hybrid treatment. That is, upon slip distribution, we used a non-uniform distribution, or time function. We determined to use a round function with a locally stochastic element defined by motion distribution and so forth. The rupture velocity also has that combination.

And this is shown as an example, for example, the Imperial Valley earthquake there are many, quite a few studies to determine the distribution of slip, amount of slip over the fault plane, and this is the distribution of strike slip component based on teleseismic recording and on slow motion recording and this is a combination of the two sets of observations. It shows that there is a pattern where the distribution of slip is non-uniform and over a relatively large scale.

So we used this pattern, then simplified it into discrete fault elements with different wave lengths. So this is how the strip distribution is described.

And for the slip time function, at a given location, the fault starts to slip. After a certain time it reaches its static displacement. In between, we allow for certain irregularities. And that is described as a Gaussian function.

DR. SIESS: The deviation from a straight line, or Gaussian? Is that what you mean?

MR. TSAI: Yes. And the rupture propagation starting from the new creation point propagates outward with a uniform velocity around locally for some variation and that variation runs between the beginning of the rupture to the end of the rupture across that sub-element or that sub-segment, fault segment. And that distribution is Gaussian distribution.

With regard to the Green's function, we used these velocity profiles in terms of P-wave, S-wave velocity profile for the region surrounding the site and then through the simulation calculate the theoretical Green's function and compare with the recordings at the site.

And these velocity profiles were derived basically on the seismic network data using P-wave arrivers. However, for ground motion simulation, S-wave is of importance. And so we need to check the S-wave velocities in terms of the velocity itself, in terms of the distribution, and so we simulate based on that model, here would be the P-wave velocity, S-wave motion and this is in terms of time, normalized time with a given velocity of 6.3 and here are distances, starting from zero up to 50 kilometers.

I'm sorry. This is vertical component.

MR. SEAVUZZO: Which is the S-wave and the P-wave there?

MR. TSAI: The first arrival is the P-wave and the second arrival is the S-wave. And this is a radio component. Again, P and S-wave.

Next one. This is the potential component on the S-wave. And I would like to show you for example, there are two distinct arrivers. One is the direct arriver, the second one is the reflection from the Franciscan interface. And these double holes were observed at the site recordings. One example is the site is over here. I will show you records from this earthquake recorded at the site.

This component is comparable to the potential component and one can see these double arrivers. The time interval is comparable to the predicted value. Also, we compared the theoretical model S minus P arrival times as function of distance versus the observed one. And here the solid symbols represent observed values whereas the open symbols are theoretical predictions for two fault depths. One is five and one is nine. And you can see they follow each other very closely.

This shows that the cluster velocity profiles we used for our simulation is consistent with the available observations at the site.

DR. SIESS: How would you like a break, Mr. Tsai?

MR. TSAI: Yes. I need a break. Thank you.

DR. SIESS: We will come back at 4:15.

(Whereupon, a brief recess was taken.)

DR. SIESS: You may proceed, Mr. Tsai.

MR. TSAI: This development of the method we then carried the method with actual recordings from the 1979 Imperial Valley earthquake in terms of the fault records, time histories, the PGA values and response spectrum.

And the record we will be comparing will be around the central array.

In this calibration we used the crustal velocity profiles of the area and used the aftershock recordings as empirical source functions. And here is the result.

On the left side is the simulation. On the right side is the observed records. In terms of this horizontal axis, is time and the scale is over here. This is the distance from the fault trace, on one side of the fault and on the other side of the fault. There are multiple recordings at different distances and for 140 degree component. That is parallel to the fault.

I can see here two arrivers. One is the arriver from the high slip location. The other line would be the predicted arriver from the closest point of the fault. And you can see the simulations to reproduce the observed pause as it predicted.

Now, we also compare the PIG values as function of distance. On this figure this is the distance of 10 kilometers and this is PGA in terms of GE. The symbol down here, observed and simulated. And you can see there are a mixture between simulations and observed and we believe that as a whole the simulations do reproduce what is observed. It is not biased on the lower side or on the higher side systematically.

And we also compare the response spectrum. Over here is the particular station components observed and simulated and here is the acceleration response spectrum, for frequency. Above about two hertz the simulations follow closely the observed.

Another station on the other side is in the viewgraph, but I will not show it here.

Next I will show you some of the simulations we made for the site.

MR. TRIFUNAC: Can I ask a question? In this comparison you are using aftershocks of Imperial Valley earthquake to simulate the main event of the Imperial Valley earthquake.

MR. TSAI: Yes.

MR. TRIFUNAC: Now, because Diablo is in such a different geologic environment, wouldn't it be more fair -- I don't know what's a better word than fair -- to compare for example your ability to simulate let us say by accelerogram during San Fernando earthquake using Imperial Valley data? Or wouldn't it be more honest to take the aftershocks of for example San Fernando and simulate Imperial Valley? Because you have ideal situation, and you don't have that in reality. Do you understand the question?

MR. TSAI: Yes. We undertake these comparisons because there are multiple recordings.1

Now, after the July workshop with NRC panel, they asked us to do so-called blind tests. That is, with field recordings and less-known fault natures, to do the comparisons. And we are in the process of doing that.

DR. SIESS: Bill?

DR. KERR: I guess you have answered part of my question. It seems to me -- well, let me ask a question. What you have done has demonstrated to your satisfaction that you can take data from a number of earthquakes and can put together a model that will simulate that data? Now, are you going to go beyond that and say I can also predict what an earthquake that has not yet occurred will produce?

MR. TSAI: This is our motivation of doing this, using this method to apply to the Diablo Canyon, which we won't have record at least for some time of that ground motion.

DR. KERR: But that says then that you know enough about earthquakes that will occur to assume that they are going to be like earthquakes that have occurred, the data for which are still, I gather, rather sparse.

MR. TSAI: Yes. Or no, to some extent. That is the, the working assumption here really is that what occurred at other places will occur at our site, to some extent, but there will be distinct characteristics in the ground motion which belong to the site.

And that is the basis for our undertaking numerical simulations. Because if we use only empirical ground motions which are recorded at other locations for other earthquakes and based on the first working assumption, we would say okay, those, whatever were observed as a group, we will be expecting that at our site.

But then we need to take account, into account the site specific information. And that is where we are using the recordings at the site to compare with what has been used as an input for the simulation so that we introduce site specific information in that process.

But before that, we test the procedure at other locations where similar information or input, and produce the simulations to compare with actual recordings at those places to show the adequacy of the simulation procedure.

DR. KERR: I may be missing some of what you have done, I'm sure. But it appears to me that you have built a model that has a great many what I would call fitting parameters involved in it, and that those fitting parameters you have arrived at by using existing data.

And as a result of that you have been able to generate a model which will regenerate the data that you have used to build it. And that takes a good bit of doing, and is an accomplishment, and will permit you to simulate earthquakes that have already occurred.

That does not give me a great deal of confidence that you can simulate future earthquakes, unless you are convinced that there will be nothing unusual about future earthquakes that has not already been observed.

DR. TSAI: Yes. That is a general criticism of the simulation method. There are just so many parameters involved which one can adjust. But in our approach, we are doing this mainly out of necessity and with the parameters which can be constrained we use what is known to constrain them and then to compare the results to understand or investigate the deficiency or some bias of that. And accordingly, when we make applications of the simulation result, we are aware of those limitations and we don't step over those limitations. And as an example, you can see the comparison earlier. Where is the Imperial Valley?

(Pause)

MR. TSAI: For example, this, the spectra acceleration would be our product for engineering applications. Now, if you compare the observed and simulated, we see that for frequency above around two hertz, they are relatively close to each other whereas at low frequency the simulation systematically is lower than the observed. And we know that there are deficiencies in our low frequency, in the low frequency range from our simulations. And so if applications require those low frequency components, then the simulations would not be appropriate.

DR. KERR: Thank you.

MR. TSAI: For our preliminary simulation, we simulate 120 cases for strike slip and so forth and out of this 120 cases we then selected 14 for the fragility analysis. We also come back to the sensitivity study on the 14 and the comparison with empirical result.

This is a summary of the 120 cases. Three types of fault, each has 40 cases and then with different combinations of location, rupture modes and source functions. Some of them use Imperial Valley, some of them use Coalinga and the simulations include three components of accelerations.

This is the geometry of the faults with respect to site. This is the site. We assume vertical strike slip fault, 60 degrees inclined oblique fault and 35 degrees inclined reverse fault.

This is the train projection. The site is over here. If you project on the ground surface, the strike slip would be a line whereas oblique would extend to this and reverse would extend to the East of the site. In other words, the site will be right above the projection in the projection of the fault on the ground surface.

MR. EBERSOLE: I wonder if you could clarify something for me, as completely ignorant on some of the technical aspects of this.

MR. TSAI: Yes.

MR. EBERSOLE: The spectral distribution at the source, at the origin, is one thing.

MR. TSAI: Yes.

MR. EBERSOLE: Are there substantial differences in the spectral distribution at the receiver, and do your calculation techniques allow for that to be calculated?

MR. TSAI: For the moment, we only distinguish between soil and rock material. Now, the irregularities under the site of even rock you have quite complicated structures. We have not done that yet. We have instruments I will show you later located at different locations around the plant and that hopefully, empirically, we can show --

MR. EBERSOLE: In general, you lose a higher amount of the higher frequencies, don't you, as you translate it through the strata?

MR. TSAI: Yes. Generally.

MR. TRIFUNAC: In running these three models, strike slip, oblique and reverse, are you using the same aftershock data as Greene's functions or different ones or what?

MR. TSAI: No, two. Two.

MR. TRIFUNAC: Which are those two?

MR. TSAI: It's randomness, like there were combinations, 40 of them, and so --

MR. TRIFUNAC: Well, just, are they still Imperial Valley aftershock data?

MR. TSAI: No, no. Coalinga and Imperial Valley. I believe they are about equal in number.

MR. TRIFUNAC: Are you are flip-flopping the two for these three geometrical cases?

MR. TSAI: Yes. All of them are mixed. Yes. And this is the dimension of the fault. For strike slip it is 48 kilometers by 9 kilometers; for oblique it is more to the square and for reverse it is 18 to 20, and the segment size is 3 by 4 kilometers.

One example of the simulation shows here. It is an oblique fault in the rupture, northward and using Coalinga source functions. And you can see the two horizontal and the vertical.

How, because of the time I would just show you the result of 120 cases. The median response spectrum, 84th percentile and 16th percentile for the east-west component at the site.

Now, this table summarized those 40 cases, strike slip, oblique and reverse. On top of here is the PGA value and over here is the spectral value averaged over these frequency bands. And what one sees is that the average of strike slip is .91 versus 1.13, normalized to one.

And over here, the peak value is about the same differences. The same ratios.

We also show the vertical versus horizontal component ratio.

So the average of the 120 cases we compare with regression result and they are quite comparable.

MR. TRIFUNAC: Excuse me. Am I correct in interpreting the time functions as indicating that your aftershocks that you use as empirical means functions are perhaps deficient in long period energy?

MR. TSAI: Yes. Yes.

MR. TRIFUNAC: Have you gotten to that situation because you had too drastic a low pass filter, because the data was of more amplitude and so it was getting in the noise or do you think there was just no energy generated at these periods?

MR. TSAI: I think it is simply no energy in the original records.

MR. TRIFUNAC: You could have just added some long period noise to get around that because the visual comparison would have been much better.

MR. TSAI: Well, that is not our intention.

MR. TRIFUNAC: But the full-year transform is non-unique anyway.

MR. TSAI: Yes. The simulations really are geared to our needs and our needs are for frequency about three, two or three hertz. And we are really not doing the simulations, for example, weaker by weaker, to try to reproduce what was observed.

And that has been done by other researchers in comparing the velocity wave forms, displaced wave forms.

What we have done new here is to simulate in terms of acceleration. And that is in the high frequency range.

MR. TRIFUNAC: Yes, but you are doing all of this I suppose because somebody down the line after you are done wants to use this in terms of time input.

MR. TSAI: Yes.

MR. TRIFUNAC: If we were concerned only with full year transform or spectral acceleration we wouldn't be looking at these details.

So it seems to me that one's strongest motivation for doing all of this that you are doing is to get a time function that is physically meaningful.

MR. TSAI: That's right. Yes. That is physically justified. And I show you the justifications for our simulation procedure and then at the end we take the result in terms of primary engineering characteristics which are PIG values, time histories, spectral acceleration, acceleration spectra. And those are three characteristics in the ground motion which are considered by engineering applications or engineering community in general.

MR. TRIFUNAC: That's agreed. But my point is merely this. That I see enormous effort here which I interpret to be motivated by the need to have a time function which is physically meaningful for the site.

MR. TSAI: Yes.

MR. TRIFUNAC: And yet you say that the constraints on coming up with that time function are really those that you just enumerated but using those constraints I can produce equally good time functions without a hundredth of the effort that has gone into this by just taking some random combinations on these programs I have. You see what my point is. I mean, if you postulate only those constraints that you have, there is such tremendous non-uniqueness that it is a question whether the whole effort is worthwhile.

MR. TSAI: Yes.

MR. TRIFUNAC: You could get at it and get time functions without doing all of this and they would still take all the constraints that you have.

MR. TSAI: Then nobody will believe it, you see. This has this physical constraint and physical justification. that is, if we believe what seismologists say is correct, then I believe that is more believable than say you just go in and change all those parameters and produce, simulate good records.

DR. KERR: But it seems to me that you have shown that your model is plausible.

MR. TSAI: Yes.

DR. KERR: But I don't see that you have shown that it is unique.

MR. TSAI: It is not unique. It is definitely not unique. Yes.

Now, I will go to this part, assessment of spatial incoherence. And the consideration behind that is that we have a site which is very close to an extended source and the waves coming from different parts of that source will have different arrival times at the site even at two very closely spaced points, as illustrated here, and that will cause the incoherence in ground motion at two points of the foundation of a structure.

Besides that, there are effects coming from paths in the site. And so to make an estimate of contributions from the two parts, we separate them in terms of source and wave passage as a factor and site and paths as another factor and combine the two to get the overall spatial incoherence.

And those two factors may be estimated for the site and path from a point source or a smaller event, whereas for the extended source impact we estimate that from the simulation before that we compare this result of this process with real records. And that comparison is then with a set of recordings from Imperial Valley main shock and aftershock recordings at different arrays.

And I will skip this.

This is a map showing Imperial earthquake main shock is located here and this is the map, rupture of the Imperial bowl. The array is located over here. There are six instruments with different spacings and I will just show examples between this one and this one.

MR. EBERSOLE: Tell me, up to now, are you looking at Diablo Canyon as a point receiver, and then are you going to later talk about it as a distributed receiver?

MR. TSAI: Yes. First we make the single point estimation and then allow for effect of the spatial incoherence as an adjustment.

MR. EBERSOLE: Okay.

MR. TSAI: So this is the combined coherence of horizontal S-wave from simulation of the rupture and from observation of aftershock recordings. So those are two parts. One is an extended source effect and then the path and site effect. And this is the combined coherence function as a function of separations, 300 meters here, for different frequencies. 3.5, 7.5 and 15 hertz. And one sees here that the coherency decreased with distance and with increasing frequency.

And this is what is actually observed from the main shock recordings, and so if one overlays the previous graph with this one, they almost overlap on each other. And the previous figure shows the simulations for the main shock combined with what is observed from the aftershock recording. And this is the real one. So that comparison does give us some confidence of the procedure we are using.

Now, at the site, when we apply that, we won't have the extended source recordings. We have to simulate that.

However, we do have some point source recordings. and I will show you one example of this. This is the site during the cluster profiling earlier described by Dr. Savage. We have a land face shot here and a series of air gun shots over here.

We have deployed quite a number of instruments around the site and here is an example of a pair between two points which are about 300 meters apart. And these are the recordings at different frequency bands and the coherent functions.

And do[illegible]e shows the result of those three bands.

MR. EBERSOLE: Are you talking about shots that are fired coincidentally?

MR. TSAI: No. Planned.

MR. EBERSOLE: Well, do you ever fire shots coincidentally and pick up the summation of them at a distant point?

MR. TSAI: No, we haven't done that, because the land shot is to be cleared. And just as part of the large program.

And the air gun shot is fired by the ship which is constantly moving.

So for simultaneous shots we would need two ships or more ships.

MR. EBERSOLE: Oh, sure.

MR. TSAI: Yes.

This is the result by combining simulations for an extended rupture along the Hosgri with the observed coherence function from the land shots and air gun shots combined, and you can see the coherence function again decreased with separation and with increase in frequencies.

This is the model which has parameters determined as a function for these coherence functions. And so this part of this result has been provided to SSI group for preliminary studies of the effect of incoherence.

MR. TRIFUNAC: Excuse me. Can I ask a question?

MR. TSAI: Sure.

MR. TRIFUNAC: I think that this coherence depends on a lot of things which we didn't mention here, but would you agree that looking at the shot data, you are looking essentially at what horizontal energy arrival at various locations throughout the plant site? Is that a fair statement? The source is basically on the surface. That is what I am getting at.

MR. TSAI: The first part is -- yes, that's the shot, basically, is close to the surface whereas the earthquake --

MR. TRIFUNAC: I didn't get to the earthquake yet. But we agree on that?

MR.TSAI: Yes.

MR. TRIFUNAC: We go to Imperial Valley for which you also did show some data. And Imperial Valley of course is a sedimentary basin and so it has all the features that are required for a horizontal wave guide as well. So that there we also have a similar situation, that energy travels mainly horizontally.

MR. TSAI: Well, in terms of Imperial Valley, basically the wave approached the site almost vertically. Now, the land shot, although the source is shallow, but because of the distance, the wave is not necessarily coming directly. The direct wave is not the first arriver but rather the refracted wave. And that is, we have done some particle orbital studies to show that they are basically approaching the receiver in a rather stiff incidence angle.

MR. TRIFUNAC: Yes. Nevertheless, you are not calculating coherence on the basis of one pulse of a rifle. You are calculating coherence on the basis of the whole function.

MR. TSAI: Yes.

MR. TRIFUNAC: And so in the case of your explosions, the source is almost on the surface, and the bulk of energy goes to the horizontal wave guide even though it is a rock site. Agreed?

MR. TSAI: Yes.

MR. TRIFUNAC: And in the Imperial Valley, the similar situation applies. The arrivals may be nearly vertical, but once they get into the soft surface layers, they keep going that way.

So you have, I suppose, essentially a horizontally propagating wave.

Now, I don't understand how you can apply that conclusion or observation to a case which you think is a reversed fault which it as some depth where the energy comes vertically directly from the source up to your site, where the face velocity of your planes of arrivals is infinite. Do you understand my question?

MR. TSAI: Well, yes, but I don't agree with you that waves are basically coming from the top layers. They are coming, going down and then up. They may be trapped in the surface layer close to the site but not in between the site and source. And that is, I think it is very essential to this approach.

MR. TRIFUNAC: The question really boils down to what is the ground motion consisting of. Where is the energy in strong ground motion? Now, if you can prove that the energy in strong ground motion is all body waves, then you have the point. But if somebody else can prove that the energy in strong ground shaking, in the case of Imperial Valley, is essentially 80, 90 percent, whatever, surface waves, or that similarly may be ray waves in case of an explosion, you don't have the point. So I think that is the issue you have to consider.

MR. TSAI: Yes. I am aware of that particular question, and the comparison between Imperial Valley main shocks, I show you, for example array 5 and 8, between observations and simulations. Those basically consisted of body waves, because in our simulation, the generalized wave theory only accounts for body waves. And the comparison for example, the two lines, the broken lines and solid lines, i particular the dashed line shows the predicted arrivers and the observed arrivers, were they are strong, they are both strong. Not only the Imperial waves but the time arrival timewise. And those are two very strong seismology constraints.

MR. TRIFUNAC: They are pulses, though. In between them there is a tremendous amount of wave formation. So if you look from the point of view of energy, those pulses, though they are visible to your educated eye, they are just parts of the whole picture. Really, they are just 10 percent of the energy that you see.

MR. TRIFUNAC: For a seismologist, it is not satisfactory. But for engineers -- and I am converting myself from a seismologist to an engineer requirement -- we are looking at the peak values and looking at the behavior of the ground motion around that peak value. I conclude that the reproduced or simulated wave forms do provide or contain the essential characteristics. Now, as a seismologist, one would like to see when he reproduced the wave, where the observed has a peak, you reproduce a peak, there is a trough, you reproduce a trough. But in this case, that is not, I don't think it is an essential requirement for this particular application. I am not saying --

MR. TRIFUNAC: You have to be careful. Because an engineer is going to say that a seismologist colleague of his has proved that incoherence allows him to do some things such as TAU effects or things that go along with that, and he is just going to quote you or another seismologist that they have demonstrated that this is the case. So you have to keep that in mind.

MR. TSAI: Yes. Yes. This, for example, the observation of Imperial Valley main shock, which has nothing to do with simulations, you see the incoherence effect.

In terms of increasing distance, increasing frequencies, those are irregardless of simulations. I think that anybody looking at that observation will conclude that there are spatial incoherences in there.

MR. TRIFUNAC: But Imperial Valley is a soft site, and I wish you plotted incoherence with this wave length rather than just the frequency. Diablo is a stiff site and so the ratio of the wave lengths in question is quite significant.

MR. TSAI: Yes. That is exactly why we need to have recordings at the site. And that is, part of that we have corrected from a shallow source, a small source.

Now, we have in store a number of additional free field accelerographs at the site. This is a larger map showing previously installed at three free field sites. Now, we have installed one on top of the overlook. So tomorrow when you go to the site if you look toward the back of the plant, on top of here, a green hut, that will be the house for the instrument.

MR. TSAI: Now closer to the plant we have in this particular location, in the open space, we have five of them distributed in a cross shape with a dimension of the basemat.

We also have instruments located around the site -- around the plant larger separations. And with this additionally the croi [ph] instruments which are solid state memory based.

We hope that if there is an earthquake occur even smaller in the nearby area you will be able to correct records which are of value to this program.

And we also -- for the last few months in the existing supplementary system which as three free field instrument; and 52 channels inside the plant.

We install a diarp unit in it which allow us to interrogate the system from a remote location using modems. And we're doing that at my office and at the plant.

DR. SIESS: Just how big an earthquake would you like to have?

(Laughter)

DR. TSAI: Well, in the past a magnitude 2.4 six kilometer from the plant triggered the instrument. Now at 30 kilometer a magnitude around five triggered the system, which produced up to 4 G percent per motion.
Okay. I now will quickly summarize what's provided for the engineering analysis, one is for fragility consistent of first

starts of empirical time histories, which I reported to you in last meeting except that I -- we have aided one records from the Canadian earthquake of 1985.

Now in addition to that we have provided 14 sets of simulated time histories based on the 120 cases simulation; and those consist of different -- four types of different rupture mode.

This is -- in the high melt is copies showing the 12 empirical records. This is the new addition. And this table shows the simulated time histories. Five of them are strike slip fold; seven of them are oblique fold; and two of them are reverse fold.

With source function from Coalinga and from Imperial Valley as a mixture. And they're all three company records. Now the -- this is spectrum of that time and period -- empirical records; and this is an average of the 14 records -- median 84th percentile and 16th percentile of the two -- average of the two horizontal components.

They are comparable -- if you over -- one over the other. Now for exercise analysis, we've provided site specific acceleration response spectrum for a median. They were in shape of three bentin values, also vertical component was provided.

Then we selected three pendulate time histories to match -- for SSI people to match the spectrum. And this is the median astorite in response spectrum of three bentins provided, shown in a graph form.

I think that concludes my presentation. Thank you very much.

DR. SIESS: Any further questions?

(Pause)

DR. SIESS: Thank you, sir.

DR. TSAI: Thank you.

DR. SIESS: I'd now like to ask the NRC staff for any comments they may have on what we've heard so far. I forgot to ask them at the end of the GSG presentation. So this will cover both the geology sized model -- the geotechnical and the ground motion work.

And I'd like to have staff comments and the status of their review.

MR. ROTHMAN: The staff has routinely, after each workshop or meeting, or report that's been submitted, given comments from the staff review; is under consultants about the PG&E.

Very often the comments were very similar to the ones that the ACRS has made today, that Dr. Trifunac has made about the -- as far as the ground motion simulation to suitability of using imperial valley aftershocks; and then matching it to the imperial valley earthquake rather than using some other earthquake to try and match.

In general, comments have been in -- have been implemented into the program. We haven't seen the results of this work yet. It has been implemented into the program. Our last meetings on some of these things were last summer and early fall.

We haven't had any meetings on geology or geophysics since then. In general so far -- except for these types of comments we've been fairly happy with the way the program has been progressing.

No, we haven't seen anything major that we disagree with. We have comments on the amount of oblique or reverse faulting that's being simulated.

Possibly we think that more should be used in the ground motion.

DR. SIESS: More should be what?

MR. ROTHMAN: More reverse component in the ground motion studies rather than --

DR. SIESS: And that gives a higher --

MR. ROTHMAN: Possibly higher. We've had to see what happens if you increase it.

DR. SIESS: Didn't I read something recently that indicated the reverse stress fault was just 20 percent more than the strike slip?

MR. ROTHMAN: Well, there's some researchers that are claiming maybe as high as 50 percent more. I mean it depends on whose work you're looking at.

So we would like to see some sensitivity studies don't on this. We've also asked for on -- because in the modeling study, if there are so many parameters that can be varied we vest for sensitivity studies on some of these parameters to see how they do effect the results to see what the assumptions that are made.

As far as the geology -- geophysics part of the program, we've had some independent work being done by University of Nevada and the U.S. Geological Survey.

University of Nevada has been doing field mapping; they've been looking at area photos. In general they agree that his most syn-form -- or snyclinorium, or has -- is rising; but it has been rising without defama -- internal defamation.

The capability of the Los Osos fault and the Wilmar fault have been agreed with. The fact that the Edna fault is not capable; has been basically accepted by the staff and its consultants.

There is some question about the ability of an earthquake to rupture through from the San Simeon fault on to the Hosgri.

The fact that there is a step there on the surface is acknowledged. But what the connection is at depth we don't know yet, so that's a question whether we could rupture through.

The nature of the connections of Los Osos, the Casmalia, of Pecho and other faults to the Hosgri has not been determined yet. Those are the kinds of questions we have been asking a lot of.

Whether faulting on the Hosgri could cause motion on some of these subsidiary faults, just what the nature of the connections are, whether they are splays off the fault, whether they are faults that are interrupted by the Hosgri, or whether they segment the Hosgri. Those questions have to be considered.

DR. SEISS: How much difference does it make in the site specific spectrum if the Hosgri connects up to the San Simeon?

MR. ROTHMAN: Well, what that does, is it gives you possibly a larger magnitude earthquake, which you would have to evaluate, because the magnitude the earthquake made would depend on the rupture length, the function of the rupture length.

If you could rupture through say, 100 kilometers rather than 50 you might increase the magnitude by quite a bit. That's something that has to be addressed.

MR. TRIFUNAC: But what difference does it make?

MR. ROTHMAN: I don't know the exact numbers. If you can could cause a higher magnitude, what the absolute number--

DR. SEISS: If you have a break on the San Simeon, which is a pretty good distance from the site, can you just add the two?

MR. ROTHMAN: Well there are, actually we have programs going on right now trying to relate magnitudes to the length of rupture, and the amount the displacement. The PG&E has been doing some studies on that, and also our consultants have been looking at a world wide data base to see what the relationships are between amount of slip, rupture length and magnitude.

DR. SEISS: That's empirical.

MR. ROTHMAN: Based on, yes. Based on knowing the faults.

DR. SEISS: This kind of study that Dr. Tsai has shown us, can that be used to show that the effect is through the San Simeon? What assumptions do you have to make about the timing of the rupture, whether it starts up there and moves down, or starts down on the Hosgri and moves up.

MR. ROTHMAN: You could possibly model that.

MR. TRIFUNAC: But don't you know this ahead of time? I mean, you know you can just ask these people to go on and on and on.

MR. ROTHMAN: Well, we're not, no. We're not--

MR. TRIFUNAC: We don't have to solve this --, which is finished. You don't have to solve the problem in general, just have a picture here, which has a site, which has a Hosgri here in San Simeon. I mean, isn't the answer almost obvious, what it should be?

MR. ROTHMAN: Not obvious to me, no. It is not obvious to me.

DR. SEISS: It won't go on and on. Like that, you know, like that condition. There is a cut off point. Yes John?

MR. MAXWELL: I just wonder why you worry about these small faults. I don't think anybody thinks there is any movement on them that would exceed the, would cause any significant damage at the plant, would it?

MR. ROTHMAN: At the present time, no, we don't.

MR. MAXWELL: It would seem rather non essential.

MR. ROTHMAN: And if it is considered non essential, I'm sure PG&E will make that argument to us. And then we will take that into consideration.

MR. MAXWELL: Well, but turn the thing around, and just as an observer, do you see any way they could be essential?

MR. ROTHMAN: Well, what we know about it now, no. Not right now. That's why I've said from the beginning, right now we don't see anything that would supersede the Hosgri as being the dominant contributor to the plant.

MR. MAXWELL: You don't, but you don't feel they have necessarily eliminated the fault, the possibility of faults closer, or stronger?

MR. ROTHMAN: No.

MR. MAXWELL: To the plant site?

MR. ROTHMAN: I think we have identified the --, the Los Osos, the St. Luis Bay fault, the Wilmar, those are probably the closest capable faults. What we know now. And they are minor players right now.

The question we come to is the junction between these faults and the Hosgri, are they segments in the Hosgri? The Hosgri would be segmented, thus limiting the magnitude. That's something that PG&E is looking at.

Limiting the length of rupture. These are the kinds of things I think that they are looking at, and it is going to become an issue on establishing the magnitude of the re-analysis, or what you would call it.

DR. SEISS: Now at this point, PG&E has developed some spectra and some time histories that they are turning over to the fragilities people, are going to be incorporated, the PRAs. Do you see anything that could change those significantly or knowingly?

MR. ROTHMAN: We've had some--

DR. SEISS: We may not know what significantly is until we have seen the results of the fragility studies and the PRA.

MR. ROTHMAN: We've had some concerns on how these various ground motion estimates are going to be used in the analysis, and we have felt that this may be a weak point in the study that is interfaced between ground motion and engineering analysis and soil structure interaction.

And we have set up a meeting to take place in May in which we are going to have all of our ground motion consultants, our PRA consultants with the fragility consultants and the soil structure interaction people, and PG&Es ground motion and engineering people to sit down and discuss just how the, what is going to be used to simulate the ground motion and how it is going to be applied in the plant.

DR. SEISS: If the PRA using these values showed that the plant had an extremely low probability of core melt, or that it could take a 50 percent greater input before it caused any damage, would you have any concern with these values?

MR. ROTHMAN: We have not as yet established the magnitude of the earthquake to be used or for the ground motion studies.

DR. SEISS: I know that.

MR. ROTHMAN: If it showed that the ground motion would be 50 percent higher than the--

DR. SEISS: You could show that it could withstand the ground motion spectra increase by 50 percent.

MR. TRIFUNAC: Not likely.

MR. ROTHMAN: I don't think you are going to see--

the incoherency review spectra.

MR. TRIFUNAC: That's a separate issue. I am asking you a simple question. That is -- buildings there, it's a free field side. What do you consider an acceptable procedure to convince you that this is okay to proceed with the design? There must be something, otherwise if it is not specific there is nothing we can see come to the end. You understand my question?

MR. ROTHMAN: No, I don't understand your question.

DR. SEISS: No, let me. As I recall, the license condition simply says this shall be done. It didn't say anything about what we're going to do about it when we get through.

MR. ROTHMAN: Well, I think it does. It says in the fault part of the license condition, it says that these motions will be accessed against the seismic margins as necessary, using deterministic and probabalistic methods. It was left very general.

DR. SEISS: That's very, very general.

MR. ROTHMAN: That's right. Well, that's the way the condition was written.

DR. SEISS: What does the staff expect to do after they've gotten the final report on this in July 1989?

MR. ROTHMAN: We'll write a review report, something equivalent to an SER on this.

DR. SEISS: Oh, I know it may not be likely, but I'm just trying to see.

MR. ROTHMAN: I don't see that. I couldn't answer that.

DR. SEISS: It's a shame we can't start off with the PRA and back up on these things, we may find it. Any other questions? Any other comments? Personally, I'll go with the question. Yes?

MR. TRIFUNAC: I have a question for the NRC people.

DR. SEISS: All right.

MR. TRIFUNAC: I still don't understand what we have said as a decision basis, as a decision maker. Are you going to ask them to simulate some scenarios and come up with different spectra at the site? Are you going to take some kind of representative spectrum and work with that or are they going to combine this into some kind of informative spectrum type and use that to go on? What is the ultimate accepting procedure that you will consider?

MR. ROTHMAN: Well, we are trying to use a multi methodology. We are looking at the empirical ground motion to see what that tells us about the estimates that were made. We are looking at the numerical modeling to see how that compares with the Hosgri reanalysis.

We are going to look at how the saw structure interaction spectra corresponds to the tall review spectra and

DR. SEISS: What will be the basis for your evaluation of part 100, of severe accident safety goal, what will you compare this with?

MR. ROTHMAN: We will compare it against what the existing, what the re-analysis that was done during the Hosgri used to see if it exceeds that, and if it does exceed it then we will have to look at the comparisons of the, implant comparisons, to see if there is anything. Weak links.

DR. SEISS: So if anything, the PRA won't be used because there was no probabalistic basis for the design of this plant.

MR. ROTHMAN: Well, that will give us a handle for looking at weak links within the plant systems that might have to, that might contribute significantly to risk.

DR. SEISS: It sounds like the IPE followed with severe ax-- policy.

MR. ROTHMAN: I'm not familiar with that, so.

DR. SEISS: That's the problem with the staff, he had three good -- analyzing it (laughter).

MR. ROTHMAN: Possibly I'd like to speak to people that are reviewing the PRA.

DR. KERR: No seriously, if you're going to be talking about severe accidents, which is what would occur if one had a major earthquake, shouldn't you be familiar with what is being done about severe accidents by the NRC?

MR. BAGCHI: Right now the IPE has none going to external events.

DR. SEISS: That's temporary.

DR. KERR: I am sorry, it is a clearly stated policy of the Commission to consider external events.

MR. BAGCHI: A generic state being prepared in that we monitor the external events.

DR. SEISS: You're talking about the IPE, Dr. Kerr is talking the severe accident policy statement. The IPE is only a partial response by the staff to the Commission's severe accident policy statement.

MR. BAGCHI: You're right.

DR. SEISS: It's just what you'll be hearing for the next six months.

MR. BAGCHI: The policy statement is going to include external events, and we are going to have to consider that.

DR. SEISS: But is this going to be considered under the severe accident policy or is it going to go back and look at it under the design basis.

MR. BAGCHI: I personally suspect that it is so close to meeting the severe accident policy, and it certainly is going to encompass all the earthquakes that are likely to cause severe accident type of scenario, that we are going to end up with something more than what Park 100 would require.

MR. EBERSOLE: Well I thought I heard that you were obligated to consider the damage to the containment in the context that it may in itself initiate a core melt. Whether or not you need the containment, it may trigger a core melt by failing. And won't that really cover the sever accident policy?

MR. BAGCHI: I think it will cover the severe accident. If the accident's condition really does not let us get into that, some of these things would have to be worked out.

DR. KERR: Is it accurate to say that at this time you do not know how you will decide what PG&E finally reports as acceptable?

MR. BAGCHI: It is fair to say that we don't know what vulnerabilities are going to be like. It depends very much on the vulnerabilities are going to be.

DR. KERR: That's not the question I asked. I'm asking how you will decide? Not what will occur, but how you will decide whether what they come up with is acceptable? You must, at some point, establish some criteria. You may not have done so now, but at some point you will have to, and at this point you have not established the criteria for acceptance. Is that an accurate statement?

MR. BAGCHI: Yes, that's fair

DR. KERR: What sort of mechanism are you going to use to establish those criteria?

MR. BAGCHI: It would have to be the PRA based. Whether or not it has, how they think that is the plant safety. Whether or not the margins are available.

DR. KERR: What margins are required by existing regulations?

DR. SEISS: That's the problem, because you cannot go back to Part 100 because the licensing condition said adequacy of seismic margins. And of course Part 100, the original design basis did not address margins. It was the deterministic approach calculate the stresses, compare them with the log.

So as soon as you bring in the idea of margins, you are right back to the Maine Yankee, seismic margin study and any other seismic margin study. And this is just a very elaborate seismic margin study.

MR. BAGCHI: That's correct.

MR. EBERSOLE: It occurs to me if you made it, you didn't know when you went into Maine Yankee what was going to be acceptable, right?

MR. BAGCHI: That's correct.

MR. EBERSOLE: It occurs to me if you are looking at damage to the containment, just the context of that precipitating a core melt, you may miss the fact, in the severe accident case you have got to have an intact containment with the same release rate that it is supposed to have.

MR. BAGCHI: Based on what I understand, they are looking into the containment at pretty high levels, structural levels, for failure.

MR. EBERSOLE: And I'm talking about no, not just damage.

DR. SEISS: Containment systems I think is a better word.

MR. BAGCHI: Yes, that's a better word to say.

DR. SEISS: Containment structure itself I wouldn't worry about for more than a couple of seconds. But other aspects to containment than the pressure containing boundary.

MR. BAGCHI: I suspect when we get into the review, PRA review, we are going to look at the containment system.

DR. KERR: It would seem to me that at some point soon you should be giving some thought to the criteria that you are going to use to make a decision. Surely it won't just be ad hoc.

DR. SEISS: I think after they get there they will know. They will look at it and decide whether they are comfortable with it. We will look at it and decide whether we are comfortable with it, I'm sure PG&E will look at it and decide whether they are comfortable with it. They've got a fair investment down there.

MR. BAGCHI: We say we don't have guidance from Part 100, we certainly don't have little guidance from the policy statement.

DR. SEISS: You don't even know what did it with the policy statement.

MR. BAGCHI: It's a very hard thing.

DR. KERR: Indeed it is, and for that reason it seems to me that we should start giving some thought to it. I don't pretend it's simple, I don't think it is. But it is necessary.

DR. SEISS: For example, I don't even know what criteria the staff used to accept the Maine Yankee seismic margin study. I don't even know whether that's a precedent or not. You look at that and nobody could really tell us, you know, what was the basis for accepting it, much less the legal basis. I'd like to stay out of that.

The seismic margins end up being a feeling. How comfortable you are with a margin. It's not something you could say it's go or no go. Nobody has defined what is an acceptable seismic margin.

MR. BAGCHI: Going back to Maine Yankee though, there were some staff studies which indicated that the SASSI value should be somewhere around .18 G, and with the seismic margin study the HCLPF value came out to be pretty high.

DR. SEISS: After you fixed up the take. What was the take, .18? And you weren't comfortable with it.

MR. BAGCHI: So that's why I wanted to emphasize that the main thrust of it is understanding the vulnerabilities. If there aren't any, then we would know that the program has served it's purpose.

DR. SEISS: You know being comfortable with something is good engineering, it's just lousy regulation. (Laughter) But until you decide on some sort of criteria, you don't have any definition of vulnerability. At what point is something vulnerable?

MR. BAGCHI: The characterization of ground motion at the site. I think people have some judgment about that. If you asked me, I cannot characterize it right now.

DR. SEISS: Well, vulnerability is more of a bottom line type thing. It's like what's a dominant failure vote? That's what I saw as a definition of vulnerability in connection with the severe accident policy. Something that dominates is a failure vote, even if it's 10 to minus 6, it's a vulnerability.

MR. BAGCHI: Well, we wouldn't fix something that's very, very low in probability.

DR. SEISS: PG&E will satisfy the licensing condition when they have completed this work, and have provided a basis for the seismic margins, whether the seismic margins are big enough, somebody else is going to have to decide.

MR. BAGCHI: That is correct.

DR. SEISS: Maybe we will be involved. Mr. Cluff, I was hoping we might get through this soil structure interaction today, and I'm willing to go until six o'clock. Do you think we could do enough on SSI in 30 minutes to make it worthwhile? It will at least be 30 minutes we don't have tomorrow morning.

MR. CLUFF: Yes, we can.

DR. SEISS: Okay. Let's start it, and we will stop at the end of the first slide after six o'clock.

(Laughter)

I will ask Bill White, who is charge of managing the SSI to take over.

(Continued on following page)

MR. TSAI (continuing): The numerical simulation consists of a number of elements. First, we started at the earthquake source. We did fault surveys of some area. We then described that into fault segments and then summed the contribution of each segment to obtain the overall motion from an extended fault rupture.

Now, in this description of the source, one has to choose the size of the sub-element, location of the sub-element. Also one needs to have a source function in terms of time.

DR. KERR: Is this a distributed source, distributed geographically?

MR. TSAI: Yes.

DR. KERR: Vertically and horizontally. In two dimensions?

MR. TSAI: This is a ground service over here and it's downward, underground.

DR. KERR: You are going to talk about the extent of those dimensions later on?

MR. TSAI: Later on. Yes.

And then a wave is generated here, propagated outward to the side, propagated through the inter-meeting paths and then of course it will be more defined by the site condition. And so we, in the simulation, there are three parts. One is the source, paths and the site contributions.

Now, there are several important features in the method we developed. First, in terms of source time functions, it meets the needs for some features which has to be accounted in the source time function. And I will be showing that in the next figure.

Basically, it can account for the degradation of radiation patterns at high frequencies. In other words, at low frequency, a radiation pattern can be relatively reliably predicted, but in high frequency, that prediction breaks down. And so we need to account for that.

Then I will show you how the source functions are selected, and the important part of that is to compare with our site recordings. And then we correct for the propagation paths.

DR. KERR: Can you give me a brief description of what you mean by the degradation of the radiation pattern?

MR. TSAI: Yes.

DR. SIESS: If you are going to do it later, just do it in sequence.

MR. TSAI: Yes. Well, it's about time, since you raised the question.

This is the S-wave radiation pattern. And over here the data, the records shown are from a 5.1 aftershock of the 1979 earthquake. So one has recordings of different actions and it is projected back to the earthquake floors. As compared to this pattern, those are theoretically predicted. And what shows here is the upper two are two different components. Radio component, transverse component. And then the upper two are in filters, the whole records. The lower part is a low pass filter, traces, in those high-frequency components. And one can see down here, near the northern lines, the recorded ground motion compared more closely to the theoretically predicted, whereas the records which have high frequency components don't show that clear correlation.

DR. KERR: So if I were naive, I could also interpret this to mean that for low frequency, this model works and for high frequency it doesn't work very well?

MR. TSAI: That's right. That's exactly what would be the extension of this.

DR. KERR: Okay.

MR. TSAI: But our job is not low frequency. Our job is to predict the high frequency one.

DR. KERR: On that basis, that wave pattern, one would not choose preferentially?z

MR. TSAI: That's right. So we cannot rely on this theoretical representation, and since we are not really sure how to represent it another way, deterministically, and so we then go to the real records where it is there.

Now, the other feature is the site of the fault segment. And there are several considerations. One is based on area studies by Joyner and Boore, in terms of the relationship between large earthquakes and smaller earthquakes. Since we are summing a large number of small earthquakes to simulate the large earthquake, how many of these smaller earthquakes or fault elements do we need to sum is of importance. And there is some concern of this.

Also, we need to consider the approximation, called Fraunhoffer approximation. That is, near, very close to the source, one uses, we are using wave tracing method. And the need to satisfy this approximation, that is, we are looking at high frequency, and we need to have the source which is not larger than the wave lengths we are looking at.

So there is a consideration needed to be made on the size of the fault elements. And then we have some observational basis to choose the segment size. And we did perform some sensitivity study in terms of simulated ground motion as function of different choices of segment size.

Then, we also consider fault heterogeneity. That is, in that big fault, in case of a single large earthquake, the amount of slip over that fault is not uniform. Some parts slip more than other parts. And that is described in terms of the special distribution in terms of the tug function of that slip at a given location and also the extension or propagation of the rupture starting at a new creation point throughout the whole fault, and we also made some sensitivity studies with

MR. WHITE: Thank you.

I'm going to show a few slides here to kind of set the stage. Then I would like to have Dr. Wen Tsing take over, because my voice is going to poop out on me pretty quickly here.

We'll make the transition from the ground motion into our actual studies.

Before, we were talking about ground motion providing empirical records and numerical records. We are taking both of those and combining this into structural analysis and equipment response predictions and then this information is in turn fed into our fragility analysis.

And in terms of what we are trying to do in the structure analysis, we are certainly directing our efforts towards support of the PRA. And when you get down to the kind of calculations we're making, even though it's a PRA, it is very deterministic calculations.

We're looking for forces in structural members, deflections, accelerations, response spectra. We will get around to equipment response. Again, we are looking for response spectra and deflections. Very familiar kinds of things.

Now, along with this, we are also looking for the dispersion of the response, how much scatter are we getting. And that's where the PRA part comes in.

But most of the studies we are making are, like I said, good, everyday engineering.

DR. KERR: When you talk about response, are you talking about staying within a linear range?f

MR. WHITE: No. We were talking about in the PRA a very large range of earthquakes. We are allowing the structures and systems to go nonlinear.

MR. KERR: Thank you.

MR. EBERSOLE: When you say equipment response, are you taking into account more than safety-related equipment and system interactive aspects of equipment performance?

MR. WHITE: Some subsystem interaction.

MR. EBERSOLE: One of the big current flaps is the effects of fire protections systems going off concurrently all over the place.

MR. WHITE: Fire protection system is in the PRA.

In terms of the studies that were performed, we've done an analysis to determine the median response spectra and also the 84th percentile spectra. That's for the auxiliary building only.

And Bob Kennedy will talk about that tomorrow. The next three items, Wen will talk about today -- the development of a median response spectra for all the buildings and the effect of the incoherent ground motion and also containment uplift.

And those are the three items that we'll be talking about this afternoon.

In terms of how they fit together in terms of an overall program, I've got a simplified flow diagram that summarizes this. We've got one that's much more complicated that we've chosen to neglect.

But the three studies we will be talking about this afternoon are these three portions here.

This is response spectra, containment uplift and the spatial incoherence. The time history stuff we'll be covering tomorrow.

So, with no further ado, I don't want to catch Wen in the middle of a slide. Let's just bring Dr. Wen Tsing up and have him go through the detailed studies that we did for SSI.

DR. WEN TSING: This is the so-called more complicated graph. I don't intend to go through this in great detail. But I just will re-emphasize that there are three parts we are going to talk about.

The first part is the so-called incoherent ground motion input, and determining the SSI response for this ground motion input.

And the second part is determining what is the modification due to incoherence of ground motion.

And then the third part is kind of like a small branching out. For containment structure, there was a question as to whether the uplifting plane is high enough to warrant a modification of the response. And we are using nonlinear analysis to address that question.

Earlier on, when Dr. Tsai presented the ground motion element of the study, the input to SSI consists of basically three elements.

One is the site specific response spectra. And based on this, this will be like a spectra prescribed at the plant site, like at one point, a receiving station. So there is no spatial coherence, spatial variation information.

Then the second part of that coming from the spatial incoherence function. And that spatial incoherence function expands the point specification of ground motion in terms of site specific spectra into a two-dimensional ground motion variation within the foundation itself.

And then the third component of the time history selected suitable for modification to fit the site specific spectra.

So I will quickly go through the first part of that. That is the coherent response, response of the structure to coherent ground motion. And this shows the median site-specific horizontal spectrum that was determined from the empirical ground motion.

This spectra is for horizontal, 5 percent damping.

This is the same spectra that Dr. Tsai has shown here. And this is the basis for us to -- there is three sets of actual earthquake records. Namely, the Pacoima Dam, the Tabas records and El Centra Station Number 4 records, where chosen by the ground motion studies to be more suitable for modifications to fit the spectra.

This shows the modified Pacoima Dam longitudinal component. And in order to make this spectra fit the site specific median spectra we performed some adjustment to the time history and after adjustment you can see the modified time history median spectra fairly closely.

And this kind of time history adjustment, as you can see, the upper one is the initial and adjusted time history and after adjustment.

They are basically quite similar in shape, in phasing, except that it introduced a slightly higher high frequency content to the spectra.

So essentially, the modified spectra still maintain quite realistic features as the initial time history.

We are doing this for two sets of time histories, the Tabas records, three component, and the Pacoima Dam three component. And those are used for input to analysis for coherent ground motion input.

Now in the coherent ground motion input , what we are doing is basically the very conventional SSI approach.

That is, we are assuming the ground motion arriving at a site vertically, propagating wave, plane wave. There is no special variation across the surface of the ground. So the incoherence component in this particular study was not introduced at all.

So using the model developed for the plant, there are three power block structures. One is containment.

And this shows the containment model that we used for the SSI study. Basically, there are two sticks. One represented the outer shell and then a stick representing interior concrete.

And for that we also developed a foundation model using the element approach, the SASSI computer program, and carried this foundation model with the stick model just shown, and run the traditional SSI analysis approach which gives us a representative spectrum, flow response spectra on this, at the component in the top of the internal concrete.

And the two curves here are the floor expression curve coming from two time histories. For the north-south modified Pacoima and modified Tabas. And as can be seen here, the two spectra from two totally different time histories really are quite consistent.

So the time history modification to fit the response spectra did a good job in matching the spectra and coming up with quite consistent response.

And in order to see, for this particular structure, what SSI effect is, we also compute the same response, assuming fixed base, and that his similar to what has been used in the original design, and the red-shaded curb indicates the fixed base response.

It is also due to two time histories, so you can see there are slight differences in shape to that and there is some drop of spectral peaks as well as CPA values, the maximum serration response.

This clearly can be attributed to the SSI effect, from inertia effect alone, because we have not considered the special coherence and special variations.

Then quickly we show the same, similar type of response. This is a stick model, showing the two unit auxiliary building. Basically a symmetrical model with respect to the center line of the building.

And for that we also developed a foundation model. We only developed for half of the model, and using half of a sugar structure stick model also.

This particular structure has some portions which are embedded into the rock. The paper grate(ph) is at the elevation 85 and there are about 25 feet imbedment for this structure.

Applying the same ground motion as for containment, it shows again one representative floor response spectra at elevation 140, which is the operating deck of the auxiliary building, due to two time history inputs.

Again, they are very consistent in response.

And to show the SSI effect for this particular building, we also compiled a fixed base response with the SSI response. The fixed base response showing as a lightly shaded curve.

For this particular building one can see an SSI effect produced much higher effect than the containment structure as can be seen by reduction of maximum acceleration as well as in the spectral peak of frequency.

And this probably is due to the imbedment effect of the building which was about 25 feet of imbedment.

Then quickly for Unit 2 turbine building, this shows a foundation plan. The turbine pedestal here and two basically north-south walls and two, three east-west walls.

For this particular building, the superstructure we have used a more detailed finite element representation for the superstructure, because of the more sparse distribution of the walls.

It is more difficult to develop a single stick model to represent the whole structure.

So for that, the foundation is also again composed of a finite model and it is the finite model of the turbine pedestal foundation.

Using this will show again representative floor response spectra at the Wall Line A which is running in a north-south direction. In the middle of the wall-line A the floor response spectra is due to a two time history input again modified about Pacoima Dam method.

Again, they were quite consistent.

Then to see the SSI effect for this building, compare the fixed base result with the shaking(ph) rate and the SSI response. One can see for this particular building the SSI effect is relatively minor.

In other words, the fixed base response provides a very good estimate of the response for this particular building.

So these are the representative results for the so-called coherent ground motion input assuming a plane wave propagating or approaching the site in vertical propagating plane waves.

Now, again, the spatial variation part of it earlier in Ben Tsai's presentation, the spatial variations were described in the form like incoherence functions.

The incoherence functions can be represented for the purpose of SSI analysis, into two components.

The first term of that represents the point representation corresponding to the site specific spectra. And this is described in power spectra density function.

So in other words, all have the response spectra consistent power spectra density function and then brought up with the incoherence functions which were determined from the ground motion study.

The function is a frequency dependent as well as separation distance dependant. And a product of that gives us a so-called co-variance matrix that we can use as input to the SSI analysis.

Now, since the specification itself is in terms of power spectra density functions and so on, in the analysis we have to depart from the traditional time history conventional analysis.

So in order to use this information, we have used the so-called stochastic or probabilistic type of approach in getting the SSI response.

And the coherence function, the incoherence function that had been determined from ground motion basically consists of two terms.

One is the amplitude term and the face term. And those are the expressions for the amplitude and expression for the face. And the constants were determined from the regression analysis described by Dr. Tsai earlier.

Using this function and the spectrum comparable pause propensity at the site, we made the process of getting to the final response in the structure basically following these steps.

I don't intend to go through it in detail but basically using the co-variance matrix, which is the product of the power spectra density function and the incoherence function, or getting the so-called scattur foundation motion. Those are average foundation input motions.

Due to incoherence or spatial variation of the free field motion, we will get an average foundation base motion in six components. There are three components in translation and three components in rocking.

Using this scatter foundation base motion and from the SSI model, we would determine the transfer function from the scatter foundation base motion to the specific structure location where we need to determine response.

The process we are using, a convolution process, to obtain the response for spectra density function, and based on the random vibration theory to go from power spectra to response spectra, we can develop the floor response spectra and the probabilistic floor response spectra.

Now, in this process, since we depart from the traditional time history type of SSI analysis which we use for the coherent part, we would like to sort of ratio out the procedure itself.

So in order to obtain the pure reduction or pure modification due to the incoherence itself, we use the same procedure to also obtain the coherent ground motion input.

So in the coherent ground motion input, the incoherence function that earlier was developed by the ground motion was assigned to the unit, that there is no dependence o frequency as well as distance.

And using the coherent and incoherent ground motion input simultaneously we can develop response at a particular point in particular component due to these two types of input. And we take ratio between the response spectra. That ratio would then later on be used to modify the response spectra in the coherent ground motion input.

So to show you a few response results, this again is an aux. building. It will show a typical response at the foundation base and the operating deck.

These are floor response spectra, the floor response spectra obtained from coherent and well as incoherent input. The upper curve coming from coherent input and the lower curve coming from incoherent input.

Taking the ratio of this we'll get a spectral reduction factor. This is at the foundation base level, so if we will consider as a spectral reduction factor in the sense like a Tau factor, this is similar to the Tau factor, just due to the spatial coherence, spatial variation of ground motion alone.

Then doing similar things we will be able to get this spectral reduction factor in any location in the structure.

And this is the location in the operating deck, elevation 140, in the aux. building.

So the spectral reduction factor shows slightly different behavior than the foundation base. And this is due to contribution not only from the reduction in translation but also due to the somewhat increase, due to rocking and motion components.

And this can be illustrated by the composition of those spectral reduction factors into different components or contributions.

The lowest curve shows at the operating deck, if we were only including the foundation average motion, due to a horizontal translation alone, we are getting the reduction factor which is very similar to the foundation base at elevation 85.

Then if we are including the rocking component of the motion, we will see that the reduction factor becomes smaller at a particular frequency range, indicating the rocking contribution to the response.

Then if we also include all components, that means besides the rocking, the tortion and other components, then we will come up with the final reduction factor.

So in this way we can see that the approach we've taken will determine the spectral reduction factor or Tau-filter factor due to the spatial incoherence at different points in the structure with different curves.

MR. TRIFUNAC: Can I ask you a question?

DR. WEN TSING: Yes.

MR. TRIFUNAC: When you look at incoherent motion, you are saying that you take the average value of the displacements across the foundation and the average value of rotation in order to put that into the rocking.

What is the phase difference that you impose or that you end up with between the rocking of the ground motion and the average translation?

DR. WEN TSING: In the probabilistic type of force, the phase is inherently included. In the incoherence function that was given to us from the ground motion study, it consists of two parts.

One part is the amplitude reduction, the amplitude function, which is the A part of the earlier slide I showed, and the exponential part of phase.

And so whatever the phase contained in that model is being included in the SSI.

MR. TRIFUNAC: I'm sorry. You didn't understand my question.

I'm not talking about the phase of the ground motion between two arbitrary points of the foundation. I'm talking about this.

You have an average translation of the foundation and you have average rotation of the foundation which you put into your stochastic transfer function in the presentation.

DR. WEN TSING: Right.

MR. TRIFUNAC: Now, to get the response up somewhere in the structure, I need to know what is the phase in time of the average translation and of the average rotation of the base? That is the phase I'm asking you about.

DR. WEN TSING: Okay. In the probabilistic, these phases are not considered explicitly. They are integrated in the process of convolution between the so-called scatter foundation motion. They are phase, inherent phase in the scatter foundation input motion.

MR. TRIFUNAC: That phase means that the rocking and the translation responses are either added or subtracted from each other or added in some vectorial fashion.

DR. WEN TSING: That is correct. And by applying the incoherence model which is amplitude and also phase, and applying the, in a sense the traction vector coming from the SSI, I mean the foundation, the foundation assumed rigid to be on the surface of the foundation media(ph) there are certain traction vectors at every point of that foundation beneath that.

Using the traction multiplied to the incoherence model, that given by the ground motion, then the scattered foundation input motion itself contains the inherent phase that is providing the ground motion itself.

And this scattered foundation input motion then was used to involve with the transfer unction. So I think the phase part is included in the scattered foundation input motion.

MR. TRIFUNAC: In other words, what you are saying is that you are taking the complex fourier transform input into your transfer function to calculate say floor response spectra and so forth?

DR. WEN TSING: Right.

MR. TRIFUNAC: And you are taking that whatever it turns out to be?

DR. WEN TSING: Right.

MR. TRIFUNAC: I understand.

DR. WEN TSING: Now, the third part of this is considering the uplift potential for the containment structure. For this we are looking at the same model as we used for the coherent ground motion study, the same stick model used for SSI analysis.

Now, for the uplift we are considering that the foundation is supported on certain distributed soil springs which has only compression capabilities. That means they will be detached as soon as the dead load is exceeded.

Now, the schematic you can see that due to the overturning moment that a certain portion of the foundation, the tension will be developed and when tension is developed, the pressure is being released and the geometry of the structure in contact with the foundation will be in partial contact.

Based on this model we can develop a non-linear moment-to-rotation relationship to be used as the soil spring barrier for the foundation in the SSI analysis.

For the Diablo Canyon containment structure, it is about 20 feet imbedment, about 12 to 14 feet basement thickness with a reactor peak. So they average about 14 feet imbedment.

For that imbedment we also incorporate the side soil spring in addition to the foundation base spring which are tensioned(ph) on it.

For the side source spring we are using a linear spring because when you rock on one side you have side source spring from one side, rock on the other side, you have side source spring from the other side.

So based on this model, then, using as the time history coming from the ground motion study, the three sets of ground motion, the Pacoima, the Tabas and El Centro Number 4, used as they are without modification in this case because it was determined to be important that the actual phasing of the ground motion is important so we directly used the ground motion, the recorded ground motion without modification to fit the site specific spectra.

The only thing that was done is in order to get to proper intensity of the ground motion, we adjust the time history by a scalar factor. That means to adjust it up or down to a target value.

And that target value is being specified for convenience of the fragility analysis.

Since uplift response is inelastic it is nonlinear. So we need to interpret the result in terms of specific level of input.

Now, for the study, we are working to target spectra as a ratio in two and a quarter g's(ph) within the range of three and eight and a half hertz. That is the spectral range where earlier Dr. Tsai was showing the straight line of spectral acceleration.

So we will take the average of these spectral values for the five percent damping within three to eight and a half hertz range and adjust the time history to an average variable of two and a quarter g's.

MR. TRIFUNAC: Excuse me. How is the ground motion coming in?

DR. WEN TSING: The ground motion gives us three sets of time history that are considered to be the most representative. And for the linear analysis earlier on we adjust them to fit the site specific spectra.

MR. TRIFUNAC: No. That was obvious. I'm sorry.

What I meant to ask is is that xyz Pacoima Dam representing the motion of all the points on the Winkler foundation? Or is there some phase between one end and the other or what?

DR. WEN TSING: No, this is purely input like a convention vertical weight, the whole point being the same.

MR. TRIFUNAC: So you are minimizing the effect of separation by the nature of the input.

DR. WEN TSING: The intention here is also to make a linear and a nonlinear analysis.

MR. TRIFUNAC: In either case, you are minimizing it.

DR. WEN TSING: I think we are using the input because uplift is more or less caused by the inertial response of the structure rather than incoherence or out of phasing.

And the inertial response itself I think for the vertical propagating wave, we are getting the higher response.

As you have seen in the earlier showing for coherent ground motion input. And that will give us higher inertial load and based on high inertia load we should be getting higher foundation overturning moment which should cause higher or conservative estimate of the base uplifting.

Now, we could reduce the motion, and in the meantime --

DR. KERR: Excuse me. How do you know what's conservative?

DR. WEN TSING: We have seen earlier that for containment structures with vertical propagating wave, plane wave of input, we are getting higher inertial load in the structure.

DR. KERR: I am simply saying, until you know what is going to happen, it seems to me what you should look for is the most accurate representation given resources and so on.

But I'm not sure, do you know initially what is conservative?

DR. WEN TSING: Well, certainly it's not, but at this point in time since we are separating the component motion into several parts.

DR. KERR: I'm not being critical of what you're doing.

I am just saying that it seems to me it may be premature to label something as being conservative until you know what the results are and what all the interactions are.

MR. BAGCHI: He's just looking to maximize uplift.

DR. WEN TSING: If you have the plane wave, vertical propagating plane wave, versus --

DR. KERR: This is a very complex system. This is part of the total analysis.

Until you know what the total analysis is going to produce, I'm not sure you know what's conservative on a component by component basis. Maybe you do. It is not obvious to me that you do.

MR. TRIFUNAC: What you are doing is you are minimizing the uplift. You are not maximizing it really, because you are assuming that the ground motion consists of vertically propagating plane waves, and the ground motion in a real situation as you imply, by incoherence studies as well, is not propagating like this.

So if you take a realistic ground motion, you have in fact imbedment, which is even helping that effect further. You have a rotation coming along with the SV, with the P and with the ray(ph) lengths.

Only low(ph) waves and SH are not doing the rocking. And so by assuming a vertical propagation and a constant motion of the base you are minimizing the effect of any circumstances.

I'm not talking about what the building does. I'm talking about what the ground does.

DR. WEN TSING: I think if you look in terms of the input motion to the structure, then you are correct.

By just taking the vertical propagating waves, we are maximizing the horizontal translation but minimizing the rocking motion whereas in reality we do have scattered rocking motion as well as translational motion, but there will be reduction in the translation and there will be induced rocking motion.

Now, how can we judge whether we are getting sort of a high inertial load?

By looking at the earlier response, the earlier study in the incoherent ground motion input. If we compare, for example, at the top of internal concrete, the coherent input versus incoherent input, we are seeing reduction of acceleration response at that level of floor response spectra as a whole.

But incoherence causes reduction in the floor response spectra. So if we are using the coherent input, then we are using the higher acceleration or inertial response.

MR. TRIFUNAC: That is if the assumptions that go along with your incoherence model are correct.

DR. WEN TSING: Of course. Based on the current incoherence model. And based on the current incoherence model, we are seeing by vertical propagating wave, we are maximizing the inertial response, and likewise, the acceleration response at various locations in the containment structure.

And that's why I'm saying that by inputting vertical propagating wave, we are relatively conservative in these two particular cases.

DR. SIESS: That figure compares linear and nonlinear. Do you have something that shows me the effect of basemat uplift?

DR. WEN TSING: This has included basemat uplift. But then it is showing, compare linear, then, if base uplift is suppressed.

DR. SIESS: Linear means no basemat uplift?

DR. WEN TSING: Right.

DR. SIESS: Okay.

DR. WEN TSING: And this is comparing at the same location, and if we suppress, assuming uplift does not occur, and nonlinear allowed the uplift to occur, what is the effect on the floor motion in terms of floor response spectra.

So this is one location at the top of internal structure, due to the Pacoima Dam records.

And we can also -- I think what we are doing is we do the same thing for three sets of time history. We are getting some variation in the same spectra.

Then we will average out these three sets of input results due to these three sets of input and get an average.

MR. SEAVUZZO: One question.

DR. WEN TSING: Yes.

MR. SEAVUZZO: Did you get significant liftoff with this comparison?

DR. WEN TSING: Yes. We are getting about 70 percent liftoff in terms of very small displacement but showing tension occurred in the foundation building.

DR. SIESS: Tension over 70 percent of liftoff --

DR. WEN TSING: -- was zero, or uplift at about 70 percent.

DR. SIESS: How much of the area is uplifted?

DR. WEN TSING: 70 percent.

DR. SIESS: 70 percent.

MR. SEAVUZZO: So there is no real effect of that phenomenon on the response as you calculated it?

DR. WEN TSING: Right.

The intention is if there were a significant effect we will use this factor to adjust the earlier response, incoherent ground motion SSI response for input to fragility analysis.

DR. SIESS: Does that conclude your presentation? Thank you.

I'm going to defer further questions until tomorrow morning. I'll defer comments from the staff until tomorrow morning.

Would anybody object to starting a little earlier tomorrow morning?

(No response)

Would that give any of the members or consultants a problem? They are all staying at the hotel.

Would it give you any problem getting in here?

(No response)

Eight O'clock tomorrow morning.

You can leave. They will lock the room up, if we wish.

(Whereupon, at 6:05 p.m. the meeting recessed, to reconvene the following day, Wednesday, February 24, 1988, at 8:00 a.m.)

CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name: ACRS: DIABLO COANYON LONG TERM SEISMIC PROGRAM

Docket Number:

Place: Burlingame, California

Date: February 23, 1988

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken stenographically by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

/S/ Joan Rose

(Signature typed): Joan Rose

Official Reporter

Heritage Reporting Corporation

Insert #1

FEBRUARY 23, 1988

NRC STAFF PRESENTATION ON DIABLO CANYON SEISMIC REEVALUATION PROGRAM

BACKGROUND

EARLY 1970's HOSGRI FAULT IDENTIFIED 5.8 KM FROM DIABLO CANYON WITH POTENTIAL FOR MAGNITUDE 7.5 EARTHQUAKE

HOSGRI REANALYSIS PERFORMED WHICH REQUIRED MODIFICATION OF SOME STRUCTURES AND COMPONENTS

IN 1978 THE ACRS RECOMMENDED THAT A SEISMIC REEVALUATION BE PERFORMED IN ABOUT 10 YEARS

IN THE EARLY 1980'S NEW GEOLOGIC INFORMATION WITH DIFFERING INTERPRETATIONS OF COASTAL CALIFORNIA TECTONICS BECAME AVAILABLE

IN 1984 NRC STAFF PROPOSED OPTIONS FOR THE REEVALUATION OF THE SEISMIC DESIGN BASES FOR DIABLO CANYON

COMMISSIONERS IMPOSED A CONDITION ON THE DIABLO CANYON UNIT 1 LICENSE REQUIRING A REEVALUATION PROGRAM

SUMMARY OF LICENSE CONDITION

EVALUATE RELEVANT GEOLOGIC AND SEISMIC DATA AVAILABLE SINCE 1979 AND REEVALUATE EARLIER INFORMATION IF NECESSARY

REEVALUATE MAGNITUDE OF EARTHQUAKE USED AS SEISMIC BASIS

REEVALUATE GROUND MOTION

ASSESS SIGNIFICANCE USING PRA AND DETERMINISTIC STUDIES TO ASSURE ADEQUACY OF SEISMIC MARGINS

THREE YEAR PROGRAM PLAN SUBMITTED JANUARY 1985 AND APPROVED BY NRC JULY 1985

UNDER THE DIRECTION OF THE COMMISSIONERS AND THE ACRS THE THE STAFF WAS URGED TO HAVE A STRONG REVIEW AND INDEPENDENT PARALLEL PROGRAM

<u>NRC REVIEW AND PARALLEL PROGRAM</u>

- TECTONICS AND GEOLOGY
- EARTHQUAKE MAGNITUDE
- SEISMOLOGY AND GROUND MOTION
- SOIL STRUCTURE INTERACTION
- DETERMINISTIC ASSESSMENT
- PROBABILISTIC RISK ASSESSMENT

GEOLOGY, TECTONICS AND GEOPHYSICS

NRR REVIEW WITH RES STAFF SUPPORT

TECHNICAL ASSISTANCE FROM USGS AND UNR

SEISMOLOGY AND GROUND MOTION

NRR REVIEW

TECHNICAL ASSISTANCE FROM USGS
AND LLNL PANEL

SOIL STRUCTURE INTERACTION

NRR WITH RES STAFF SUPPORT

TECHNICAL ASSISTANCE FROM BNL PANEL

PROBABILISTIC RISK ASSESSMENT

RES WITH NRR STAFF SUPPORT

TECHNICAL ASSISTANCE FROM BNL REVIEW TEAM

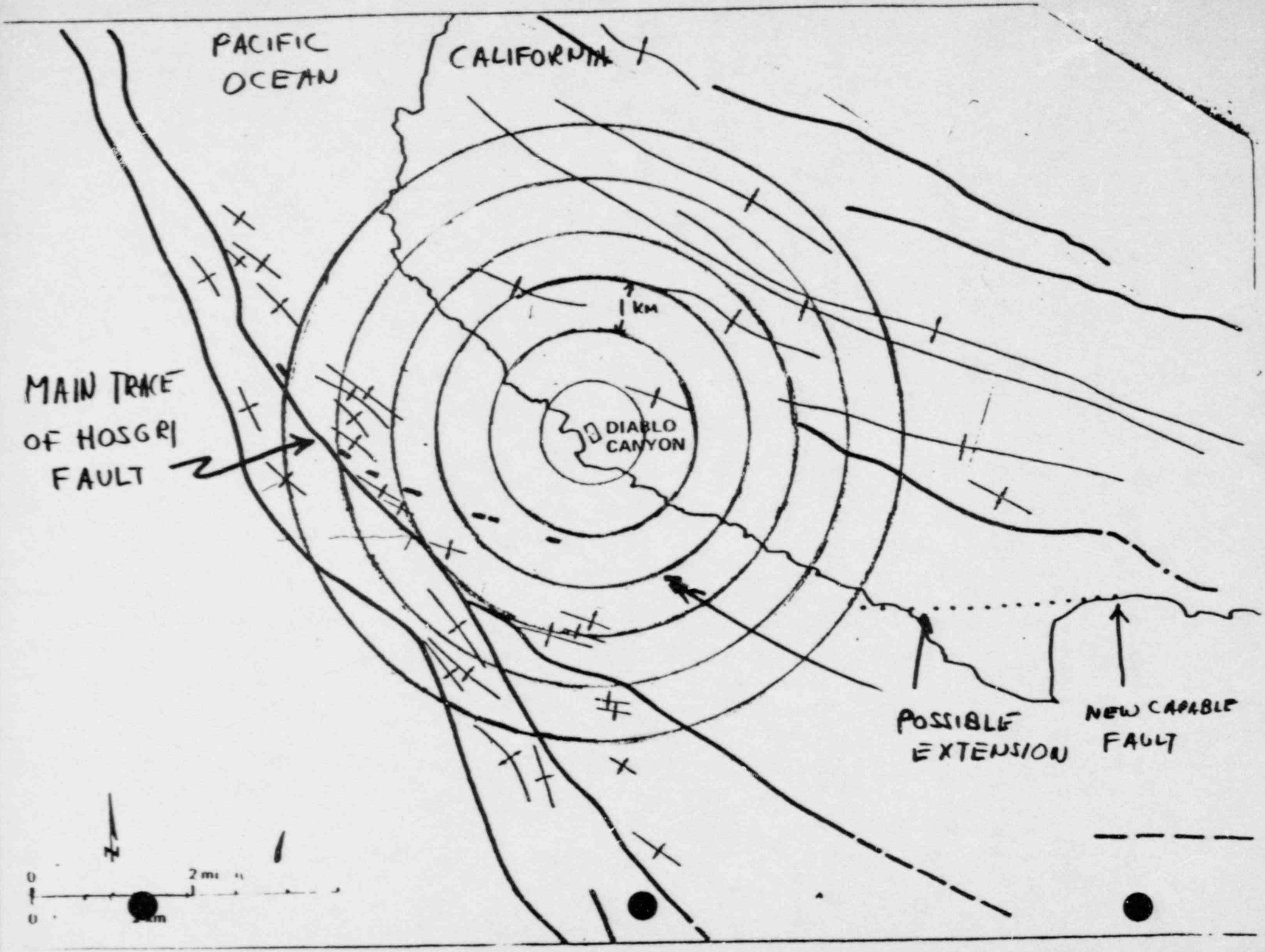
WORKSHOPS, MEETINGS, FIELD TRIPS AND AUDITS

GENERAL OVERALL PROGRAM REVIEW	2
GEOLOGY-TECTONICS-GEOPHYSICS	7
GROUND MOTION	3
SOIL STRUCTURE INTERACTION	4
PROBABILISTIC RISK ASSESSMENT	4
DETERMINISTIC ANALYSIS	1

BOARD NOTIFICATION

SPRING 1987 PG&E INFORMED STAFF OF A NEWLY DISCOVERED CAPABLE FAULT IN THE SEA CLIFF APPROXIMATELY 10 KM FROM THE PLANT AND THE POSSIBILITY OF AN EXTENSION CLOSER TO THE SITE. ALSO, THE ACTIVE STRAND OF THE HOSGRI WAS FOUND TO BE ABOUT 4 KM FROM THE SITE RATHER THAN THE PREVIOUSLY ASSUMED 5.8 KM.

THE STAFF INFORMED THE COMMISSIONSERS VIA A BOARD NOTIFICATION


PACIFIC OCEAN
CALIFORNIA
1 KM
DIABLO CANYON
MAIN TRACE OF HOSGRI FAULT
POSSIBLE EXTENSION
NEW CAPABLE FAULT
0
2 mi
0
km

Insert #2

BACKGROUND

MATERIAL

DIABLO CANYON LONG TERM SEISMIC PROGRAM
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS SUBCOMMITTEE MEETING
FEBRUARY 23-24, 1988
SHERATON INN - SAN FRANCISCO
1177 AIRPORT BOULEVARD, BURLINGAME, CA 94030

AGENDA

TUESDAY, FEBRUARY 23, 1988

8:30 a.m. - 9:15 a.m.	Introductions . ACRS . NRC Staff . PG&E
9:15 a.m. - 10:00 a.m.	Background - PG&E . The 1978 ACRS Letter . The License Condition . The LTSP Program Plan . The LTSP Scoping Study
10:00 a.m. - 10:15 a.m.	Break
10:15 a.m. - 11:00 a.m.	Background - PG&E (Continued)
11:00 a.m. - 12:00 noon	Current Status of LTSP - PG&E . Geology/Seismology/Geophysics . Earthquake Ground Motions . Soil/Structure Interaction . Fragilities . Probabilistic Risk Assessment
12:00 noon - 1:00 p.m.	Lunch
1:00 p.m. - 2:00 p.m.	Current Status of LTSP - PG&E (Continued)
2:00 p.m. - 2:15 p.m.	Break
2:15 p.m. - 4:00 p.m.	Current Status of LTSP - PG&E (Continued)

WEDNESDAY, FEBRUARY 24, 1988

8:30 a.m. - 10:30 a.m.	Current Status of LTSP - PG&E (Continued)
10:30 a.m. - 10:45 a.m.	Break
10:45 a.m. - 12:00 noon	Closing Statements . NRC Staff . PG&E . ACRS
1:00 p.m. - 6:00 p.m.	Field Visit . For ACRS members interested in visiting Diablo Canyon Power Plant

BACKGROUND

- o Advisory Committee on Reactor Safeguards (ACRS) letter of July 14, 1978 in which ACRS suggests "that the seismic design of Diablo Canyon be reevaluated in about ten years taking into account applicable new information."

- o ACRS Meeting to Review the Proposed License Condition
  - -- May 24, 1984 - ACRS Subcommittee Meeting in Los Angeles, CA
  - -- June 14-15, 1984 - ACRS Meeting in Washington, D.C.

BACKGROUND

- ACRS Letter of June 20, 1984

  - . . . the elements outlined in the NRC Staff's proposal (license condition) will provide a suitable basis for the seismic reevaluation.

  - . . . it is appropriate for PG&E to take the lead in the seismic reevaluation and . . . the NRC Staff's independent evaluation can provide adequate review of the PG&E work. We recommend that the NRC effort include a significant support role for the USGS . . .

  - . . . we note that the seismic reevaluation includes the performance of a PRA. We believe that useful insight from the PRA would best be gained by PG&E if their personnel have an active role in this work.

  - We request that we be given the opportunity to review and comment on the PG&E program plan and schedule. We request also that the NRC Staff meet with us as appropriate to discuss their evaluation of the PG&E work.

- November 2, 1984, Facility Operating License DRR-80, for Diablo Canyon Unit No. 1 issued, including License Conditions which requires the Long Term Seismic Program.

DIABLO CANYON NUCLEAR POWER PLANT
LICENSE CONDITION

1. PG&E shall identify, examine, and evaluate all relevant geologic and seismic data, information, and interpretations that have become available since the 1979 ASLB hearing in order to update the geology, seismology, and tectonics in the region of the Diablo Canyon Nuclear Power Plant. If needed to define the earthquake potential of the region as it affects the Diablo Canyon Plant, PG&E will also reevaluate the earlier information and acquire additional new data.

DIABLO CANYON NUCLEAR POWER PLANT
LICENSE CONDITION

2. PG&E shall reevaluate the magnitude of the earthquake used to determine the seismic basis of the Diablo Canyon Nuclear Power Plant using the information from Element 1.

3. PG&E shall reevaluate the ground motion at the site based on the results obtained from Element 2 with full consideration of site and other relevant effects.

DIABLO CANYON NUCLEAR POWER PLANT
LICENSE CONDITION

4. PG&E shall assess the significance of conclusions drawn from the seismic reevaluation studies in Elements 1, 2, and 3, utilizing a probabilistic risk analysis and deterministic studies, as necessary, to assure adequacy of seismic margins.

Program Schedule

LTSP final report to be submitted to NRC three years following approval of Program by NRC staff.

Program Progress

- Quarterly Progress Reports
- Meetings with NRC staff
- ACRS Progress Meetings

BACKGROUND

o January 30, 1985 - PG&E submitted its LTSP Program Plan for review and approval by the NRC staff.

-- LTSP Program Plan

Geological Investigations

Earthquake Magnitude

Earthquake Ground Motion by Empirical Analysis

Earthquake Ground Motion by Numerical Analysis

Soil/Structure Interaction

Seismic Hazard Analysis

Fragility Analysis

Probabilistic Risk Assessment

-- Dynamic Character of Long Term Seismic Program

Program must be flexible to achieve successful completion of Program objectives.

Elements of Program Plan must not be viewed as absolutes.

To be successful, Program must be structured to accommodate change.

Program evolves as work progresses within framework of approved Plan.

BACKGROUND

o PG&E/NRC Staff Meetings to Review Program Plan:

-- October 4, 1984 - To discuss proposed geologic investigations

-- November 15-16, 1984 - To discuss proposed earthquake magnitude and ground motions investigations December 11, 1984 - To discuss proposed PRA

-- January 10, 1985 - To respond to NRC comments, and discuss NRC/PG&E interaction during implementation of the LTSP

-- May 22, 1985 - PG&E response to NRC Staff comments on the Program Plan

-- June 24, 1985 - PG&E/NRC field trip to review geologic features

-- March 21, 1985 - PG&E and the NRC Staff met with the ACRS subcommittee to review the Program Plan

-- July 10, 1985 - PG&E and the NRC Staff met with the ACRS to review the Program Plan

-- July 30, 1985 - The NRC Staff approved the LTSP Program Plan

DIABLO CANYON LONG TERM SEISMIC PROGRAM CONSULTING BOARD

Clarence R. Allen	Seismic Geology and Tectonics
Bruce A. Bolt	Seismology and Ground Motions
C. Allin Cornell	Probability/Risk Assessment
Thomas M. Leps	Engineering
Cole R. McClure	Geology
H. Bolton Seed	Ground Motions and Soil/Structure Interaction

BOARD FORMED OCTOBER 1984

TO PROVIDE ADVICE, GUIDANCE, AND REVIEW FOR:

- PHASE I PROGRAM PLAN DEVELOPMENT
- PHASE II ACTIVITIES TO ESTABLISH PRIORITIES AND SCOPE OF WORK
- PHASE III ACTIVITIES, CONDUCT OF WORK
- FINAL REPORT

LTSP CONSULTING BOARD MEETINGS

1. October 25, 1984
2. January 7, 1985
3. January 21, 1985
4. March 7, 1985
5. June 12, 1985
6. July 17, 1985
7. September 26, 1985
8. November 1, 1985
9. January 21, 1986
10. May 1, 1986
11. August 7, 1986
12. November 14 and 15, 1986
13. January 7, 1987
14. April 29, 30, and May 1, 1987
15. July 2 and 3, 1987
16. October 12, 1987

NRC/LTSP REVIEWERS

Staff Advisor for Geology/Seismology/Geophysics

Dr. D.B. Slemmons, University of Nevada, Reno

Ground Motion Panel

Jean B. Savy - Lawrence Livermore National Laboratory
Ralph J. Archaleta - University of California, Santa Barbara
Steven M. Day - S - Cubed
Keiti Aki - University of Southern California

Soil/Structure Interaction Panel

Dr. Morris Reich - Brookhaven National Laboratory
Dr. Carl J. Costantino - City College of New York
Dr. Geogre Gazetas - Rensselaer Polytechnic Institute
Dr. Andrew S. Veletsos - Rice University, Texas

Fragility Panel

Dr. R. Fitzpatrick - Brookhaven National Laboratory
Dr. Michael P. Bohen - Sandia National Laboratory
Dr. James J. Johnson - EQE, Inc.
Dr. M. Ravindra - EQE, Inc.

PRA Advisory Group--Brookhaven National Laboratory

Robert Fitzpatrick
G. Bezoki
K. Aliefendioglu

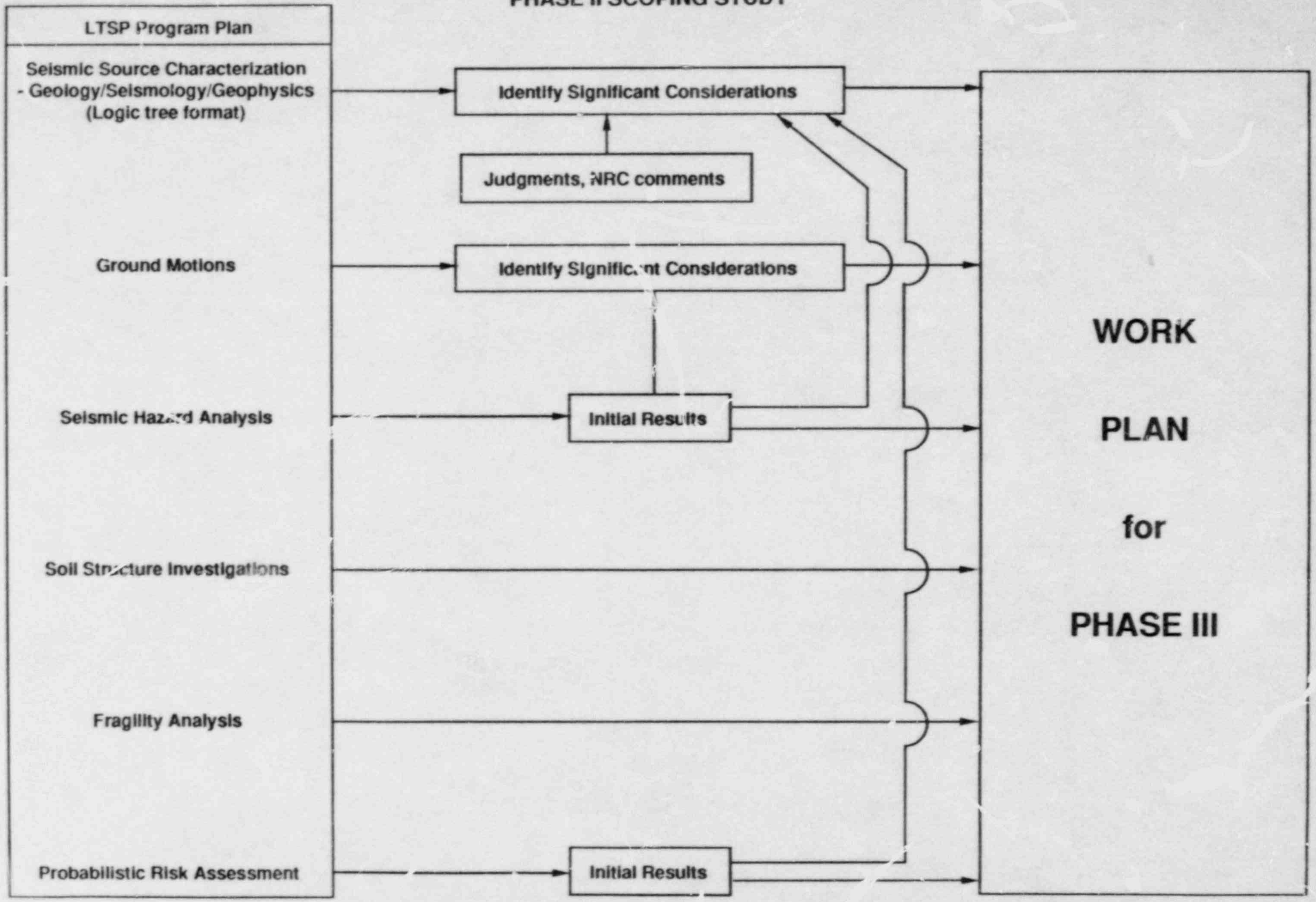
LTSP PHASE II SCOPING STUDY

PURPOSE

Develop Scope of Work for Phase III

- Balanced
- Integrated
- Focused on Important Topics
- Clear Sense of Priorities
- Realistic Schedule

PHASE II SCOPING STUDY



LTSP Program Plan

Seismic Source Characterization
- Geology/Seismology/Geophysics
(Logic tree format)

Ground Motions

Seismic Hazard Analysis

Soil Structure Investigations

Fragility Analysis

Probabilistic Risk Assessment

Identify Significant Considerations

Judgments, NRC comments

Identify Significant Considerations

Initial Results

Initial Results

WORK
PLAN
for
PHASE III

PHASE II - DEVELOPMENT OF SCOPE OF WORK FOR PHASE III
(SCOPING STUDY)

OBJECTIVES

- Comprehensive response to License Condition
- Develop clearly defined Scope of Work for Phase III for each Program Element
- Develop integrated schedule to complete project within allotted time.

PROGRAM ELEMENTS

GEOLOGY/SEISMOLOGY/GEOPHYSICS

- Objectives
  - To identify and address significant technical considerations relating to assessing the earthquake potential of seismic sources important to Diablo Canyon.
  - Technical considerations include:
    - Fault Location and Orientation
    - Fault Length
    - Fault Type and Geometry
    - Rate of Slip
    - Fault Segmentation
    - Earthquake Size
    - Earthquake Recurrence

- Work Tasks

  Task 1 - Characterization of Hosgri Fault

  - Review Existing Data
  - Onshore Geologic Studies
  - Geophysics Analysis
  - Interpretive Maps

  Task 2 - Quaternary Studies

  - Geologic Mapping
  - Fold Analysis
  - Interpretation of Quaternary Deformation

  Task 3 - Seismology

  - Review and Analysis
  - Crustal Velocity
  - 1927 Lompoc Earthquake

GEOLOGY/SEISMOLOGY/GEOPHYSICS

- Work Tasks (Continued)

Task 4 - Edna, San Miguelito Faults, San Luis-Pismo Folds

- Review Existing Data
- Geologic Mapping
- Offshore Geophysics Review

Task 5 - Little Pine-Foxen Canyon Trend

- Review Existing Data
- Geology Mapping

Task 6 - West Huasna, Rinconada Nacimiento Faults

- Review Existing Data
- Geologic Mapping
- Geophysical Analysis

Task 7 - Deep Crustal Studies

- Review Existing Data
- Santa Maria Basin Region
- Data Integration and Interpretation

Task 8 - Tectonic Model

- Review and Synthesize Existing Data
- Integration of Additional Data

Task 9 - Seismic Source Characterization

- Specification of Sources
- Maximum Earthquake Assessments
- Earthquake Recurrence Assessments

GROUND MOTIONS

- Technical Considerations:
  - Empirical Ground Motion Models
  - Incorporation of Recent Earthquake Recordings
  - Evaluation of Dispersion, Truncation and Saturation Effects
  - Wave Propagation and Site Effects
  - Numerical Methods
- Work Tasks

  Task 1 - Attenuation Relationships

  - Select Data for Rock Site
  - Refine Relationships with Recent Recordings

  Task 2 - Response Spectra

  - Select Spectra for Rock Site
  - Refine Spectra with Recent Earthquake Data

  Task 3 - Time Histories

  - Select Time Histories
  - Generate Realistic Time Histories Rock Site
  - Assess Response Spectral Amplification Factor

  Task 4 - Site Effects

  - Assess Ground Motion Variability
  - Assess Wave Types and Spatial Coherency
  - Install Ground Motion Instruments

  Task 5 - Numerical Modeling

  - Evaluate Attenuation Relationships, Response Spectra and Time Histories
  - Assess Effects (Fault Types, Geometry, Rupture)
  - Assess Local Site Effects

SEISMIC HAZARDS ANALYSIS

- Objective
  - Develop Probabilistic Ground Motion Estimates

- Work Tasks

  Task 1 - Evaluate Ground Motion Descriptions

  - Peak Acceleration
  - Peak Acceleration Plus Duration
  - Spectral Acceleration

  Task 2 - Seismic Hazard Analysis

  - Develop Hazards Curves
  - Sensitivity Analysis
  - Parametric Studies

SOIL/STRUCTURE INTERACTION

- Work Tasks

  Task 1 - Assemble and Review Site Rock Data

  - Boring and Geophysical Data
  - Assess Rock Profile and Properties
  - Perform Simplified Sensitivity Analysis
  - Evaluate Response Sensitivity

  Task 2 - Free-Field Input Motions

  - Literature Evaluation - Spatial Coherenc
  - Site Specific Free-Field Response Spectra
  - Free-Field Seismic Wave Incidence Characteristics

  Task 3 - Implementation and Testing of CLASSI and SASSI Programs

  - Verification and Documentation

  Task 4 - Development of Soil/Structure Interaction Analytical Model

  - Review Dynamic Models of Power Block Structures
  - Develop 3-D Structural Dynamic Models
  - Develop 3-D Foundation Models

  Task 5 - Correlation with Recorded Data

  - Analysis of Recorded Data
  - Correlation Between Analytical Models and Recorded Data

  Task 6 - Parametric Studies

  - Reconciliation of CLASSI and SASSI Solutions
  - Basemat Flexibilities
  - Structural Embedment
  - Variations of Soil/Structure Interaction Properties
  - Variations of Input Motion Parameters
  - Soil/Structure Nonlinearities

  Task 7 - Soil/Structure Interaction Responses

FRAGILITIES

- Work Tasks

  Task 1 - Reevaluation of Dominant Contributor to Seismic Risk

  - Incorporate Results of Soil/Structure Interaction
  - Improve Phase II Fragilities

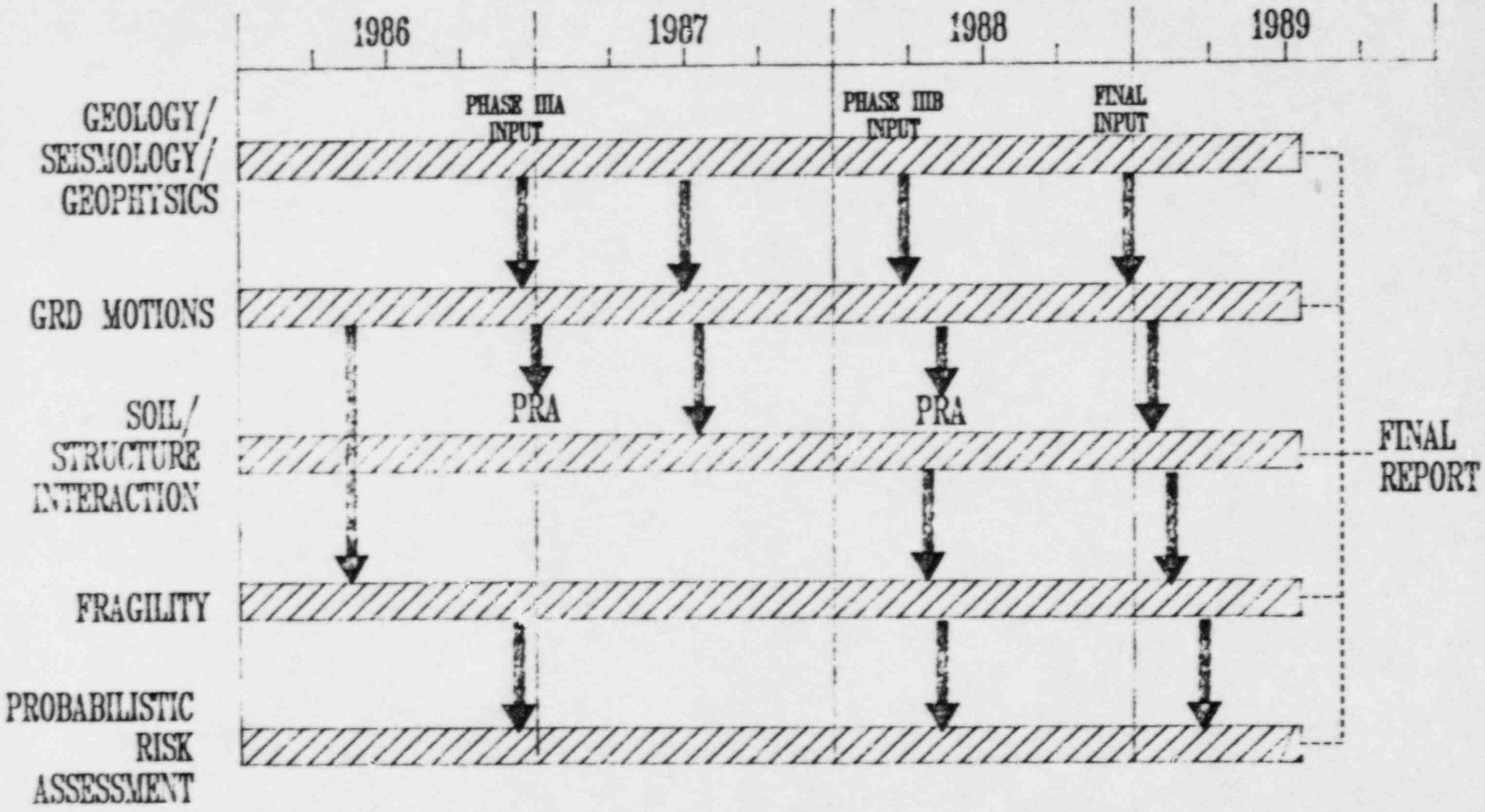
  Task 2 - Median In-Structure Response Spectra

  Task 3 - Assess Lower Tails of Fragility Curves

  Task 4 - Improve Balance-of-Plant Piping Fragilities

  Task 5 - Assess Items Not Considered in Phase II Studies

DIABLO CANYON LONG TERM SEISMIC PROGRAM
SUMMARY SCHEDULE-PHASE III



PRESENTATIONS AT PROFESSIONAL SOCIETY MEETINGS

- SEISMOLOGICAL SOCIETY OF AMERICA
- GEOLOGICAL SOCIETY OF AMERICA
- AMERICAN GEOPHYSICAL UNION

EIGHTY-THIRD ANNUAL MEETING
CORDILLERAN SECTION
THE GEOLOGICAL SOCIETY OF AMERICA
HILO, HAWAII

SEISMOTECTONICS OF THE CENTRAL CALIFORNIA COAST RANGES I: GENERAL SEISMOLOGY AND SEISMIC REFLECTION

Ina Alterman, Robert Brown, Lloyd Cluff, Richard McMullen, and Burton Slemmons, Presiding

1) D. Burton Slemmons: CAPABLE FAULTS AND TECTONICALLY ACTIVE FOLDS OF THE CALIFORNIA CENTRAL COAST RANGES

2) Ray Weldon, Eugene Humphreys: PLATE MODEL CONSTRAINTS ON THE DEFORMATION OF COASTAL SOUTHERN CALIFORNIA NORTH OF THE TRANSVERSE RANGES

3) Thom L. Davis, Kirk D. McIntosh: a RETRODEFORMABLE STRUCTURAL SOLUTION ACROSS THE SOUTHERN COAST RANGES AND IMPLICATIONS FOR SEISMICALLY ACTIVE STRUCTURES

4) Eutizio Vittori: STRUCTURAL ANALYSIS OF LATE CENOZOIC DEFORMATION, SOUTHERN COAST RANGES, CENTRAL CALIFORNIA

5) P. Dehlinger, B. A. Bolt: TECTONIC PATTERNS AND THEIR VARIATIONS ACROSS A PART OF THE CENTRAL COAST RANGES OF CALIFORNIA

6) W. U. Savage, M. K. McLaren: RECENT SEISMICITY OF SOUTH-CENTRAL COASTAL CALIFORNIA

7) C. M. Poley, J. P. Eaton, A. G. Lindh: RECENT SEISMICITY OF THE CENTRAL CALIFORNIA REGION FROM SAN FRANCISCO TO THE TRANSVERSE RANGES

8) William U. Savage, Donald V. Helmberger: SOURCE CHARACTERISTICS AND TECTONIC ASSOCIATION OF THE 1927 LOMPOC, CALIFORNIA, EARTHQUAKE

9) James K. Crouch, Steve B. Bachman: THE NATURE OF THE OFFSHORE HOSGRI FAULT ZONE

10) John W. Steritz, Bruce P. Luyendyk: HOSGRI FAULT ZONE OFFSHORE SANTA MARIA BASIN, CALIFORNIA

EIGHTY-THIRD ANNUAL MEETING
CORDILLERAN SECTION
THE GEOLOGICAL SOCIETY OF AMERICA
HILO, HAWAII

SEISMOTECTONICS OF THE CENTRAL CALIFORNIA COAST RANGE II: SAN SIMEON, PISMO SYNCLINE - SANTA MARIA BASIN

Ina Alterman, Robert Brown, Lloyd Cluff, Richard McMullen, and Burton Slemmons, Presiding

1) W. U. Savage, J. M. Howie, C. R. Willingham: INTEGRATED DEEP CRUSTAL STUDIES ONSHORE/OFFSHORE SOUTH-CENTRAL COASTAL CALIFORNIA

2) David Cummings, T. A. Johnson, R. A. Gaal: STRUCTURAL GEOLOGY, OFFSHORE SANTA MARIA RIVER TO POINT ARGUELLO, CENTRAL CALIFORNIA

3) K. L. Hanson, W. R. Lettis, E. L. Mezger, G. E. Weber: LATE PLEISTOCENE DEFORMATION ALONG THE SAN SIMEON FAULT ZONE NEAR SAN SIMEON, CALIFORNIA

4) Barbara Matz, D. Burton Slemmons: REMOTE SENSING STUDY OF PISMO SYNCLINE AND SANTA MARIA BASIN, CENTRAL COASTAL CALIFORNIA

5) Katheryn M. Killeen, D. Burton Slemmons, Kirk E. Swanson: TIMING OF FOLDING AND UPLIFT OF THE PISMO SYNCLINE, SAN LUIS OBISPO COUNTY, CALIFORNIA

6) E. L. Mezger, K. L. Hanson, N. T. Hall, T. D. Hunt: EVIDENCE FOR QUARTERNARY FAULTING IN LOS OSOS VALLEY, SAN LUIS OBISPO COUNTY, CALIFORNIA

7) Steve P. Nitchman, D. Burton Slemmons: LATE PLEISTOCENE FLEXURAL-SLIP FAULTING POSSIBLY TRIGGERED BY CRUSTAL UNLOADING, PISMO BEACH, CENTRAL COASTAL CALIFORNIA

8) John M. Coyle, N. Timothy Hall, James V. Hengesh, William R. Lettis: QUATERNARY DEFORMATION ALONG THE SOUTHWESTERN MARGIN OF THE SAN LUIS-PISMO SYNFORM, PISMO BEACH, CALIFORNIA

9) K. I. Kelson, W. R. Lettis, G. E. Weber, G. L. Kennedy, J. F. Wehmiller: AMOUNT AND TIMING OF DEFORMATION ALONG THE WILMAR AVENUE, PISMO, AND SAN MIGUELITO FAULTS, PISMO BEACH, CALIFORNIA

EIGHTY-THIRD ANNUAL MEETING
CORDILLERAN SECTION
THE GEOLOGICAL SOCIETY OF AMERICA
HILO, HAWAII

SEISMOTECTONICS OF THE CENTRAL CALIFORNIA COAST RANGE III: FOLD-FAULT AND SLIP RATES

Ina Alterman, Robert Brown, Lloyd Cluff, Richard McMullen, and Burton Slemmons, Presiding

1) Thom L. Davis, Martin B. Lagoe: THE 1952 ARVIN-TEHACAPI EARTHQUAKE (M=7.6) AND ITS RELATIONSHIP TO THE WHITE WOLF FAULT AND THE PLEITO THRUST SYSTEM

2) E. A. Keller, R. L. Zepeda, D. B. Seaver, T. K. Rockwell, D. M. Laduzinsky, D. L. Johnson: ACTIVE FOLD-THRUST BELTS & THE W. TRANSVERSE RANGES, CALIFORNIA

3) N. Timothy Hall: LATE QUATERNARY HISTORY OF THE EASTERN PLEITO THRUST FAULT, SAN EMIGDIO MOUNTAINS, CALIFORNIA

4) David P. Schwartz, Ray J. Weldon: SAN ANDREAS SLIP RATES: PRELIMINARY RESULTS FROM THE 96 ST. SITE NEAR LITTLEROCK, CALIFORNIA

5) G. E. Weber, W. R. Lettis, K. L. Hanson: LATE PLEISTOCENE UPLIFT RATES ALONG THE CENTRAL CALIFORNIA COAST, CAPE SAN MARTIN TO SANTA MARIA VALLEY

6) C. R. Willingham, Douglas H. Hamilton: THE NATURE OF THE HOSGRI FAULT ZONE-PART I: STRUCTURE AND EXTENT

7) R. G. Heck, C. Richard Willingham, D. H. Hamilton: THE NATURE OF THE HOSGRI FAULT - PART II. EFFECT ON STRATIGRAPHY AND TIMING OF TECTONIC EVENTS

8) Douglas H. Hamilton: CHARACTERIZATION OF THE SAN GREGORIO-HOSGRI FAULT SYSTEM, COASTAL CENTRAL CALIFORNIA

9) Charles N. Branch, N. Timothy Hall: EVIDENCE FROM HIGH-RESOLUTION SEISMIC REFLECTION DATA FOR STRIKE-SLIP MOVEMENT ALONG THE HOSGRI FAULT ZONE, OFFSHORE CENTRAL CALIFORNIA

10) Douglas H. Hamilton, N. T. Hall: STRUCTURE AND TECTONICS OF THE SAN LUIS-PISMO-SANTA MARIA REGION, COASTAL CENTRAL CALIFORNIA

11) Frank R. Bickner, Patrick R. Vaughan: EVIDENCE FOR HOLOCENE ACTIVITY OF THE SAN SIMEON FAULT FROM DEFORMED FLUVIAL TERRACES NEAR SAN SIMEON, COASTAL CENTRAL CALIFORNIA

SEISMOTECTONICS OF THE CENTRAL CALIFORNIA COAST RANGE III: FOLD-FAULT AND SLIP RATES (CONTINUED)

12) N. Timothy Hall, T. Dwight Hunt, Patrick A. Vaughan, Frank R. Bickner, William R. Lettis: TRENCHING AND MAPPING INVESTIGATIONS OF THE LATE QUATERNARY BEHAVIOR OF THE SAN SIMEON FAULT, SAN LUIS OBISPO COUNTY, CALIFORNIA

13) Tom K. Rockwell, Frank R. Bickner, Patrick R. Vaughan, Kathryn L. Hanson: APPLICATIONS OF SOIL GEOMORPHOLOGY TO DATING AND CORRELATION COASTAL TERRACE DEPOSITS ACROSS THE SAN SIMEON FAULT ZONE, CENTRAL CALIFORNIA

SUMMARY: Lloyd Cluff

EDGE & RELATED SEISMIC PROJECTS
ONSHORE/OFFSHORE CENTRAL CALIFORNIA (S31B)

Presiders, M. Talwani, Geotechology Research Institute, and W. Mooney, USGS, Menlo Park

1) B. M. Page: GEOLOGY AND TECTONICS OF THE SOUTHERN COAST RANGES, CENTRAL CALIFORNIA: CURRENT MODELS AND MAJOR UNCERTAINTIES
2) David S. McCulloch: OFFSHORE GEOLOGY OF THE SANTA MARIA AREA, CENTRAL CALIFORNIA
3) Manik Talwani, Walter Mooney, William U. Savage, C. Richard Willingham, George A. Thompson, Alan Levander, and Anne Trehu: EDGE AND RELATED SEISMIC PROJECTS - ONSHORE, OFFSHORE CALIFORNIA
4) Anne S. Meltzer, and Alan R. Levander: INTERPRETATION OF DEEP CRUSTAL REFLECTION PROFILES OFFSHORE SOUTHERN CENTRAL CALIFORNIA
5) Kirk D. McIntosh, Eli A. Silver, and Donald L. Reed: SEISMIC EXPRESSION OF COMPRESSIONAL DEFORMATION OFFSHORE CENTRAL CALIFORNIA: EDGE PROFILE RU-3
6) Douglas H. Clark, Douglas H. Hamilton, N. Timothy Hall, and Ronald G. Heck: TIMING AND STYLE OF NEOGENE DEFORMATION WITHIN THE OFFSHORE SANTA MARIA BASIN, CALIFORNIA
7) C. Richard Willingham, and Jan D. Rietman: DEEP SEISMIC AND POTENTIAL FIELD CRUSTAL STUDY ACROSS THE SOUTH CENTRAL CALIFORNIA BORDERLAND AND ADJACENT ONSHORE AREAS
8) Anne Trehu, John Shay, Greg Miller, and Bob Brown: LARGE-OFFSET DATA RECORDED BY OCEAN-BOTTOM SEISMOMETERS ALONG PG&E LINE 1
9) John M. Howie, and William U. Savage: INITIAL CRUSTAL VELOCITY MODEL FOR SOUTH-CENTRAL CALIFORNIA COASTAL MARGIN
10) Alan R. Levander: INTERPRETATION OF A CONTINUOUS-OFFSET SEISMIC PROFILE IN THE CENTRAL CALIFORNIA MARGIN
11) Allan Walter, and Susan Sharpless: CRUSTAL VELOCITY STRUCTURE OF THE SUR-OBISPO (FRANCISCAN) TERRANE BETWEEN SAN SIMEON AND SANTA MARIA, CALIFORNIA
12) Carl M. Wentworth: IMPLICATIONS FRO CRUSTAL STRUCTURE IN THE WESTERN COAST RANGES, CALIFORNIA, FROM STUDIES ALONG THEIR EASTERN MARGIN
13) Marica K. McLaren, and William U. Savage: RELOCATION OF EARTHQUAKES OFFSHORE FROM POINT SAL, CALIFORNIA

EIGHTY-SECOND ANNUAL MEETING OF THE SEISMOLOGICAL SOCIETY OF AMERICA
SANTA BARBARA, CALIFORNIA, MARCH 25, 1987

STRONG GROUND MOTION

David Wald, and Francis Wu, Presiding

1) M. J. Rymer: ASPECTS OF THE SAN SALVADOR, EL SALVADOR, EARTHQUAKE OF OCTOBER 10, 1986

2) Randall A. White: STATISTICS OF VOLCANIC CHAIN EARTHQUAKES IN AND NEAR SAN SALVADOR

3) David H. Harlow, Randy A. White, Martinez, Carlos, Alvarez, Salvador: THE SAN SALVADOR EARTHQUAKE OF OCTOBER 10, 1986

4) A. F. Shakal, M. J. Huang, C. E. Ventura, R. Linares: PROCESSED STRONG-MOTION DATA FROM THE SAN SALVADOR EARTHQUAKE OF OCTOBER 10, 1986 AND COMPARISON TO SOME EXISTING CLOSE-IN RECORDS

5) J. Anderson, J. Brune, J. Prince, S. Singh, R. Quaas: GUERRERO ACCELEROGRAPH ARRAY-STATUS REPORT

6) D. Y. Papastamatiou, N. Mouyaris, V. N. Margharis, N. P. Theodoulidis, P. M. Hatzidimitriou, C. A, Papaioannou, B. K. Papazachos: THE KALAMATA SEPTEMBER 13, 1986 EARTHQUAKE IN SOUTHERN GREECE

7) Francis T. Wu: A TALE OF TWO COALINGA ACCELEROGRAMS

8) Wan, Peide, Wu, Francis, T: SYNTHETIC OF STRONG GROUND MOTION IN THE NEAR SOURCE REGION WITH EMPIRICAL GREEN'S FUNCTIONS--YUNNAN, CHINA

9) D. Wald, P. Somerville, D. Helmberger: COMPATIBILITY OF ACCELEROGRAMS OF THE 1979 IMPERIAL VALLEY EARTHQUAKE WITH SLIP-DISTRIBUTION ASPERITY MODELS

10) A. J. Mendez, J. E. Luco: SIMULATION OF NEAR-FIELD EARTHQUAKE GROUND MOTION BY A STEADY-STATE DISLOCATION MODEL IN A LAYERED HALF-SPACE

11) C. B. Crouse, B. Hushmand: EXPERIMENTAL INVESTIGATIONS OF SOIL/STRUCTURE INTERACTION AT CDMG AND USGS ACCELEROGRAPH STATIONS

12) A. Anooshehpoor, N. James R. H. Lovberg: SOIL/STRUCTURE INTERACTION AND TOPOGRAPHIC AMPLIFICATION IN FOAM RUBBERA

INTERNATIONAL ASSOCIATION OF SEISMOLOGY
AND PHYSICS OF THE EARTH'S INTERIOR
19TH GENERAL ASSEMBLY, VANCOUVER, CANADA
AUGUST 11, 1987

INTERPRETATION OF STRONG MOTION WAVE FORMS (ORAL AND POSTER)

CONVENOR: Dr. D. H. Weichert

COCONVENORS: Prof. B. A. Bolt, and Prof. Lili Xie, Harbin

CHAIRING: D. H. Weichert, Li-Li Xie, B. Bolt, and V. Schenk

1) John Boatwright: THE ACCELERATION RADIATED BY DISCRETE SUB-EVENTS EMBEDDED IN A COMPOSITE RUPTURE PROCESS

2) P. Somerville, D. Wald, and D. Helmberger: COMPATIBILITY OF ACCELEROGRAMS WITH SLIP-DISTRIBUTION ASPERITY MODELS

3) Kojiro Irikura and Keiiti Aki: SCALING LAW OF SEISMIC SOURCE SPECTRA AND EMPIRICAL GREEN'S FUNCTION FOR PREDICTING STRONG GROUND MOTIONS

4) V. Schenk: ANALYSIS OF STRONG GROUND MOTIONS IN AMPLITUDE DOMAIN--REVIEW AND APPLICATIONS

5) V. M. Graizer: BEARING ON THE STRONG-MOTION REGISTRATION PRINCIPLES

6) D. M. Boore: STOCHASTIC MODELS FOR PREDICTION OF GROUND MOTIONS AND INSTRUMENT RESPONSE: A STATUS REPORT

7) Edmund Reiter, Anton M. Dainty, and M. Nafi Toksoz: NEAR FIELD ATTENUATION IN THE NORTHEASTERN UNITED STATES AND EASTERN CANADA

8) Bruce Bolt, and Shyh-Jeng Chiou: STRONG MOTION ARRAY ANALYSIS OF THE NOVEMBER 14, 1986 TAIWAN EARTHQUAKE

9) S. K. Upadhyay, and Sudhir Kumar: EARTHQUAKE SOURCE PROPERTIES AND WAVE PATH ATTENUATION CHARACTERISTICS FOR EARTHQUAKES IN HIMALAYA AND NORTHEAST INDIA

10) Jafar Shoja-Taheri: RUPTURE VELOCITY AND STRESS DROP OF THE TABAS, IRAN EARTHQUAKE

11) D. H. Weichert, R. B. Horner, and R. Baldwin: NAHANNI STRONG MOTION RECORDS

12) P. Suhadolc, F. Vaccari, and G. F. Panza: THE RUPTURE TIME HISTORY AND THE MECHANISM OF THE 1980 IRPINA, ITALY EARTHQUAKE FROM COMPLETE SYNTHETIC MODELING OF STRONG MOTION DATA

INTERPRETATION OF STRONG MOTION WAVE FORMS (ORAL AND POSTER) (CONTINUED)

13) S. Yoshikawa, T. Kitano, Y. Iwasaki, and M. Tai: THE SYNTHESIS OF THE NEAR FIELD STRONG GROUND MOTION CONSIDERING RADIATION AND DIRECTIVITY

14) Li-Li Xie: AN INTERPRETATION OF THE VARIANCE OF GROUND MOTION IN A SMALL AREA

15) Klaus H. Jacob, and Junho Um: STRONG GROUND MOTIONS OF THE Mw=8 EARTHQUAKE OF MAY 7, 1986, IN THE ANDREANOF ISLANDS, ALASKA

INTERPRETATION OF STRONG MOTION WAVE FORMS
TUESDAY, AUGUST 11 POSTER SESSION

1) J. M. Churcher, S. M. Spottiswood, and D. Brawn: MINE TREMOR STUDIES AT A SOUTH AFRICAN GOLD MINE

2) A. Rovelli, M. DiBona, and G. Valensise: THE INFLUENCE OF LOCAL SITE FREQUENCY-DEPENDENT AMPLIFICATIONS ON THE SCALING OF THE PEAK GROUND MOTION

3) Zheng-xing Yao, and Tian-yu Zheng: STRONG MOTION MODELING FOR THE 1982 LULONG EARTHQUAKE

AMERICAN GEOPHYSICAL UNION
1987 FALL MEETING
SAN FRANCISCO, CALIFORNIA
DECEMBER 7, 1987

STRONG GROUND MOTION

S. Seale, and K. Yomogida, Presiding

1) J. Hill, H. Benz, G. Schuster: A FINITE DIFFERENCE SIMULATION OF SURFACE WAVES AND RESONANCE EFFECTS IN SALT LAKE VALLEY, UTAH

2) B. A. Bolt, S. J. Chiou: MODAL CONVERSION AND AMPLIFICATION OF STRONG GROUND MOTION BY ALLUVIAL BASINS

3) S. H. Seale, R. J. Archuleta: SITE EFFECTS AND SEISMIC AMPLIFICATION AT MCGEE CREEK, CALIFORNIA

4) J. A. Rial: EIGENMODES AND EIGENFREQUENCIES OF RESONANT THREE DIMENSIONAL SEDIMENTARY BASINS

5) H. Kawase, F. J. Sanchez-Sesma, K. Aki: SITE AMPLIFICATION FAR BEYOND THE IMPEDANCE RATIO FOR INCIDENT SV WAVES

6) K. Aki, S. Steacy, M. Campillo, H. Kawase, F. J. Sanchez-Sesma: SOURCE, PATH AND SITE EFFECTS ON STRONG GROUND MOTION DURING THE MICHOACAN EARTHQUAKE OF 1985

7) S. M. Day, J. L. Stevens: SIMULATION OF GROUND MOTION FROM THE 1985 MICHOACAN, MEXICO EARTHQUAKE

8) S. J. Steacy, K. Aki, M. Campillo: THE MICHOACAN EARTHQUAKE OF 1985: DISLOCATION OR CRACK GROWTH?

9) K. Yomogida: DYNAMIC RUPTURE PROCESSES INFERRED FROM NEAR-FAULT OBSERVATIONS

10) S. D. Ruppert, K. Yomogida: NEAR-FIELD SYNTHETIC SEISMOGRAMS FOR THE MICHOACAN, MEXICO EARTHQUAKE OF SEPTEMBER 19, 1985

11) A. Reyes, L. Mendoza, J. Acosta, F. Favela, R. Lopez, M. Diaz A. Vazques, J. Otero: STRONG MOTION INSTRUMENTATION PROGRAM (STATE OF DEVELOPMENT)

12) D. J. Wald, P. G. Somerville: SEMI-EMPIRICAL MODELING OF RECORDED ACCELERATIONS FROM THE 1979 IMPERIAL VALLEY EARTHQUAKE

13) P. G. Somerville, J. P. McLaren, C. K. Saikia: FORMULATION AND VALIDATION OF A PROCEDURE FOR THE SITE-SPECIFIC ESTIMATION OF SPATIAL COHERENCE OF GROUND MOTIONS CLOSE TO AN EXTENDED SOURCE

AMERICAN GEOPHYSICAL UNION FALL MEETING
SPECIAL SESSION ON
THE WHITTIER NARROWS OF OCTOBER 1, 1987
DECEMBER 11, 1987

1) E. Hauksson: THE 1987 WHITTIER NARROWS EARTHQUAKE IN THE LOS ANGELES METROPOLITAN AREA, CALIFORNIA: OVERVIEW, LOCATIONS AND SEISMOTECTONICS

2) L. M. Jones: SPATIAL VARIATIONS IN THE LOCATIONS AND FOCAL MECHANISMS OF AFTERSHOCKS OF THE 1987 WHITTIER NARROWS EARTHQUAKE, LOS ANGELES COUNTY, CALIFORNIA

3) A. J. Michael: STRESS AND STRAIN IN THE WHITTIER NARROW AFTERSHOCKS

4) S. L. Salyards: THE WHITTIER NARROWS EARTHQUAKE AFTERSHOCK SEQUENCE: FEWER AFTERSHOCKS THAN TYPICAL FOR SOUTHERN CALIFORNIA

5) P. A. Reasenberg: PRELIMINARY ANALYSIS OF SEISMICITY PRECURSORS OF THE 1987 WHITTIER NARROWS EARTHQUAKE

6) T. L. Davis: THE WHITTIER NARROWS EARTHQUAKE (M-5.9) AND ITS RELATIONSHIP TO ACTIVE FOLDING AND THRUST FAULTING ALONG THE NORTHERN MARGIN OF THE LOS ANGELES BASIN

7) J. Lin: COSEISMIC FOLDING DURING THE WHITTIER NARROWS, CALIFORNIA, EARTHQUAKE

8) E. M. Gath: THE WHITTIER FAULT IN SOUTHERN CALIFORNIA; PRELIMINARY RESULTS OF INVESTIGATIONS

9) G. Ekstrom: PRELIMINARY CMT SOLUTION OF THE WHITTIER EARTHQUAKE

10) W. W. Chan: SOURCE-TIME FUNCTIONS FOR THE WHITTIER NARROWS EARTHQUAKE OF OCTOBER 1, 1987 AND ITS AFTERSHOCK FROM MAXIMUM-LIKELIHOOD MULTICHANNEL DECONVOLUTION

11) A. Brent: BODY WAVE MODELING OF THE WHITTIER NARROWS, CALIFORNIA EARTHQUAKE OF OCTOBER 1, 1987

12) B. A. Bolt: EXTENDED REGIONAL BROADBAND WAVE RESOLUTION OF THE 1987 WHITTIER NARROWS, CALIFORNIA EARTHQUAKE

13) M. J. S. Johnston: STATIC MOMENT OF THE OCTOBER 1, 1987, WHITTIER NARROWS EARTHQUAKE FROM BOREHOLE STRAIN DATA

14) A. F. Shakal: STRONG-MOTION DATA FROM THE WHITTIER EARTHQUAKE OF OCTOBER 1, 1987

15) D. J. Wald: SIMULATION OF ACCELEROGRAMS OF THE 1987 WHITTIER NARROWS EARTHQUAKE

AMERICAN GEOPHYSICAL UNION FALL MEETING
SPECIAL SESSION ON
THE WHITTIER NARROWS OF OCTOBER 1, 1987
DECEMBER 11, 1987 (CONTINUED)

16) O. Banamassa: DIGITAL RECORDING OF AFTERSHOCKS OF THE OCTOBER 1, 1987, WHITTIER NARROWS, CALIFORNIA, EARTHQUAKE

17) G. W. Simila: NEAR-FIELD ACCELERATIONS FROM THE AFTERSHOCKS OF THE OCTOBER 1, 1987 (M=5.9) WHITTIER NARROWS EARTHQUAKE

18) T. C. Hanks: THE MOTION OF MILLIKAN LIBRARY AT VERY SMALL AMPLITUDES

19) C.G. Bufe: SITE RESPONSE INFORMATION FROM THE WHITTIER NARROWS EARTHQUAKE AND ITS AFTERSHOCKS

20) J. P. Mutschlecner: INFRASONIC OBSERVATIONS OF THE WHITTIER, CALIFORNIA, EARTHQUAKE

21) S. D. Oaks: THE OCTOBER 1, 1987, WHITTIER NARROWS, CALIFORNIA EARTHQUAKE: A VIEW FROM CONGRESS

DIABLO CANYON LONG TERM SEIMIC PROGRAM
PG&E/NRC MEETINGS

1. May 8, 1984	PG&E/NRC - To Discuss Draft Elements of License Condition
2. May 24, 1984	ACRS Subcommittee
3. June 14, 1984	ACRS
4. October 4, 1984	PG&E/NRC - To Discuss Proposed Geologic Investigation
5. November 15-16, 1984	PG&E/NRC - To Discuss Proposed Earthquake Magnitude and Ground Motions Investigations
6. December 11, 1984	PG&E/NRC - To Discuss Proposed PRA
7. January 10, 1985	PG&E/NRC - To Respond to NRC Comments, and Discuss NRC/PG&E Interaction
8. March 21-22, 1985	ACRS Subcommittee
9. May 22, 1985	PG&E/NRC - Response to NRC Comments on Program Plan
10. June 24-25, 1985	PG&E/NRC - Field Trip
11. July 10-11, 1985	ACRS Subcommittee & ACRS

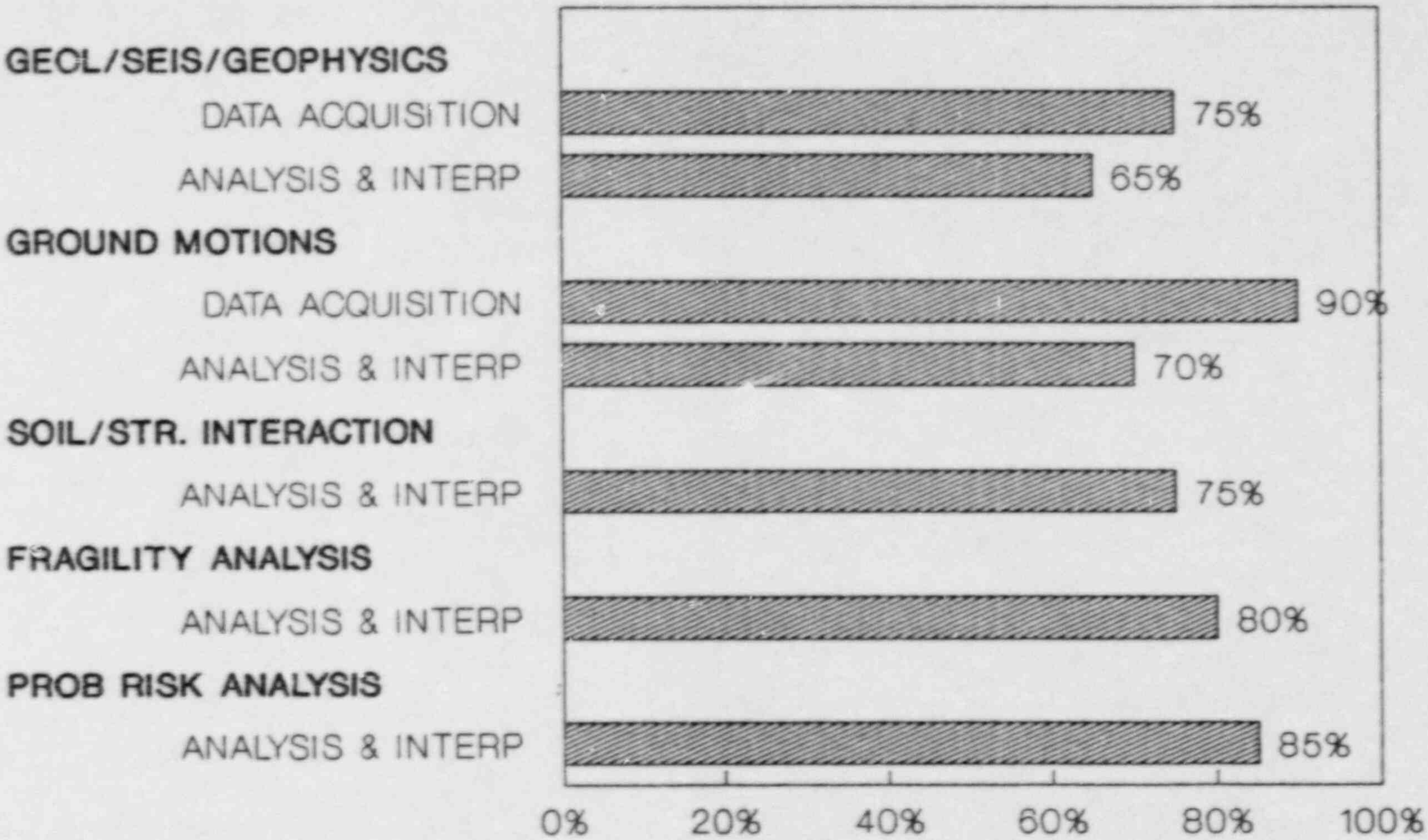
PGE&E/NRC MEETINGS (CONTD)

12. October 21, 1985	PG&E/NRC - Soil/Structure Interaction Workshop
13. December 12, 1985	PG&E/NRC - Ground Motions Workshop
14. March 11-12, 1986	PG&E/NRC - LTSP Coordination
15. April 14-15, 1986	PG&E/NRC - Ground Motions Workshop
16. May 28-29, 1986	PG&E/NRC - G/S/G Workshop
17. August 15-16, 1986	PG&E/NRC - Field Trip
18. August 20-21, 1986	PG&E/NRC - PRA Workshop
19. October 21-22, 1986	PG&E/NRC - G/S/G Workshop
20. October 23-24, 1986	PG&E/NRC - Ground Motions Workshop
21. November 20, 1986	ACRS Subcommittee
22. December 10-12, 1986	PG&E/NRC - Soil/Structure Interaction Workshop
23. December 16, 1986	PG&E/NRC - Ground Motions Workshop

PG&E/NRC MEETINGS (CONTD)

24. February 17-18, 1987	PG&E/NRC - PRA Workshop
25. May 5-8, 1987	PG&E/NRC - G/S/G Workshop and Field Trip
26. July 15-16, 1987	PG&E/NRC - Ground Motions Workshop
27. November 2-3, 1987	PG&E/NRC - Fragilities Workshop
28. November 4-6, 1987	PG&E/NRC - Soil/Structure Interaction Workshop
29. January 14-15, 1988	PG&E/NRC - PRA Workshop

DIABLO CANYON LONG TERM SEISMIC PROGRAM PROGRESS



Insert #3

GEOLOGY/SEISMOLOGY/GEOPHYSICS WORK PLAN

--Focused

--Data-Driven

DATA ACQUISITION

DATA ANALYSIS

DATA INTERPRETATION

SEISMIC SOURCE CHARACTERIZATION

DATA ACQUISITION

LITERATURE REVIEW

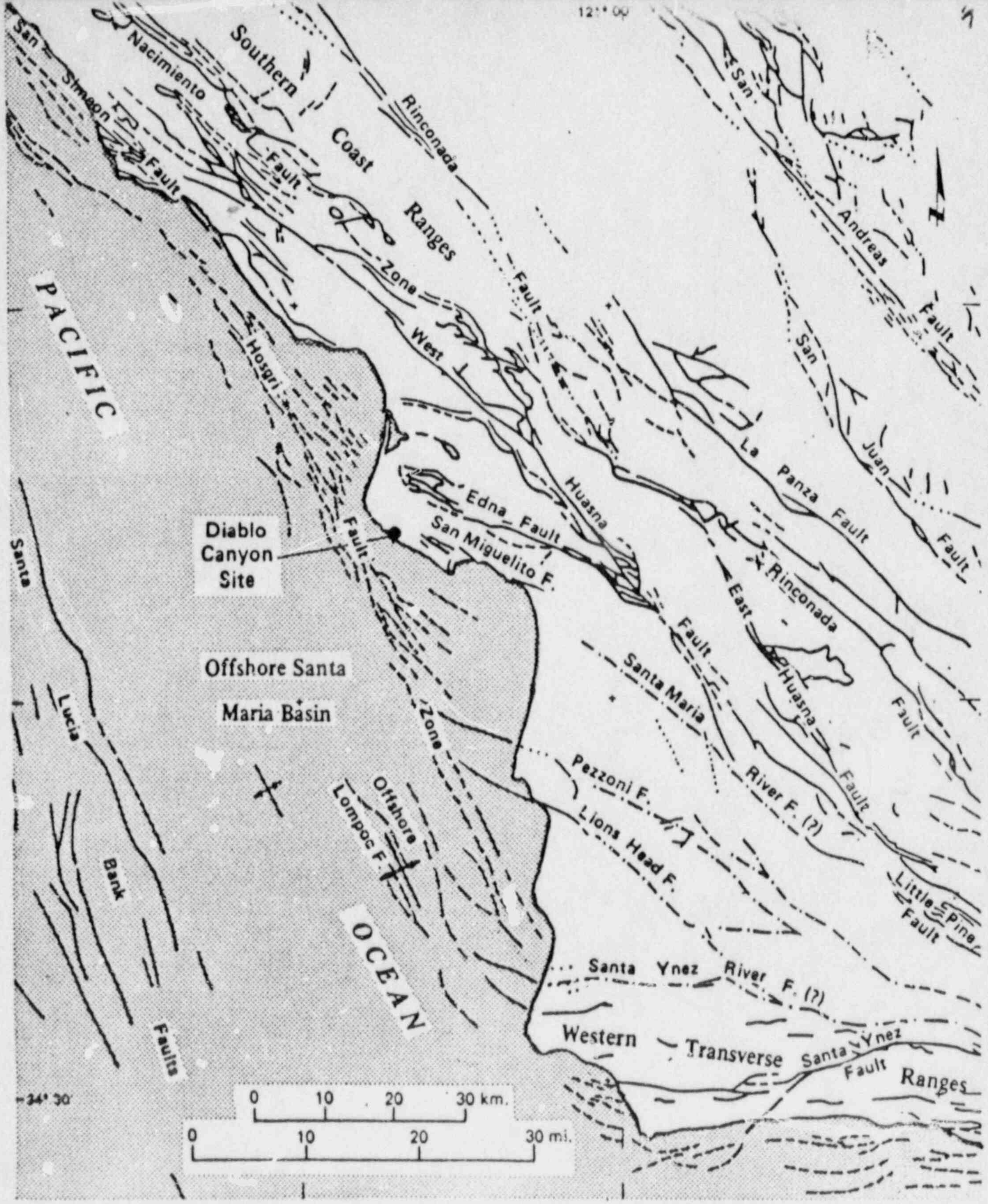
GEOLOGIC STUDIES

- --marine and fluvial terraces
- --age dating
- --fault trenching

OFFSHORE AND ONSHORE GEOPHYSICS

- --COMAPS high-resolution near-shore study done by PG&E
- --Digicon/PG&E deep crustal survey; includes Rice, HARC, USGS
- --Additional proprietary Western and Nekton CDP lines
- --Reprocessing of selected lines
- --California State Lands data collected within 3-mile limit

CENTRAL COAST SEISMIC NETWORK



Map Symbols	
—— ···	Mapped fault, dotted where concealed.
— · — · —	Trend of proposed subsurface fault.
—+—	Anticlinal fold, expressed as topographic feature of the sea floor.

Fault Data Sources

Jennings (CDMG), 1975

McCulloch et. al. (USGS), 1980 (Santa Lucia Bank area)

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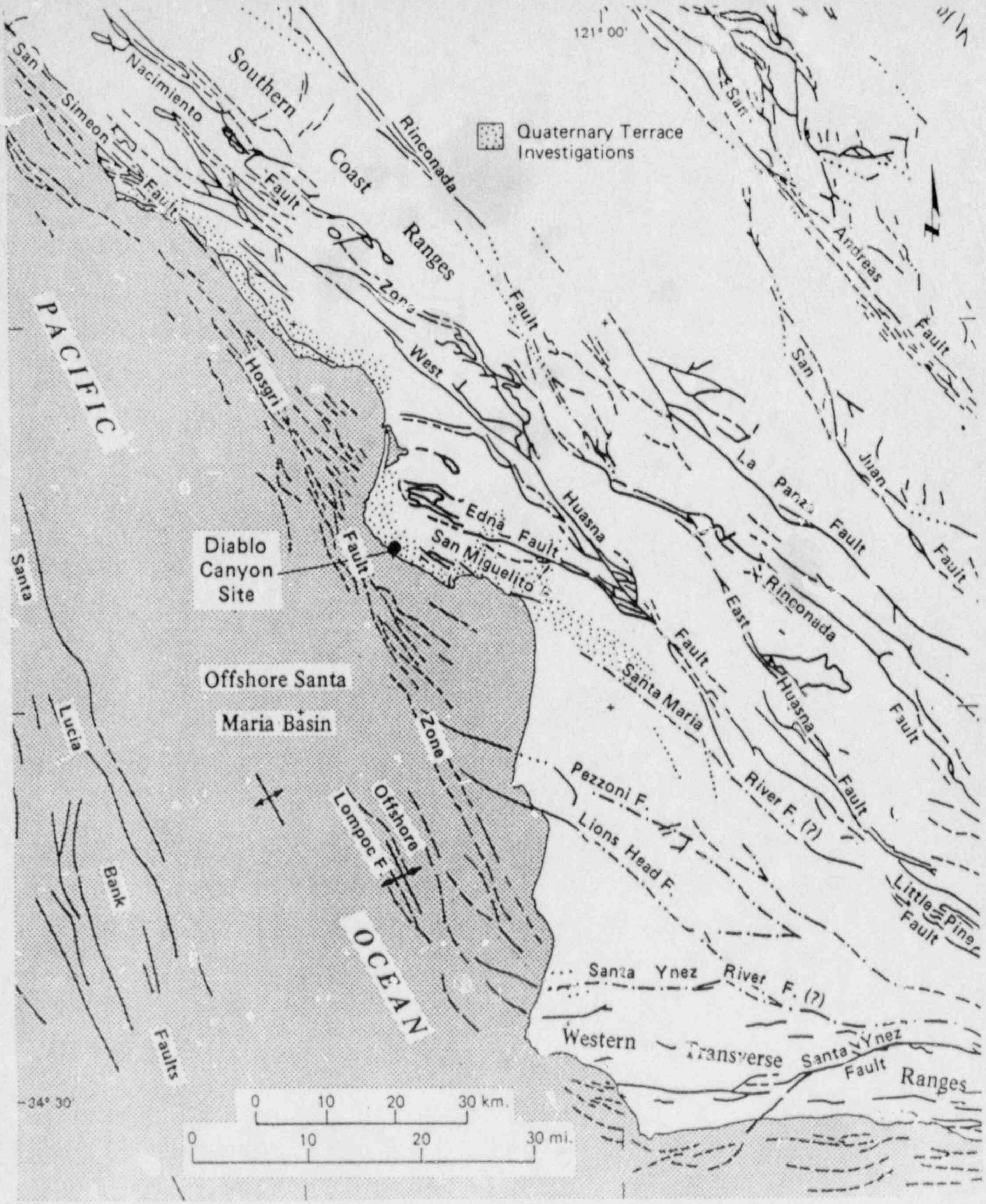
Hall, 1977 (Santa Maria River F. (?))

Sylvester and Darrow, 1978 (Santa Ynez River F. (?))

SANTA MARIA BASIN REGION



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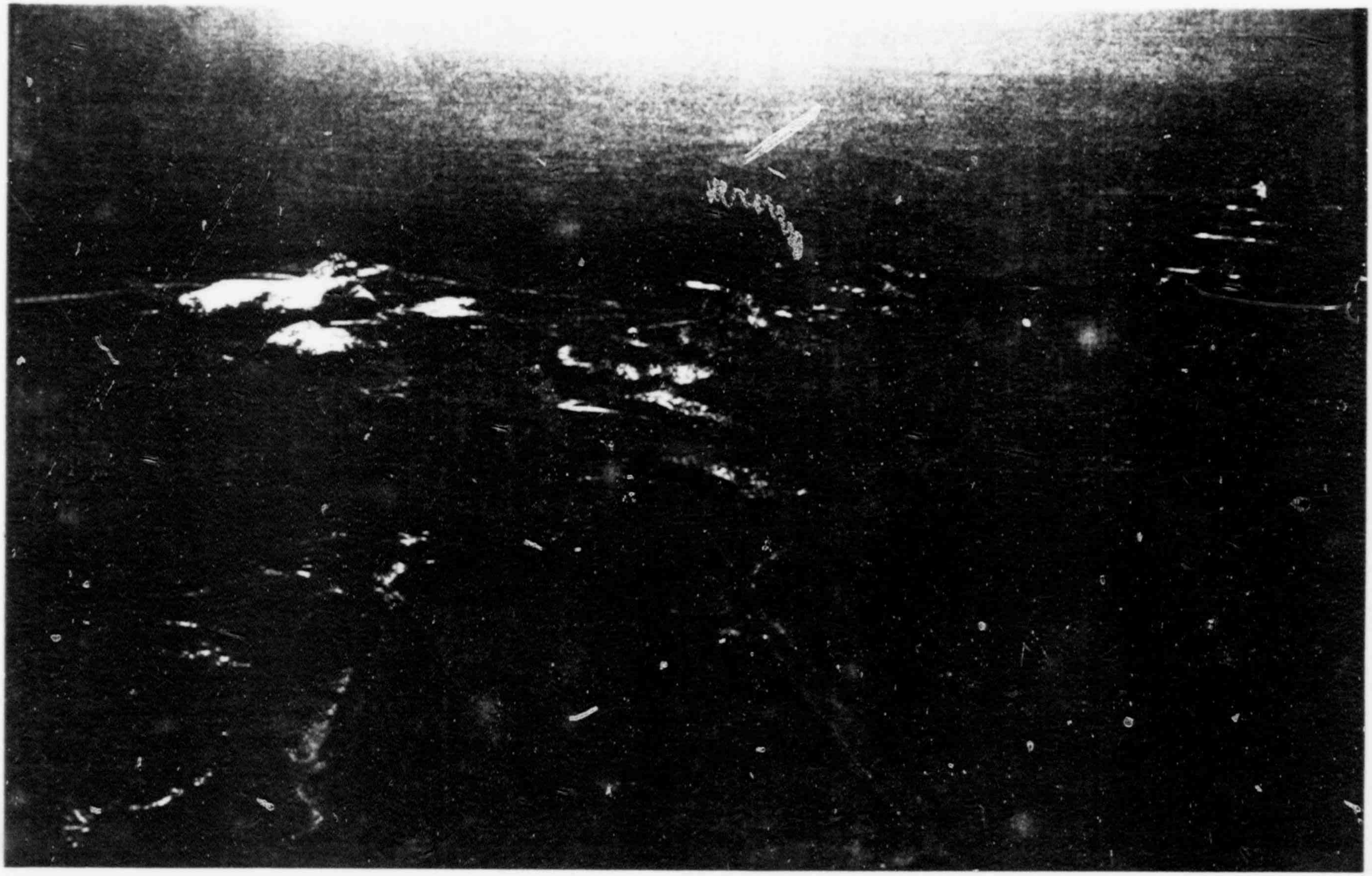

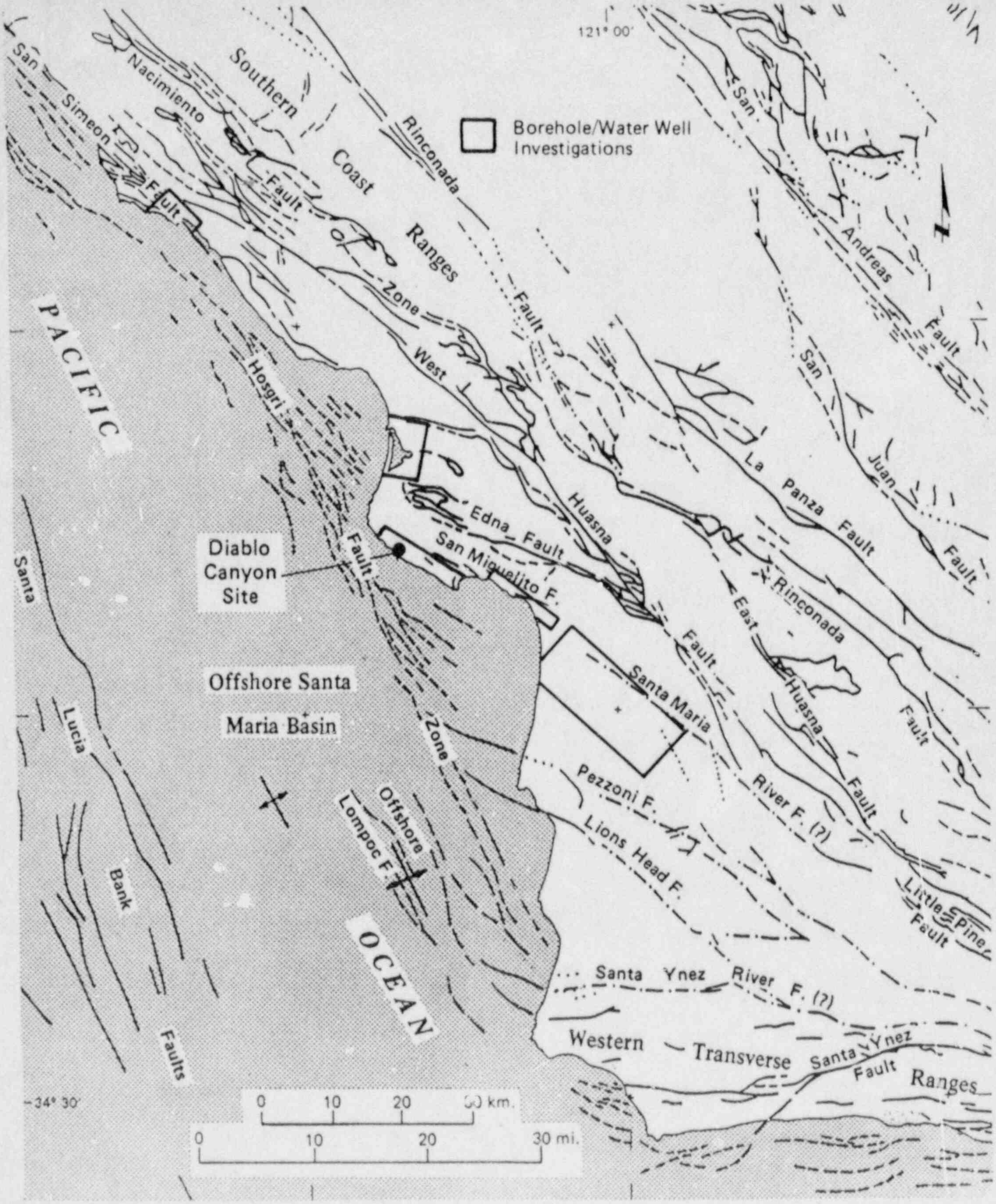

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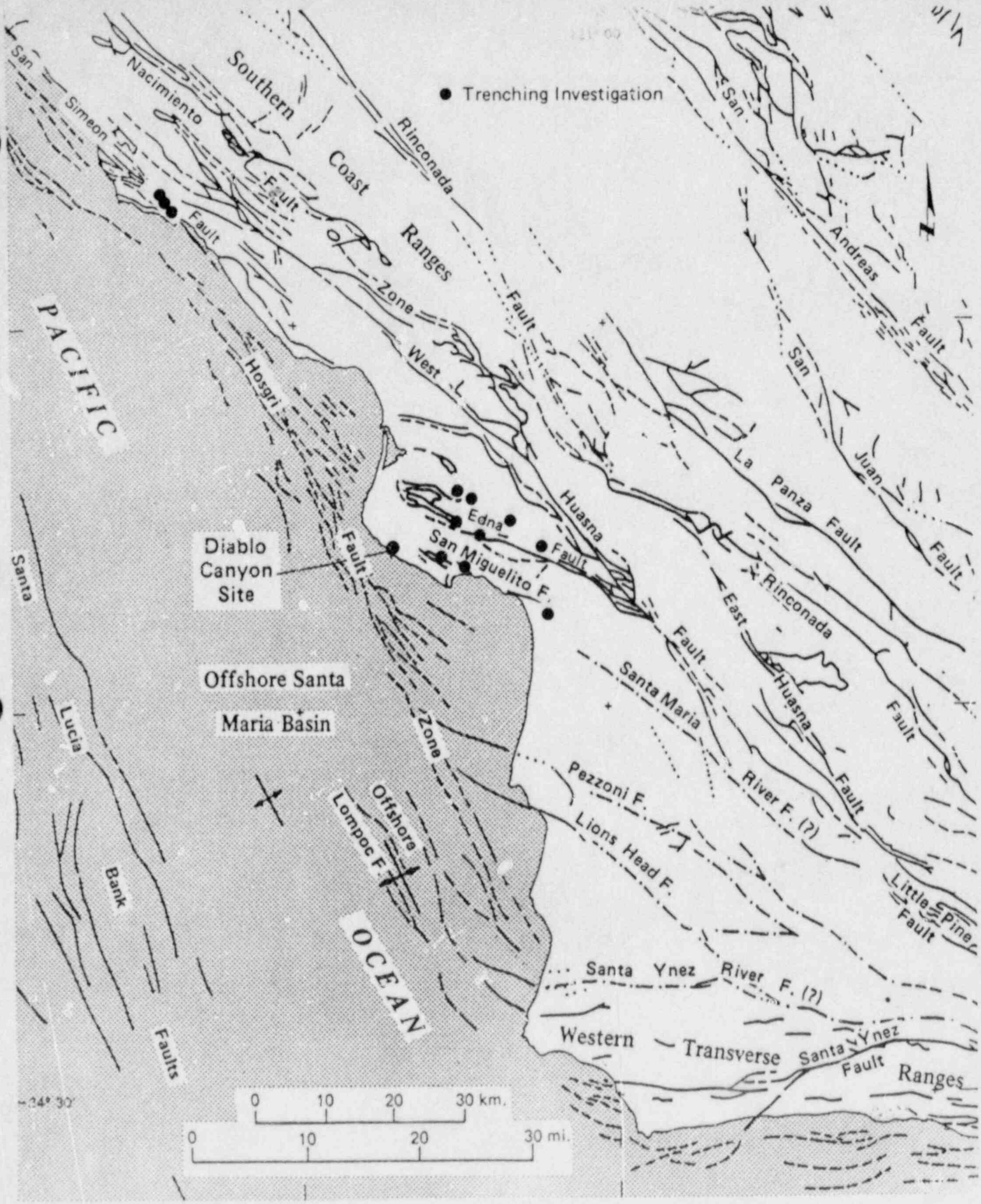

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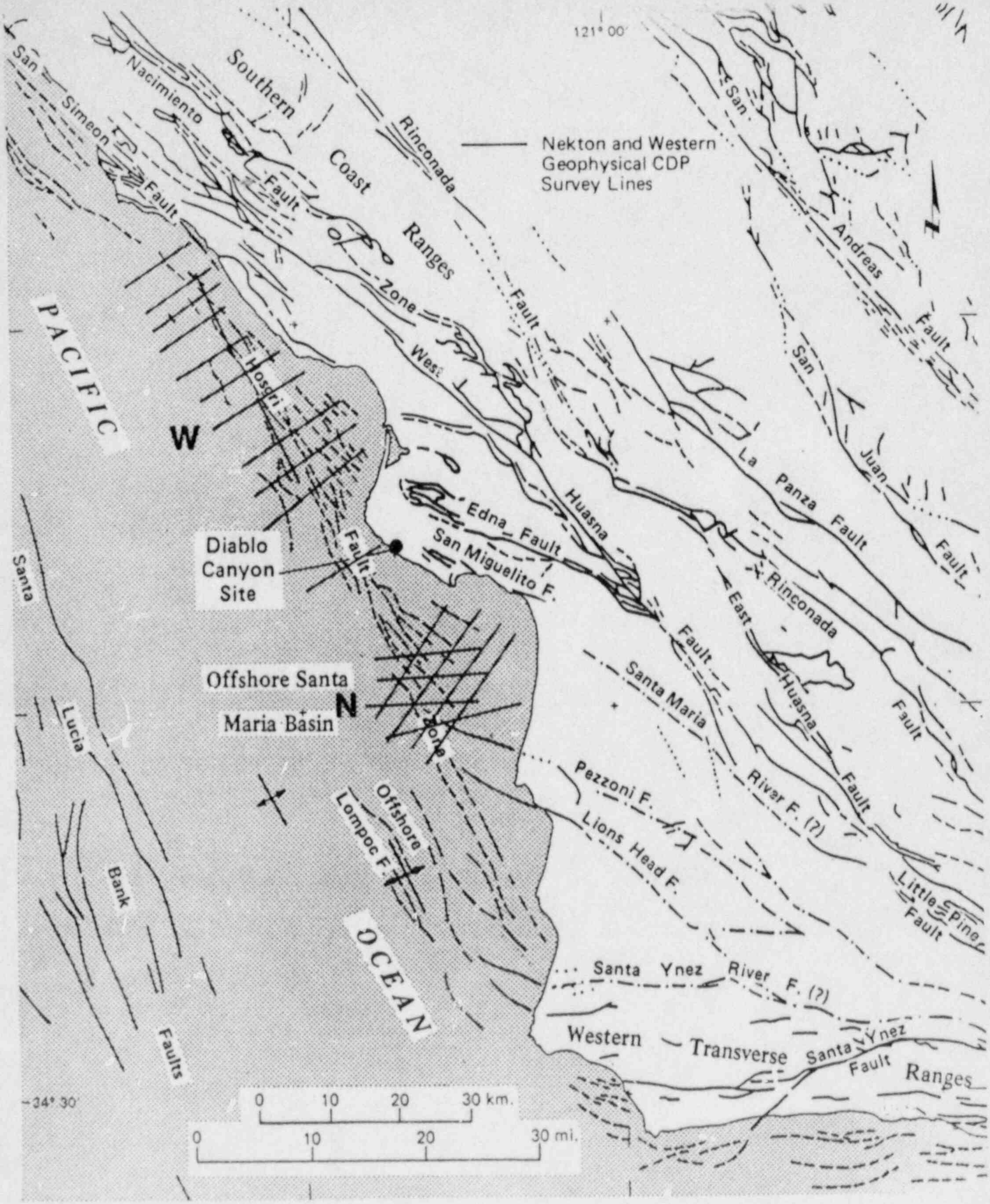

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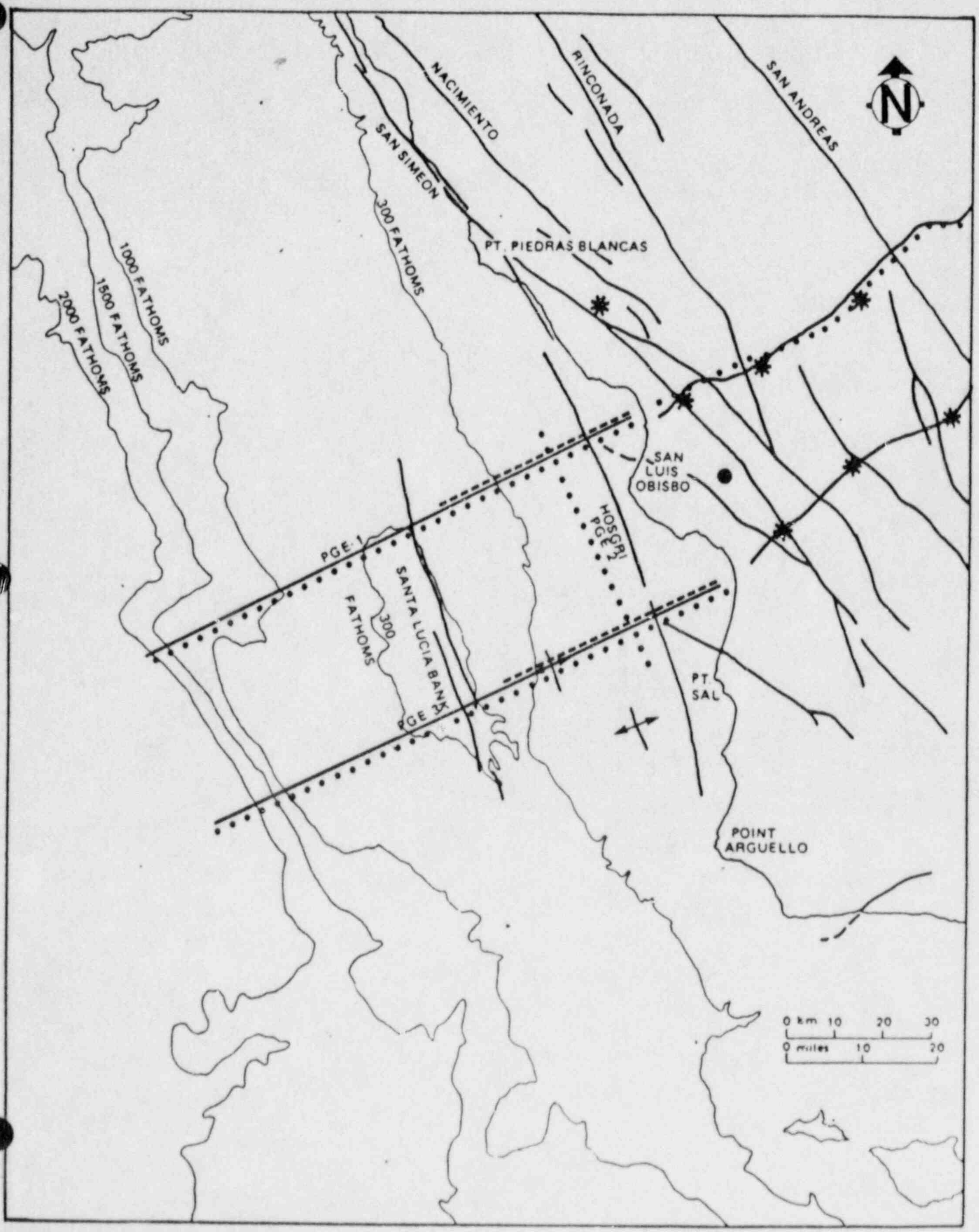

N
NACIMIENTO
RINCONADA
SAN ANDREAS
SAN SIMEON
300 FATHOMS
PT. PIEDRAS BLANCAS
1000 FATHOMS
1500 FATHOMS
2000 FATHOMS
SAN LUIS OBISBO
HOSGRI
PGE 2
PGE 1
SANTA LUCIA BANK
300 FATHOMS
PGE 3
PT. SAL
POINT ARGUELLO
0 km 10 20 30
0 miles 10 20

DIGICON DEEP CRUSTAL MARINE SURVEY SPECIFICATIONS

DATE: November 1986

NAVIGATION: SYLEDIS Primary
LORAN C Backup

SHIP: ATLANTIC SEAL

REFRACTION SURVEY

SOURCE: 10,000 cubic inch tuned airgun array

SHOT INTERVAL: 1 minute (approx. 150 m)

REFLECTION SURVEY

SOURCE: 6,000 cubic inch airgun array

CHANNELS: 180

GROUP INTERVAL: 25 m

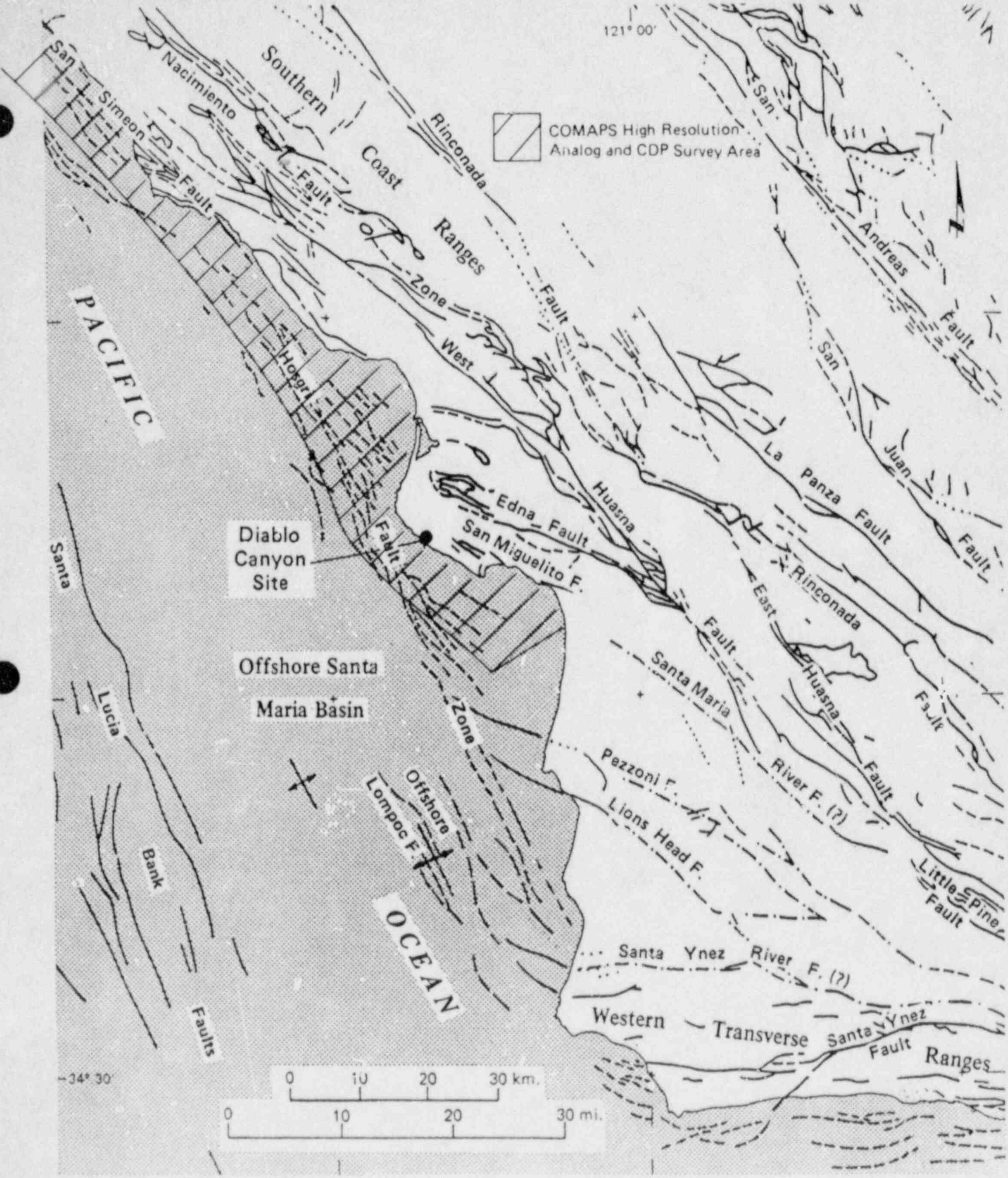
SHOT INTERVAL: 50 m

OFFSET: 241.5 TO 4716.5 m

FILTER: 3 TO 80 Hz

RECORD LENGTH: 16 sec

SAMPLE RATE: 4 ms



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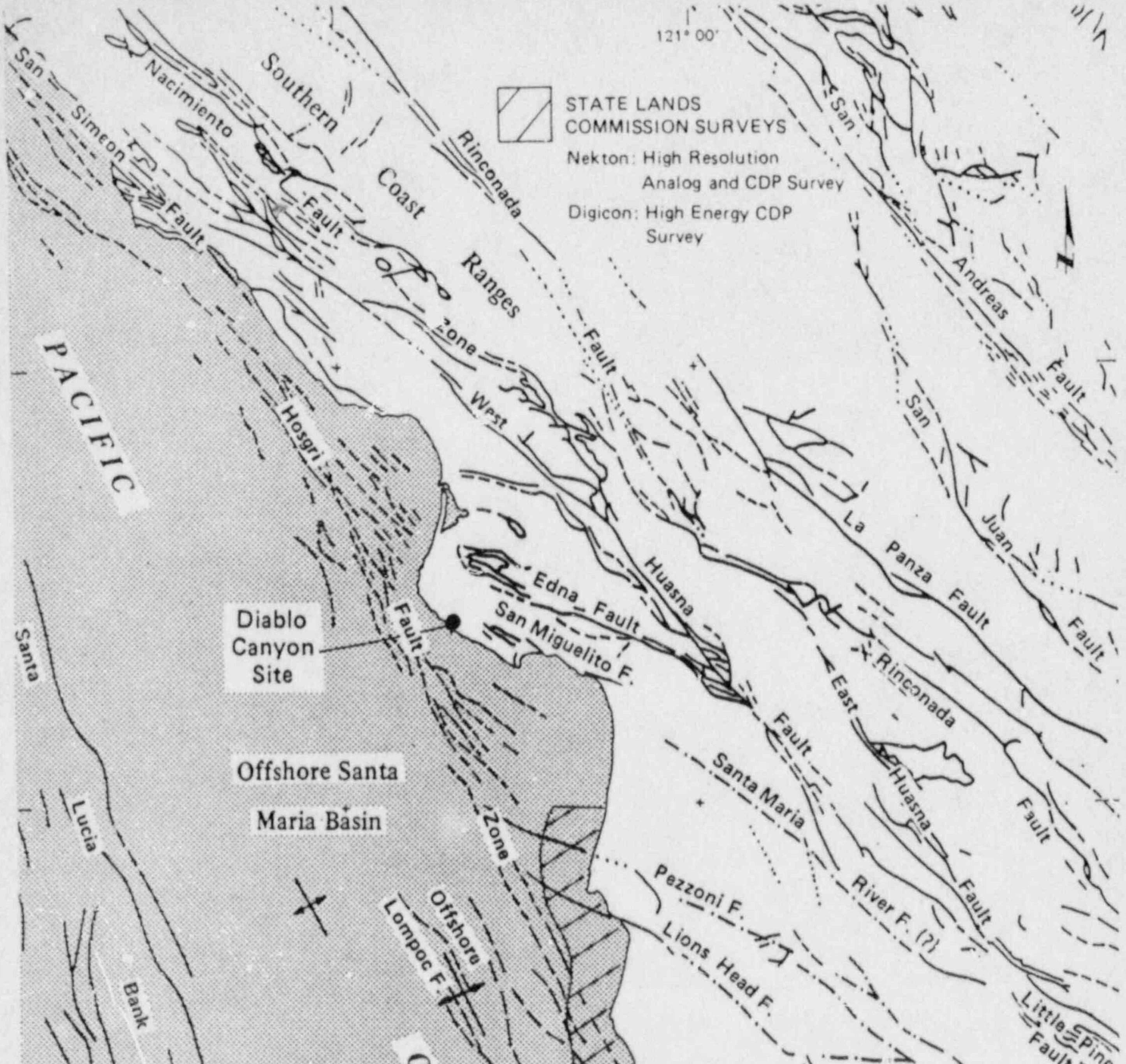
Sylvester and Darrow, 1978 (Santa Ynez River F. (?))

SANTA MARIA BASIN REGION



Map Symbols

—— ··· Mapped fault, dotted where concealed.

—·—·— Trend of proposed subsurface fault.

—+— Anticlinal fold, expressed as topographic feature of the sea floor.

Fault Data Sources

Jennings (CDMG), 1975

McCulloch et. al. (USGS), 1980 (Santa Lucia Bank area)

Ogle, 1985 (Southern Offshore Santa Maria Basin)

Hall, 1977 (Santa Maria River F. (?))

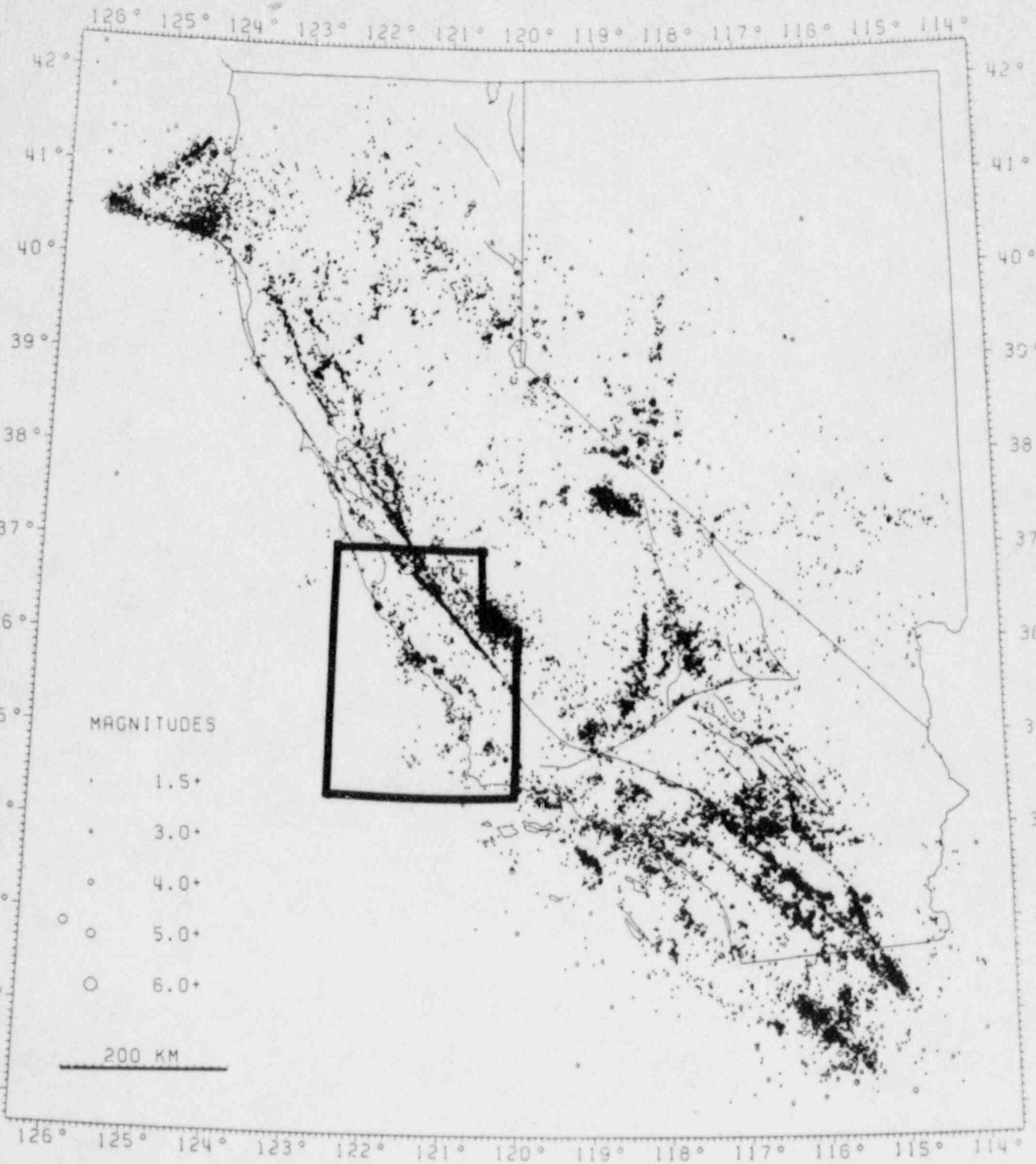
Sylvester and Darrow, 1978 (Santa Ynez River F. (?))

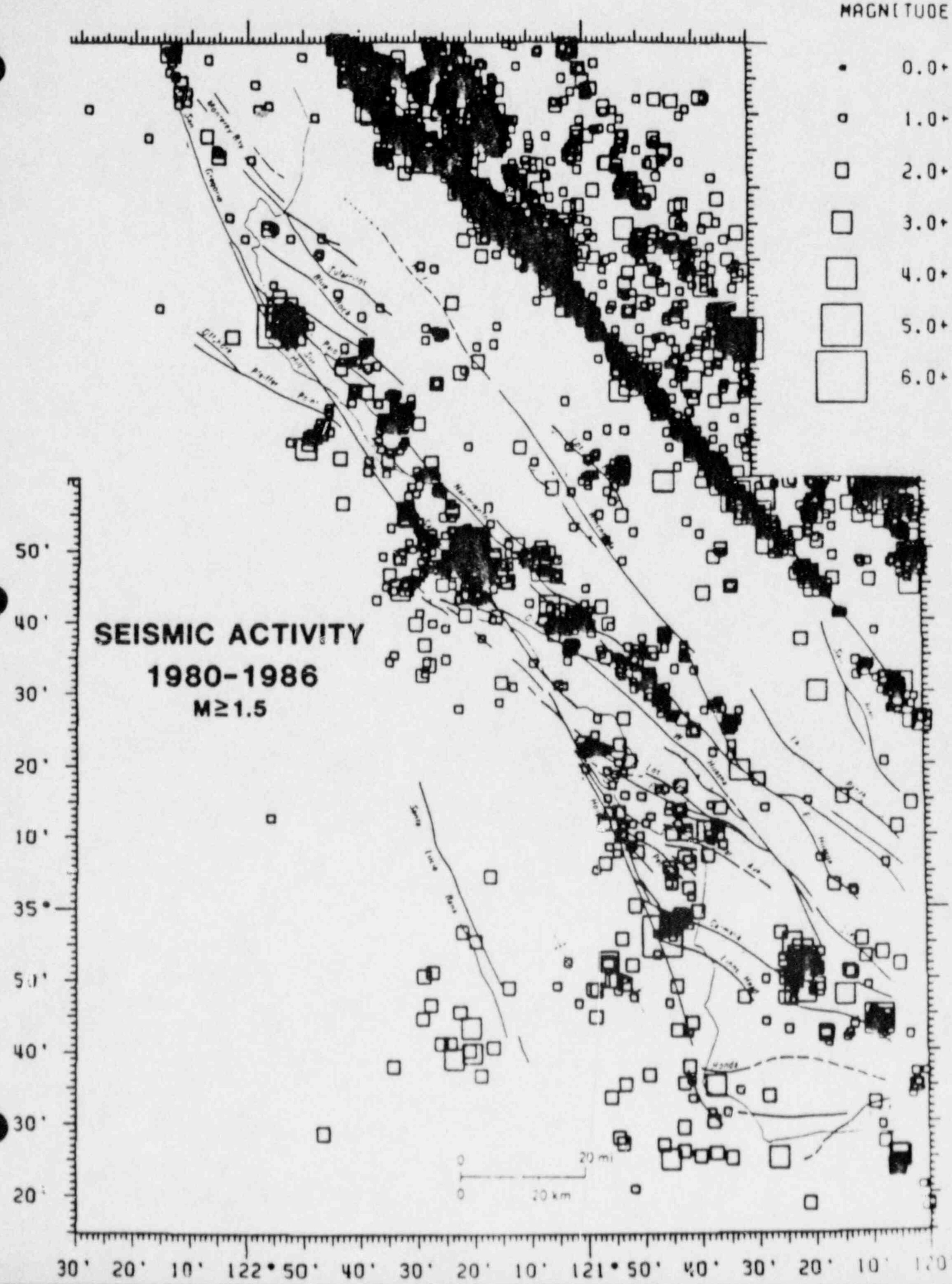
SANTA MARIA BASIN REGION

CALIF - NEVADA 1980-1984

M > 1.5

CALNEY.COM CSVAX2::STSI:IS 9-JUN-86 16:57:58

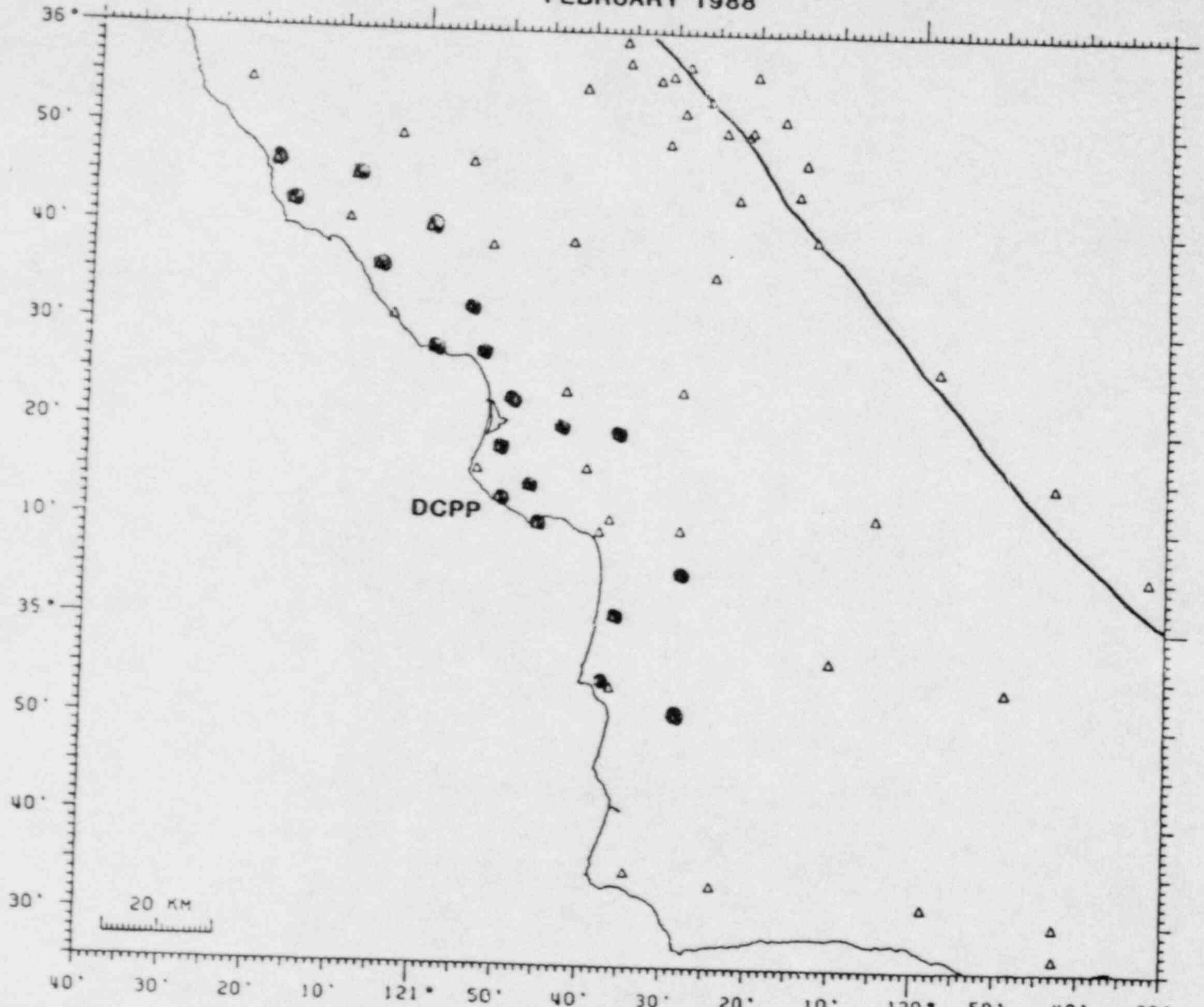


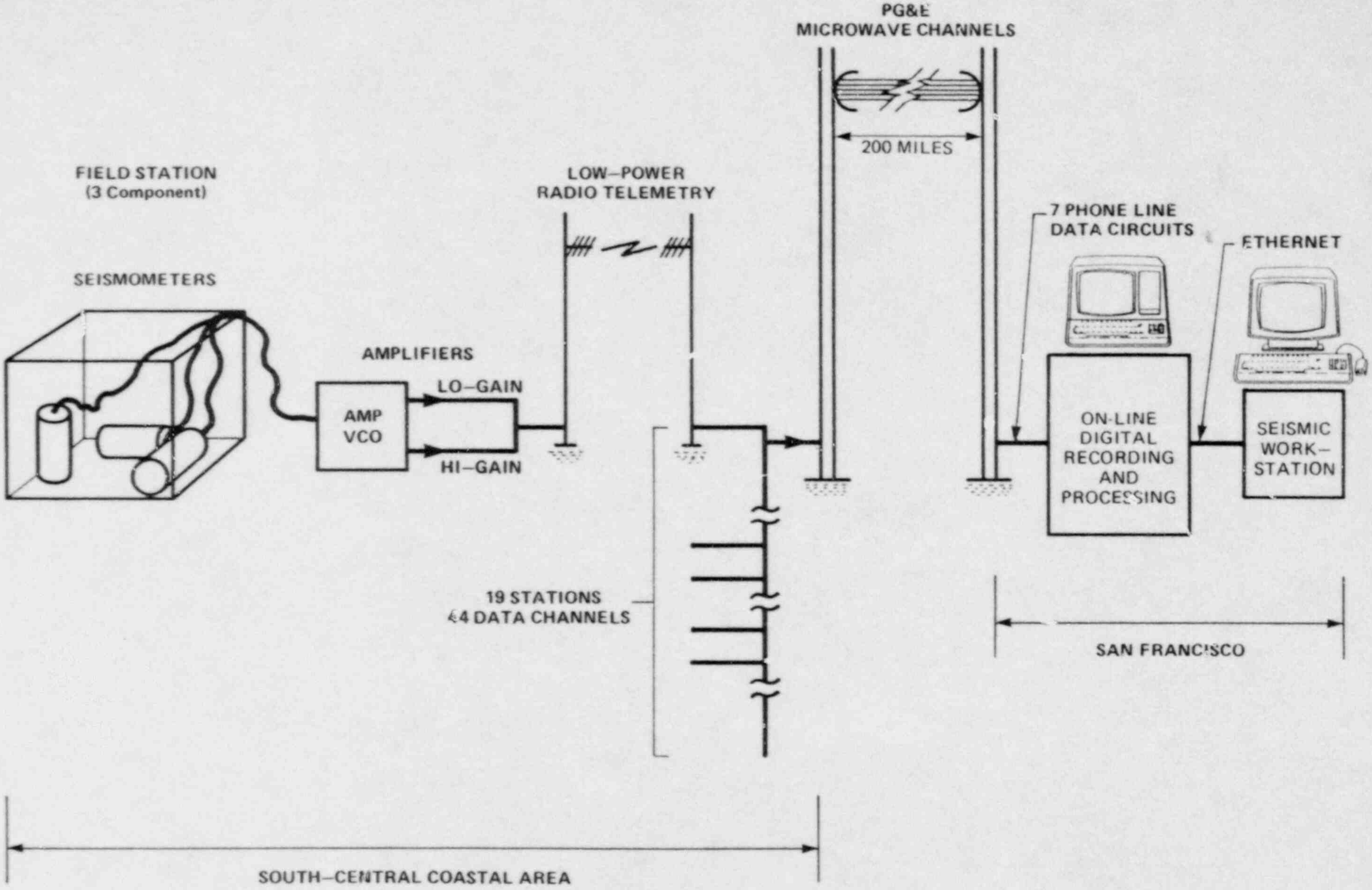


SEISMIC ACTIVITY
1980-1986
M≥1.5

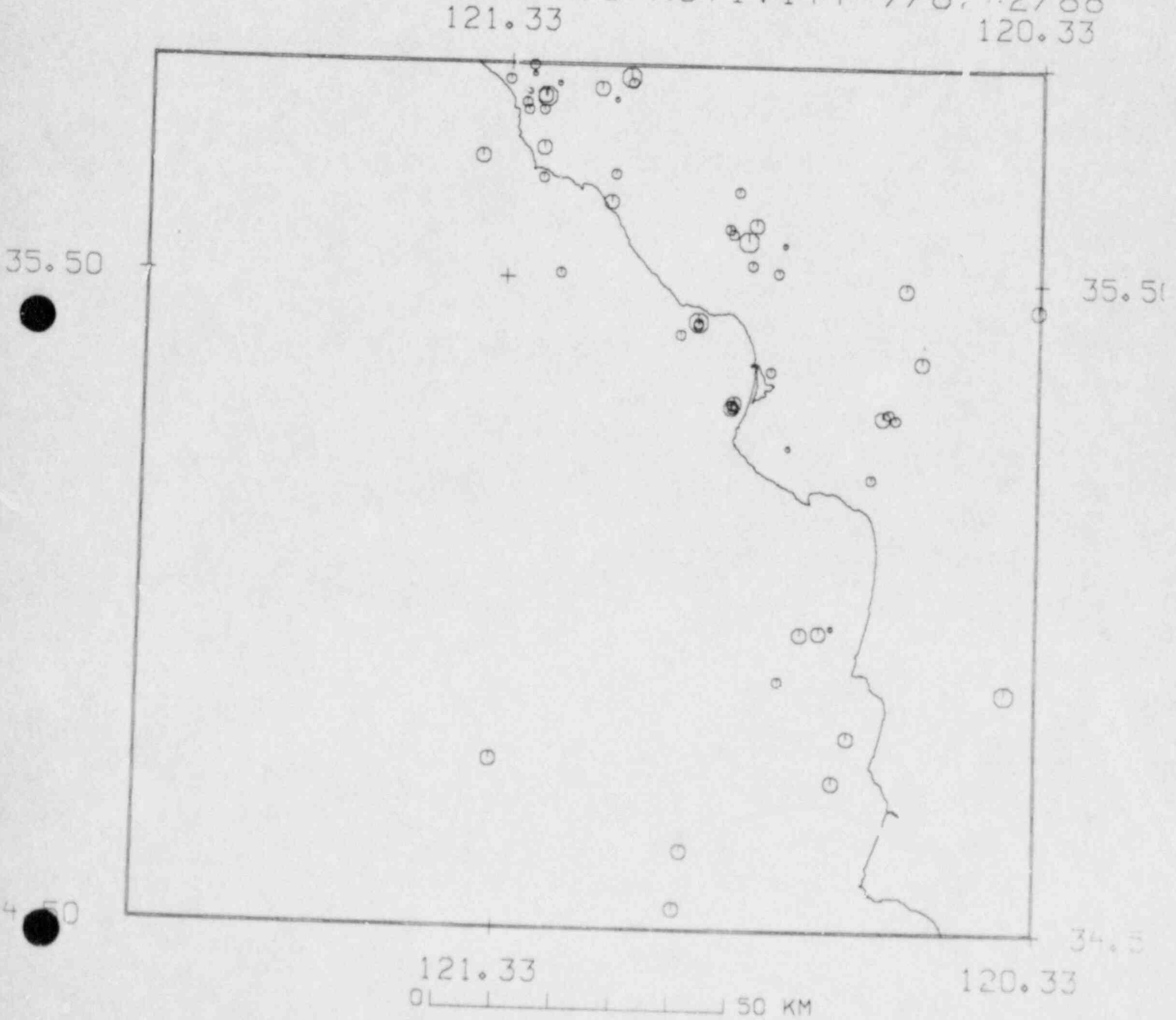
CENTRAL COAST SEISMIC NETWORK/USGS NETWORK

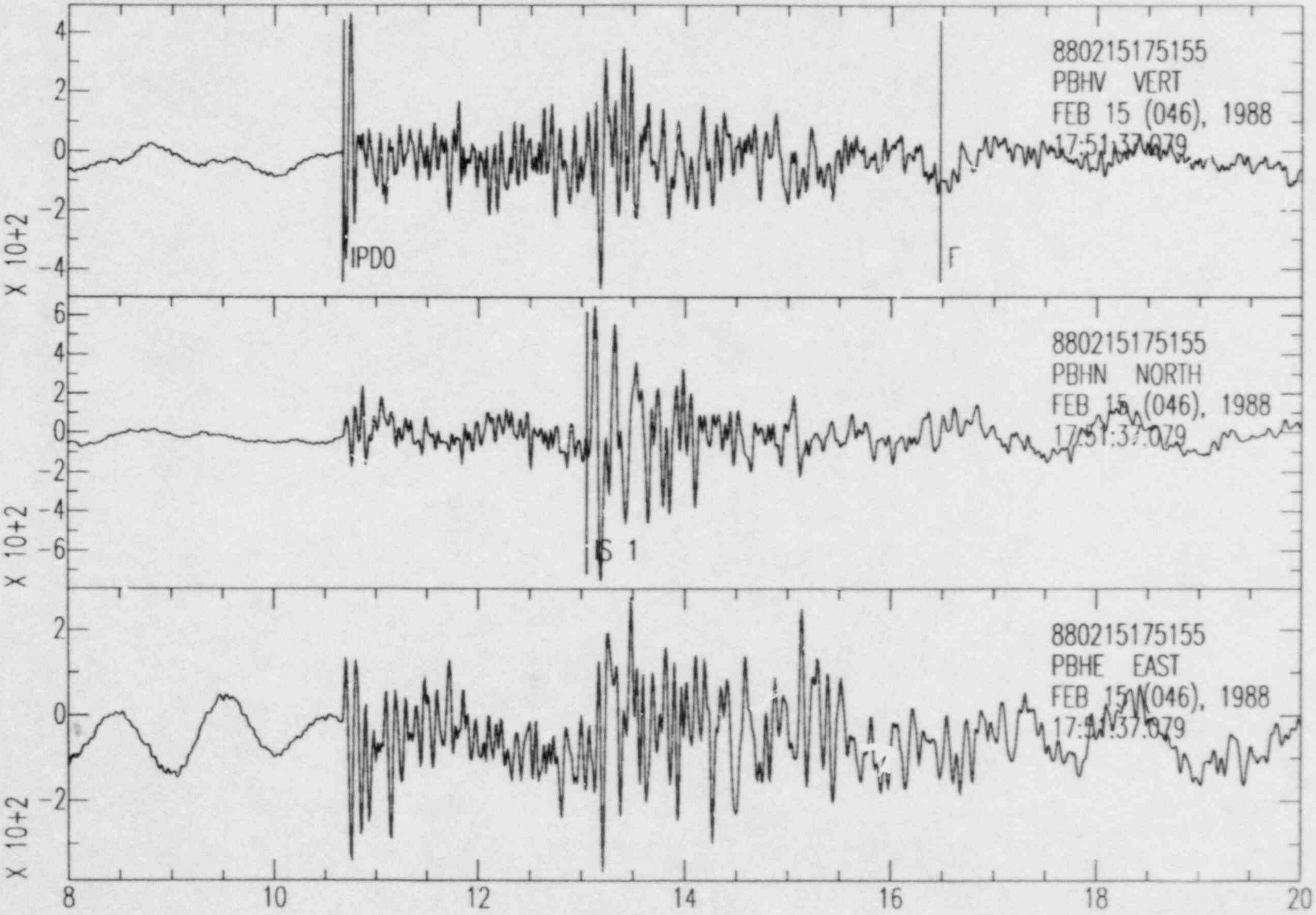
FEBRUARY 1988

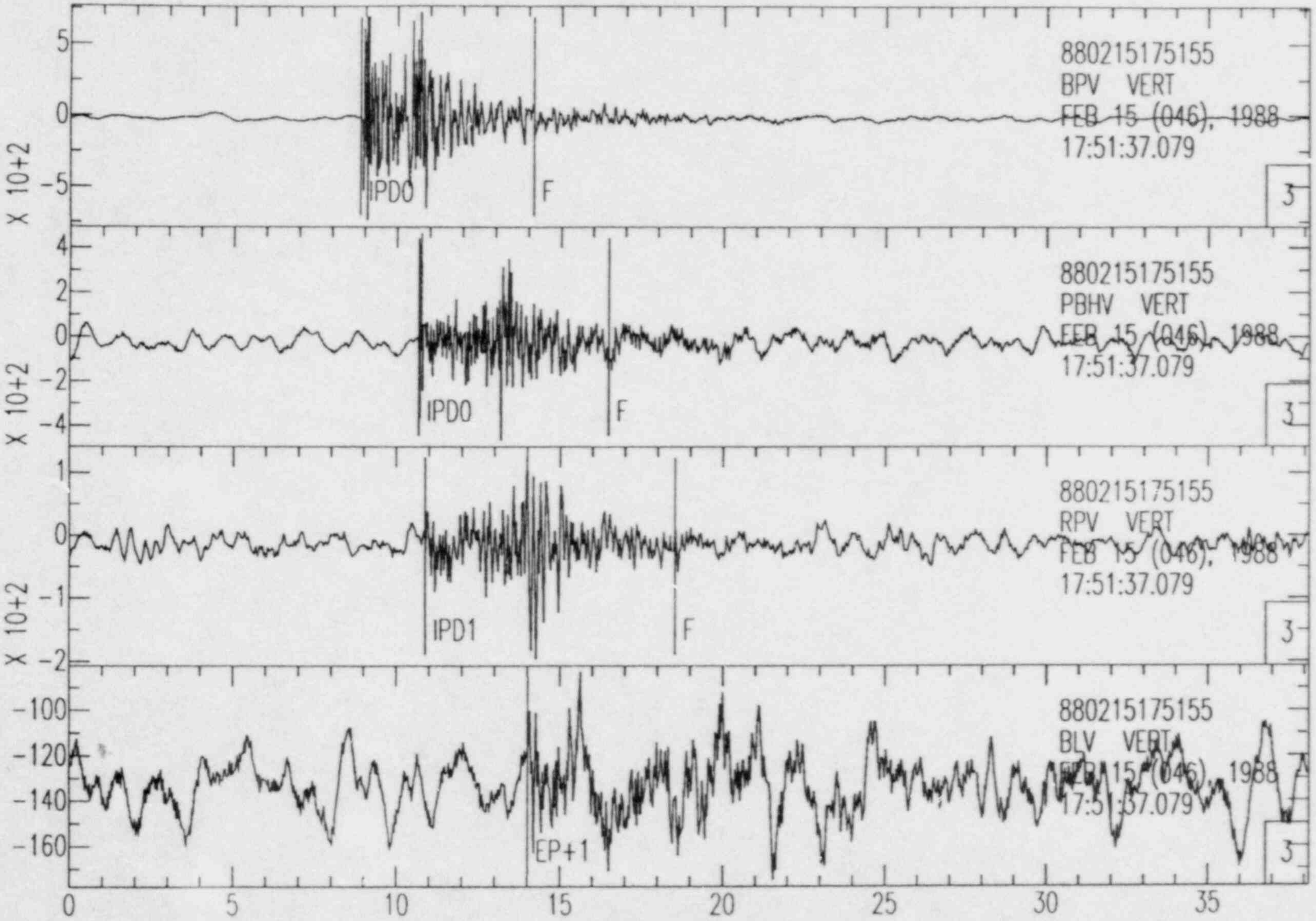



PG&E
MICROWAVE CHANNELS
200 MILES
FIELD STATION
(3 Component)
LOW–POWER
RADIO TELEMETRY
7 PHONE LINE
DATA CIRCUITS
ETHERNET
SEISMOMETERS
AMPLIFIERS
AMP
VCO
LO–GAIN
HI–GAIN
ON-LINE
DIGITAL
RECORDING
AND
PROCESSING
SEISMIC
WORK–
STATION
19 STATIONS
44 DATA CHANNELS
SAN FRANCISCO
SOUTH–CENTRAL COASTAL AREA

CENTRAL COAST SEISMIC ACTIVITY 9/87-2/88




880215175155
PBHV VERT
FEB 15 (046), 1988
17:51:37.079
IPD0
F
X 10+2
4
2
0
-2
-4
880215175155
PBHN NORTH
FEB 15 (046), 1988
17:51:37.079
IS 1
X 10+2
6
4
2
0
-2
-4
-6
880215175155
PBHE EAST
FEB 15 (046), 1988
17:51:37.079
X 10+2
2
0
-2
8
10
12
14
16
18
20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BPV VERT
FEB 15 (046), 1988
17:51:37.079
IPD0
F
3
5
0
-5
X 10+2
880215175155
PBHV VERT
FEB 15 (046), 1988
17:51:37.079
IPD0
F
3
4
2
0
-2
-4
X 10+2
880215175155
RPV VERT
FEB 15 (046), 1988
17:51:37.079
IPD1
F
3
1
0
-1
-2
X 10+2
880215175155
BLV VERT
FEB 15 (046), 1988
17:51:37.079
EP+1
3
-100
-120
-140
-160
0
5
10
15
20
25
30
35

DATA ANALYSIS

OFFSHORE GEOPHYSICS ANALYSIS

- --Trend maps
- --Structure contour and isopach maps
- --Structural sections
- --Fault surfaces
- --Bathymetry

FAULT BEHAVIOR

- --Stratigraphic Correlations
- --Timing of fault and fold development
- --Recency of faulting/folding
- --Slip/deformation rate

SEISMICITY ANALYSIS

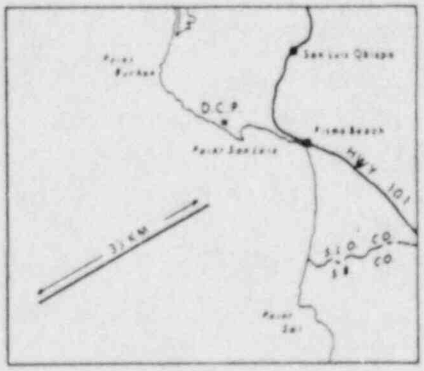
- --Earthquake relocations
- --1927 Lompoc earthquake

LEGEND

SEISMIC DATA

Geophysical Services Inc. 1980 Line 97

Location Map



Length: 33 Km. (21mi.)

Record Length: 5 Sec.
Sample Rate: 4 Ms
CDP STACK: 4800%
Wave Equation Migration

WELL INFORMATION

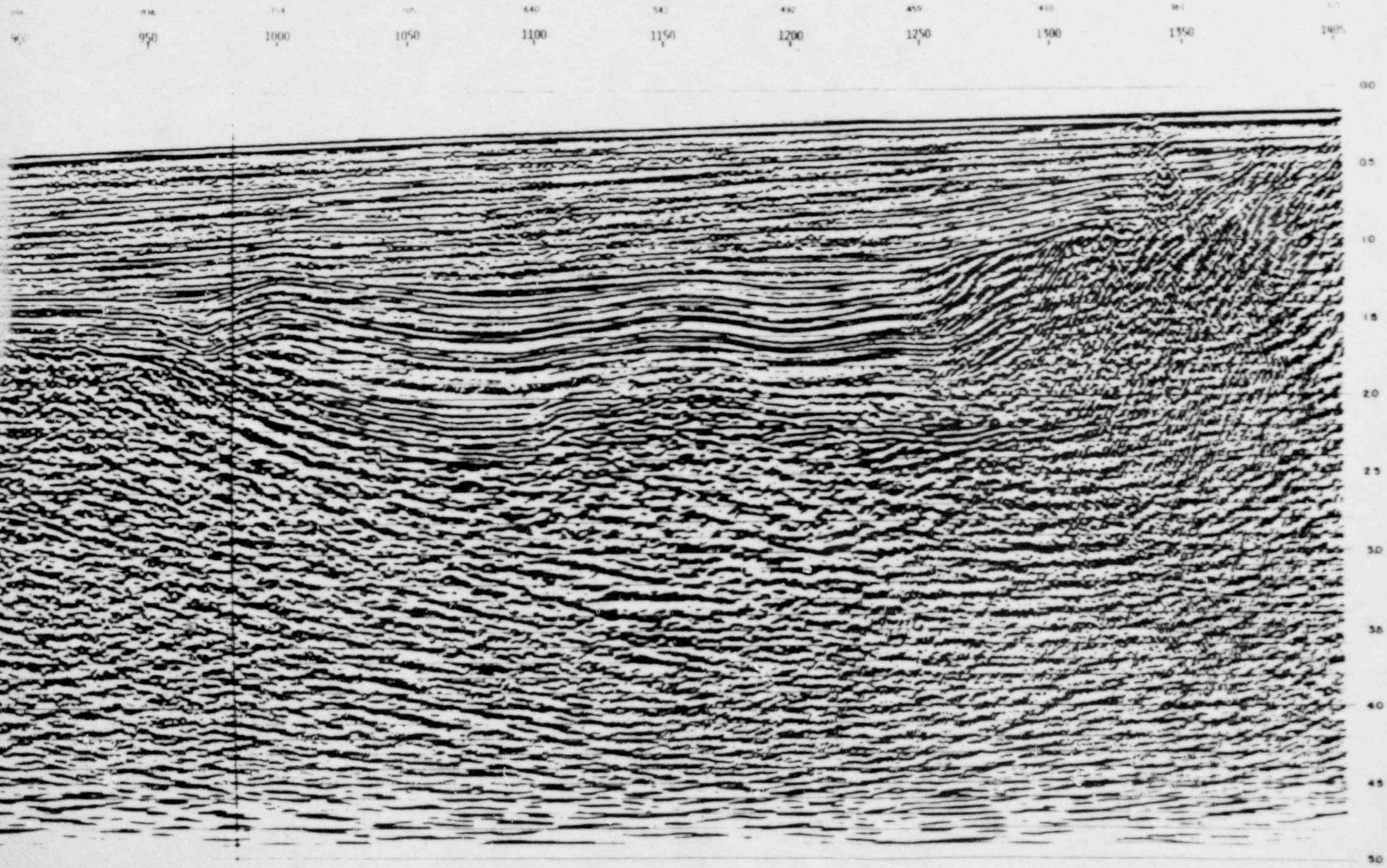
- Chevron OCS P-060-1
  Location $\frac{X: 693{,}625m}{Y: 3{,}877{,}265m}$ $\frac{UTM}{Z\,10}$ Drilled 1964
  T.D. 2445m (8020ft.) W.D. 168m (550ft.)
  Projected 1463m (4800ft.) NW into line of section
- Getty OCS P-0395-1
  Location $\frac{X: 690{,}174m}{Y: 3{,}877{,}480m}$ $\frac{UTM}{Z\,10}$ Drilled 1983
  T.D. 2377m (7800ft.) W.D. 236m (774ft.)
  Projected 610m (2000ft.) SE into line of section

GEOLOGIC HORIZON

NAME	AGE GEOLOGIC	 CHRONOLOGIC
Base "Foxen"	Early/Late Plio Unconf.	2.8-3.0 ma
Si quoc Unconf.	Plio/Mio Unconf.	5.2 ma
Top Monterey	Upper Mio, Mohnian Stage	6.5 ma
Top Point Sal	Lower Mio, Relizian Stage	16.0 ma
Base Point Sal	Lower Mio, Relizian/Saucesian	17.5 ma

SYMBOLS

- Unconformity	~~~~~~~~~
- Fault	———
- Fault, location inferred or projected	— — —
- Dip of strata or fault in "Franciscan" or older based on discontinuous seismic reflectors	- - - -
- Seismic Line Shot Point Location	700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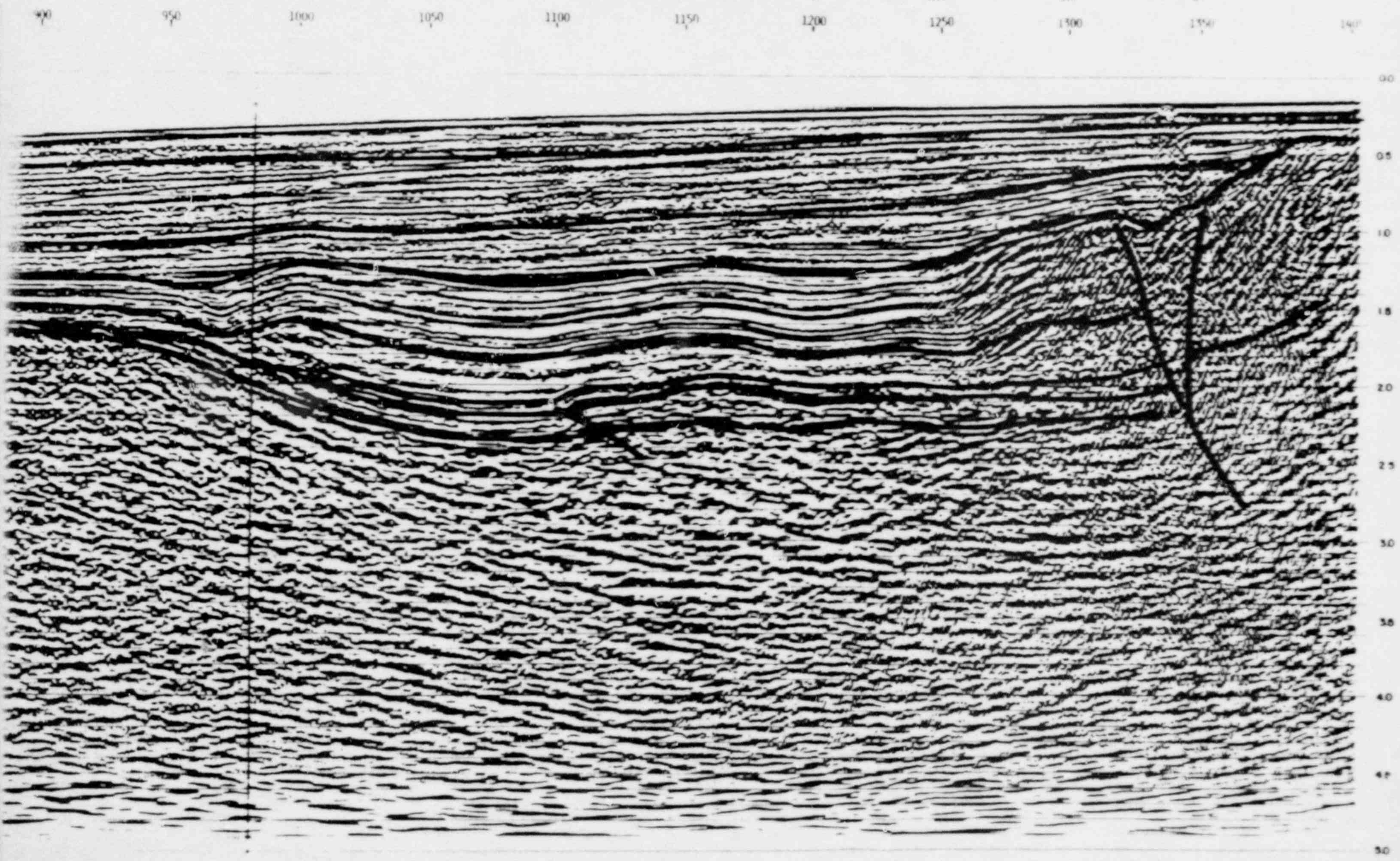
492
459
410
361
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1405
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0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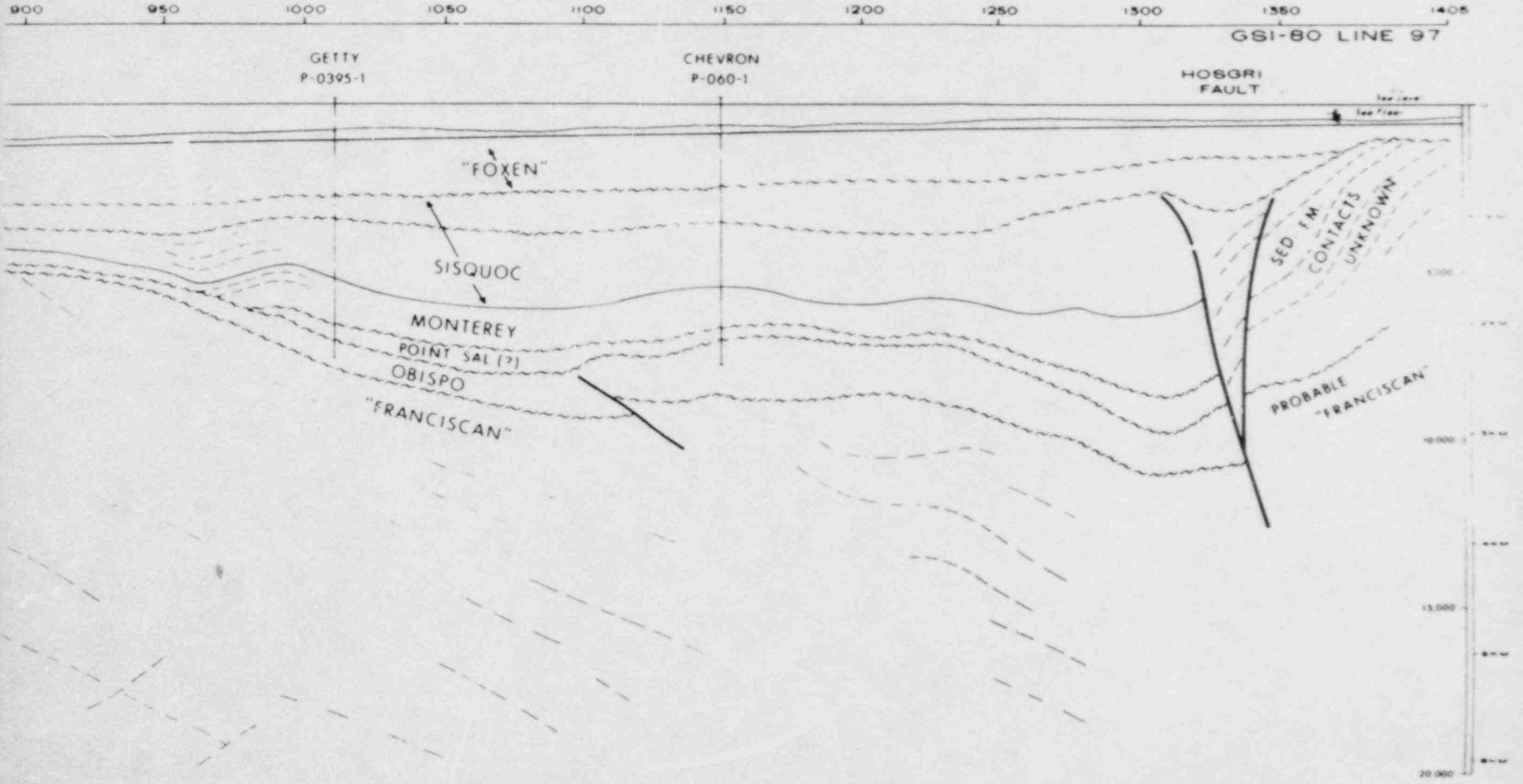
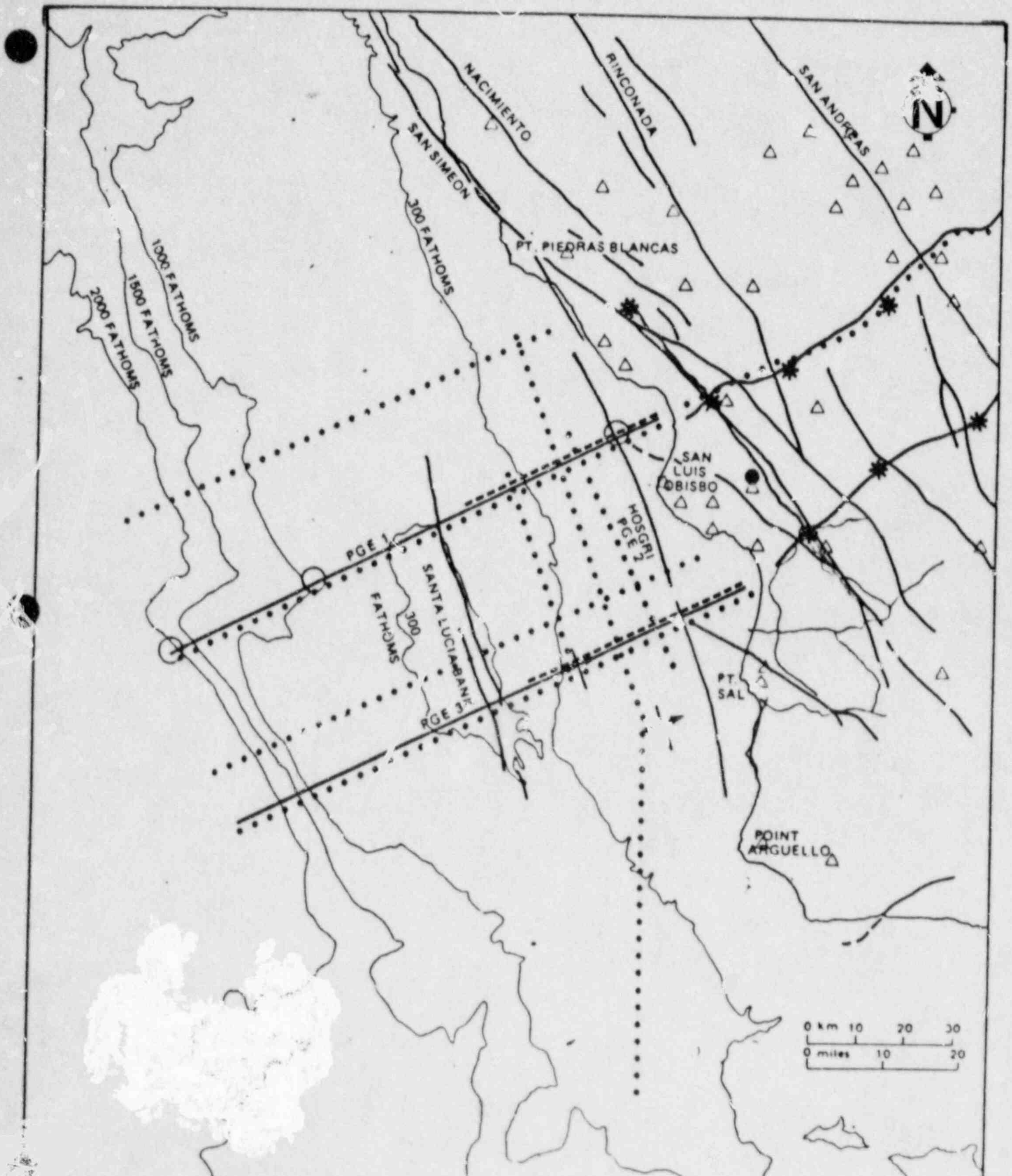
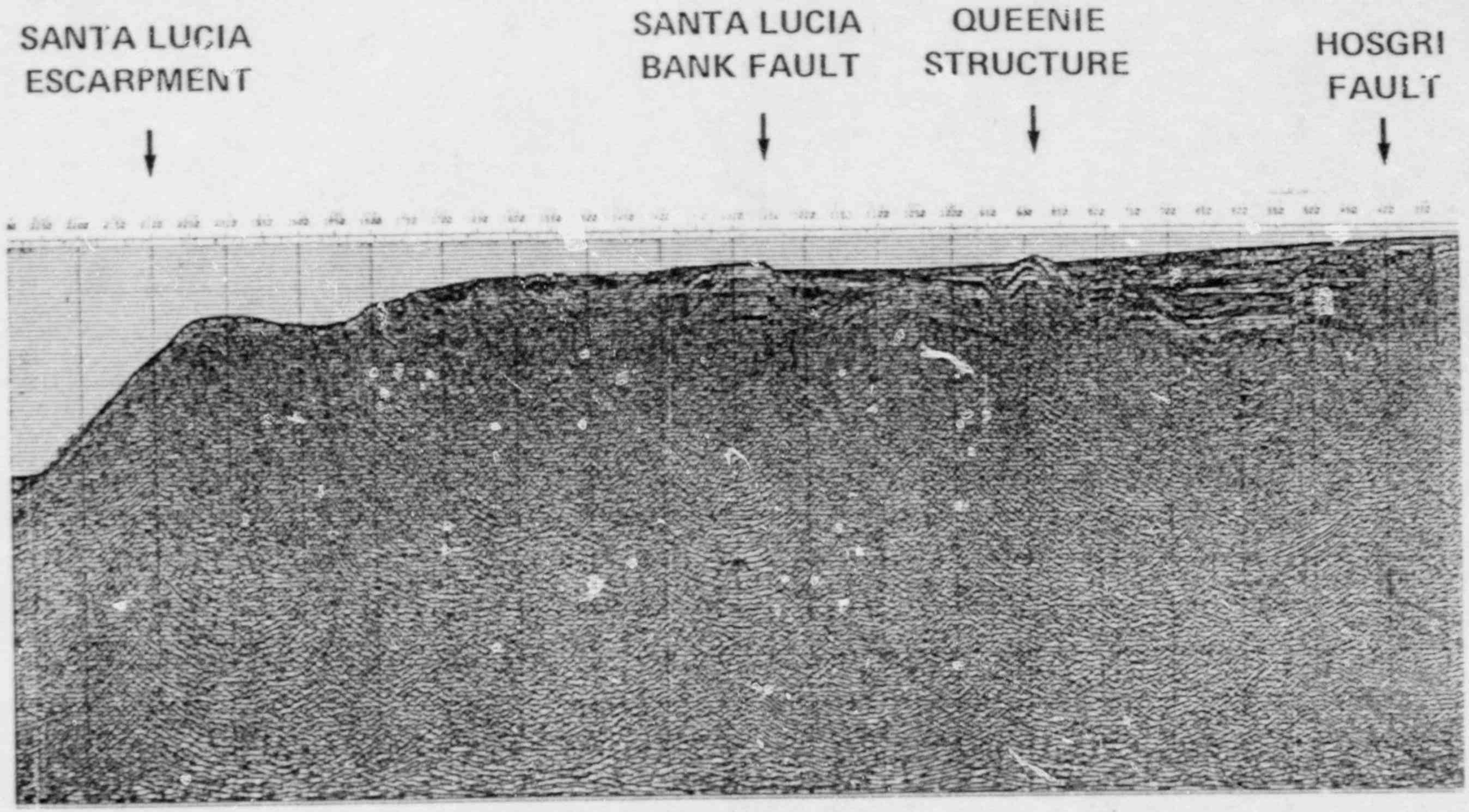
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


900
950
1000
1050
1100
1150
1200
1250
1300
1350
1405
GSI-80 LINE 97
GETTY
P-0395-1
CHEVRON
P-060-1
HOSGRI
FAULT
Sea Level
Sea Floor
"FOXEN"
SISQUOC
MONTEREY
POINT SAL (?)
OBISPO
"FRANCISCAN"
SED FM
CONTACTS
UNKNOWN
PROBABLE
"FRANCISCAN"
0
5,000
10,000
15,000
20,000
1 KM
2 KM
3 KM
4 KM
5 KM
6 KM


N
NACIMIENTO
RINCONADA
SAN ANDREAS
SAN SIMEON
PT. PIEDRAS BLANCAS
300 FATHOMS
1000 FATHOMS
1500 FATHOMS
2000 FATHOMS
SAN LUIS OBISBO
HOSGRI
PGE 2
PGE 1
SANTA LUCIA BANK
300 FATHOMS
PGE 3
PT. SAL
POINT ARGUELLO
0 km 10 20 30
0 miles 10 20

SOUTH-COASTAL CALIFORNIA INTEGRATED CRUSTAL STUDIES

	SJ-6 PGE-1	PGE-3	SLO-1	RICE/HARC/EDGE
ONSHORE	USGS SJ-6 REFR WESTERN SJ-6 REFL PGE REFR (Land Shots) RICE REFR/REFL (Land Shots)	PGE REFR/REFL (Land Shots) SSI REFL (Vibroseis)	USGS REFR (Land Shots) USGS FAN (Land Shots)	
TRANSITION	PGE REFR (Airgun) PGE SONOBUOY (Land Shots) RICE REFR/REFL (Airgun) USGS OBS (Land Shots)	PGE REFR/REFL (Airgun) PGE SONOBUOY (Land Shots)	USGS FAN (Airgun)	
OFFSHORE	PGE REFL PGE REFR (Airgun) PGE SONOBUOY (Airgun) RICE REFR/REFL (Airgun) USGS OBS (Airgun)	PGE REFL PGE REFR/REFL (Airgun) PGE SONOBUOY (Airgun)		RICE REFL (5 Lines)

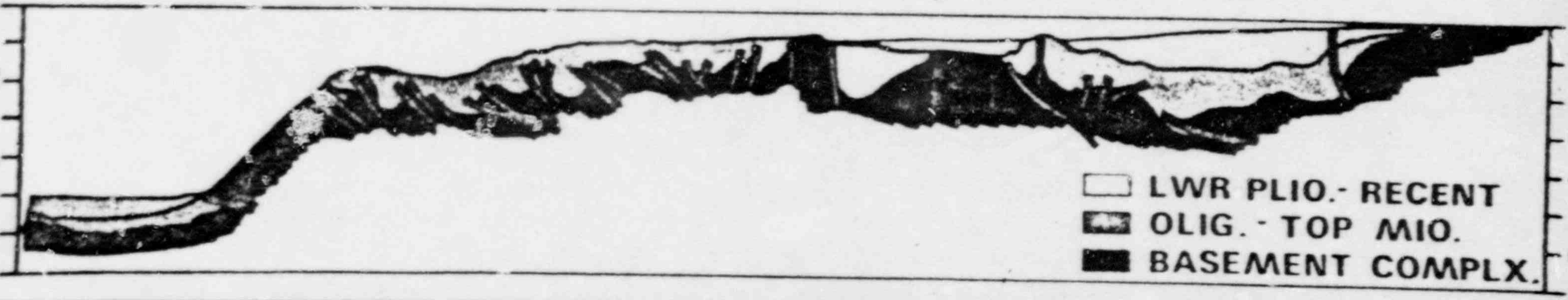


MIGRATED SECTION PGE-3

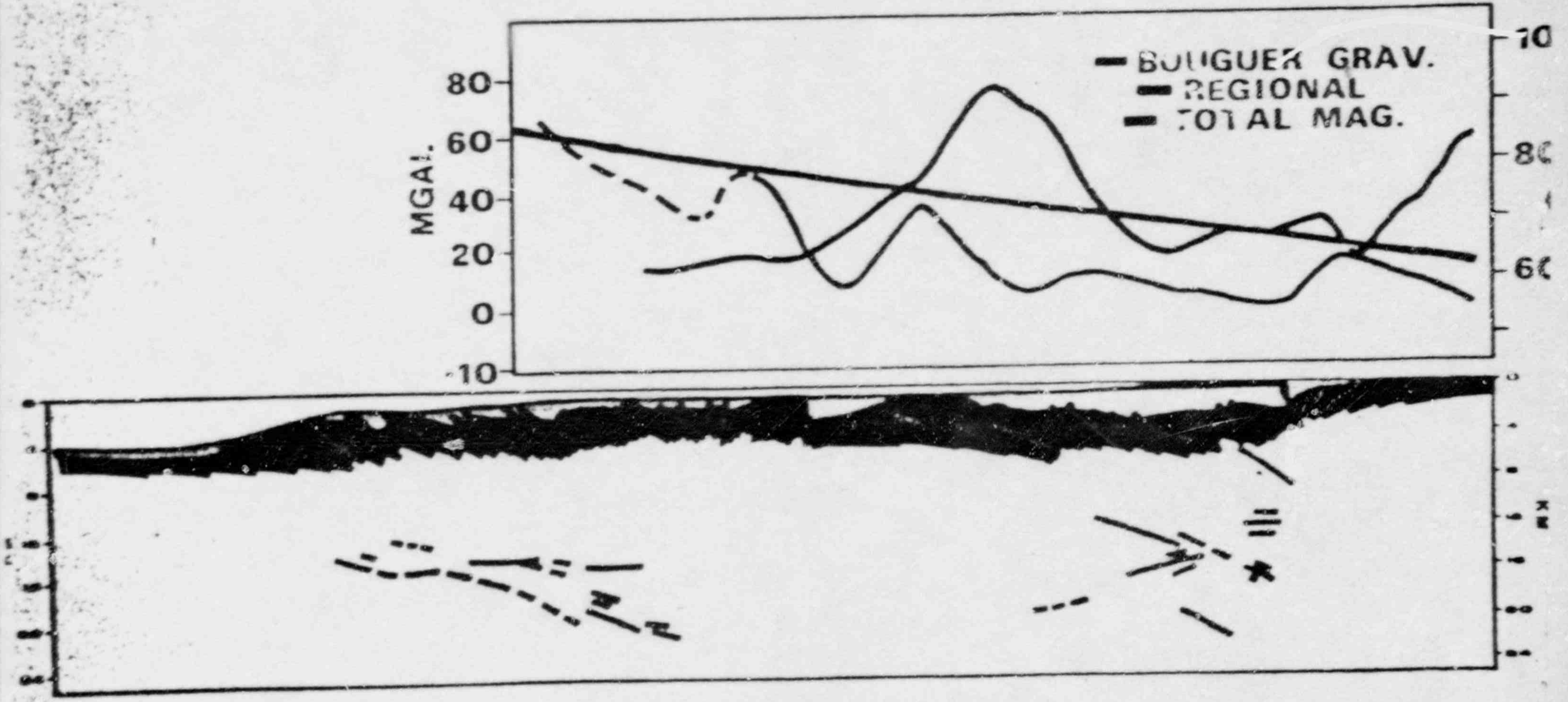
FLEC - 3

STACKED SECTION

INTERP. BASED ON MIGR.

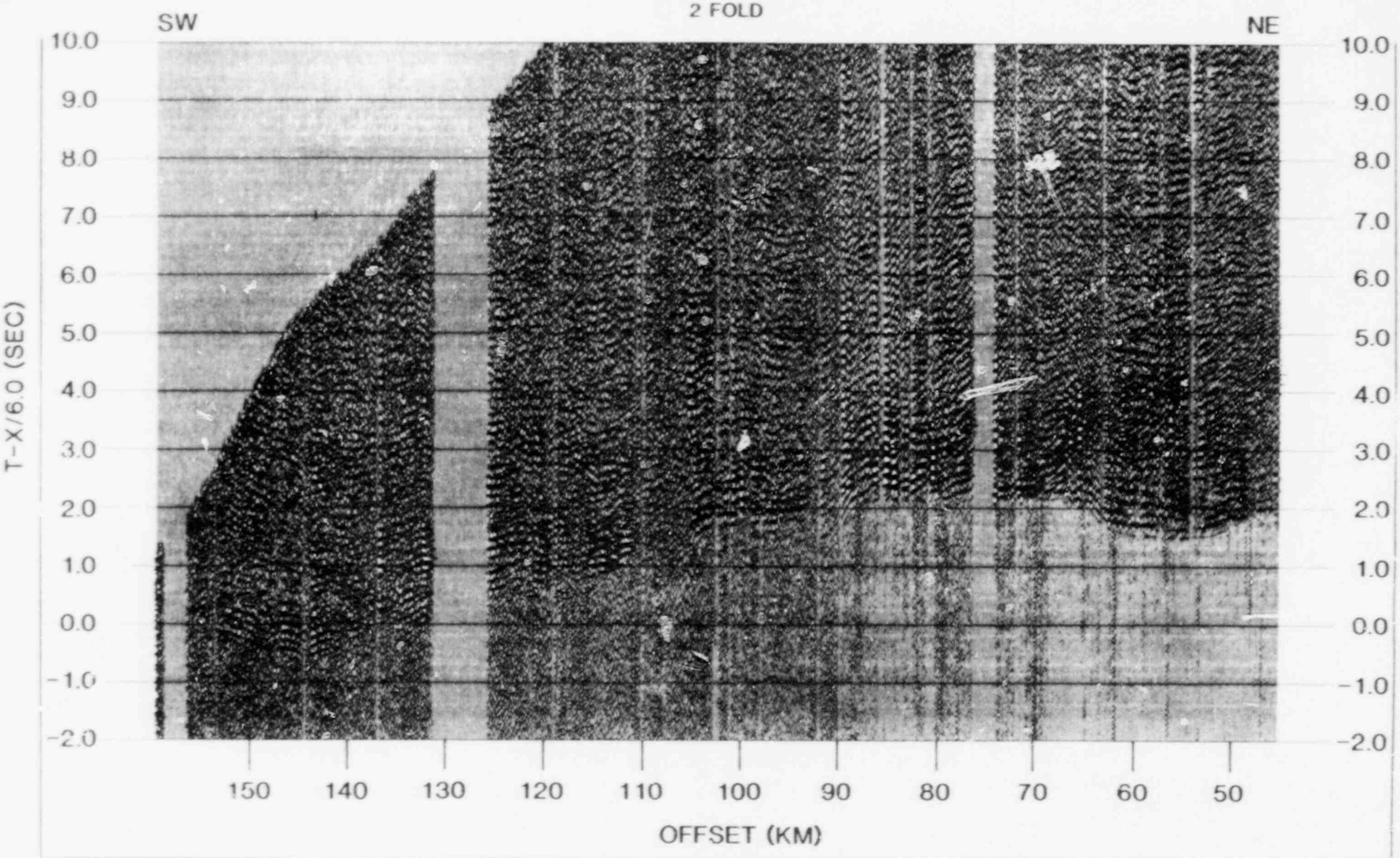


FLEC 3

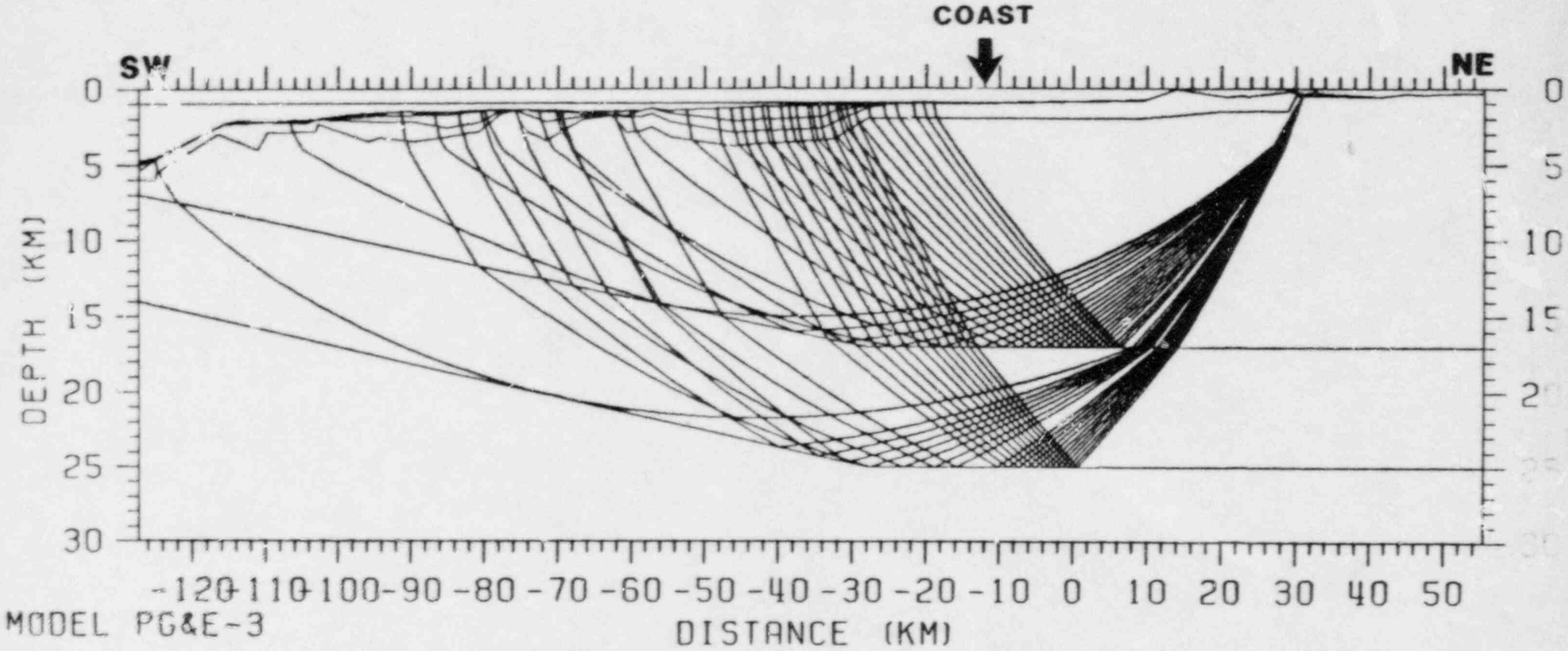


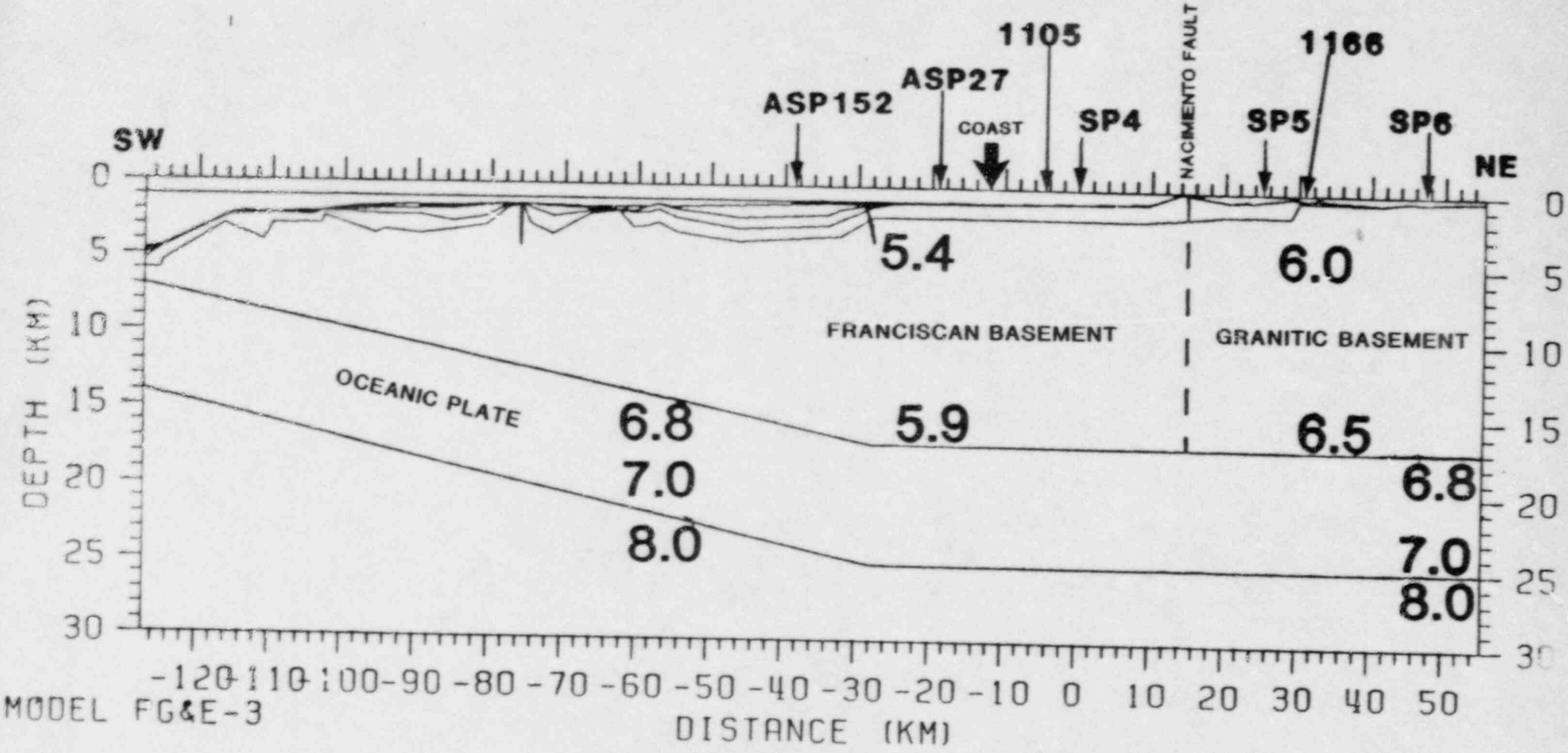
RECEIVER GATHER 1166

2 FOLD



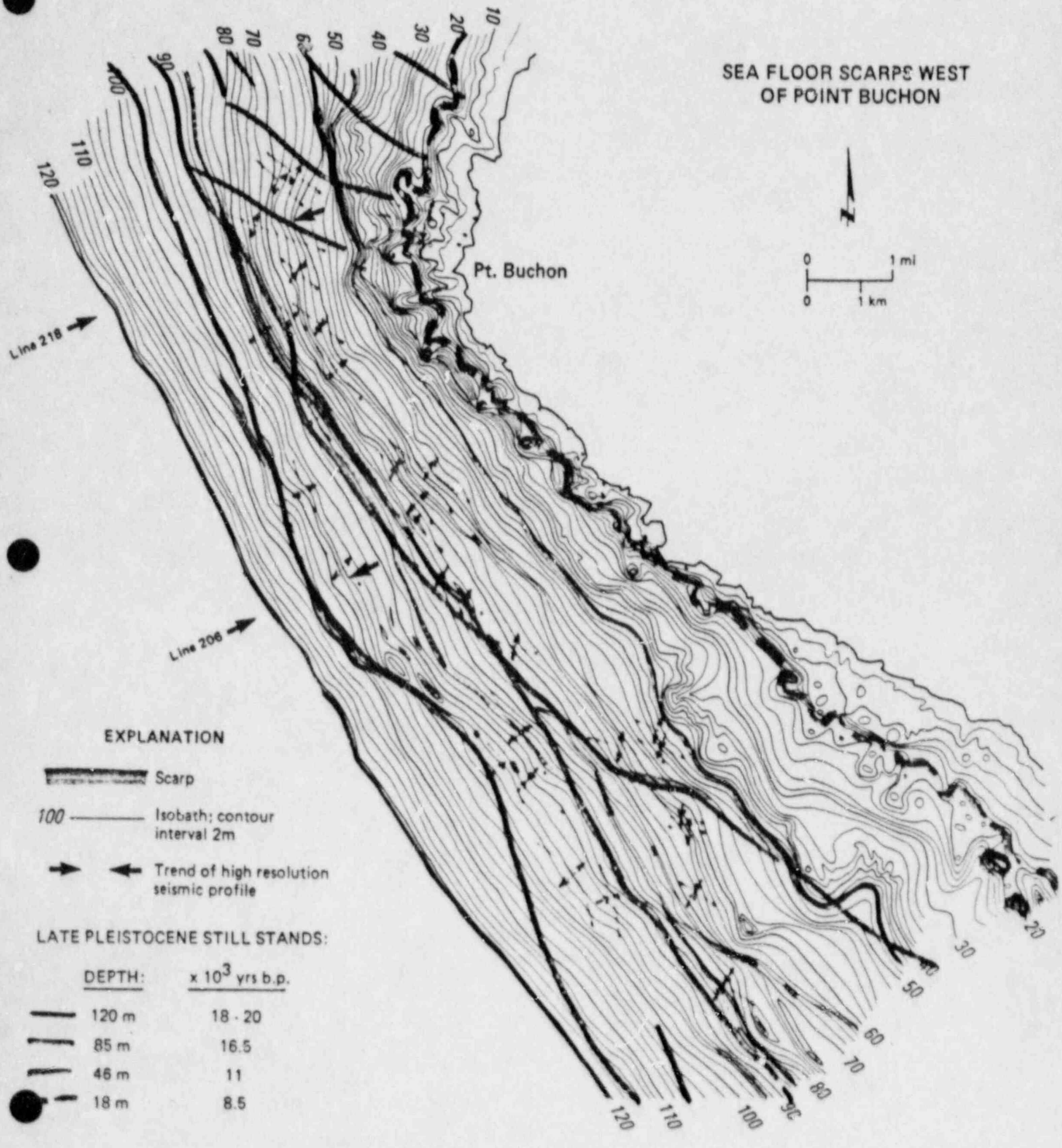
RECEIVER 1166





SW
NE
ASP152
ASP27
COAST
1105
SP4
NACIMIENTO FAULT
SP5
1166
SP6
5.4
6.0
FRANCISCAN BASEMENT
GRANITIC BASEMENT
OCEANIC PLATE
6.8
5.9
6.5
7.0
6.8
8.0
7.0
8.0
DEPTH (KM)
0
5
10
15
20
25
30
-120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50
DISTANCE (KM)
MODEL FG&E-3

SEA FLOOR SCARPS WEST OF POINT BUCHON



SOURCE PARAMETERS OF THE 1927 LOMPOC EARTHQUAKE

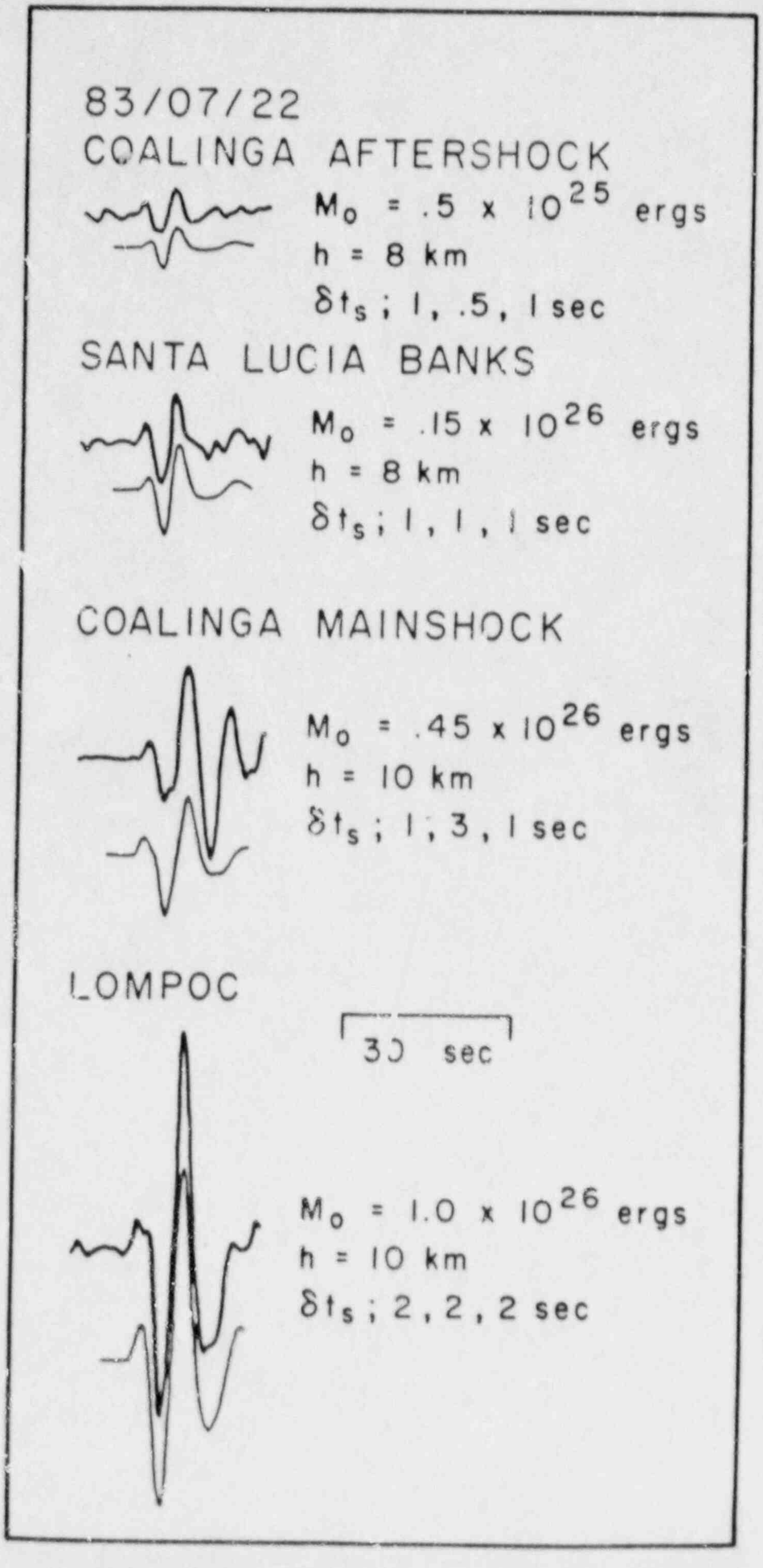
DATA: LONG-PERIOD SEISMOGRAMS AT DE BILT, NETHERLANDS; REGIONAL SEISMOGRAMS AT TUCSON, ARIZONA; BERKELEY AND MOUNT HAMILTON, CALIFORNIA

APPROACH: COMPARISON OF 1927 LOMPOC SEISMOGRAMS WITH SEISMOGRAMS OF THE 1969 SANTA LUCIA BANK AND 1983 COALINGA EARTHQUAKES, WHOSE SEISMIC MOMENTS AND FOCAL MECHANISMS ARE KNOWN.

METHOD: COMPARISON OF RECORDED AND SYNTHETIC BODY WAVES:

P- WAVES

S- WAVES


83/07/22
COALINGA AFTERSHOCK
M_o = .5 x 10^{25} ergs
h = 8 km
δt_s ; 1, .5, 1 sec
SANTA LUCIA BANKS
M_o = .15 x 10^{26} ergs
h = 8 km
δt_s ; 1, 1, 1 sec
COALINGA MAINSHOCK
M_o = .45 x 10^{26} ergs
h = 10 km
δt_s ; 1, 3, 1 sec
LOMPOC
30 sec
M_o = 1.0 x 10^{26} ergs
h = 10 km
δt_s ; 2, 2, 2 sec

NOVEMBER 4, 1927 LOMPOC EARTHQUAKE

Focal Depth: 10 km

Focal Mechanism: Strike N23W, Dip 66 NE

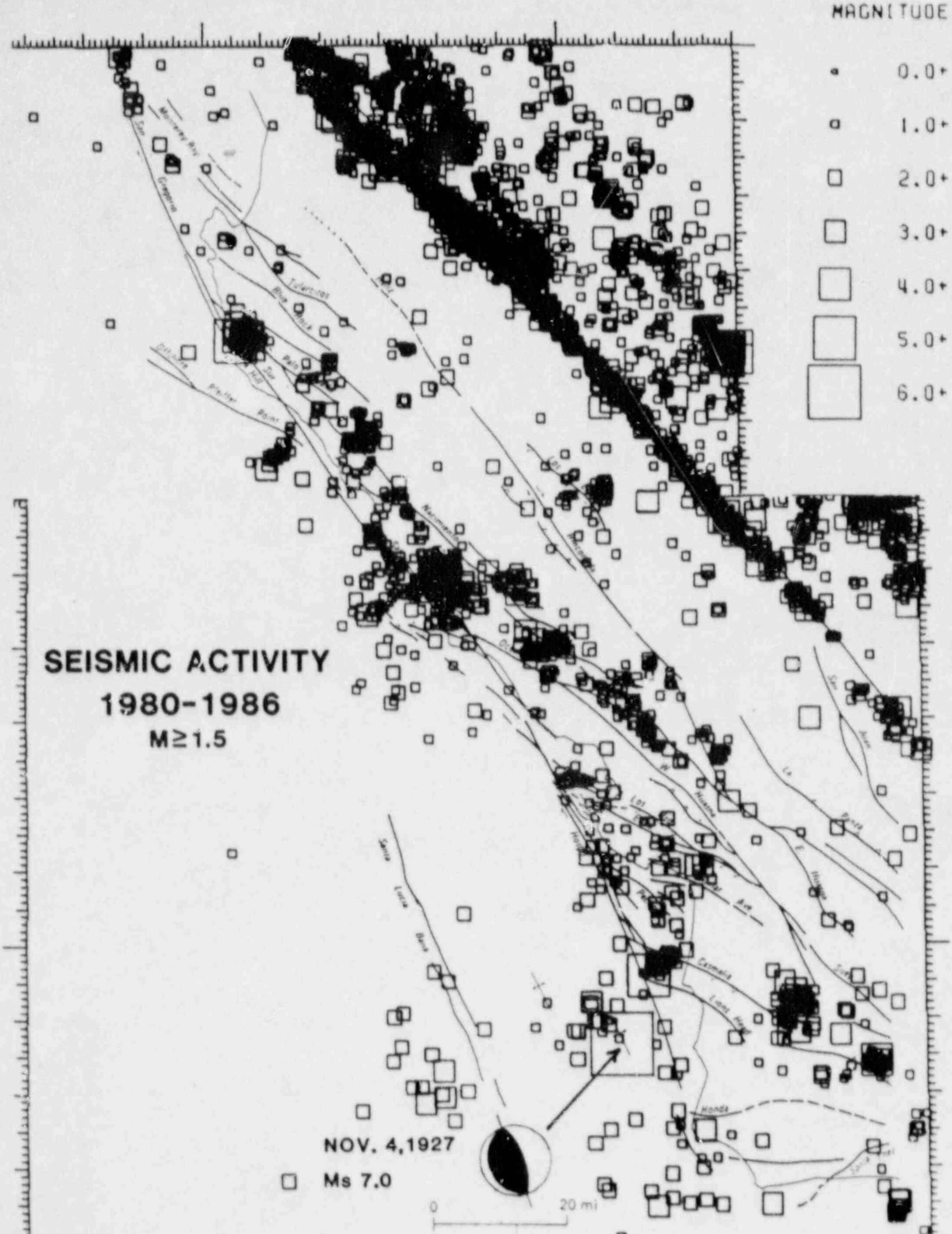
Strike N23W, Dip 23 SW

Seismic Moment: 1×10^{26}

Moment magnitude: 6.6

Surface Wave Magnitude: 7.0 (Gutenberg notepad)

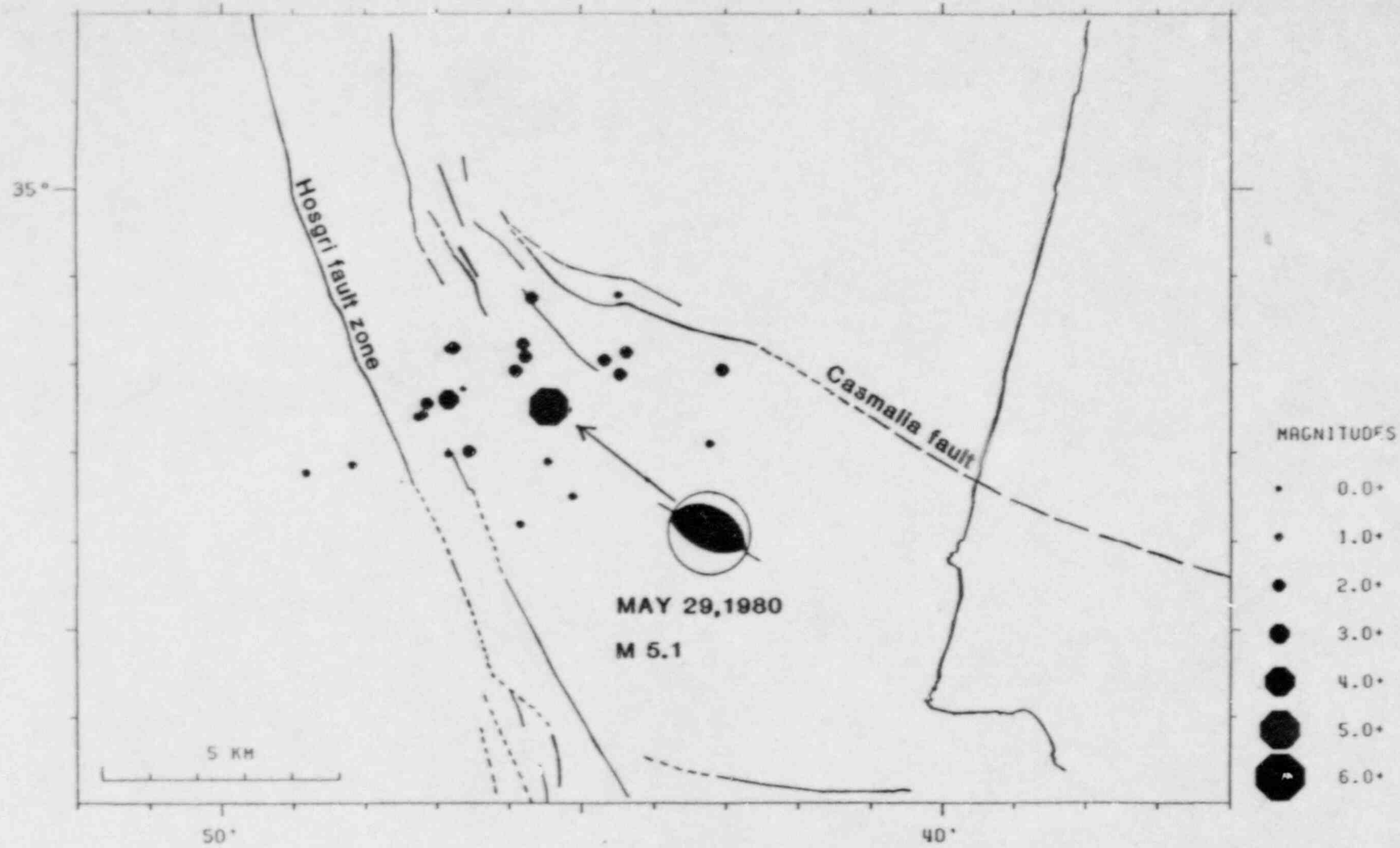
Long-Period Body-Wave Magnitude: 7.3 (Gutenberg notepad)



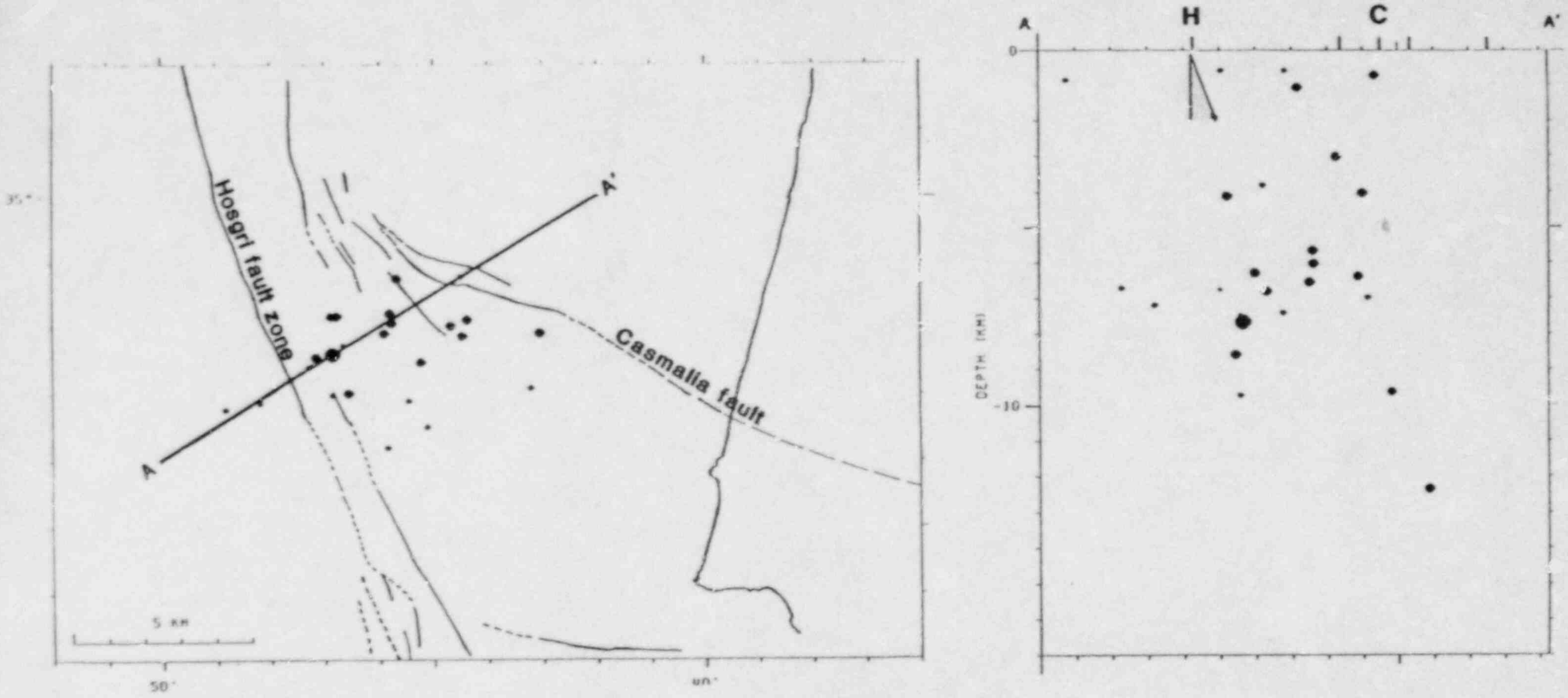
SEISMIC ACTIVITY
1980-1986
M≥1.5

NOV. 4, 1927
□ Ms 7.0

POINT SAL MASTER EVENT LOCATIONS



POINT SAL MASTER EVENT LOCATIONS



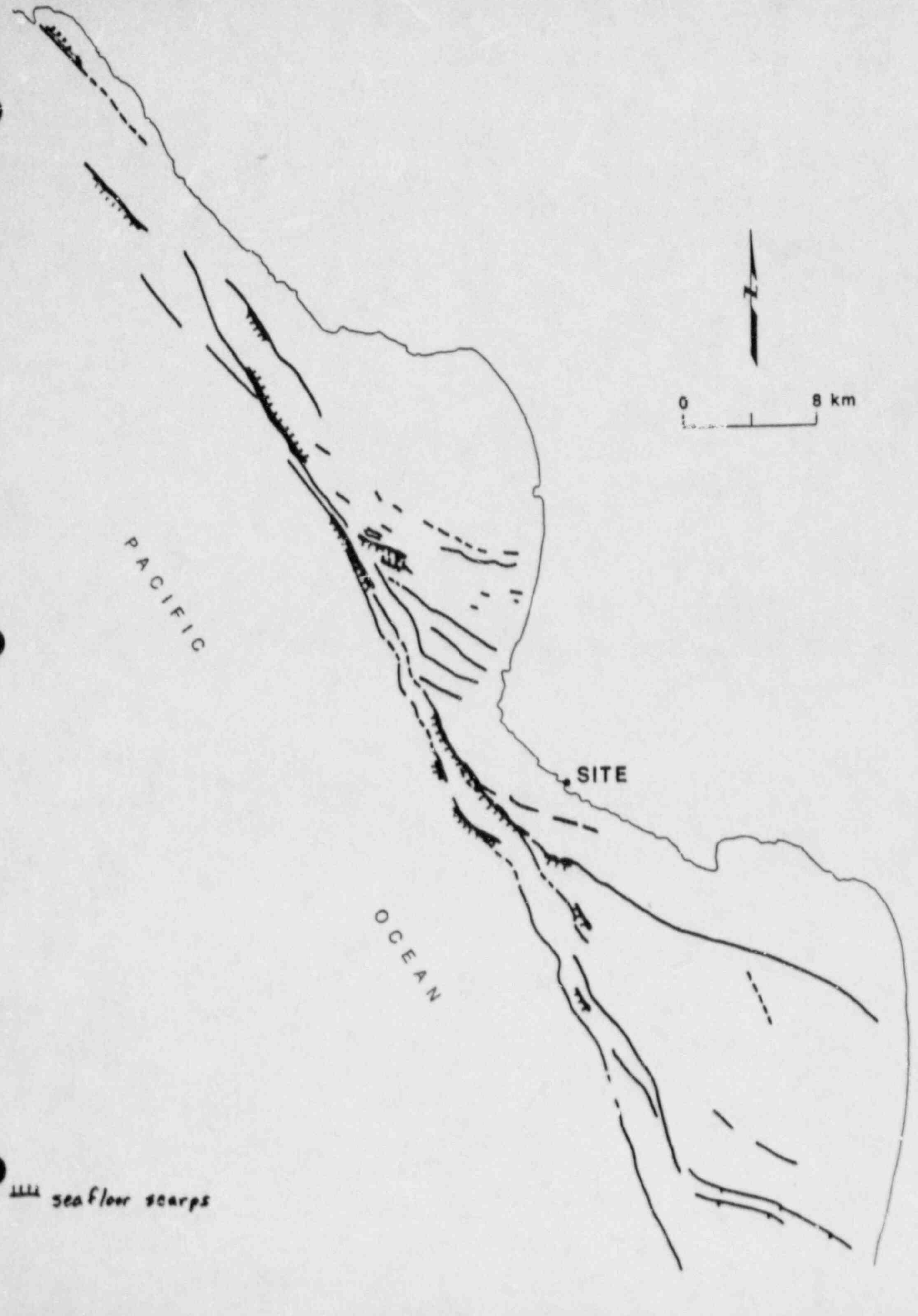
DATA INTERPRETATION

OVERVIEW OF THE HOSGRI FAULT ZONE

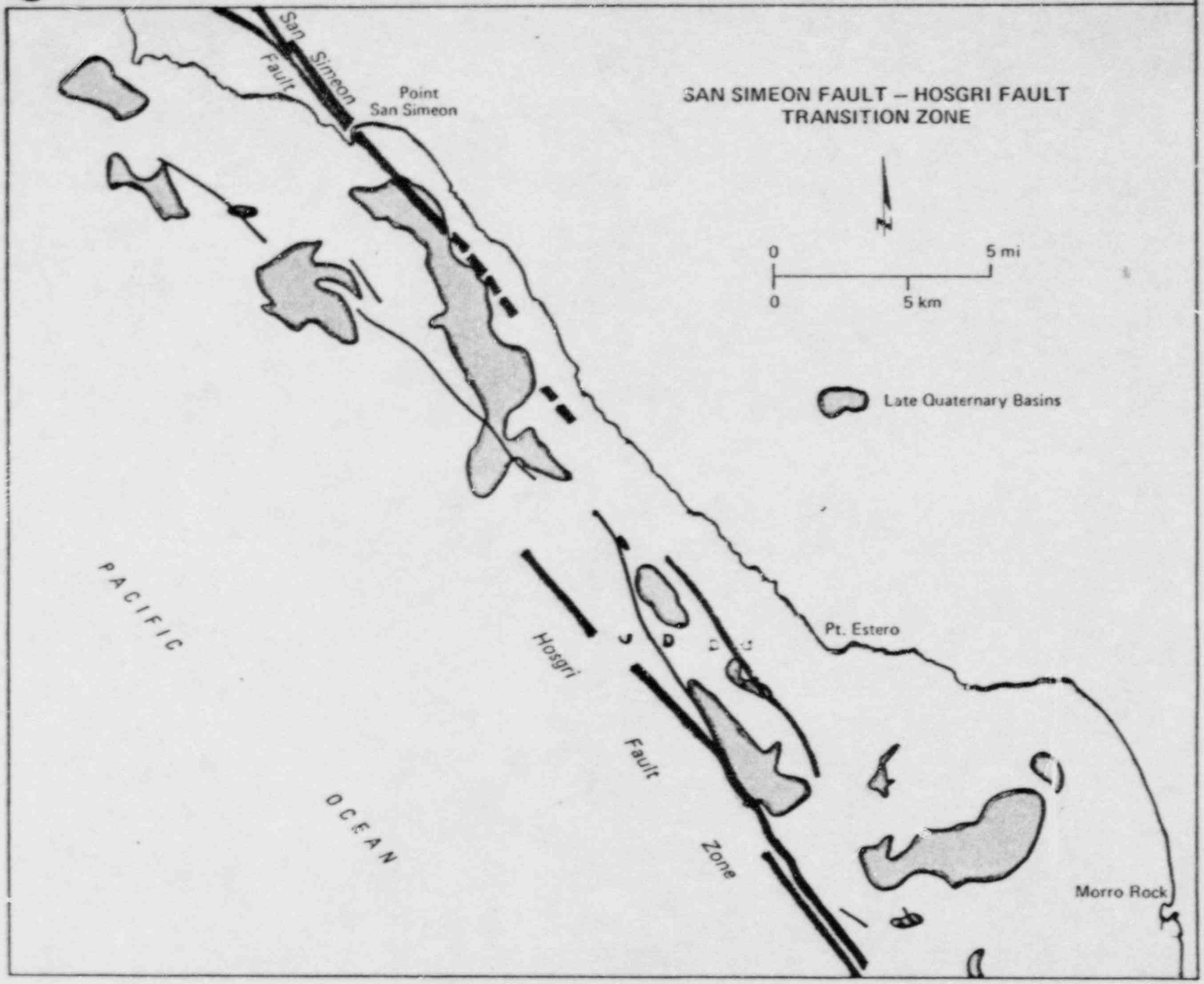
- --Northern termination
- --San Luis/Pismo reach
- --Point San Luis to Point Sal reach
- --Southern Termination

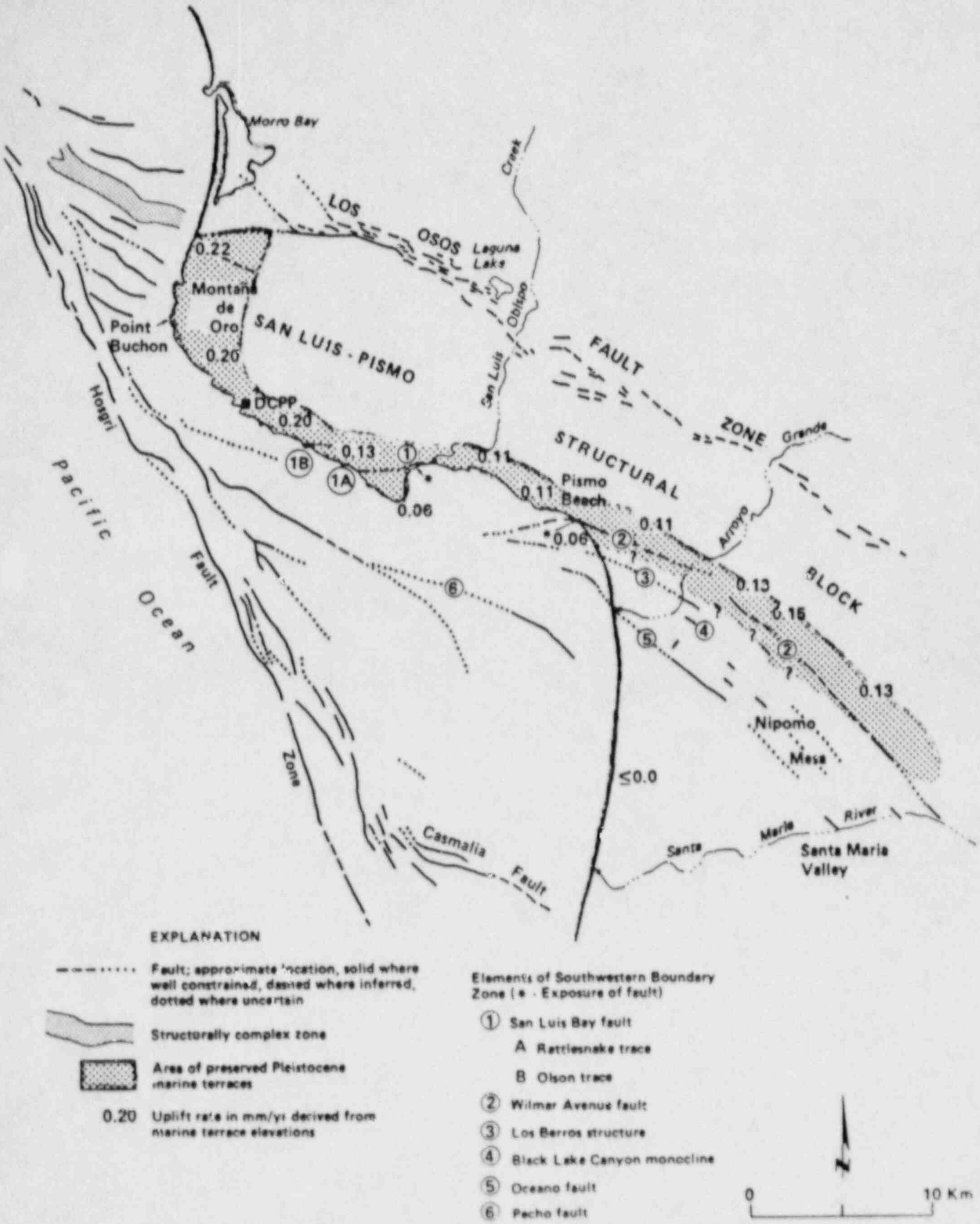
SAN LUIS/PISMO BLOCK

- --Folding versus faulting
- --Rates of uplift
- --Other items?


N
0
8 km
PACIFIC
SITE
OCEAN
sea floor scarps

SAN SIMEON FAULT – HOSGRI FAULT TRANSITION ZONE





Index map of the San Luis Pismo structural block illustrating distribution of marine terraces and uplift rates derived from marine terrace elevations.

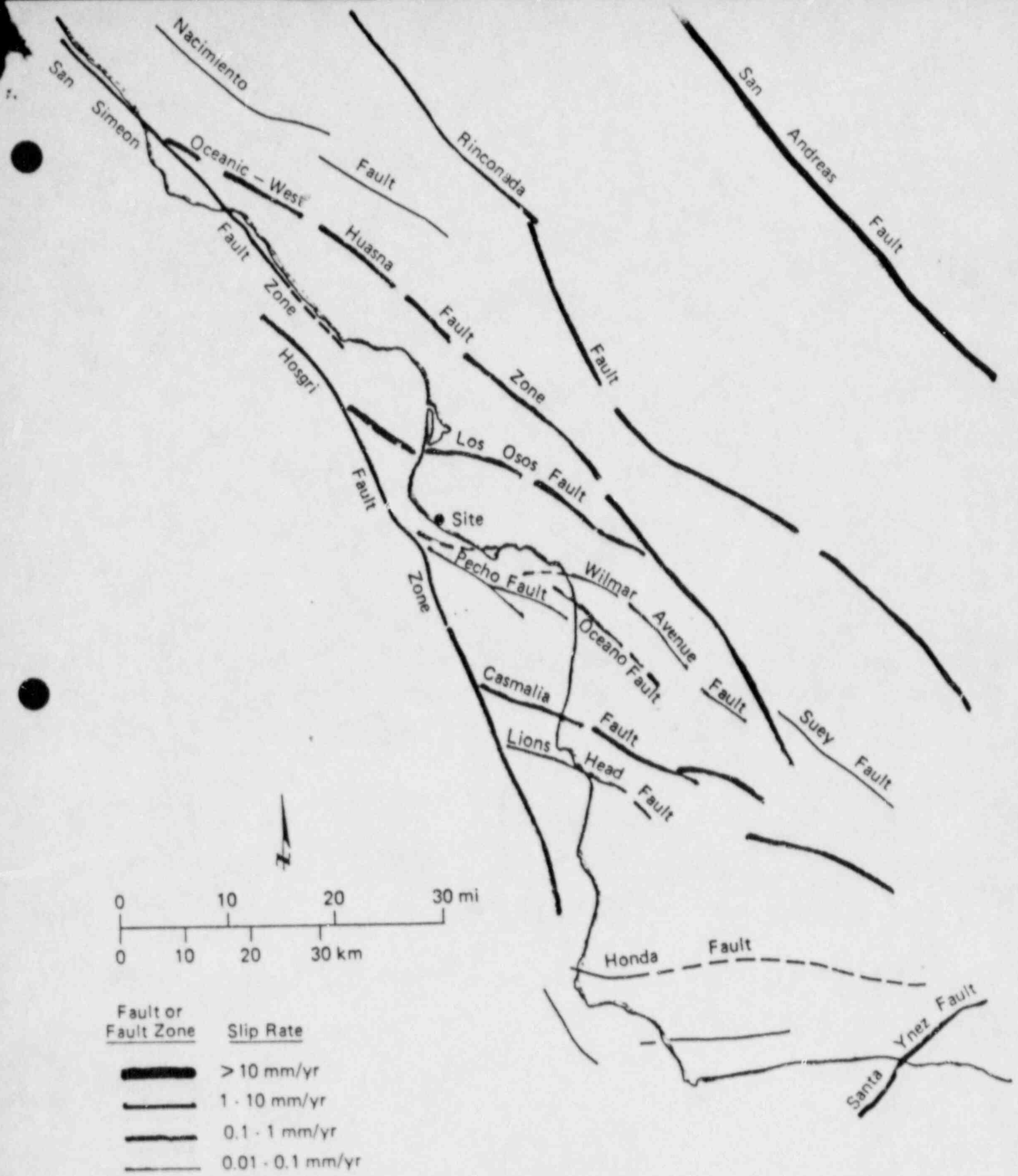
SEISMIC SOURCE CHARACTERIZATION

DEVELOP SOURCE PARAMETERS USING INTEGRATION OF MULTIPLE DATA SETS AND METHODOLOGIES

- --Fault Geometry
- --Magnitude
- --Recurrence

EVALUATE UNCERTAINTY

ASSESS ALTERNATIVES



SLIP RATES OF FAULTS
IN COASTAL CENTRAL CALIFORNIA

SEISMIC SOURCE CHARACTERIZATION

PRELIMINARY RESULTS - 11/14/86

- Onshore and near-shore geologic studies in San Simeon area are valuable to characterizing Hosgri: sense of slip; near-surface geometry, slip rate, earthquake recurrence, displacement per event.

- Offshore geophysics is helping to clarify lateral continuity, segmentation, structural relationships, history of slip. Promise for down-dip expression, crustal models, etc.

- No "surprises" or significant findings have been identified that were not effectively included for source characterization in the Phase II study.

PRELIMINARY RESULTS - 2/23/88

- The LTSP Geology, Seismology, and Geophysics activities are emphasizing data interpretation leading to seismic source characterizations that integrate multidisciplinary data sets and analyses, explicitly treat uncertainties, and address alternative source characterization models.

- The San Miguelito and Edna faults are not capable according to Appendix A criteria.

- Pismo synclinorium has not been subject to active folding for the past 700,000 years or longer and is subject to block uplift. The San Luis/Pismo block is bounded by the dip-slip Los Osos fault along this northeastern edge. The Wilmar Avenue, Oceano, Pecho, and San Luis Bay faults lie southwest of the block and are discontinuous and have very low slip rates. The Hosgri fault zone bounds the western edge of the block.

- The November 4, 1927, earthquake was a nearly pure dip-slip event having strike about N23W and had a focal depth of 10 km. The seismic moment of the earthquake was 1×10^{26}, corresponding to a moment magnitude of 6.6. The surface wave magnitude was 7.0.

Insert #4

Diablo Canyon Long Term Seismic Program
Ground Motion Studies

- Objectives
  - To update the ground motion assessment for the site
  - To provide ground motion data for engineering analyses
- Approaches
  - Compile and use an updated strong motion data base
  - Use refined geology/seismology/geophysics information
  - Use available ground motion recordings at the site
  - Use both empirical and numerical modeling methods

Current Status of Ground Motion Studies

- Empirical Studies
  - Compilation of strong motion data base
  - Refinement of PGA and SA attenuation relationships
  - Progress in site-specific ground motion characterization

- Numerical Modeling Studies
  - Development of the semi-empirical simulation method
  - Calibration of the Semi-empirical simulation method
  - Preliminary results of simulations

- Assessment of Spatial Incoherence
  - Assessment of the effects of extended fault rupture
  - Analysis of existing site recordings
  - Operation of a free-field ground motion array

Ground Motion Data Provided to Date for Engineering Analyses

- For Fragility Analysis
  - 12 sets of empirical acceleration time histories
  - 14 sets of simulated acceleration time histories
- For Soil-Structure Interaction Analysis
  - Median site-specific spectral shape
  - 3 sets of candidate acceleration time histories to match the site-specific spectral shape
  - Spatial incoherence functions

Strong Motion Data Base Compiled for the DCLTSP

- 47 Shallow-focus Crustal Earthquakes
- Moment Magnitude (Mw) from 4.6 to 7.4
- Closest Distance to Fault Rupture Surface (R) from 1 to 300 km for PGA and from 1 to 50 km for SA
- Rock or Rock-like Recording Sites
- 154 Recordings for PGA
  65 Recordings for SA

TABLE 11-2: EARTHQUAKES PRODUC[illegible] RECORDS INCLUDED IN THE LTSP DATABASE

Earthquake Name	Date	Rupt Mech		Magnitude Mw	
Helena, MT (Main)	10/31/35	NM	(19)[1]	(5.6)[3]	(20)[1]
Helena, MT (AS)	11/28/35	NM	(**)[2]	(5.0)	(20)
Kern County, CA	07/21/52	RV	(10)	7.4	(04)
San Francisco, CA	03/22/57	SS	(12)	(5.3)	(12)
Parkfield, CA	06/27/66	SS	(13)	6.1	(14)
Koyna, India	12/10/67	SS	(54)	6.3	(04)
Borrego Mountain, CA	04/09/68	SS	(15)	6.6	(16)
Santa Rosa, CA	10/02/69	SS	(55)	(5.6)	(02)
Santa Rosa, CA	10/02/69	SS	(55)	(5.7)	(02)
Lytle Creek, CA	09/12/70	RV	(53)	5.3	(06)
San Fernando, CA	02/09/71	TH	(17)	6.6	(06)
Hollister, CA	11/28/74	SS	(53)	(5.2)	(56)
Oroville, CA (Main)	08/01/75	NM	(21)	5.9	(11)
Oroville, CA (AS A)	08/03/75	NM	(**)	(4.6)	(22)
Oroville, CA (AS F)	08/06/75	NM	(**)	(4.7)	(22)
Oroville, CA (AS K)	08/08/75	NM	(**)	(4.9)	(22)
Gazli, USSR	05/17/76	RV	(23)	6.8	(04)
Calipatria, CA	11/04/76	SS	(25)	(4.9)	(25)
Tabas, Iran	09/16/78	TH	(27)	7.4	(28)
Coyote Lake, CA	08/06/79	SS	(29)	5.7	(11)
Imperial Valley, CA (Main)	10/15/79	SS	(30)	6.5	(32)
Imperial Valley, CA (AS31)	10/15/79	SS	(**)	(5.5)	(50)
Livermore, CA (A)	01/24/80	SS	(33)	5.8	(33)
Livermore, CA (B)	01/26/80	SS	(33)	5.4	(33)
Horse Canyon, CA	02/25/80	SS	(57)	(5.3)	(58)
Mammoth Lakes, CA (A)	05/25/80	SS	(36)	6.2	(11)
Mammoth Lakes, CA (B)	05/25/80	SS	(36)	5.7	(11)
Mammoth Lakes, CA (C)	05/25/80	SS	(36)	6.0	(11)
Mammoth Lakes, CA (C01)	05/25/80	SS	(36)	(5.7)	(35)
Mammoth Lakes, CA (C02)	05/26/80	SS	(36)	(5.7)	(35)
Mammoth Lakes, CA (D)	05/27/80	SS	(36)	6.0	(11)
Mexicali Valley, Mexico	06/09/80	SS	(37)	[6.4][4]	(37)
Westmorland, CA	04/26/81	SS	(39)	(5.6)	(38)
Coalinga, CA (Main)	05/02/83	RV	(41)	6.5	(59)
Coalinga, CA (AS03)	05/09/83	RV	(41)	5.1	(42)
Coalinga, CA (AS08)	06/10/83	RV	(41)	5.3	(42)
Coalinga, CA (AS10)	07/09/83	TH	(41)	5.2	(42)
Coalinga, CA (AS12)	07/21/83	TH	(41)	5.9	(42)
Coalinga, CA (AS13)	07/21/83	TH	(41)	4.9	(42)
Coalinga, CA (AS14)	07/25/83	TH	(41)	5.2	(42)
Coalinga, CA (AS16)	09/09/83	RV	(41)	(5.3)	(41)
Morgan Hill, CA	04/24/84	SS	(43)	6.2	(43)
Bishop, CA	11/23/84	SS	(44)	5.8	(44)
Nahanni, Canada	12/23/85	TH	(45)	[6.9]	(45)
Hollister, CA	01/26/86	SS	(46)	(5.5)	(46)
North Palm Springs, CA	07/08/86	SS	(47)	(5.9)	(47)
Chalfant Valley, CA	07/21/86	SS	(49)	6.0	(49)

NOTES:

1. (19) indicates reference number in following pages.
2. ** indicates that aftershock rupture mechanism has been inferred to be similar to the main shock preceeding it.
3. A parenthesis ( ) around a magnitude value indicates that the M_L value is being used for M_w.
4. A bracket [ ] around a magnitude value indicates that the M_s value is being used for M_w.

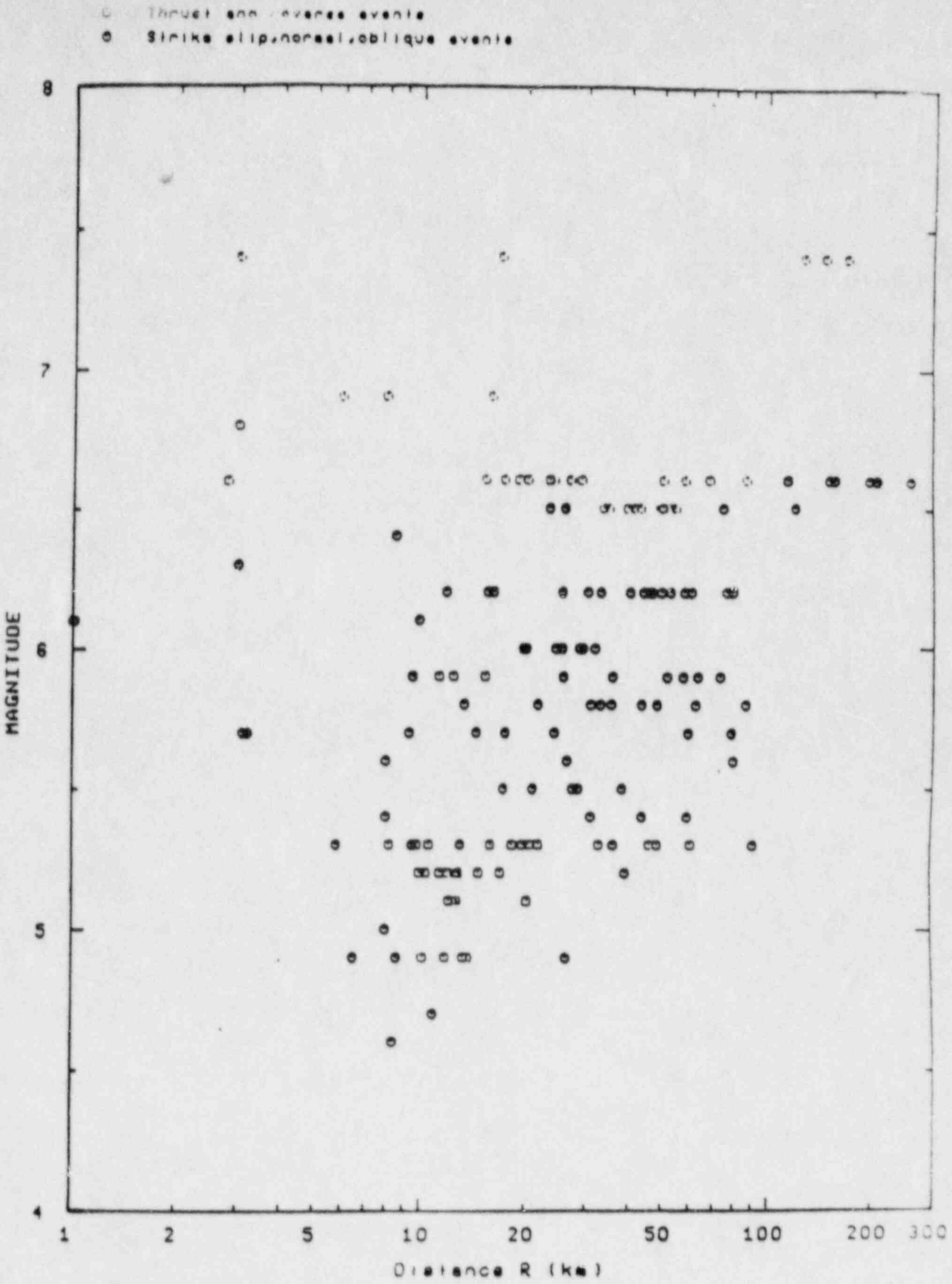


FIGURE II-1. Scatter Diagram of Peak Ground Acceleration Data for Rock-Site Recordings

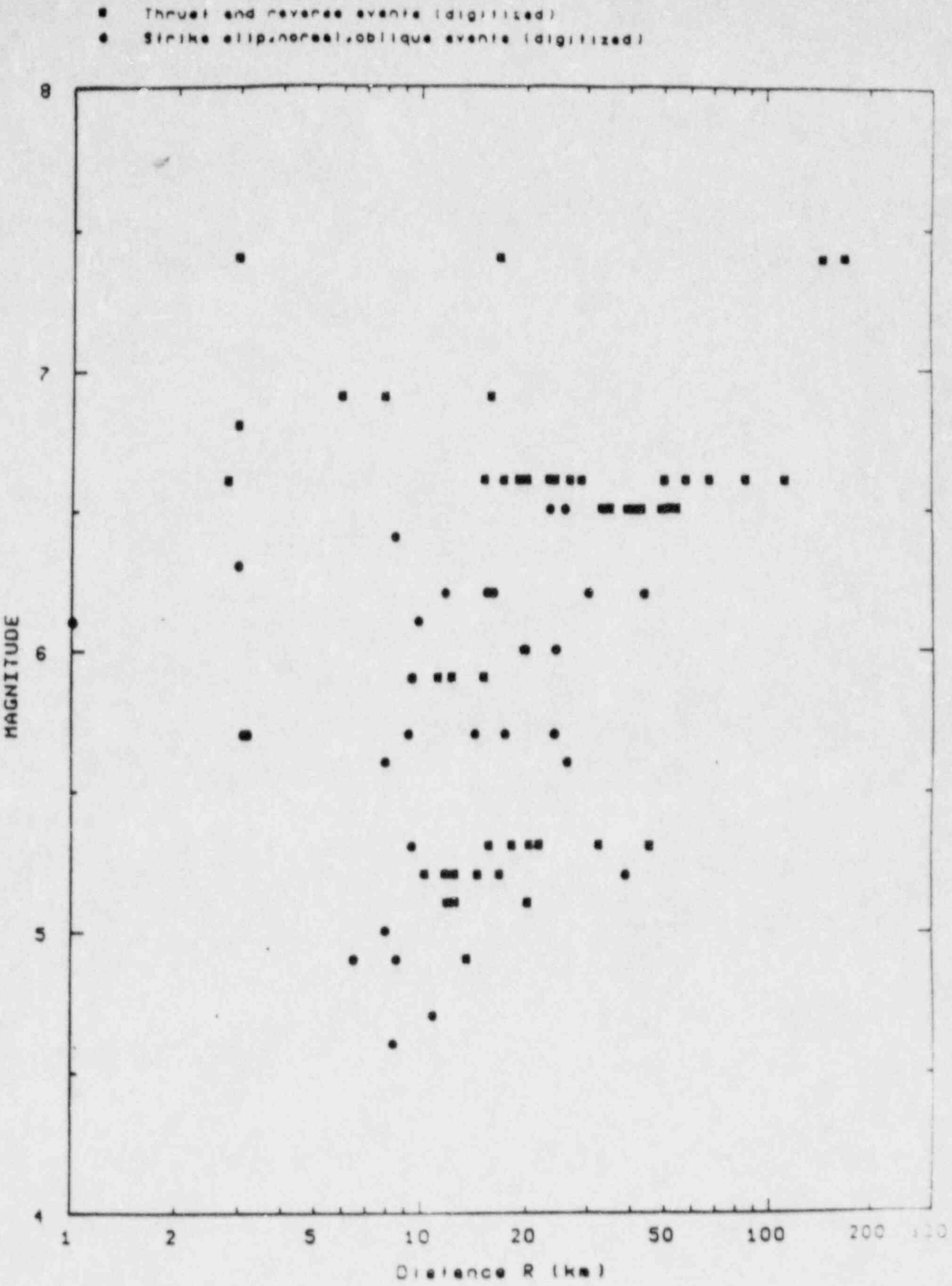
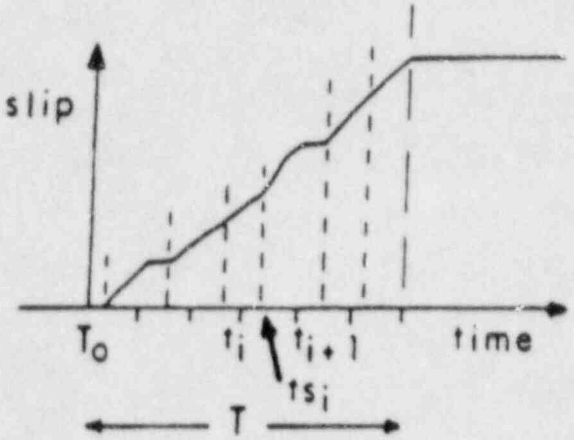


FIGURE II-2. Scatter Diagram of Response Spectral Data for Rock-Site Processed Recordings

Randomization Of Slip Time Function



$$t_i = T_o + (i - 1)\,Te$$

$$t_{si} = R(t_i, t_{i+1})$$

$$(i = 1, nsrc)$$

Figure 9

Regression for PGA Attenuation Relationships

- Functional Form

$$\ln(PGA) = B1 + B2*M + B3*\ln[R + C(M)] + E$$

where PGA = peak ground acceleration in g

R = closest distance to fault rupture surface in km

M = moment magnitude

E = random variable with zero mean

$C(M) = B4*\exp(B5*M)$

- Regression Procedure

Step 1 - Single regression for narrow magnitude bands

Step 2 - Multiple regression for all magnitude bands

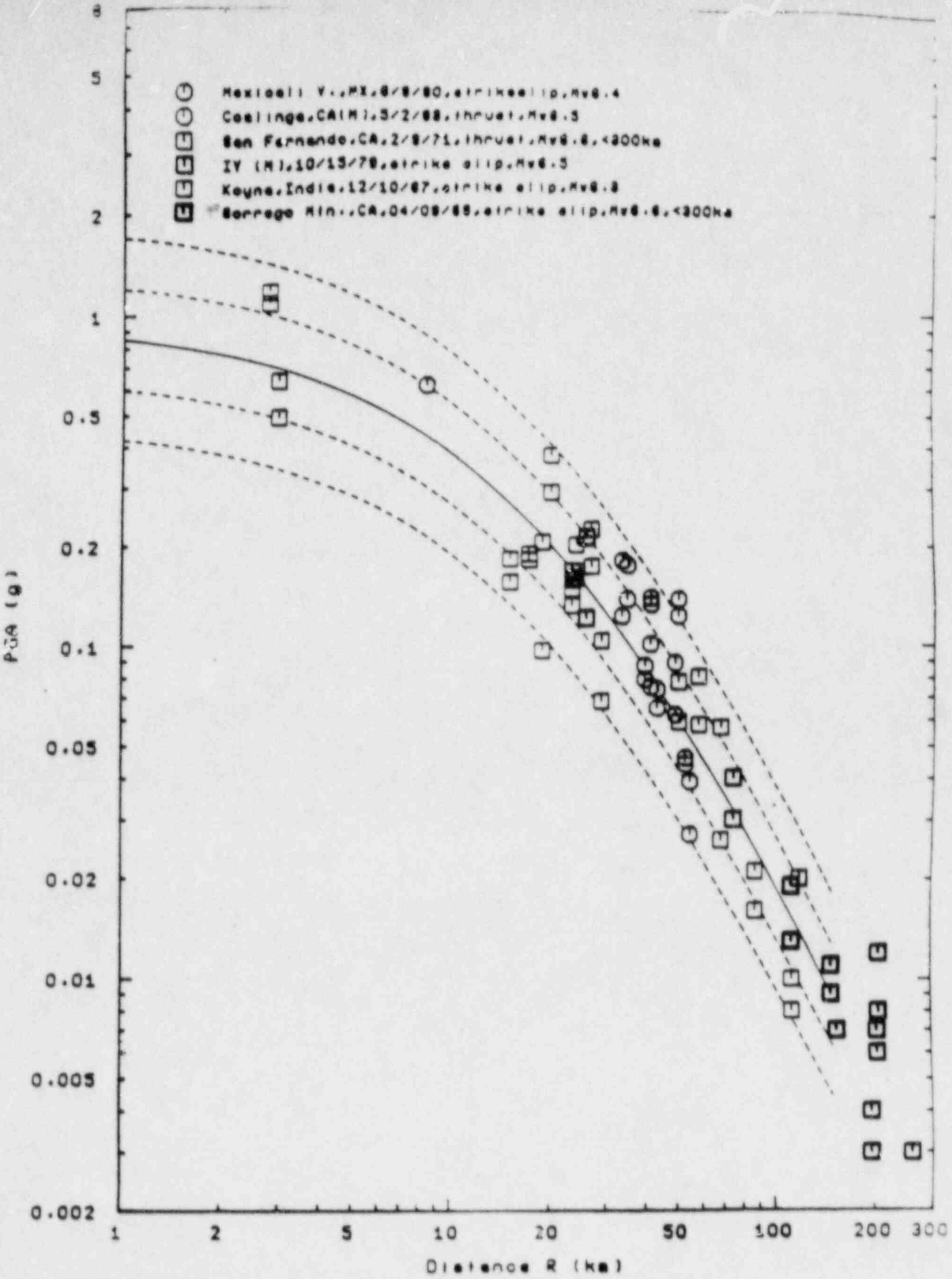


FIGURE IV-1. Regression Results for PGA for M=6.5
Data Magnitude Range 6.3 to 6.6
(Reverse/Thrust Attenuation Relationships)

Regression for SA Attenuation Relationships

- Functional Form for Spectral Shape

$$\ln(SA/PGA) = B1' + B2' * (8.5 - M) + B3' * \ln[R + C(M)] + E'$$

where SA/PGA = normalized response spectral acceleration

R = closest distance to fault rupture surface in km

M = moment magnitude

E' = random variable with zero mean

$C(M) = B4 * \exp(B5 * M)$

- Regression Procedure

Step 1 - Obtain PGA attenuation relationships from all data

Step 2 - Obtain SA/PGA attenuation relationships from all data

Step 3 - Combine PGA and SA/PGA attenuation relationships, $\ln(SA) = \ln(PGA) + \ln(SA/PGA)$

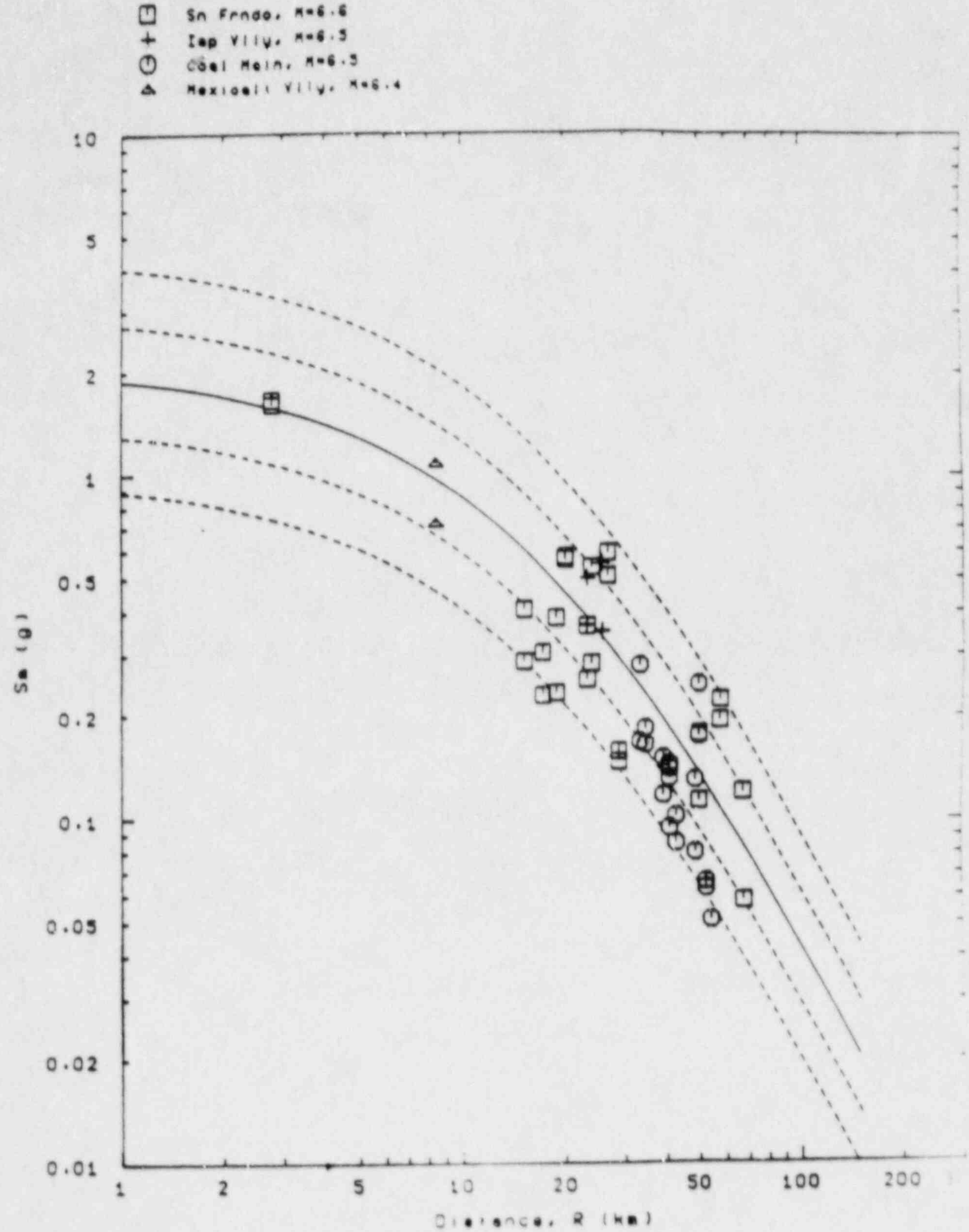


FIGURE IV-4. Regression Results for Sa(T=0.12 sec) for M=6.5
Data Magnitude Range 6.4 to 6.6
(Reverse/Thrust Attenuation Relationships)

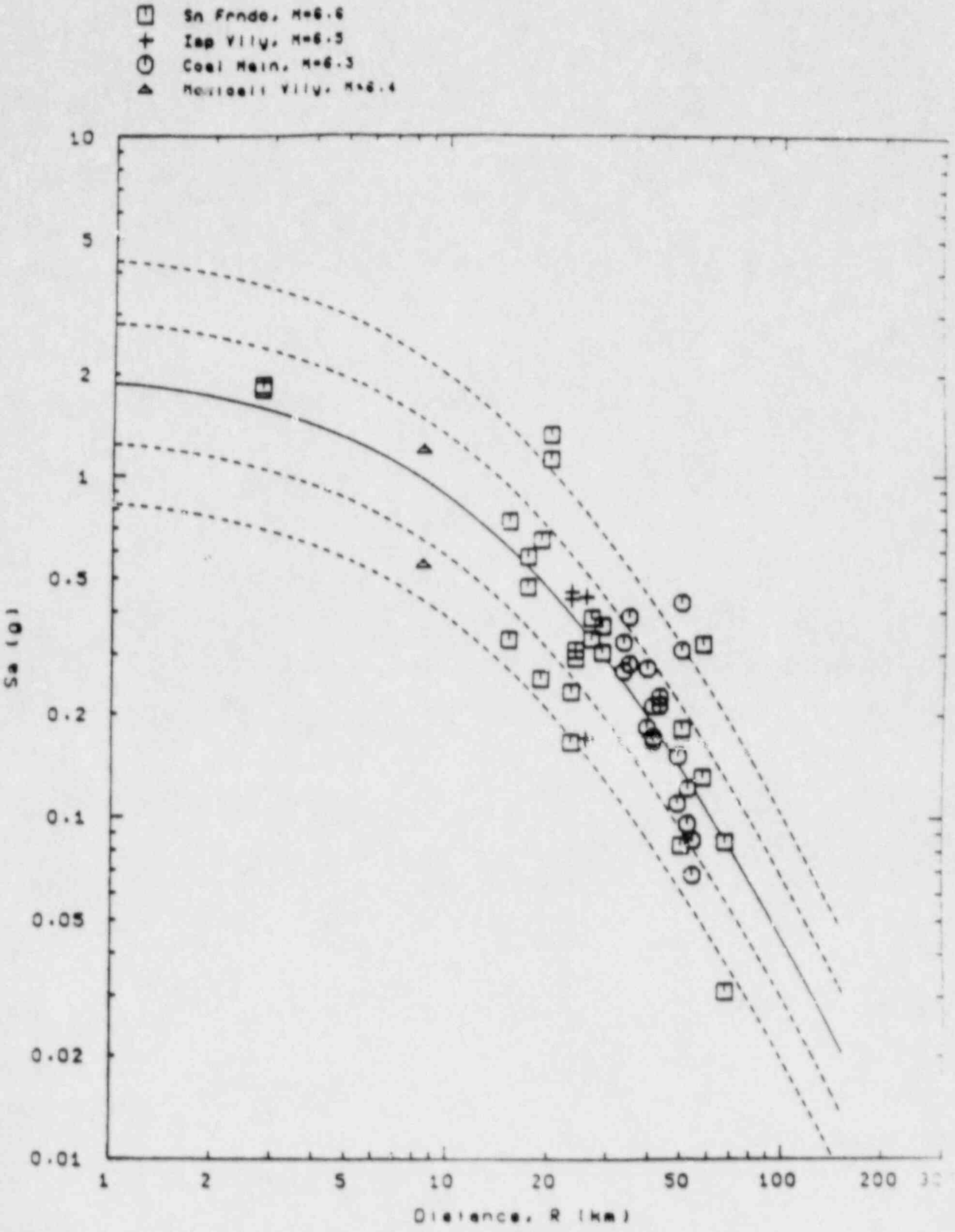


FIGURE IV-5. Regression Results for Sa(T=0.24 sec) for M=6.5
Data Magnitude Range 6.4 to 6.6
(Reverse/Thrust Attenuation Relationships)

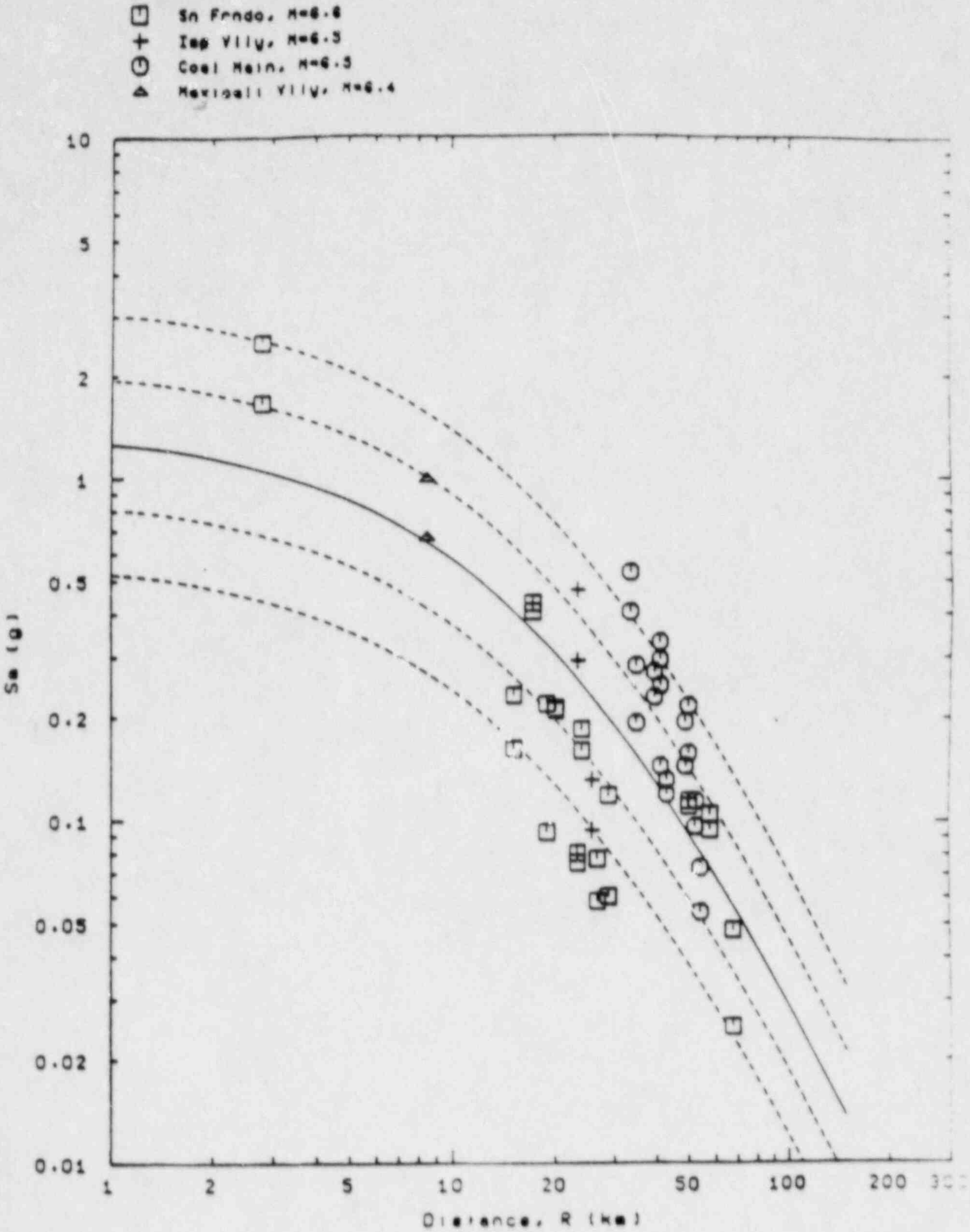


FIGURE IV-6. Regression Results for Sa(T=0.5 sec) for M=6.5
Data Magnitude Range 6.4 to 6.6
(Reverse/Thrust Attenuation Relationships)

Development of Site-specific Response Spectra

- Characterization of Site-specific Response Spectra
  - Median
  - Dispersion about the median

- Site-specific Criteria
  - Earthquake magnitude
  - Source-to-site distance
  - Site condition
  - Style of faulting

- Working Model for Site-specific Response Spectra
  - Earthquake magnitude ~ 7
  - Source-to-site distance ~ 4.5 km
  - Rock site
  - The same likelihood of strike-slip or reverse faulting

Approaches for Developing DCPP Site-specific Response Spectra

- Direct Statistical Analysis on SA of a Sufficiently Large Ensemble of Near-source Strong Motion Recordings
  - 36 horizontal components
  - Mw ≥ 6.3
  - R ≤ 20 km
  - Rock or rock-like site condition
  - Average of strike-slip and reverse faulting styles
- Derivation through SA Attenuation Relationships from Regressions of All Available Rock or Rock-like Recordings
  - 308 horizontal PGA values
  - 130 sets of horizontal SA values
  - Mw = 4.7 - 7.4
  - R = 1 - 300 km for PGA
    = 1 - 50 km for SA
  - Strike-slip and reverse faulting styles

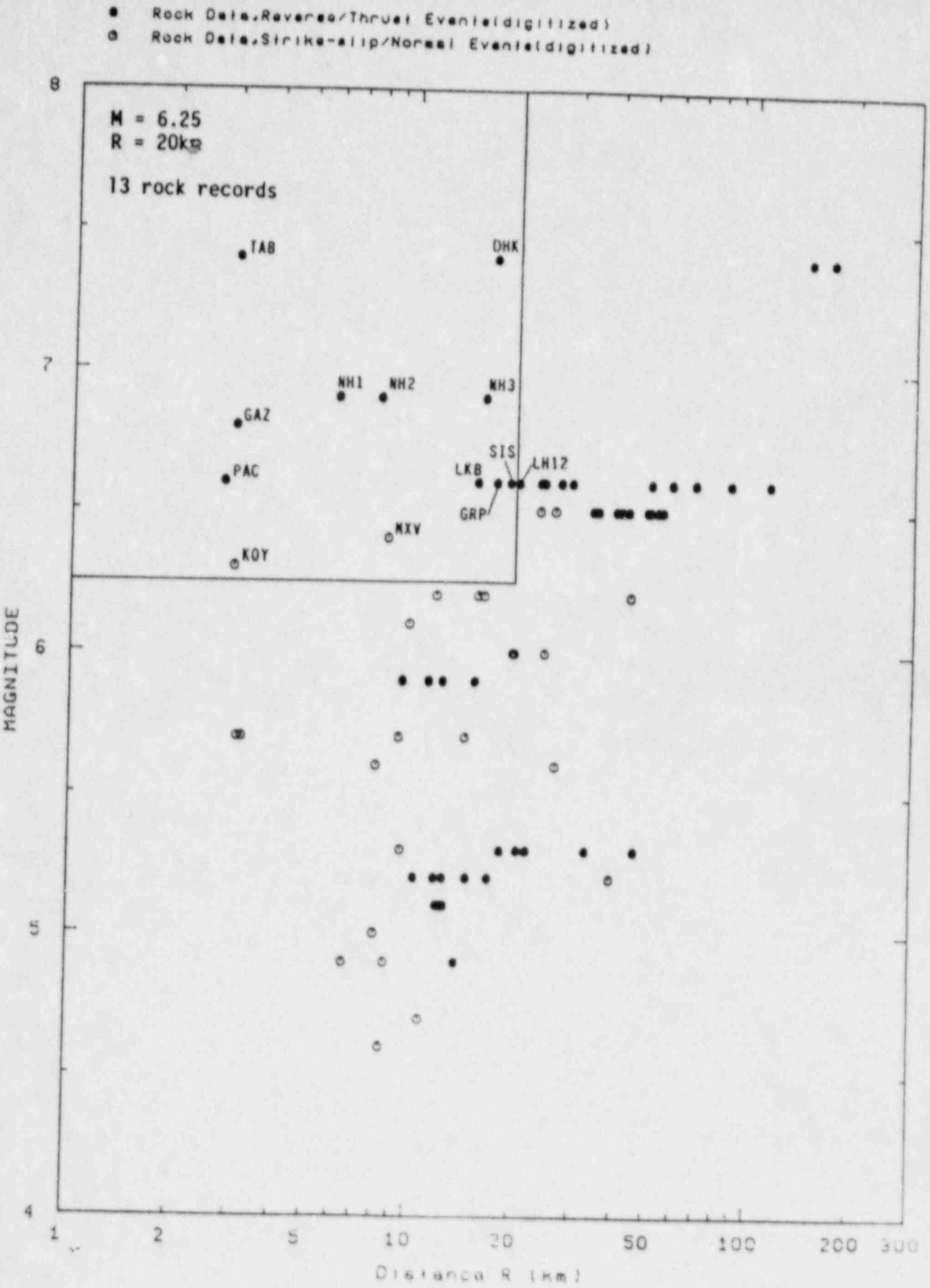


FIGURE III-1: Summary of Ground Motion Data Used From Rock Sites

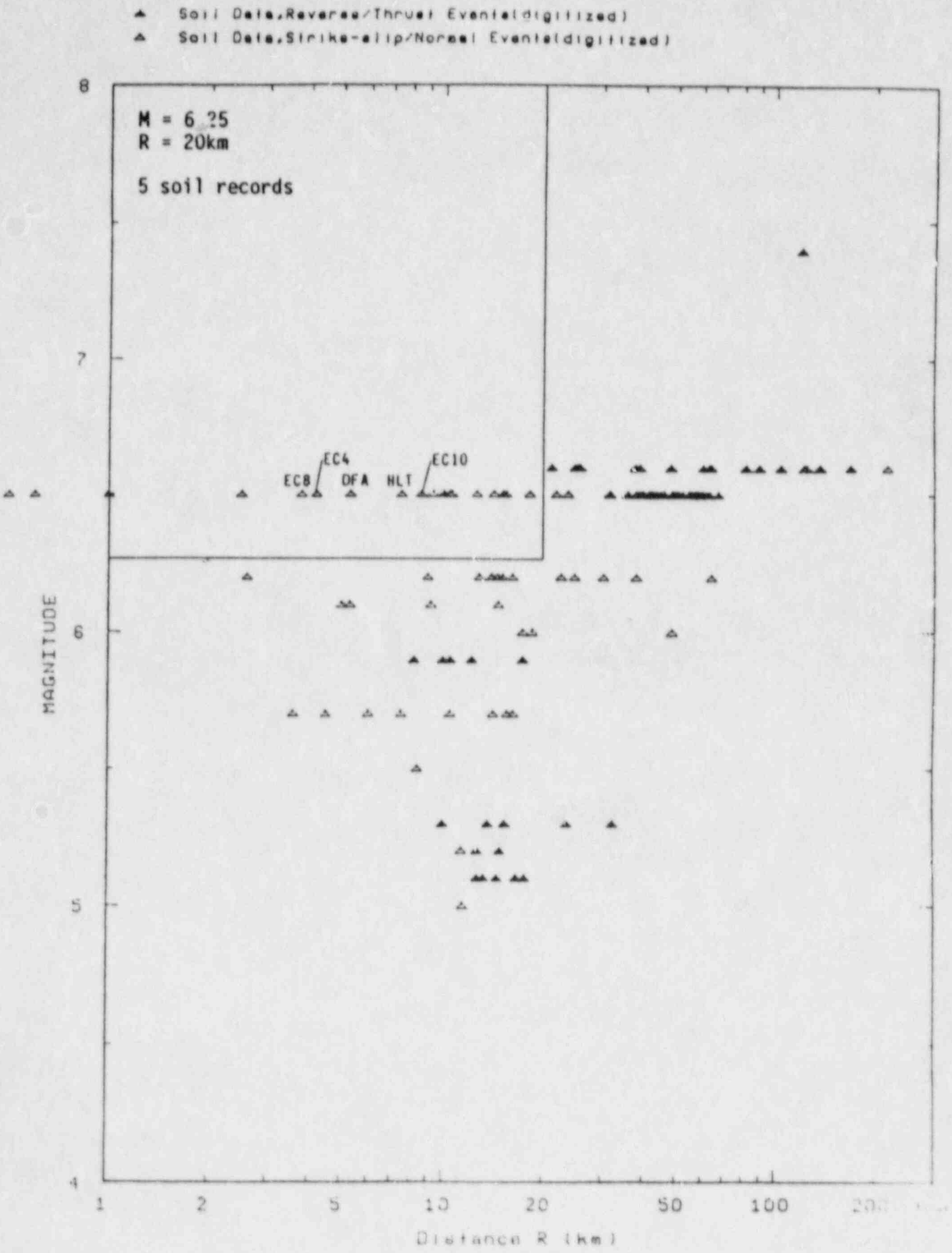


FIGURE III-2: Summary of Ground Motion Data Used From Soil Sites

Strong Motion Recordings Used for Developing Site-specific Spectra

Earthquake	M	R(km)	Fault Style	Site Cond.	# of Rec.
1967Koyna	6.3	3	SS	Rock	1
1971San Fernando	6.6	3-20	R	Rock	5
1976Gazli	6.8	3	R	Rock-like	1
1978Tabas	7.4	3-17	R	Rock-like	2
1980Maxicali	6.4	9	SS	Rock	1
1985Nahanni	6.9	6-16	R	Rock	3

1979Imperial Valley	6.5	4-9	SS	Soil	5

Procedure for Statistical Analysis on SA of Near-source Recordings

- Assemble a Large Ensemble of Near-source Strong Motion Recordings from Large Shallow Crustal Earthquakes

- Adjust the Candidate Recordings to Meet the Site-specific Criteria for DCPP
  - Magnitude adjustment
  - Distance adjustment
  - Adjustment for site condition
  - Adjustment for style of faulting

- Compute Average SA Value over Frequency Range of 3 to 8.5 Hz for Each Adjusted Recording

- Compute the Median and Dispersion of the Whole Ensemble of Recordings for PGA and Averaged SA

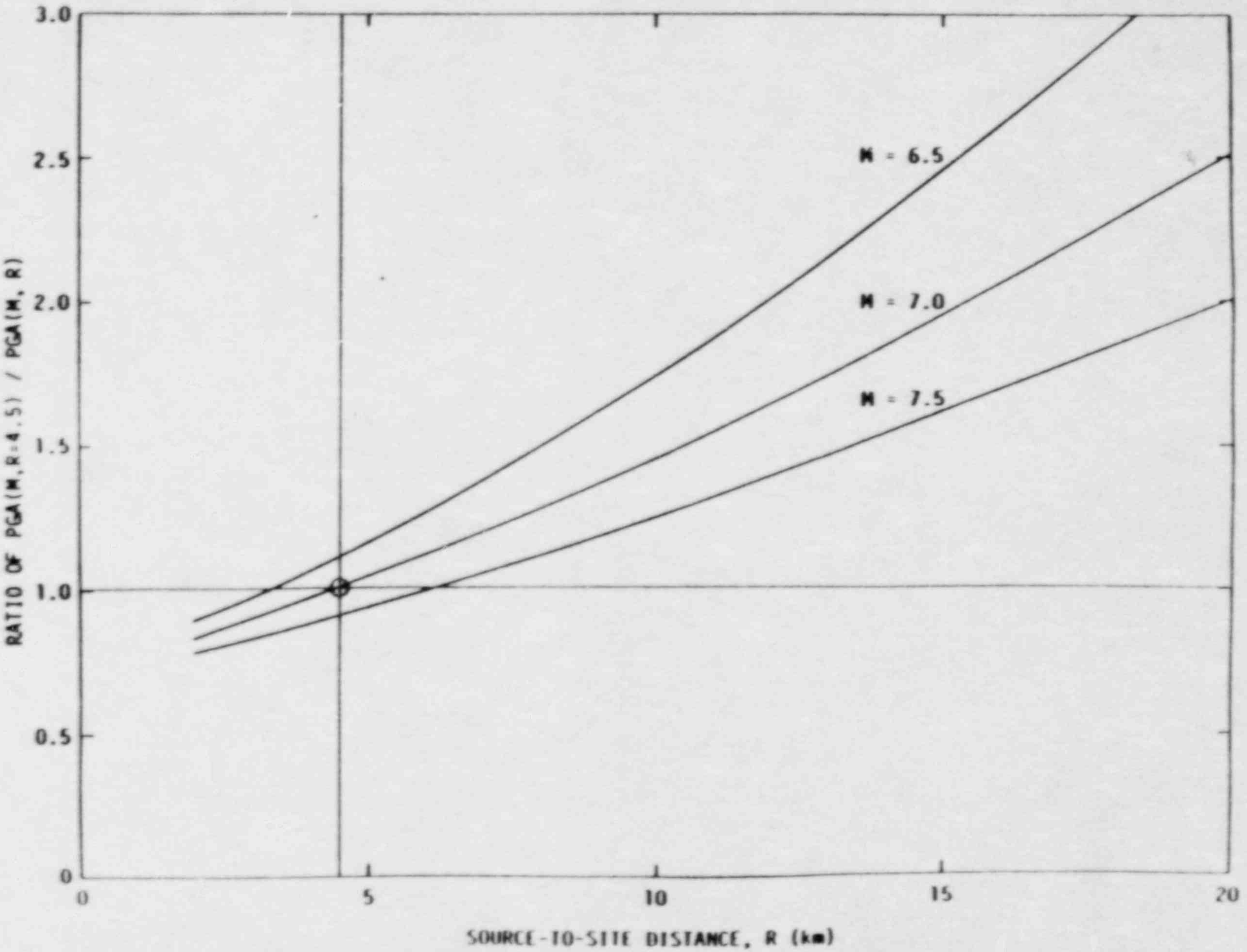
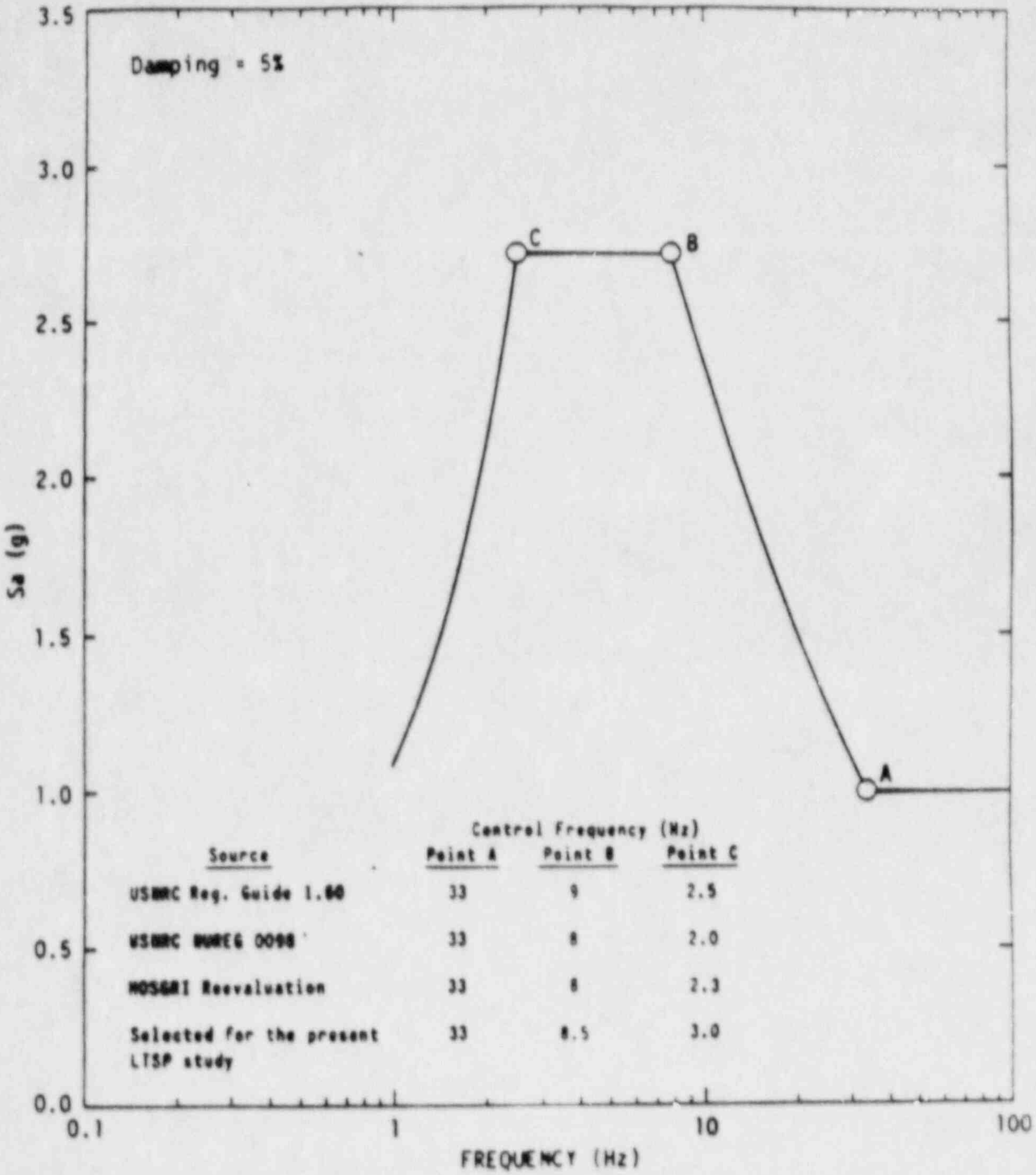


FIGURE III-7. Scaling Relationships for Magnitude and Distance Used for this Study



	Control Frequency (Hz)		
Source	**Point A**	**Point B**	**Point C**
USNRC Reg. Guide 1.60	33	9	2.5
USNRC NUREG 0098	33	8	2.0
HOSGRI Reevaluation	33	8	2.3
Selected for the present LTSP study	33	8.5	3.0

FIGURE III-4. Basis for Selection of Control Frequencies

Modified spectra :

M = 7
R = 4.5km

Fault type = strike-slip
Site conditions = rock

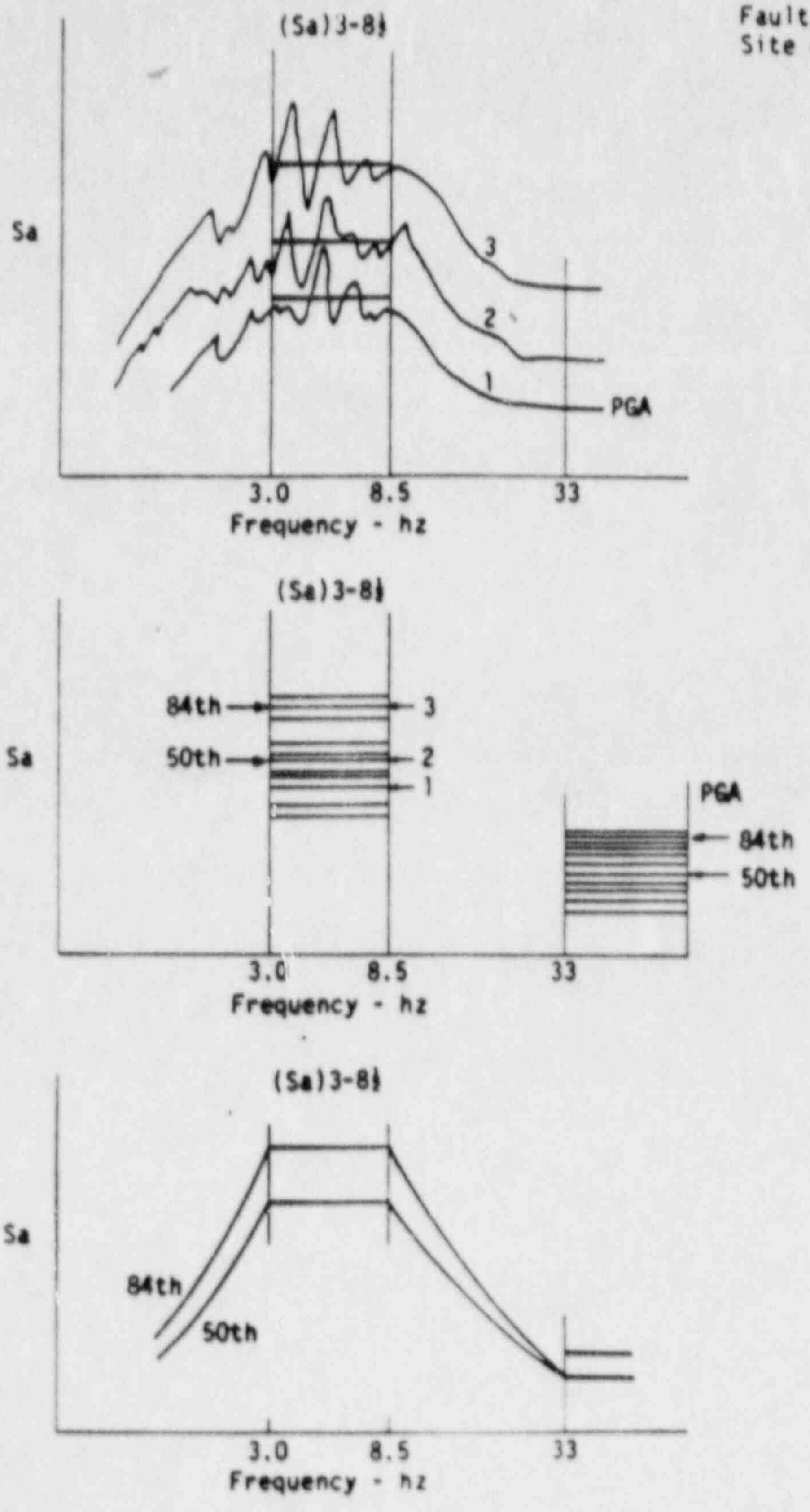


FIGURE III-9. Schematic Presentation of Statistics of Site Specific Spectral Evaluation

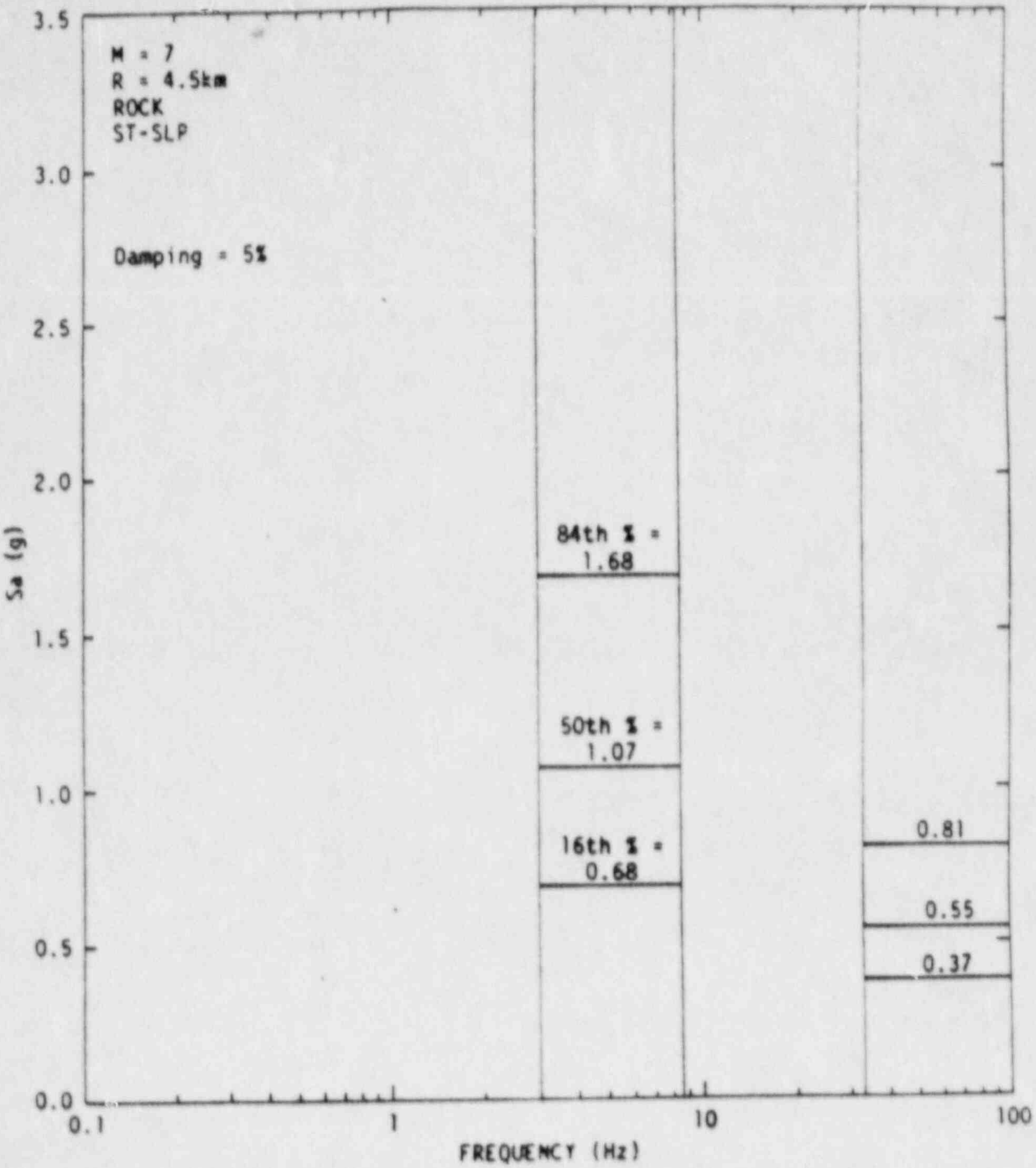


FIGURE III-11. Estimated Spectra for Site Specific Criteria for a Strike Slip-Model

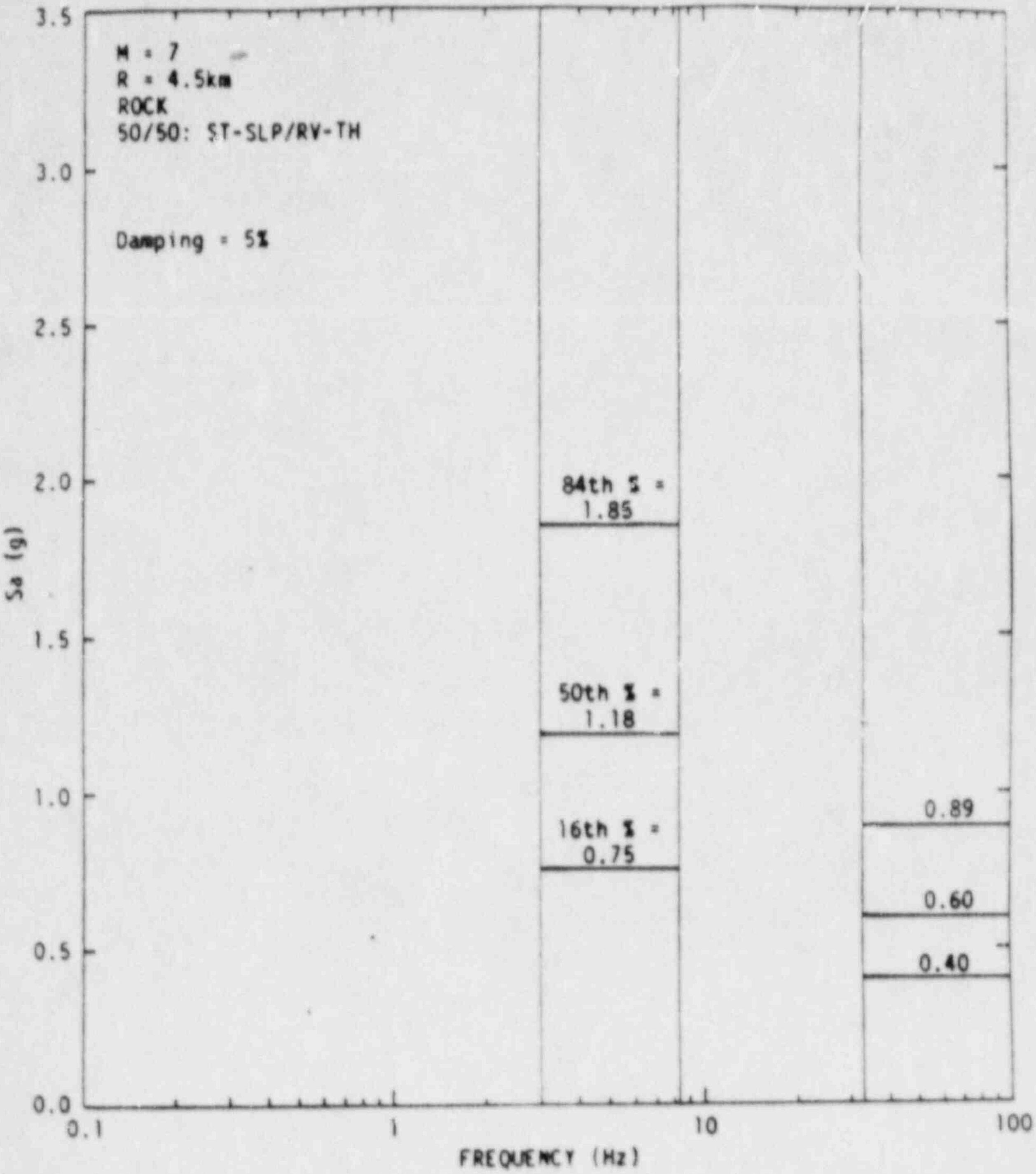


FIGURE III-13. Estimated Spectra for Site Specific Criteria for Equal Probability Strike-Slip and Reverse Models

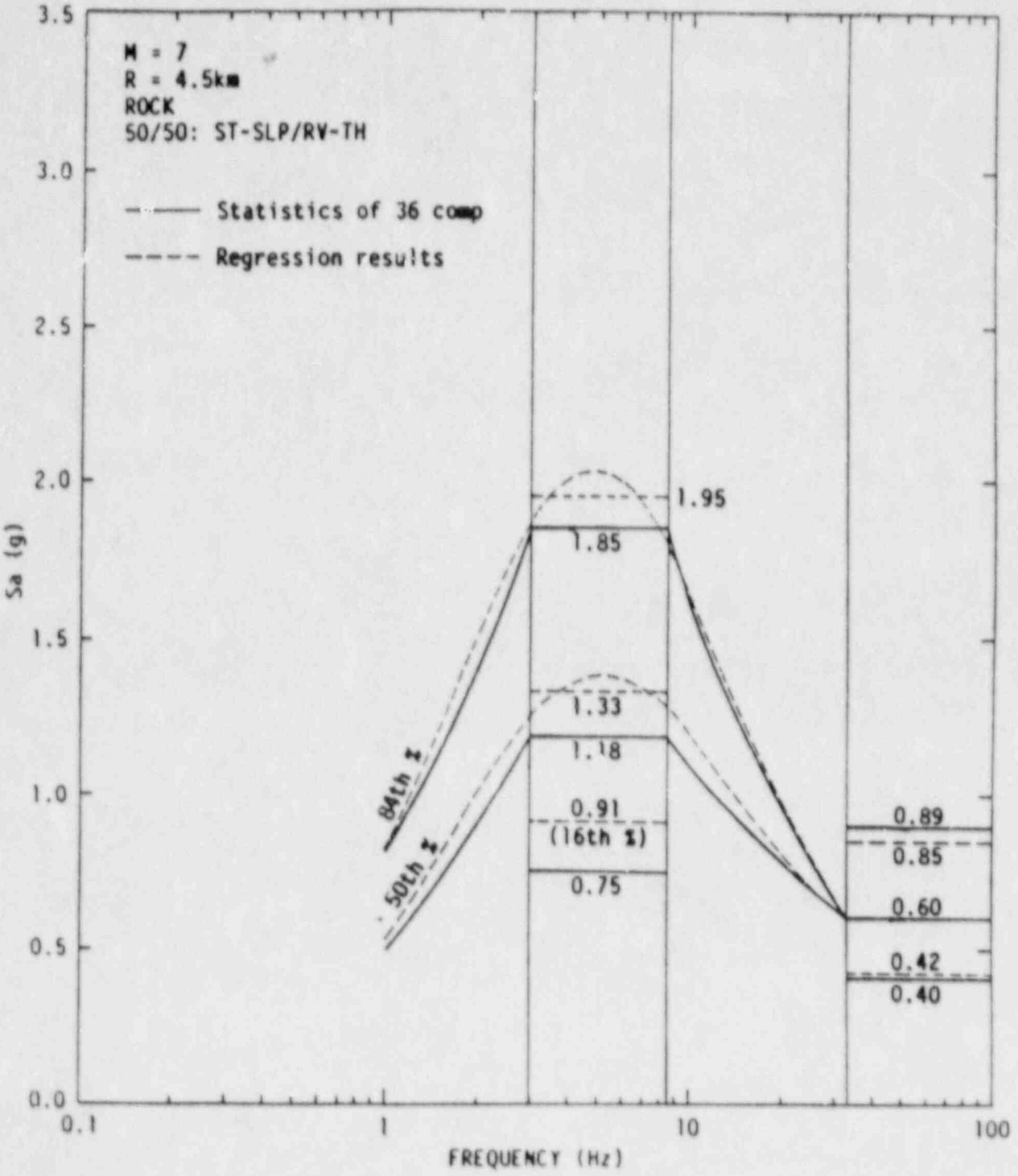


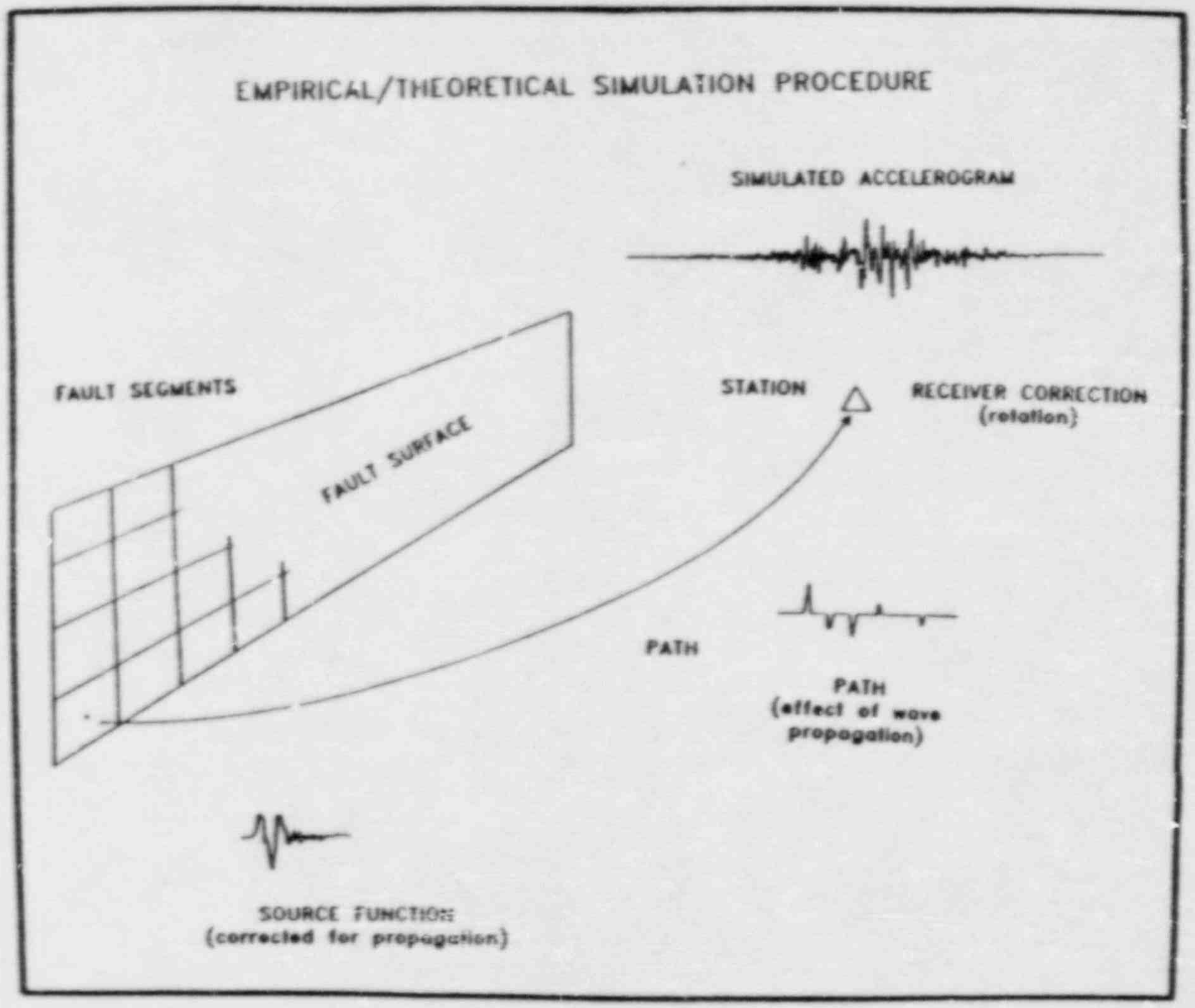
FIGURE III-15. Estimated Site Specific Response Spectra from Statistics of Near Field Ground Motions and from Regression Analyses

Application of Numerical Ground Motion Simulation Methods in DCLTSP

- Purposes of Numerical Simulations
  - To generate realistic acceleration time histories for engineering analyses by incorporating as much site-specific geology/seismology/geophysics information as possible
  - To perform sensitivity studies on ground motion characteristics at the site with respect to seismic source, propagation path, and site properties

- Simulation Methods Developed in DCLTSP
  - Empirical Green's function summation method
  - Semi-empirical simulation method on single empirical source function
  - Semi-empirical simulation method on multiple empirical source functions

Fig. 5.2



EMPIRICAL/THEORETICAL SIMULATION PROCEDURE

Main Features of the Refined Semi-empirical Simulation Method

- Source Time Functions
  - Needs for empirical source functions
  - Degradation of radiation pattern at high frequencies
  - Selection of source functions
  - Comparison with site recordings
  - Correction for propagation effects

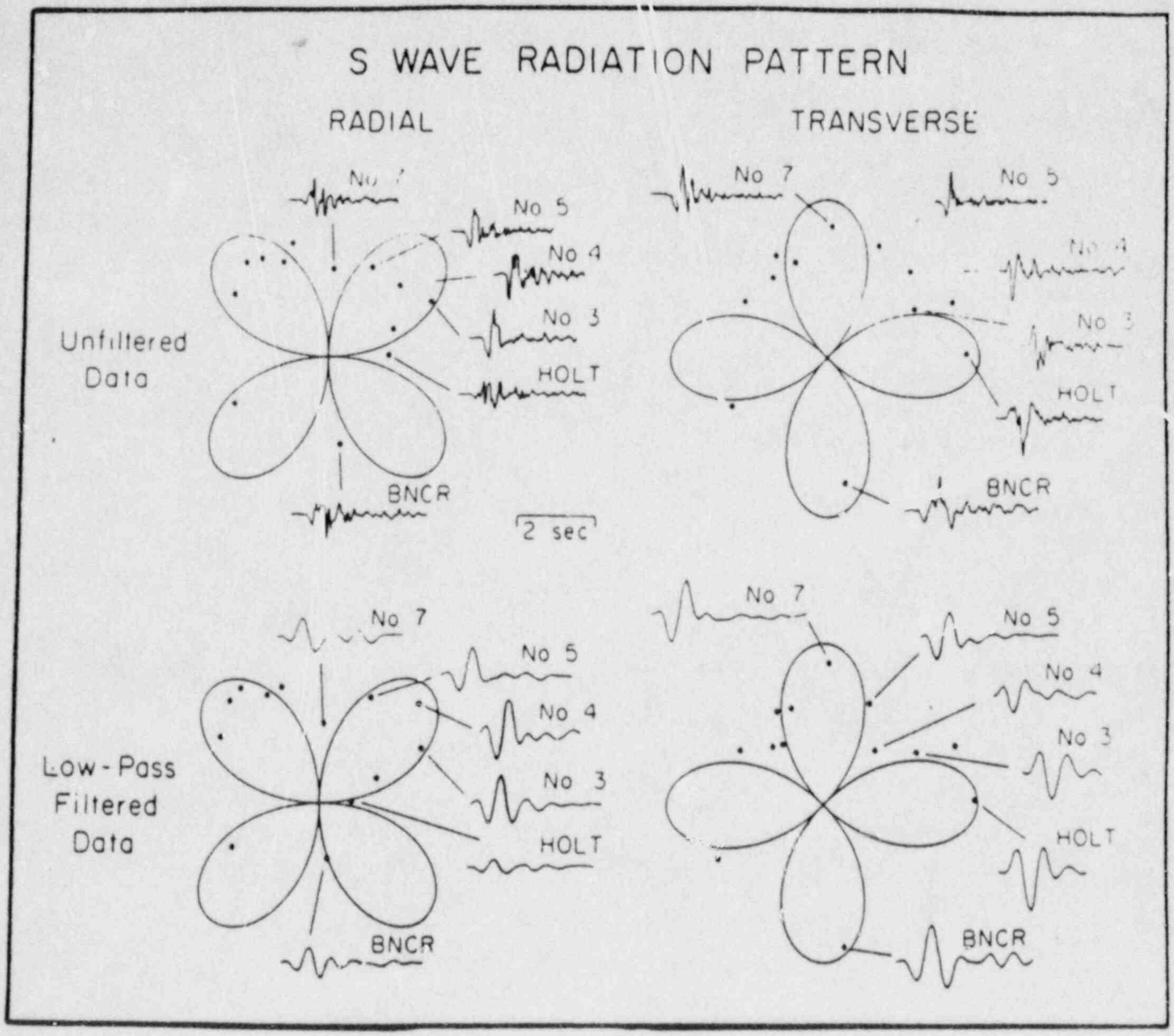
- Fault Segment Size
  - Joyner and Boore constraint
  - Fraunhoffer approximation
  - Barrier interval
  - Sensitivity study

- Fault Heterogeneity
  - Slip distribution
  - Slip time function
  - Rupture velocity
  - Sensitivity study

- Green's Functions
  - Computed by generalized ray method
  - Crustal model constrained by site recordings
  - Compared with f-k integration method

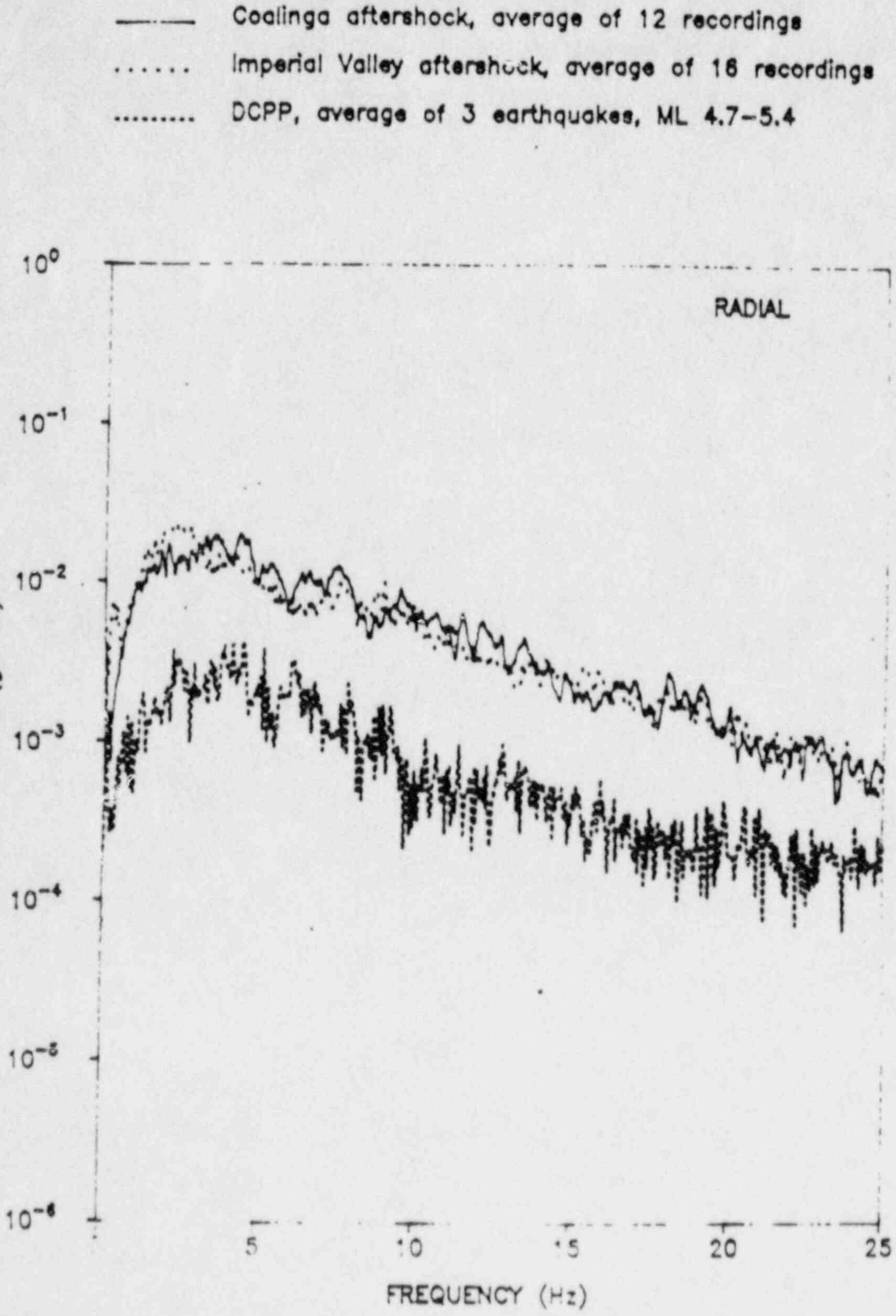
Needs for Empirical Source Functions

- Source Spectrum
  - Frequency-dependent radiation pattern
- Near-source Scattering
- Unmodeled Propagation Complexity
  - Multipathing
  - Reverberations
- Anelastic Absorption
  - $Q(f, r)$
- Near-site Scattering


S WAVE RADIATION PATTERN
RADIAL
TRANSVERSE
Unfiltered Data
Low-Pass Filtered Data
No 7
No 5
No 4
No 3
HOLT
BNCR
2 sec

Selection of Empirical Source Functions

- Subevent Size
  - Large enough for:
    - Adequate signal-to-noise ratio
    - Reliable seismic moment estimate
    - Adequate subevent/mainevent moment ratio (Joyner-Boore constraint)
    - Compatability with fault barrier interval of the main event
  - Small enough for:
    - Fraunhoffer approximation to hold
- Recordings
  - Accurate location of subevent source
  - Multiple recordings within about one source depth
  - Adequate sampling of the radiation pattern
- Selected Empirical Source Functions
  - 16 recordings of the 1979 Imperial Valley aftershock
  - 12 recordings of the 1983 Coalinga aftershock



Coalinga aftershock, average of 12 recordings
Imperial Valley aftershock, average of 16 recordings
DCPP, average of 3 earthquakes, ML 4.7-5.4
RADIAL
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
ACCELERATION (g-sec)
5
10
15
20
25
FREQUENCY (Hz)

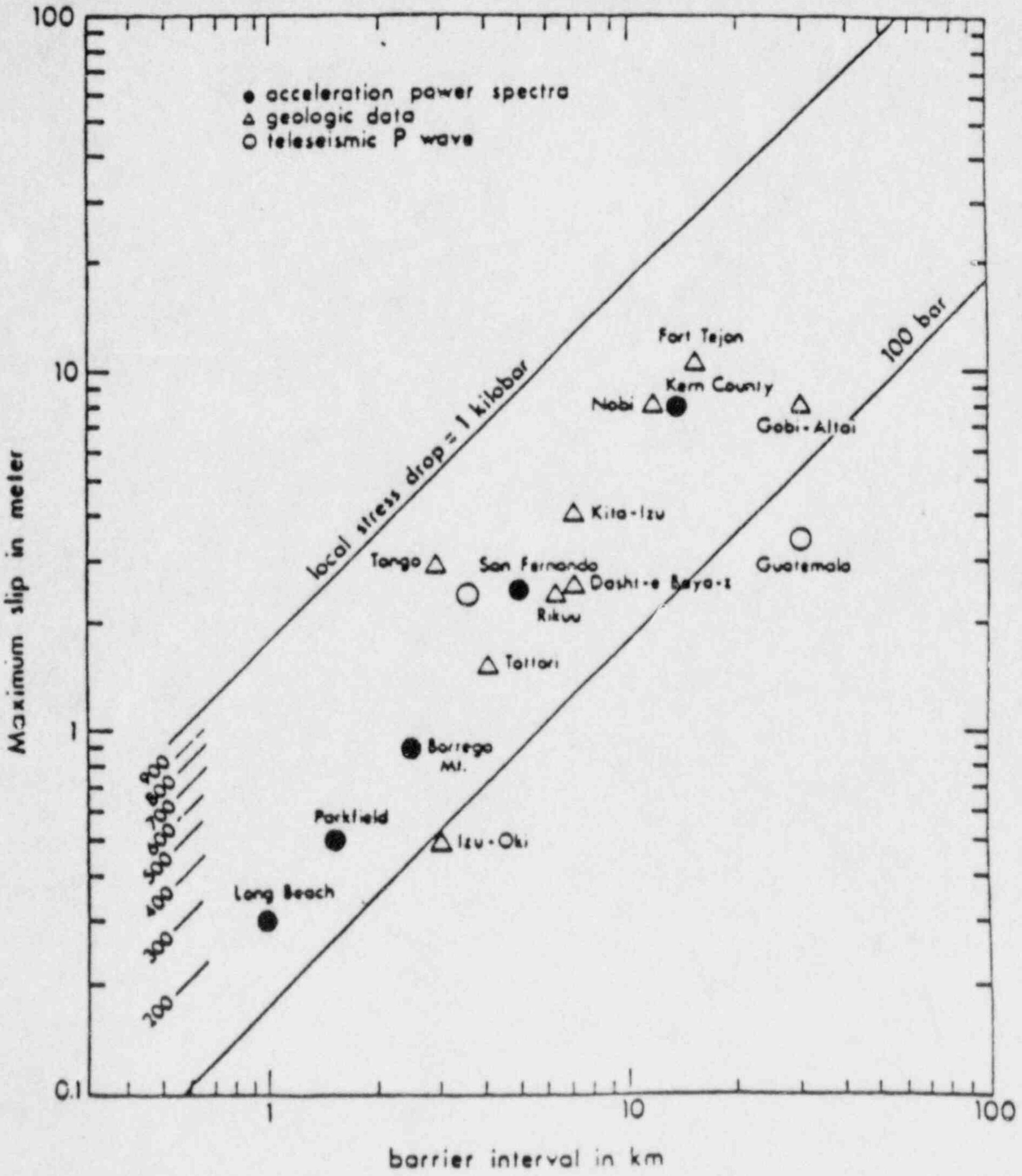


Figure 11-1. Maximum fault slip _versus_ barrier interval.

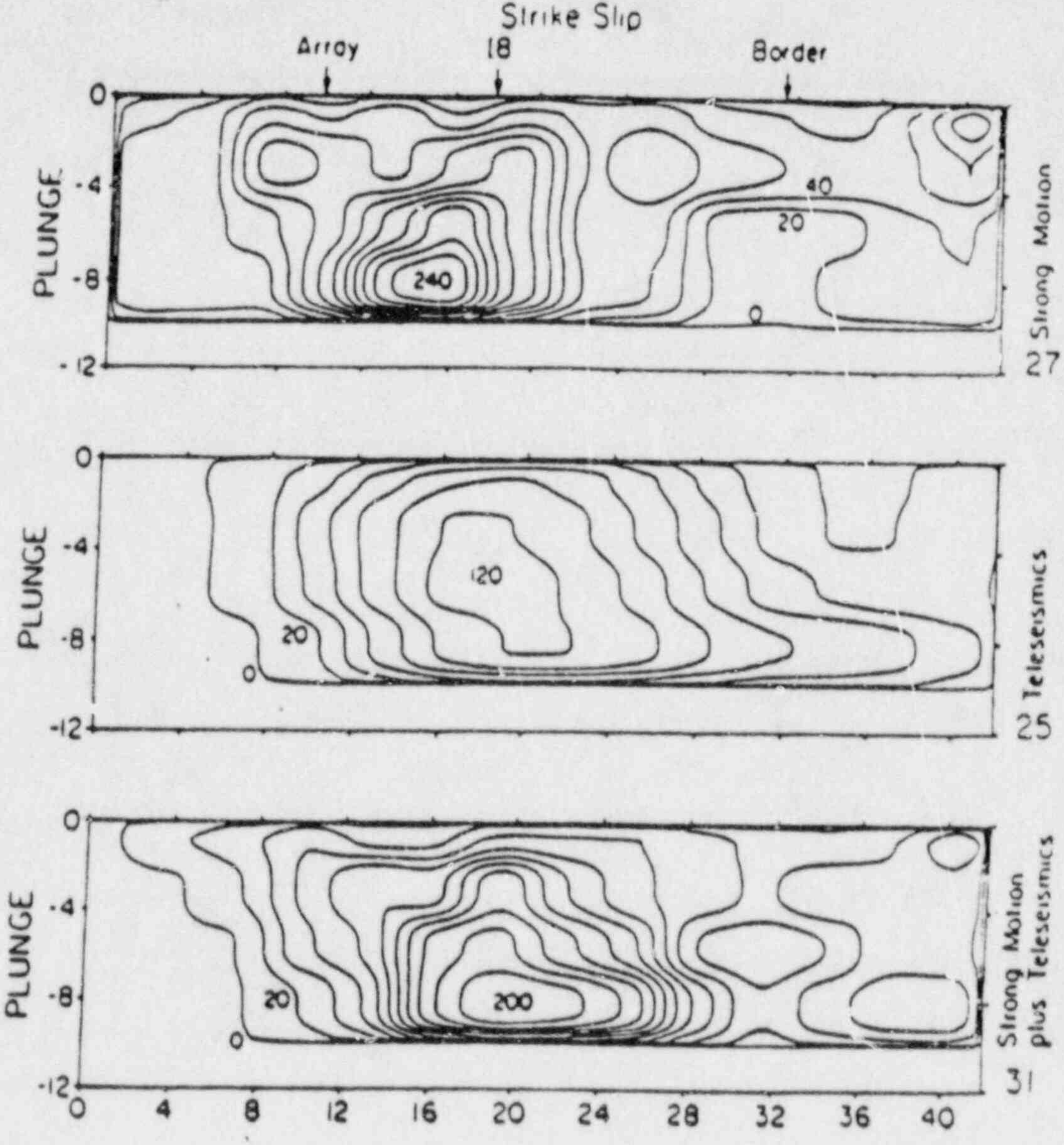
Treatment of Fault Heterogeneity

- Static Slip Distribution
  - Globaly nonuniform
  - Deterministic

- Slip Time Function
  - Prescribed total rise time
  - Globaly deterministic (ramp)
  - Locally stochastic (Gaussian)

- Rupture Velocity
  - Rupture initiating at lower part of the fault, then propagating outward
  - Globaly deterministic (0.8*Vs)
  - Locally stochastic (Gaussian)

ASPERITY MODEL OF 1979 IMPERIAL VALLEY EARTHQUAKE, CONTOURED (IN CENTIMETERS) ON THE FAULT PLANE FROM STRONG MOTION AND TELESEISMIC VELOCITY DATA (PERIODS ABOUT 1 SECOND)



.10	.30	.60	.65	.90	.70	.50	.30	.40	.55
.02	.20	.80	1.10	1.60	1.15	.50	.40	.45	.50
0	.10	.55	1.65	2.05	1.88	.78	.35	.50	.58
0	.02	.10	.30	.40	.40	.20	.05	.10	.10

SUBFAULT WEIGHTS

FROM HARTZELL AND HEATON

FIGURE

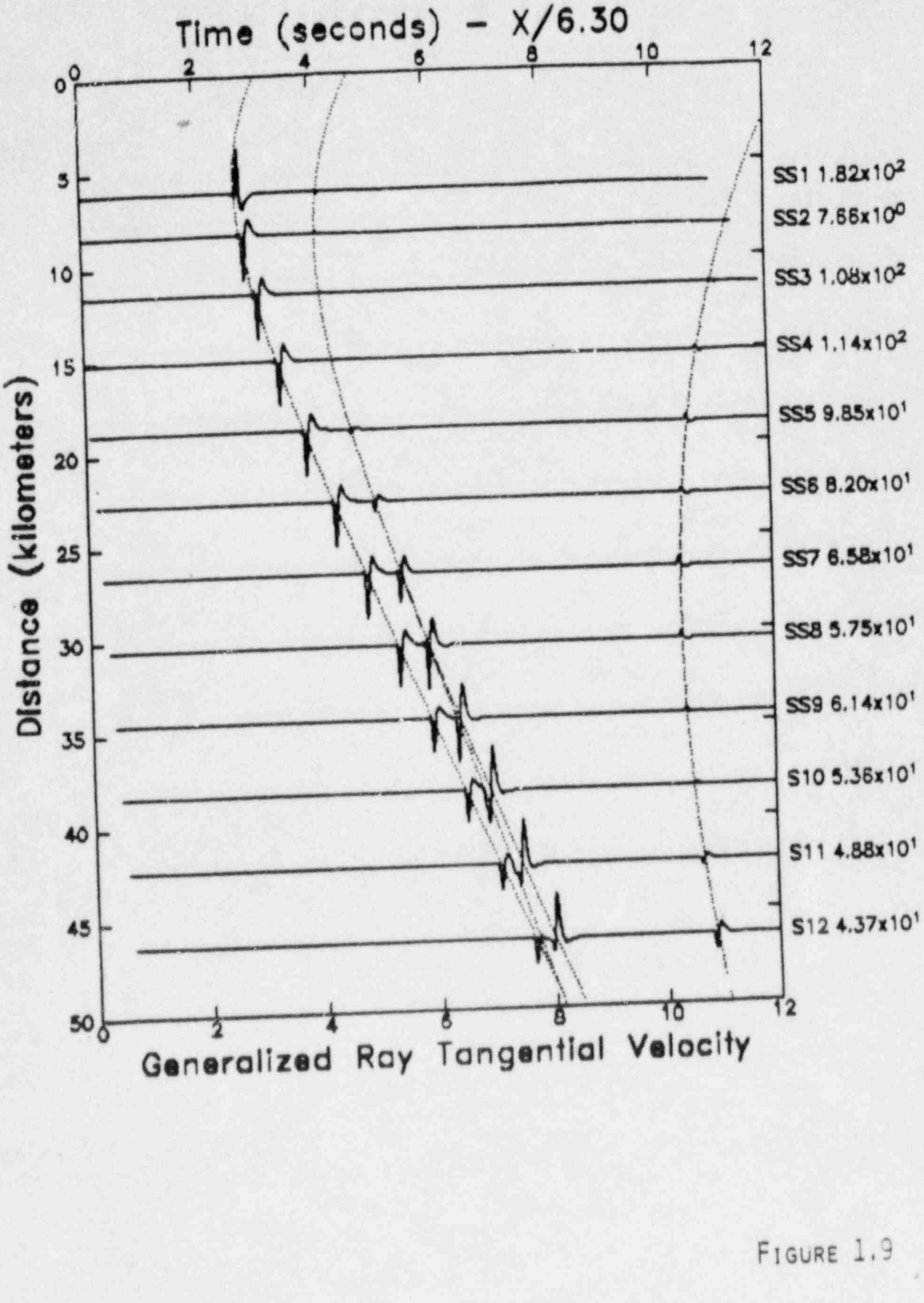

Time (seconds) - X/6.30
0
2
4
6
8
10
12
Distance (kilometers)
0
5
10
15
20
25
30
35
40
45
50
SS1 1.82x10^2
SS2 7.66x10^0
SS3 1.08x10^2
SS4 1.14x10^2
SS5 9.85x10^1
SS6 8.20x10^1
SS7 6.58x10^1
SS8 5.75x10^1
SS9 6.14x10^1
S10 5.36x10^1
S11 4.88x10^1
S12 4.37x10^1
Generalized Ray Tangential Velocity

FIGURE 1.9

DCPP Strong motion quakes

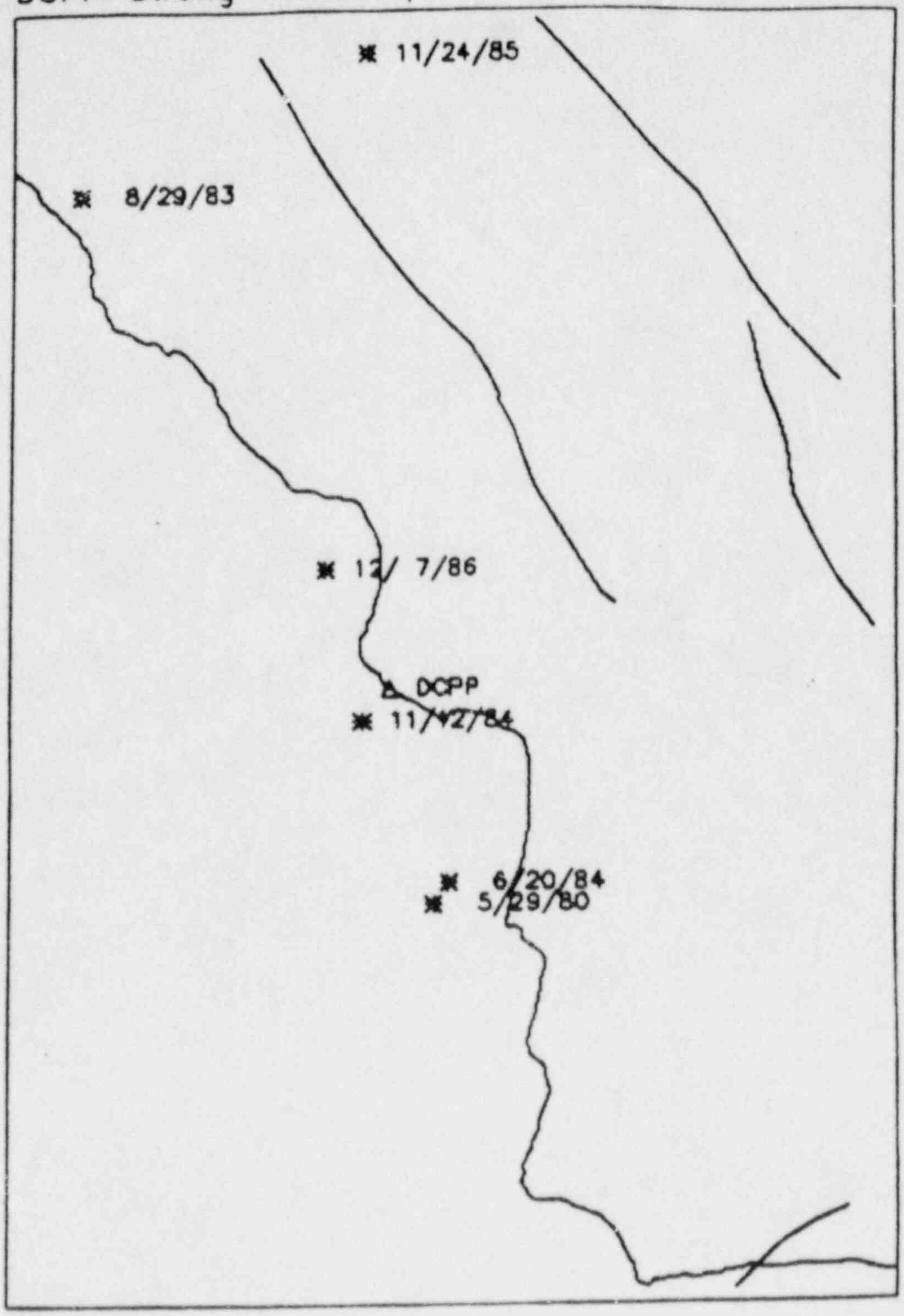
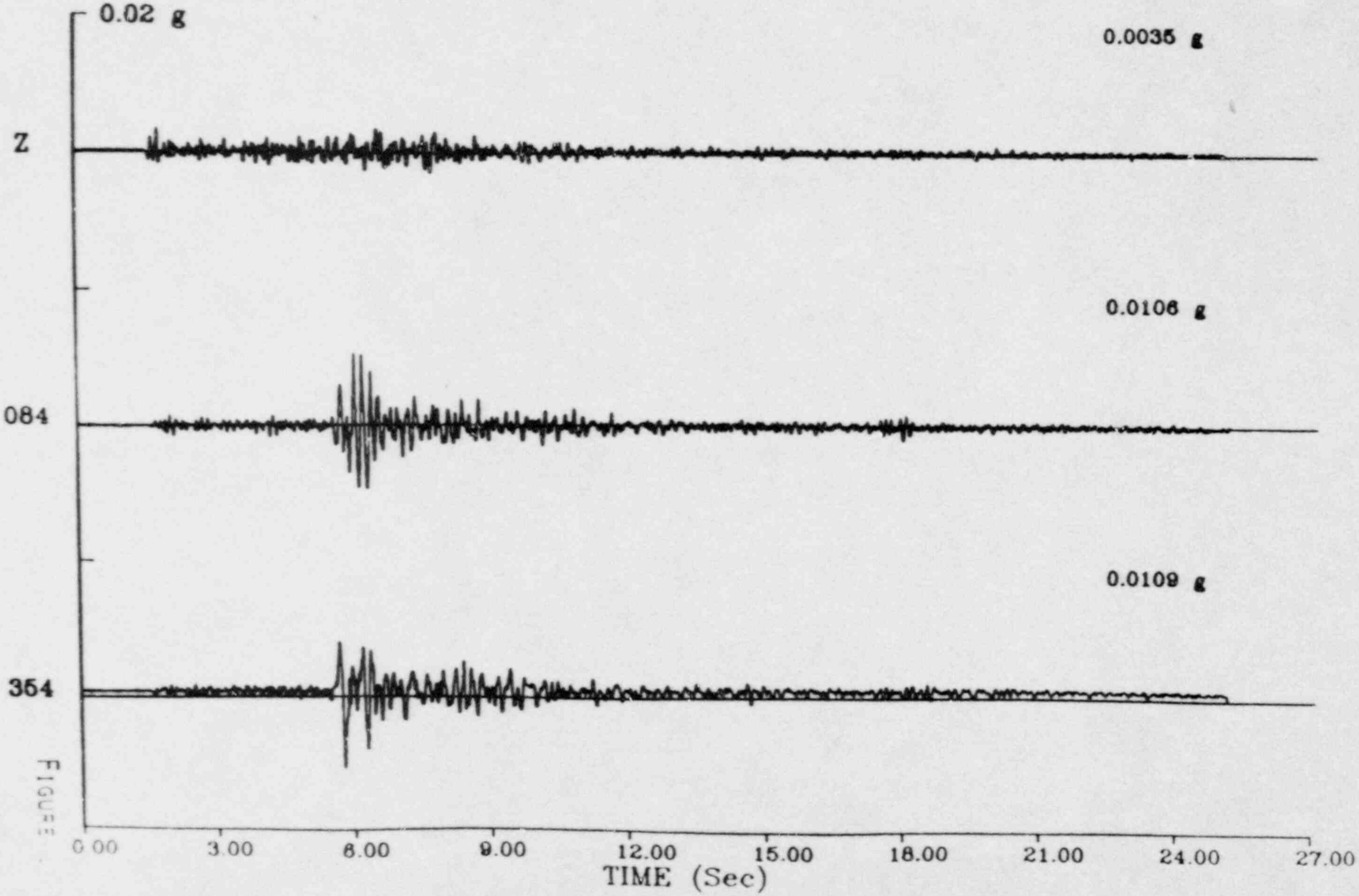
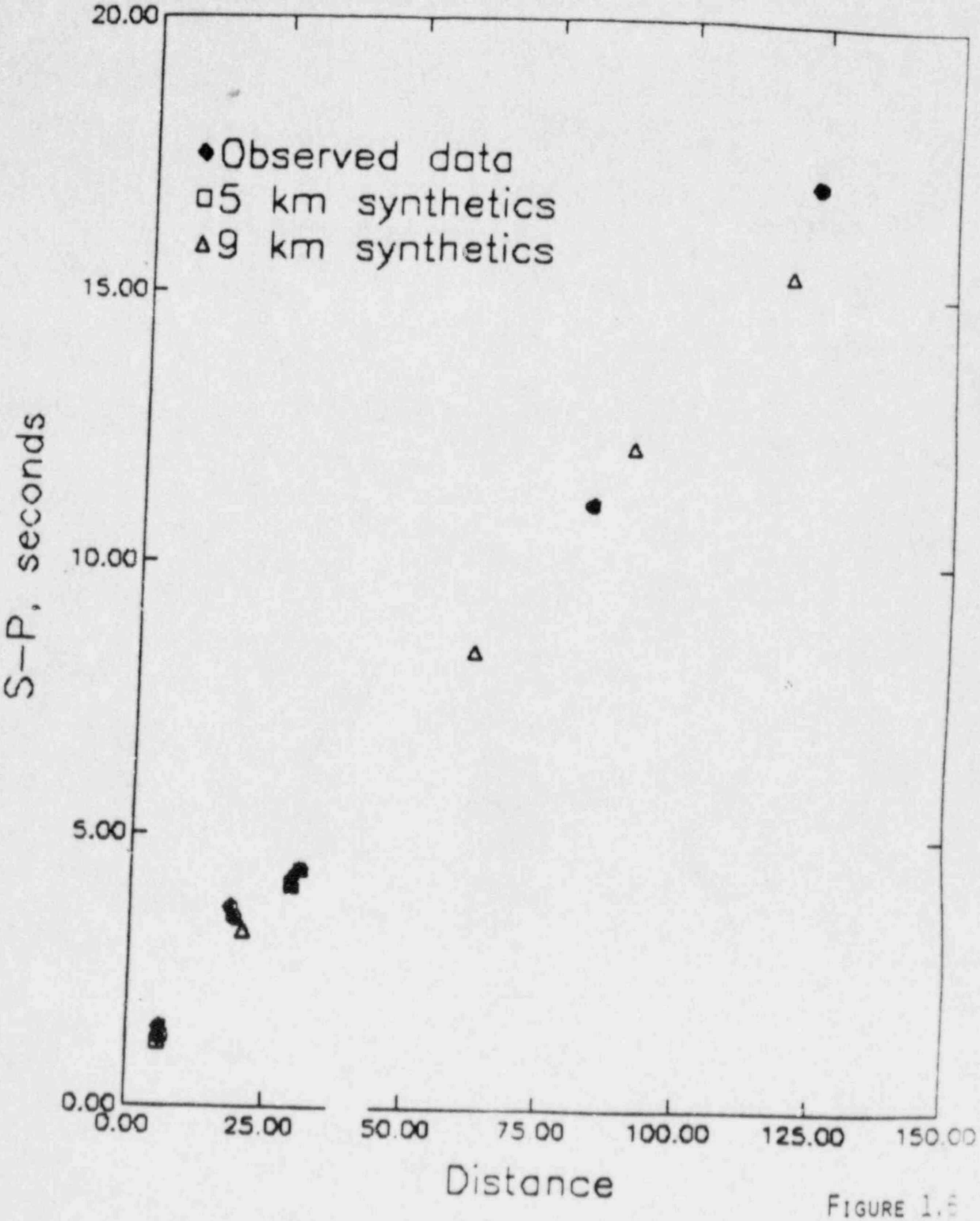


FIGURE 1

20 Jun 84 Santa Maria; Free Field, Near Meteorological Tower
Deck 5-4





20.00
15.00
10.00
5.00
0.00
S–P, seconds
◆Observed data
□5 km synthetics
△9 km synthetics
0.00
25.00
50.00
75.00
100.00
125.00
150.00
Distance

FIGURE 1.

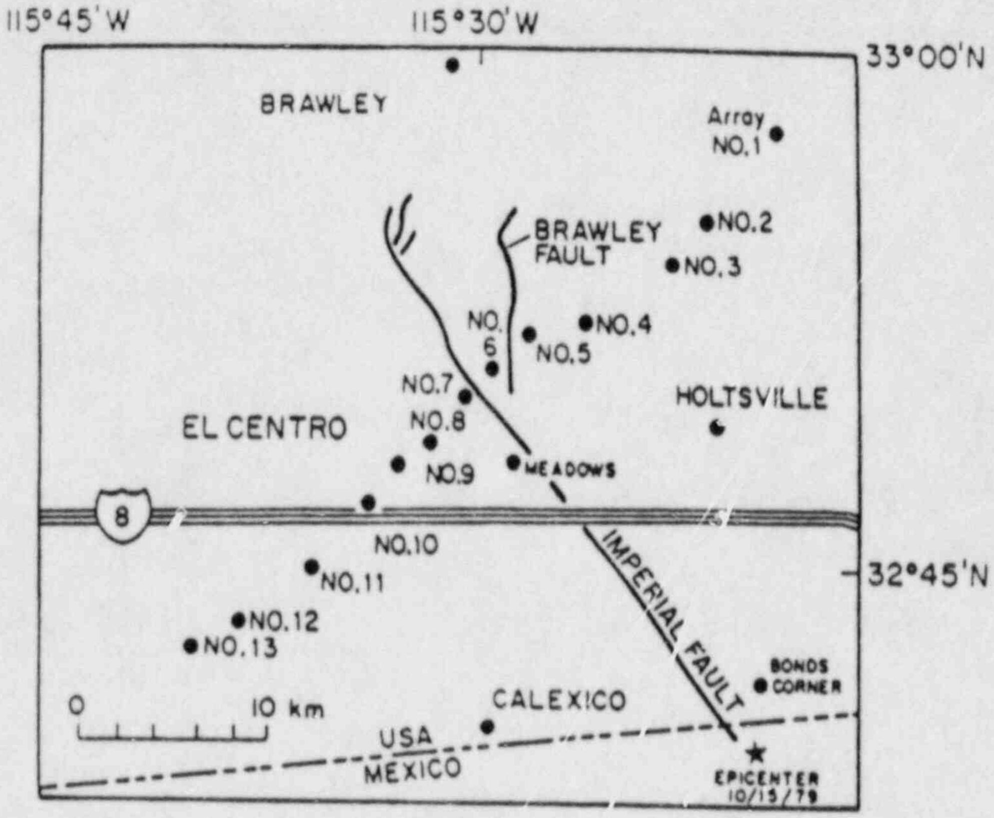
Calibration of the Refined Semi-empirical Simulation Method

- Comparison with Actual Recordings of the 1979 Imperial Valley earthquake
  - Acceleration time histories
  - Attenuation of PGA with distance
  - Acceleration response spectra

- Important Finding
  - The refined semi-empirical simulation method is capable of generating realistic acceleration time histories which contain key characteristics essential to DCLTSP engineering applications

Fig. 3.1

EL CENTRO STRONG GROUND MOTION ARRAY



(AFTER HARTZELL AND HEATON, 1983)

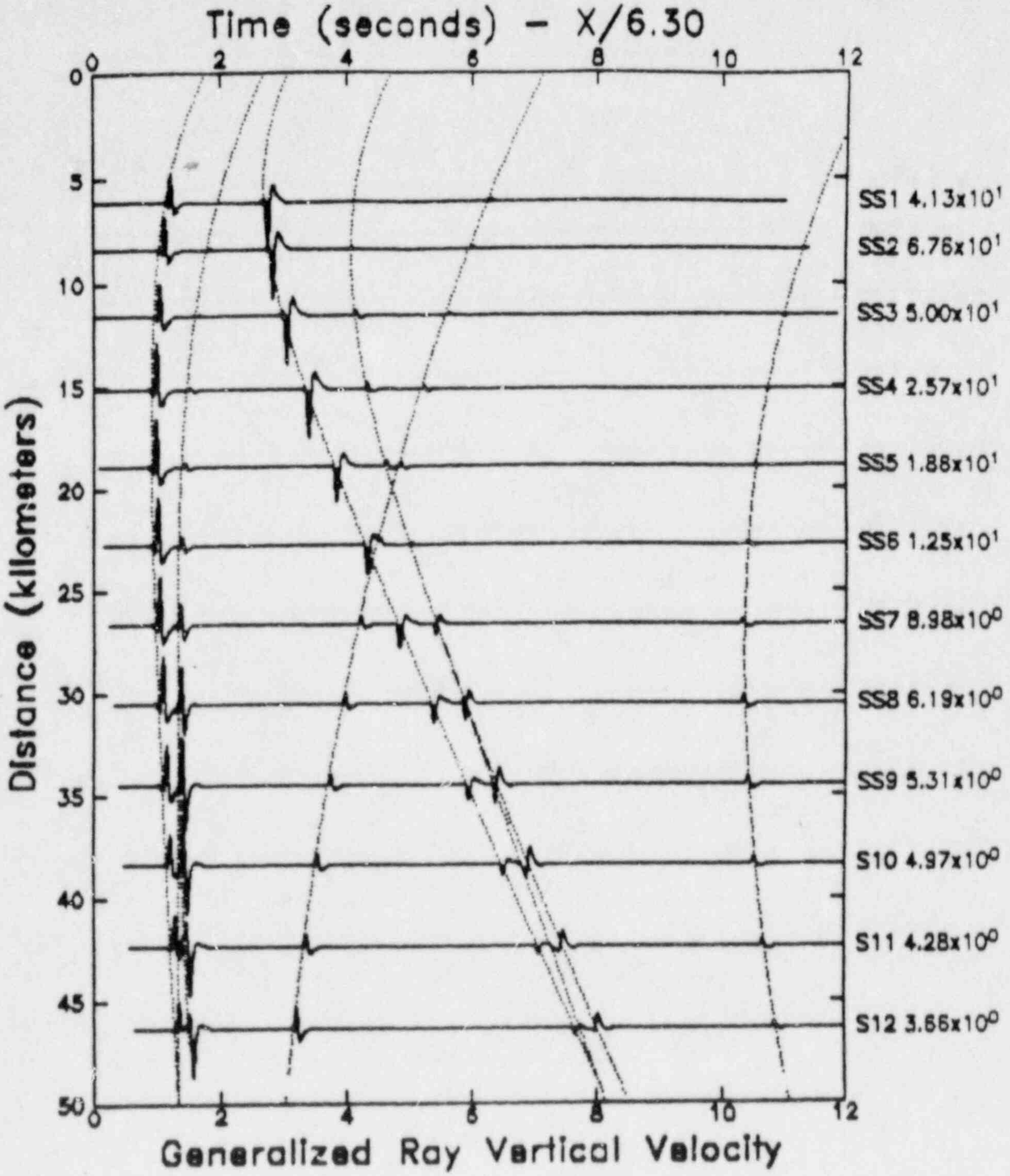

Time (seconds) - X/6.30
0
2
4
6
8
10
12
Distance (kilometers)
0
5
10
15
20
25
30
35
40
45
50
SS1 4.13x10¹
SS2 6.76x10¹
SS3 5.00x10¹
SS4 2.57x10¹
SS5 1.88x10¹
SS6 1.25x10¹
SS7 8.98x10⁰
SS8 6.19x10⁰
SS9 5.31x10⁰
S10 4.97x10⁰
S11 4.28x10⁰
S12 3.66x10⁰
Generalized Ray Vertical Velocity

FIGURE 1.7

Randomization Of Rupture Velocity

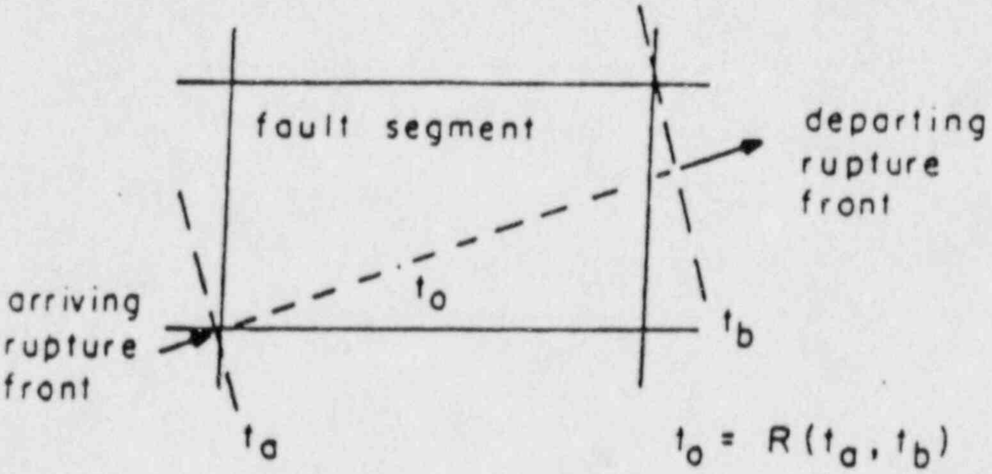


Figure 2

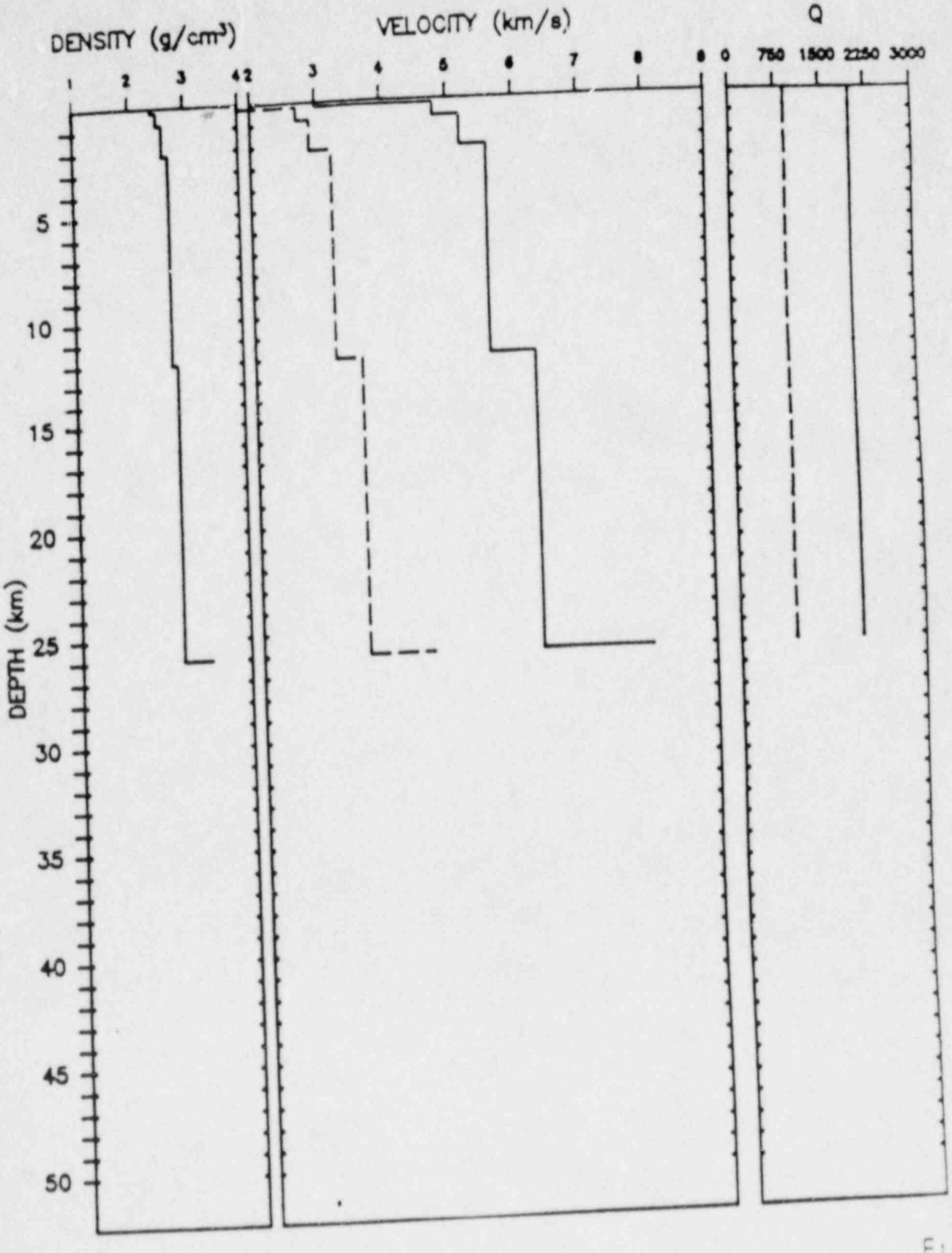

DENSITY (g/cm³)
VELOCITY (km/s)
Q
1
2
3
4
2
3
4
5
6
7
8
8
0
750
1500
2250
3000
DEPTH (km)
5
10
15
20
25
30
35
40
45
50

FIGURE 1.

Fig. 4.2

IMPERIAL VALLEY CRUSTAL STRUCTURE MODEL

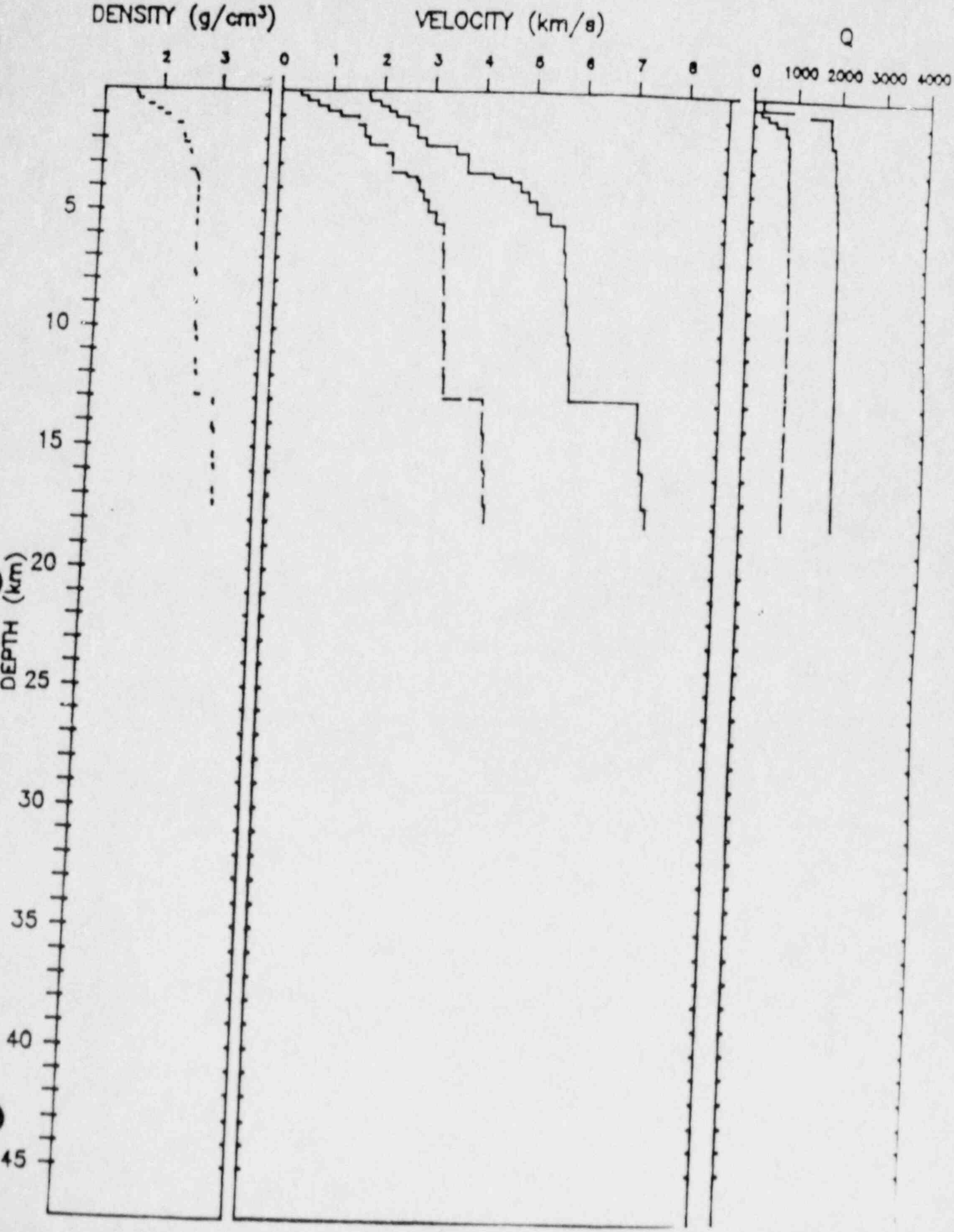


Fig. 5.3

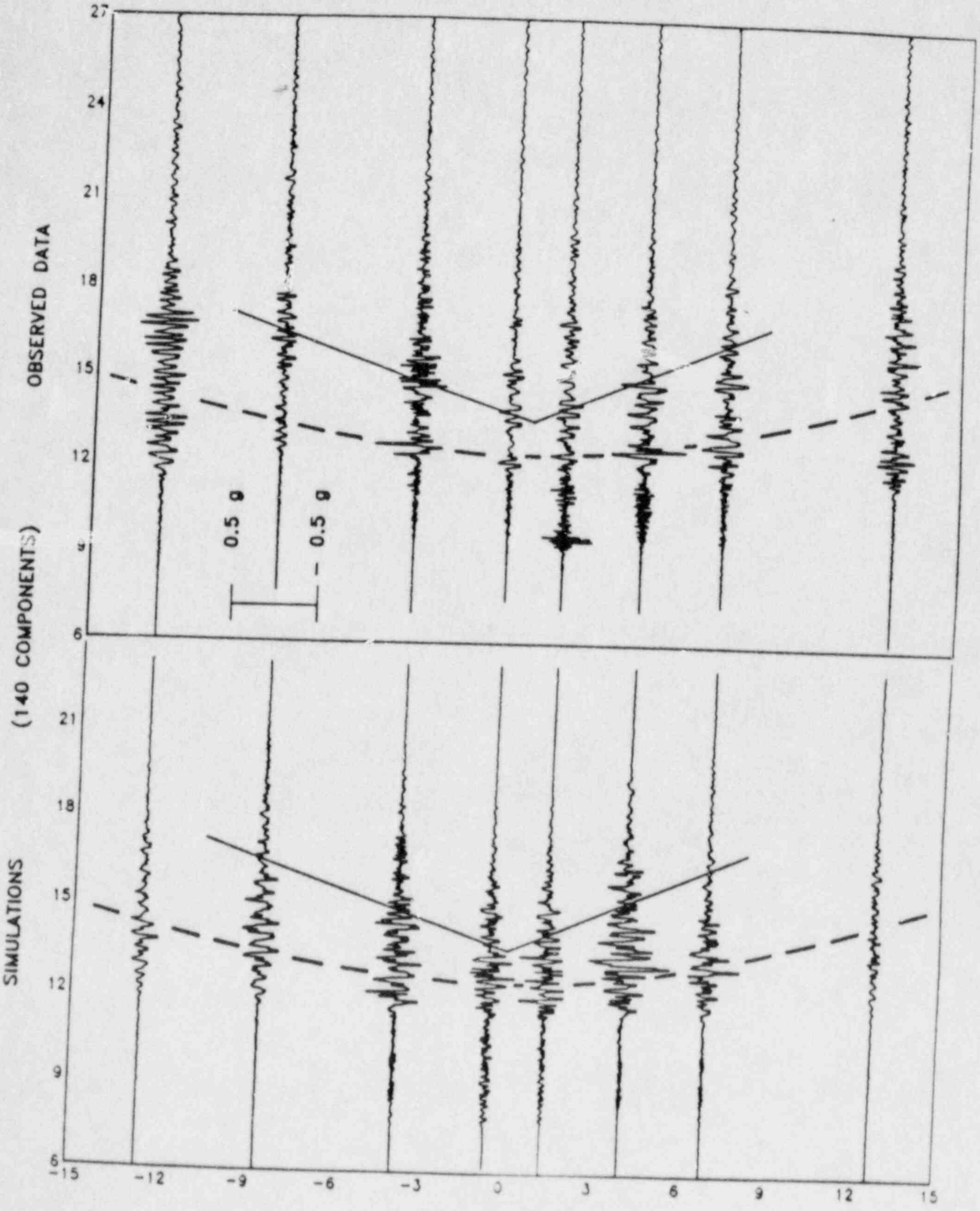

OBSERVED DATA
(140 COMPONENTS)
SIMULATIONS
0.5 g
- 0.5 g
27
24
21
18
15
12
9
6
21
18
15
12
9
6
-15
-12
-9
-6
-3
0
3
6
9
12
15

Fig. 5.7

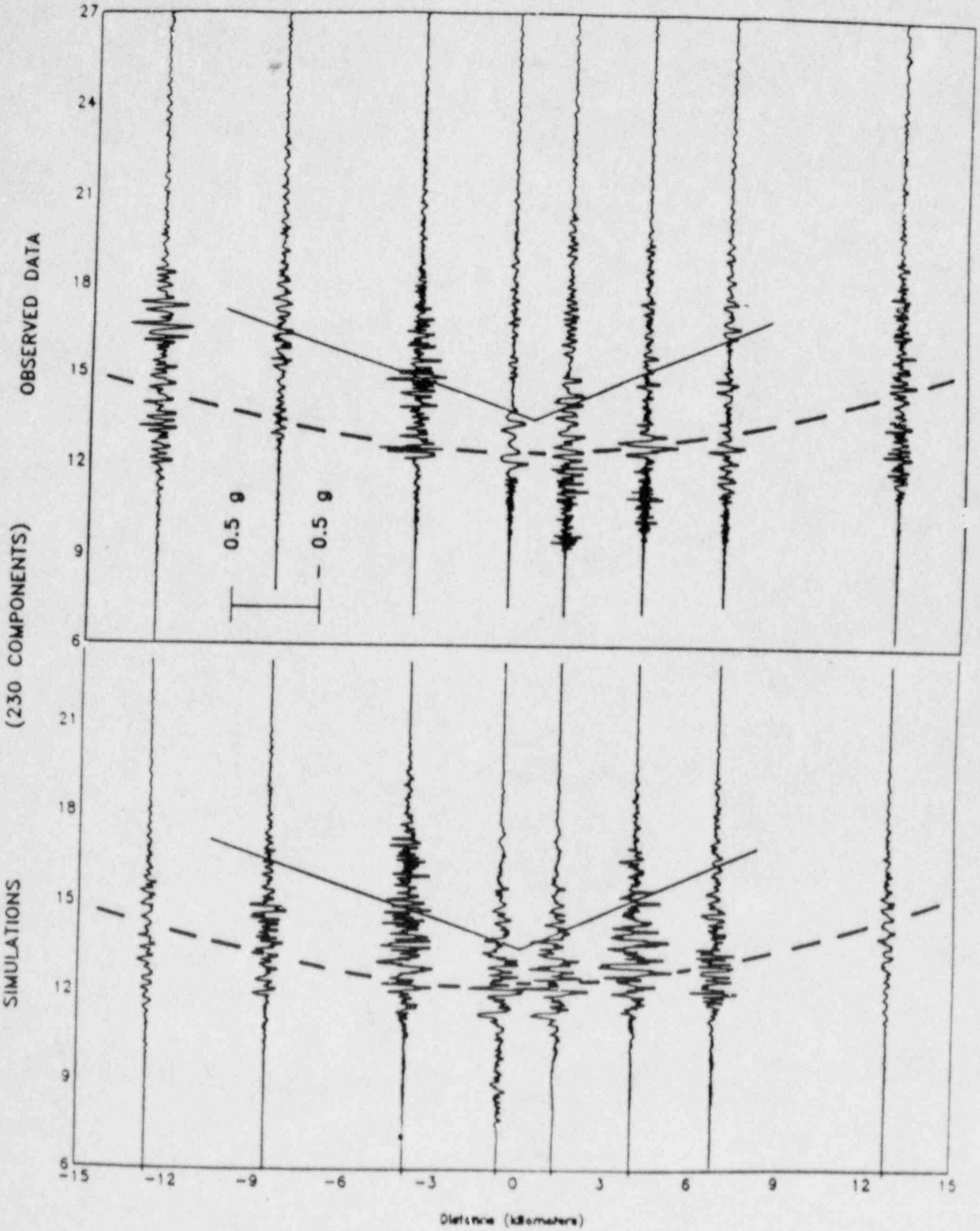
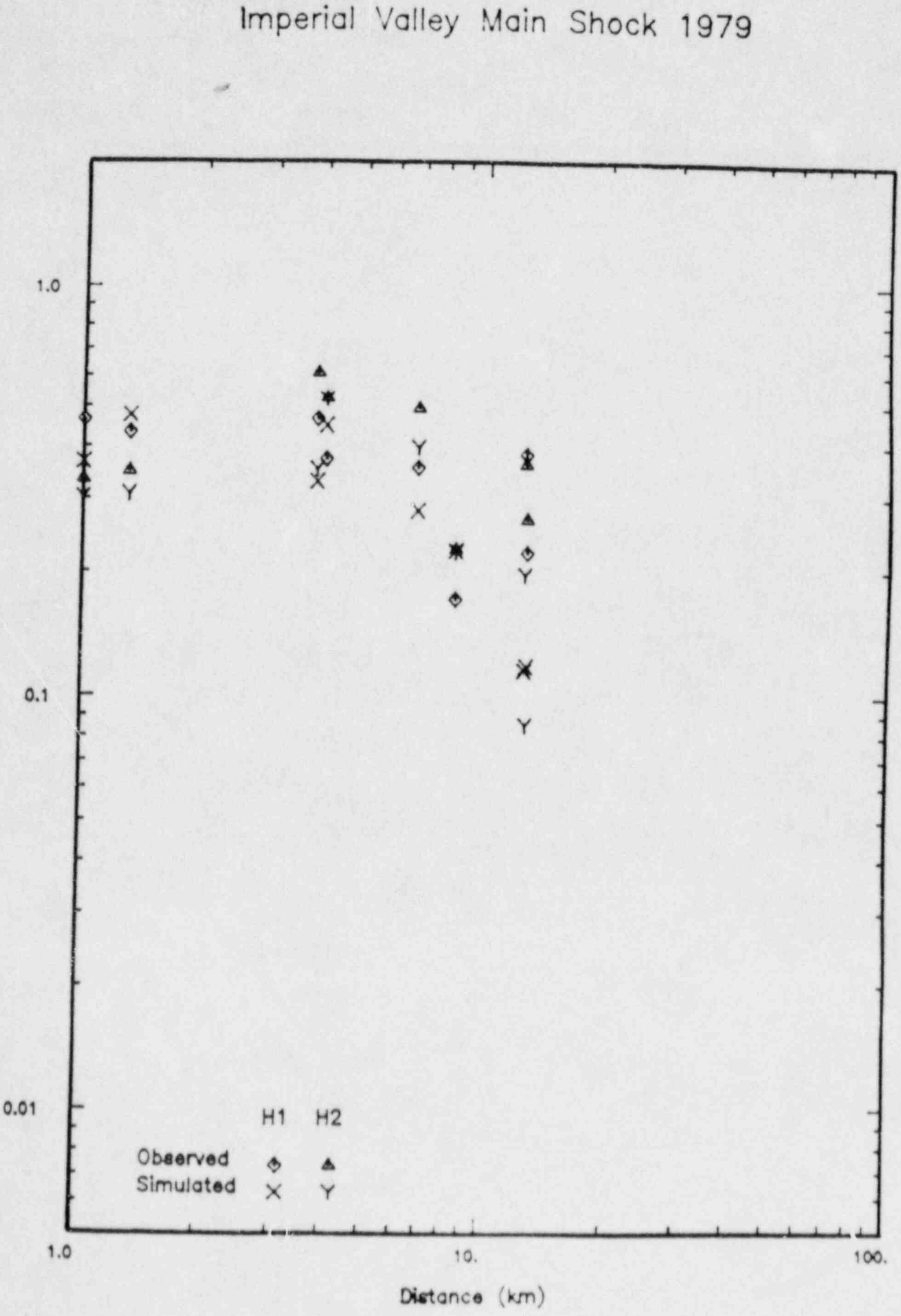
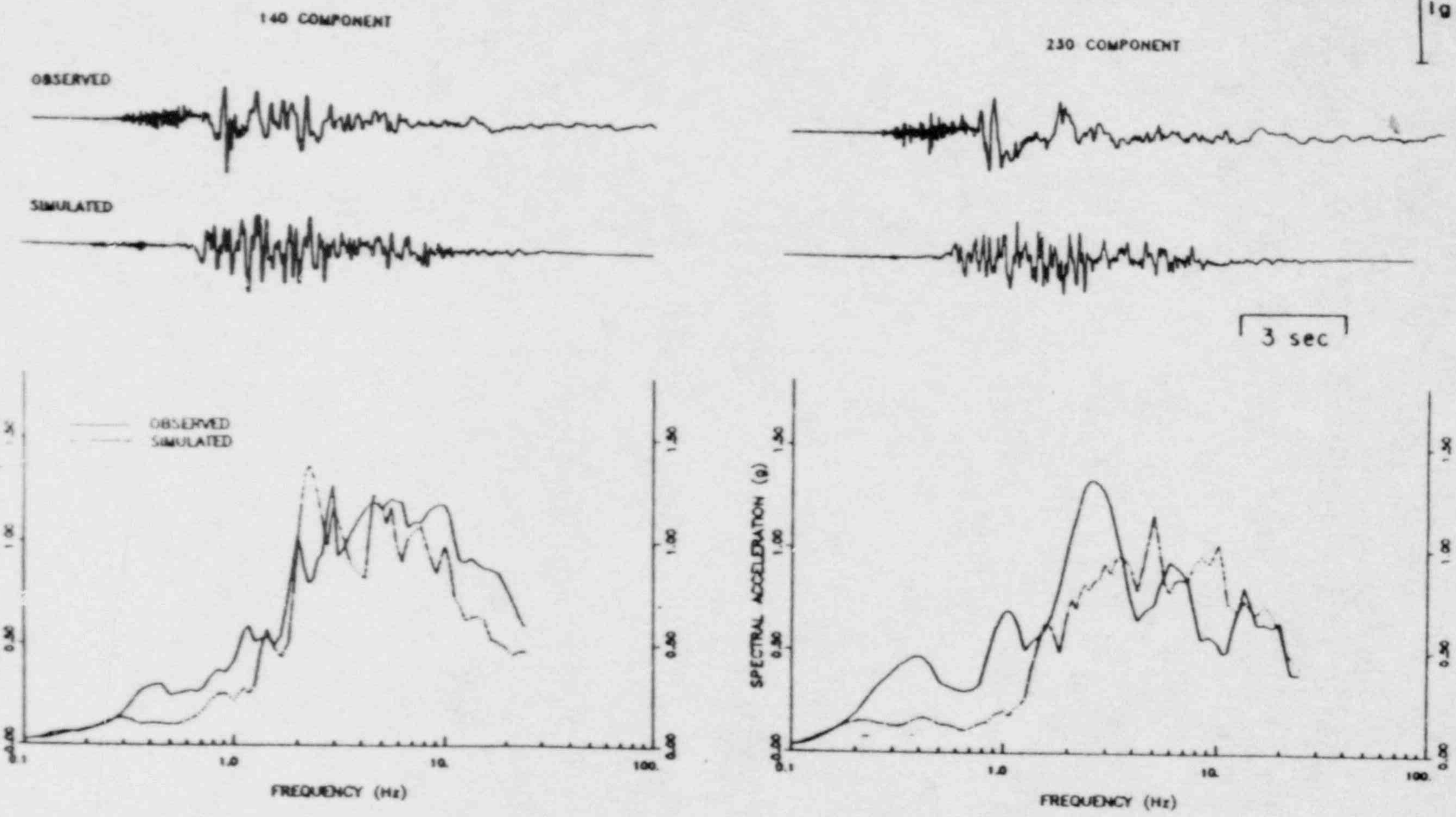

OBSERVED DATA
(230 COMPONENTS)
SIMULATIONS
0.5 g
0.5 g
27
24
21
18
15
12
9
6
21
18
15
12
9
6
-15
-12
-9
-6
-3
0
3
6
9
12
15
Distance (kilometers)

Fig. 5.10

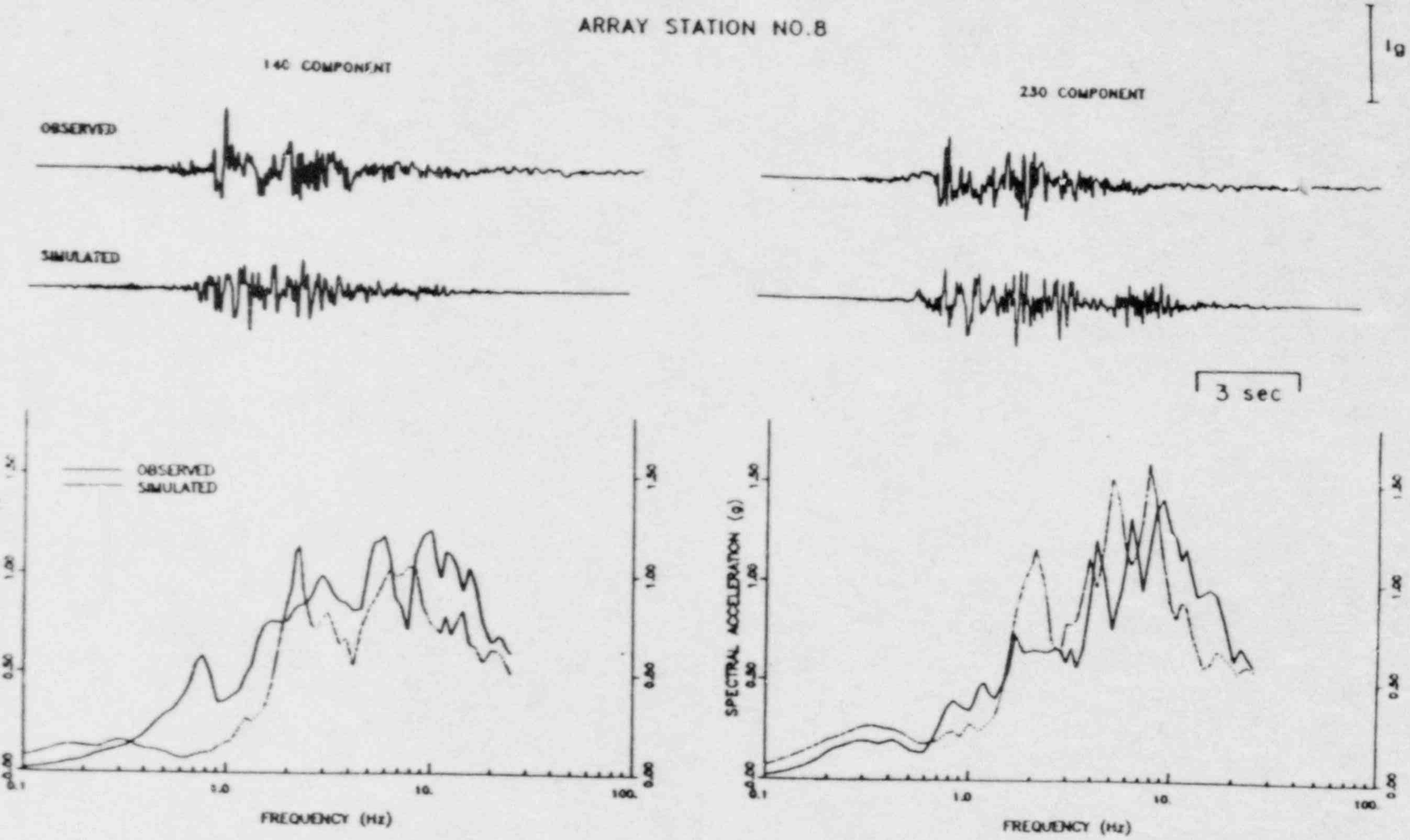


Imperial Valley Main Shock 1979
Peak Acceleration (g)
1.0
0.1
0.01
Distance (km)
1.0
10.
100.
H1
H2
Observed
Simulated

ARRAY STATION NO.5



ARRAY STATION NO.8



Preliminary Simulations for DCPP Site

- Magnitude 7 on Hosgri Fault Zone
- 120 Cases Simulated
  - 40 cases for strike-slip fault
  - 40 cases for oblique fault
  - 40 cases for reverse fault
- 14 Cases Selected for Fragility Analysis
- Sensitivity of Ground Motions on Faulting Type
- Comparison with Empirical Results

FAULT MODELS - MAGNITUDE 7

3 FAULT TYPES
- STRIKE-SLIP (SS)
- OBLIQUE (OB)
- REVERSE (RV)

7 RUPTURE LOCATIONS
- SITE LOCATION RANGING FROM CENTERED TO OFF END OF RUPTURE

3 RUPTURE MODES
- BILATERAL (BIL)
- UNILATERAL NORTHWARD (UNIN)
- UNILATERAL SOUTHWARD (UNIS)

3 ASPERITY MODELS
- CENTRAL ASPERITY
- ASPERITY NEAR END OF RUPTURE
- DIFFERENT RANDOM NUMBERS

2 SOURCE FUNCTIONS
- IMPERIAL VALLEY AFTERSHOCK (IV)
- COALINGA AFTERSHOCK (COAL)

3 COMPONENTS
- VERTICAL (Z)
- PLANT NORTH (N)
- PLANT EAST (E)

TOTAL OF 120 3-COMPONENT TIME HISTORIES, 40 FOR EACH OF THREE FAULT TYPES

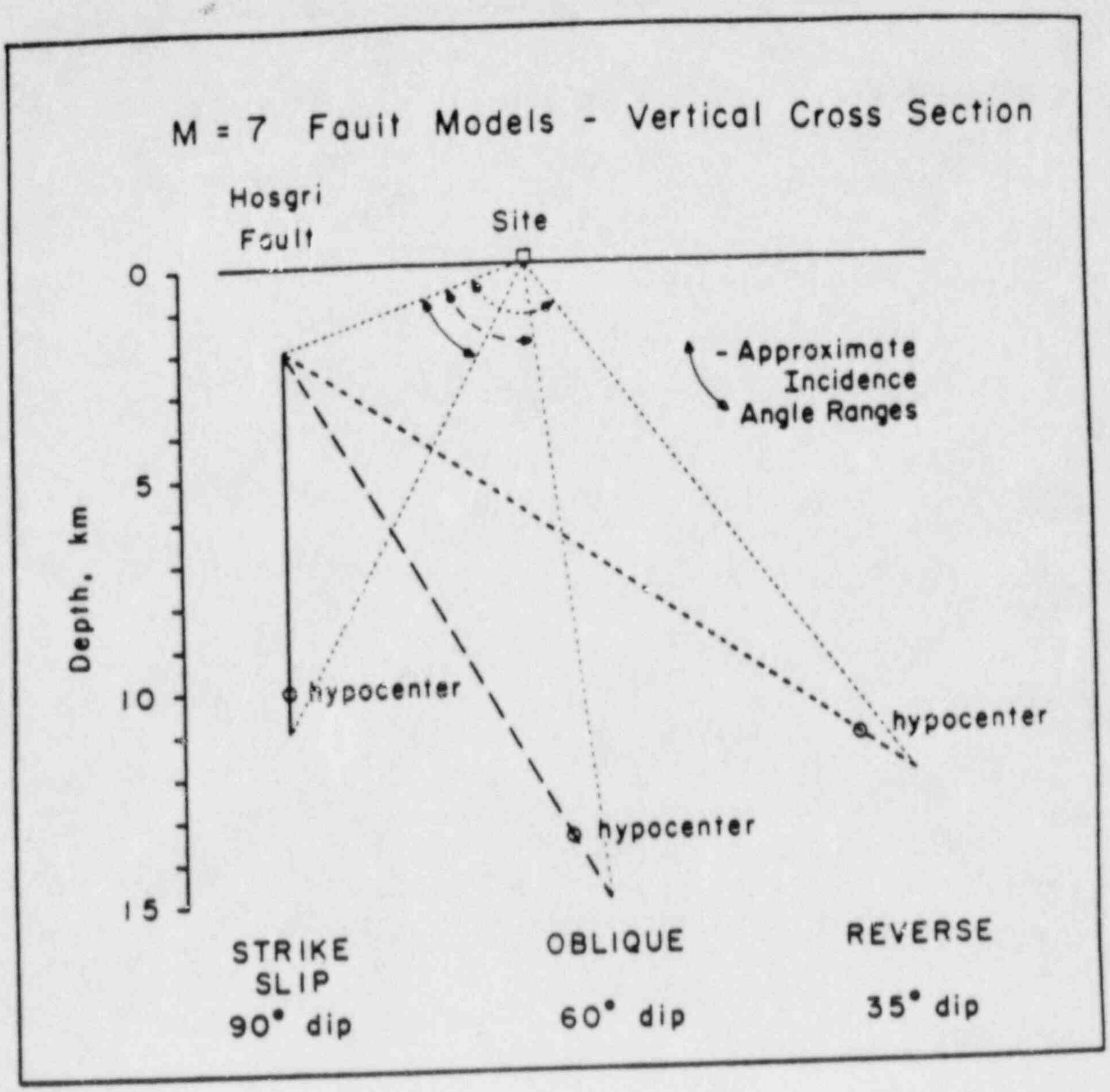
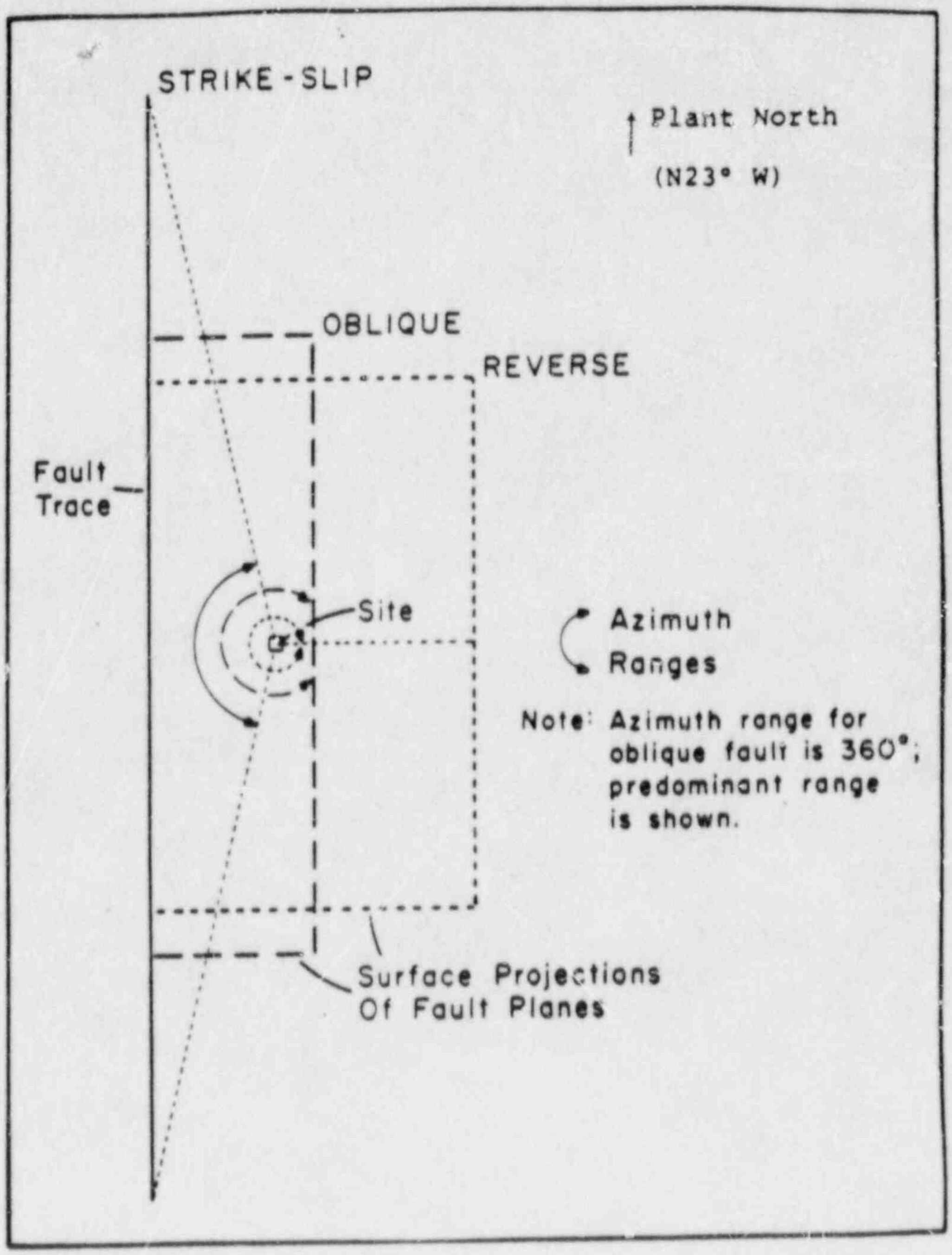

M = 7 Fault Models - Vertical Cross Section
Hosgri Fault
Site
0
5
10
15
Depth, km
- Approximate Incidence Angle Ranges
hypocenter
hypocenter
hypocenter
STRIKE SLIP
90° dip
OBLIQUE
60° dip
REVERSE
35° dip

FIGURE 2.



Note: Azimuth range for oblique fault is 360°; predominant range is shown.

FIGURE 2.2

M = 7 Fault Models Showing Segmentation

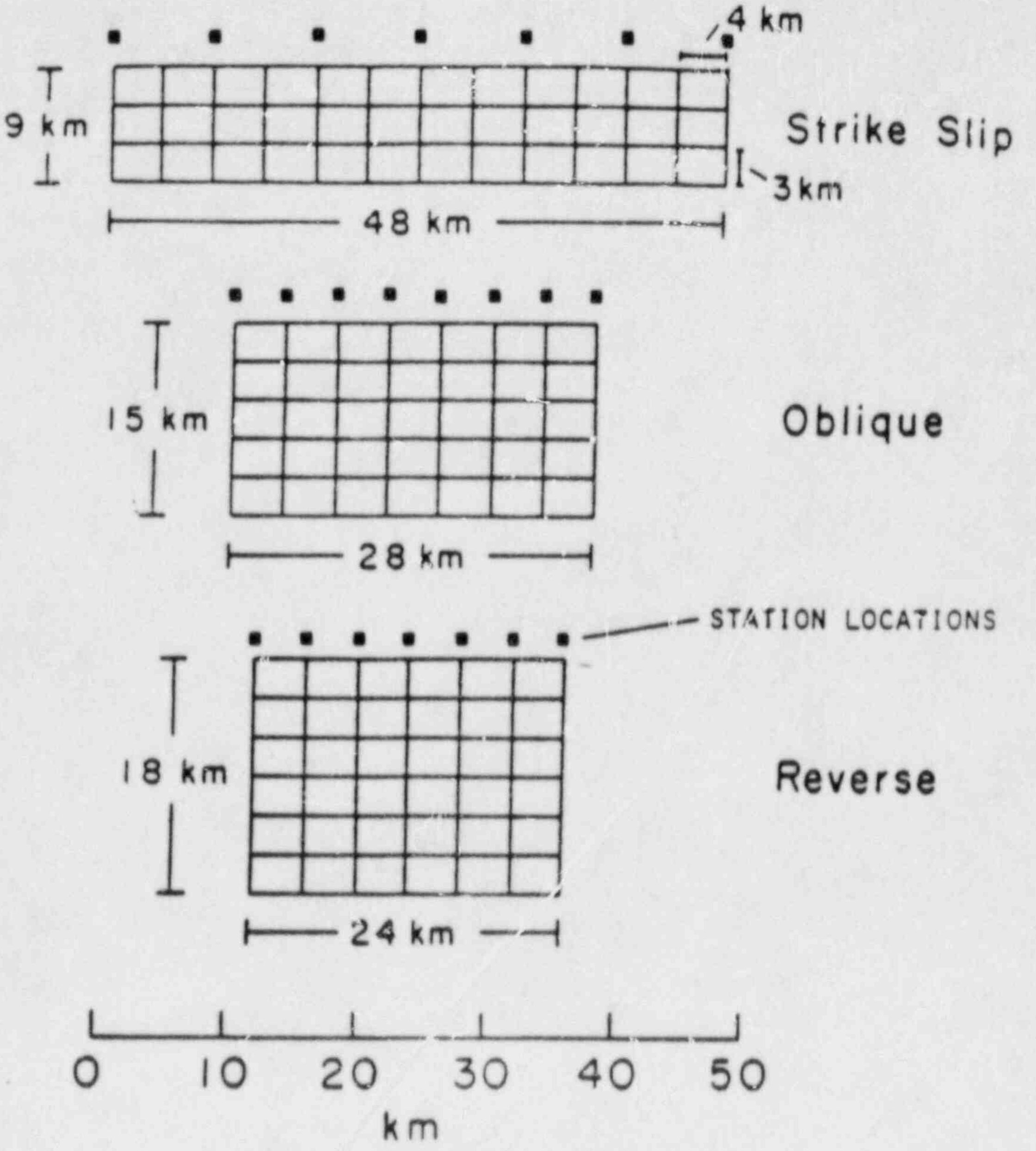


FIGURE 2.3

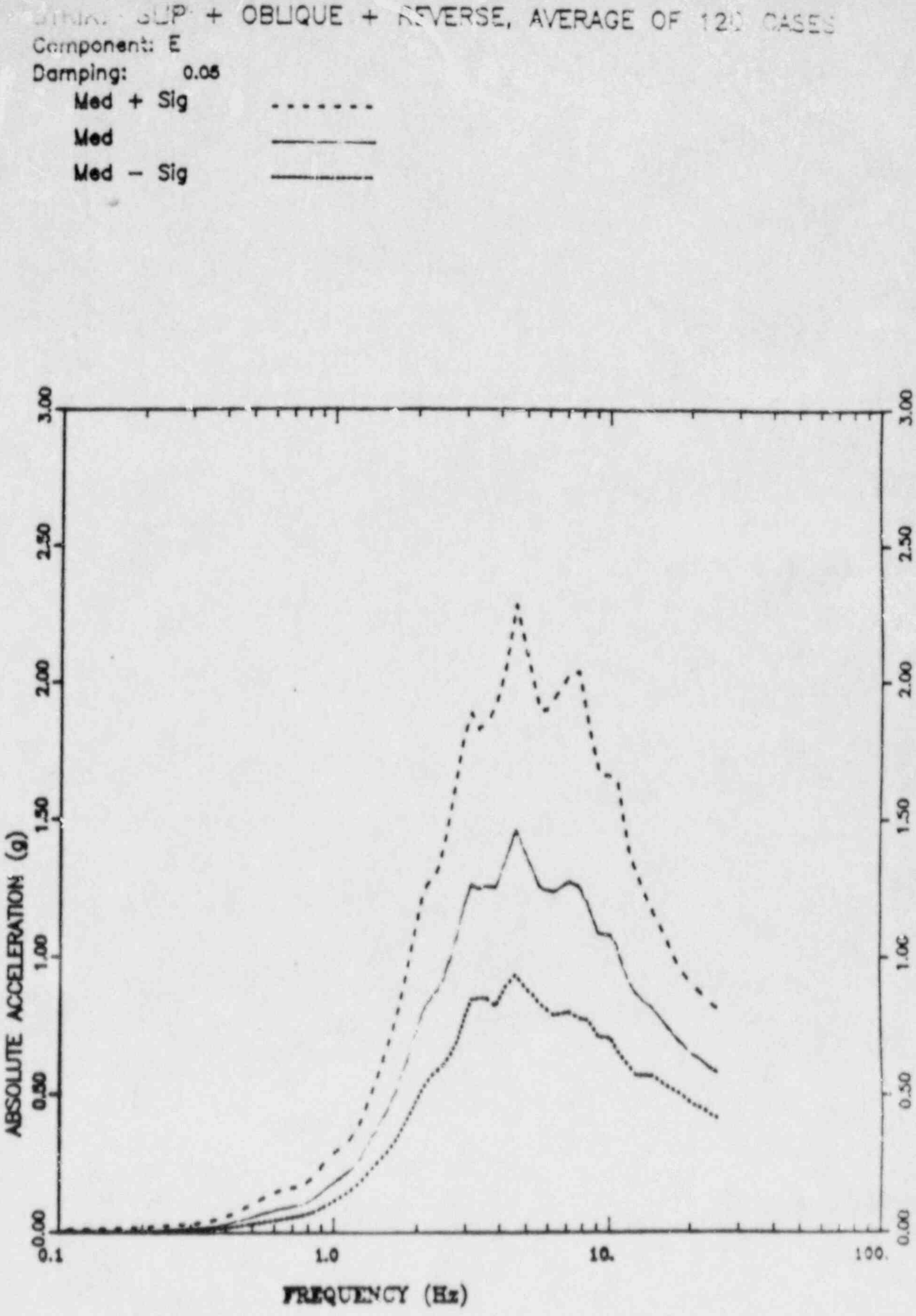

STRIKE SLIP + OBLIQUE + REVERSE, AVERAGE OF 120 CASES
Component: E
Damping: 0.05
Med + Sig
Med
Med – Sig
ABSOLUTE ACCELERATION (g)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
0.1
1.0
10.
100.
FREQUENCY (Hz)

FIGURE 2.6

TABLE 2.2

MEDIAN PEAK ACCELERATION PARAMETERS OF 120 SIMULATED TIME HISTORIES

	PARAMETER	COMBINED FAULTS (120)	STRIKE-SLIP (40)	OBLIQUE (40)	REVERSE (40)
1a.	Z	0.351	0.286	0.361	0.419
2.	N	0.552	0.453	0.582	0.636
3.	E	0.571	0.495	0.478	0.562
4.	H	0.532	0.474	0.530	0.599
5.	Z/H	0.66	0.60	0.68	0.70
6.	H(TYPE)	-	0.89	1.00	1.13

TABLE 2.3

MEDIAN SPECTRAL ACCELERATION PARAMETERS OF 120 SIMULATED TIME HISTORIES

	PARAMETER	COMBINED FAULTS (120)	STRIKE-SLIP (40)	OBLIQUE (40)	REVERSE (40)
1b.	Z	0.694	0.602	0.707	0.790
2.	N	1.400	1.142	1.483	1.622
3.	E	1.284	1.252	1.213	1.397
4.	H	1.341	1.202	1.348	1.509
5.	Z/H	0.52	0.50	0.52	0.52
6.	H(TYPE)	-	0.90	1.00	1.13

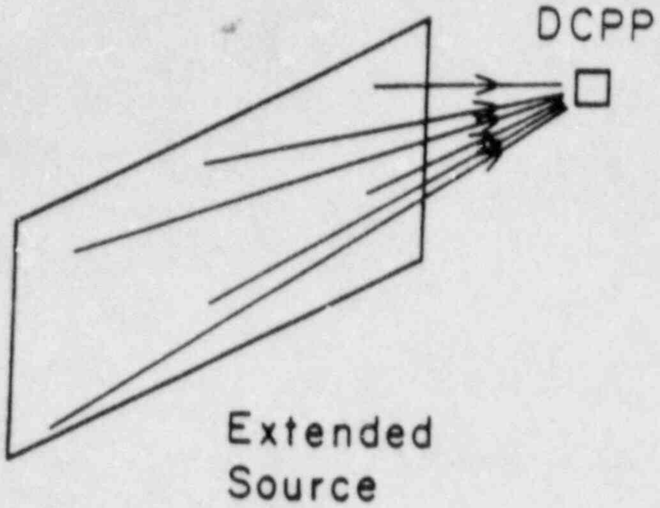
NOTES:

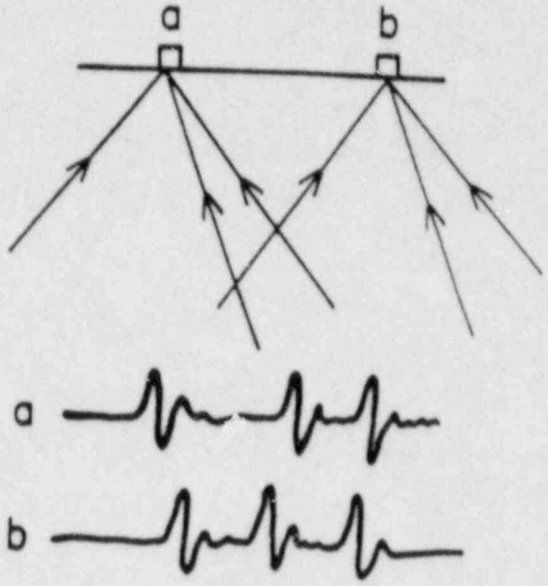
1a. Vertical median PGA
1b. Vertical median spectral acceleration (g), averaged from 3 to 8.5 hz.
2. Plant north
3. Plant east
4. Average horizontal (N+E)/2
5. Vertical horizontal
6. Ratio of median horizontal spectral acceleration for individual fault types to that of for combined faults.

Assessment of Spatial Incoherence of Ground Motions

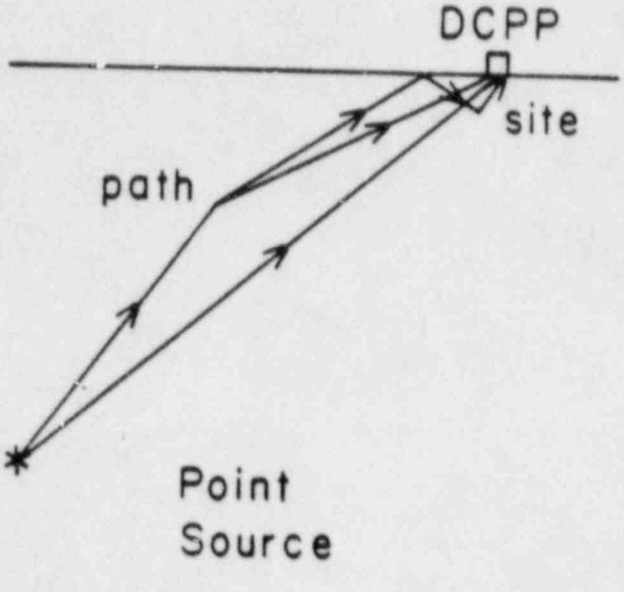
- Development and Calibration of Spatial Incoherence Model
  - Effects of extended fault rupture
  - Validation by El Centro Differential Array data of 1979 Imperial Valley main shock and aftershock
- Preliminary Spatial Incoherence Functions for Soil/Structure Interaction Analysis
- New Free-field Ground Motion Array at DCPP Site

SOURCE AND WAVE PASSAGE





PATH AND SITE



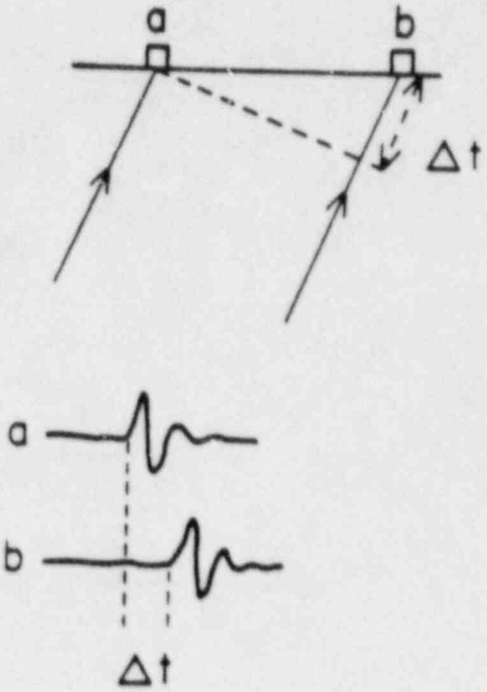


FIGURE 4.13

Spatial Incoherence Model

Incoherence Effect	Contribution from Extended Source		Contribution from Point Source	
Wave Passage	Yes (1)	Cs (f)	No (2)	
Source	Yes		No (3)	
Path & Site	No		Yes	Cp (f)
Combined	C (f) =	Cs (f)	X	Cp (f)

---

1 Included by taking zero-lag correlation
2 Excluded by taking peak correlation
3 Assuming broadband point spectrum

Table 4.3

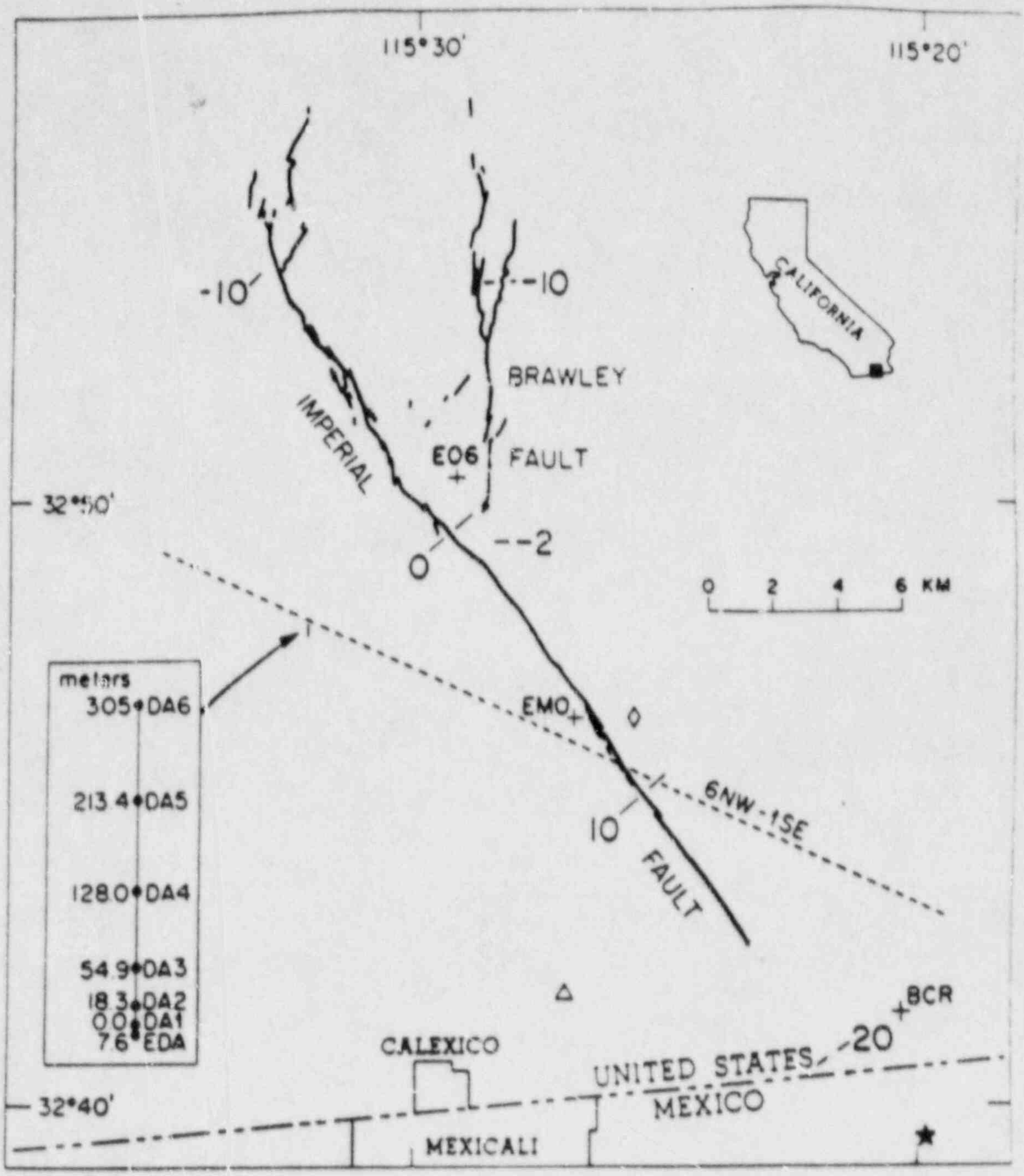
VALIDATION AND ESTIMATION OF COHERENCE MODEL

INCOHERENCE EFFECT		I.V. VALIDATION	DCPP ESTIMATION
Wave Passage	$C_s(F)$	——	DCPP Large Eq. Simulations
Source		I. V. Mainshock Simulations	
Path & Site	$C_p(F)$	I.V. Aftershock Recordings	DCPP explosion Recordings
Combined Model	$C(F)$	$C_s(F) \times C_p(F)$	$C_s(F) \times C_p(F)$
Combined Effect		I.V. Mainshock Recordings	——

DCLTSP Spatial Incoherence Model

C(f,r) = A(f,r)*exp{i*P(f,r)}

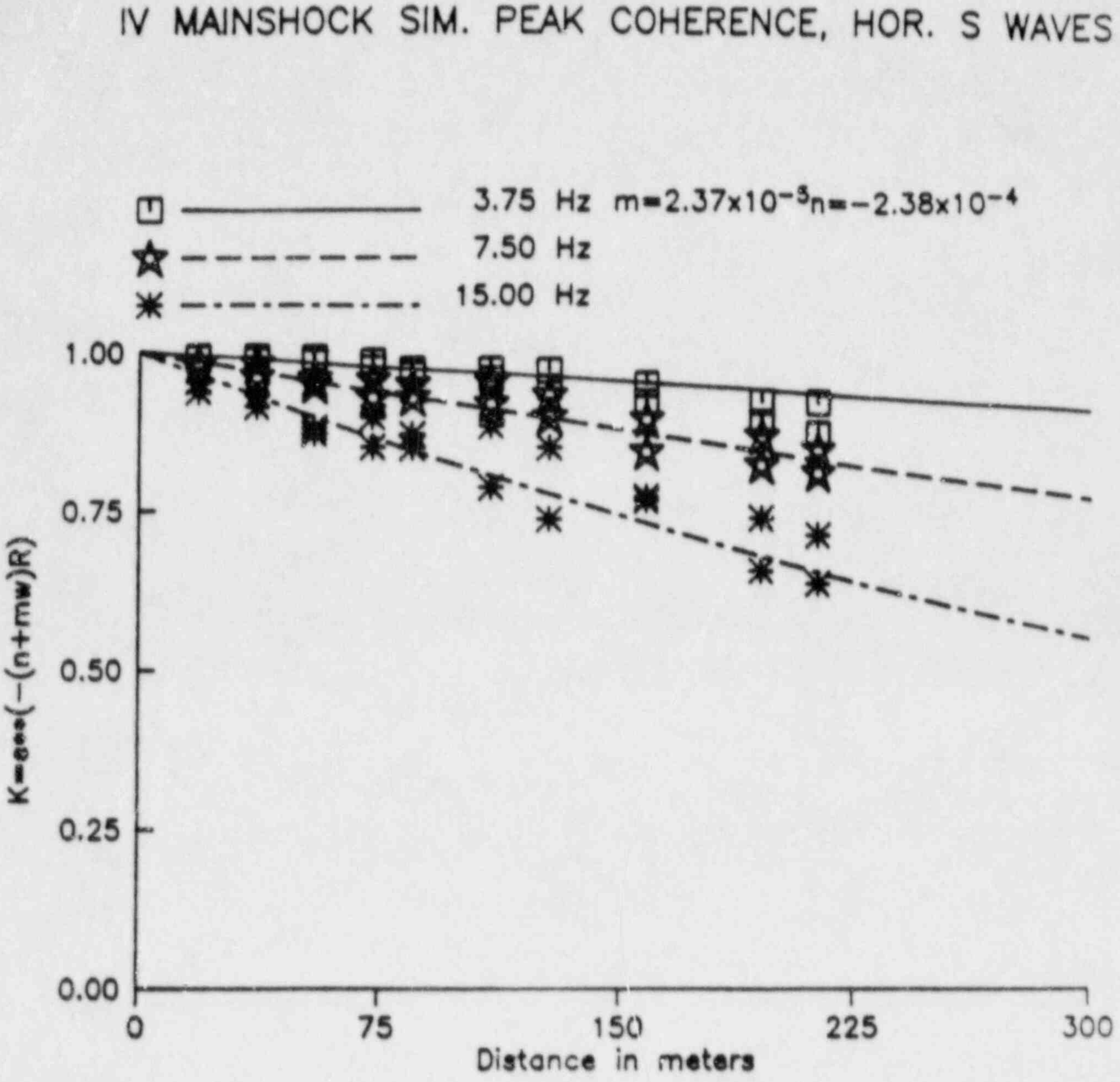
Where C(f,r) is the complex coherence function
A(f,r) = exp{-(N+2*pi*M*f)*r}
P(f,r) = 2*pi*B*f + D*r*sin(2*pi*E*f)*sin(2*pi*G*f)
f = frequency in Hz
r = separation in meters
M, N, B, D, E, G = constants determined by fitting observed data



Location of differential array near the Imperial fault. Heavy lines show surface rupture associated with the 1979 event. The inset shows the layout of the array elements and their spacing from DA1. E06, EMO, and BCR are analog SMA-1 accelerometers which recorded the main shock. The star is the main shock epicenter of Archuleta (1982a) and the triangle and diamond are the epicenters of the 288 2319 aftershock used by Smith *et al.* (1982) and ourselves, respectively. The *stippled lines* are the surface outcrops of the planes we used to represent the Imperial and Brawley faults, and the numbers along them are a horizontal coordinate system. The 6NW-1SE refraction line is also shown.

Source: Spudich and Cranswick, 1984.

FIGURE 4.15



IV MAINSHOCK SIM. PEAK COHERENCE, HOR. S WAVES

FIGURE 4.16

IV AFTERSHOCK PEAK COHERENCE, HORIZ. S WAVES

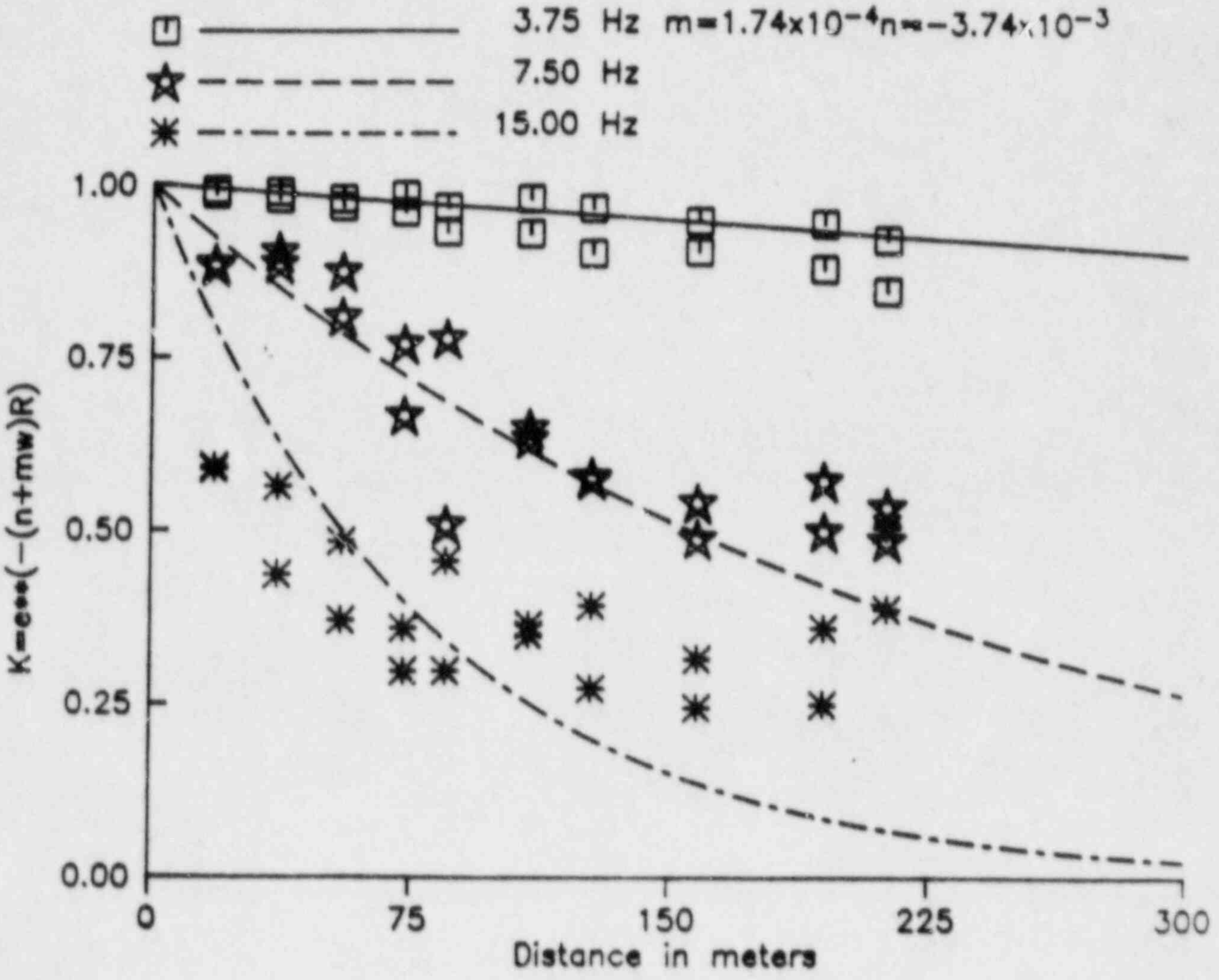


FIGURE 4.17

COMBINED I.V. PEAK COHERENCE MODEL, HORIZ. S WAVES

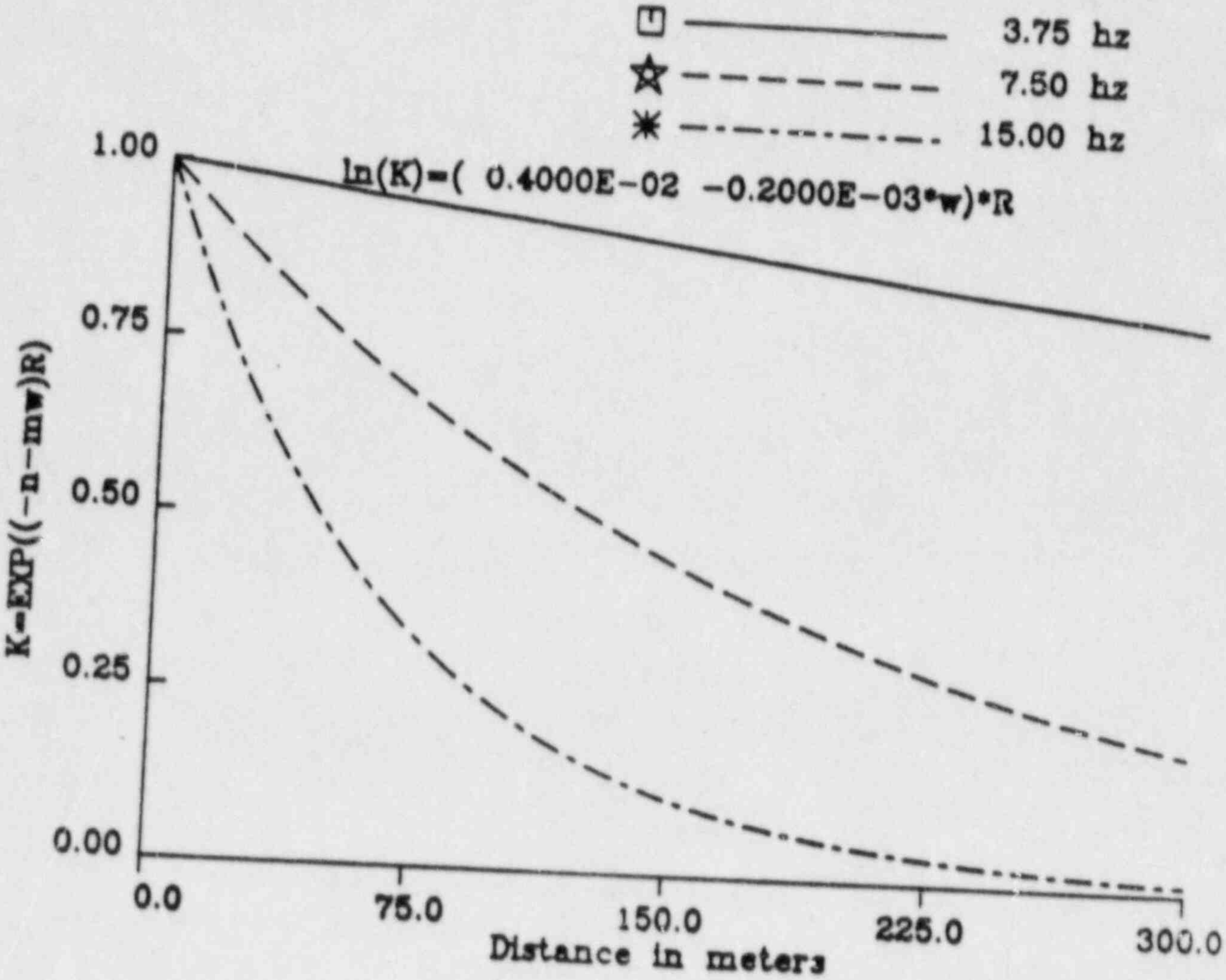


FIGURE 4.18

IV Mainshock Peak Coherence, Horiz. S Waves

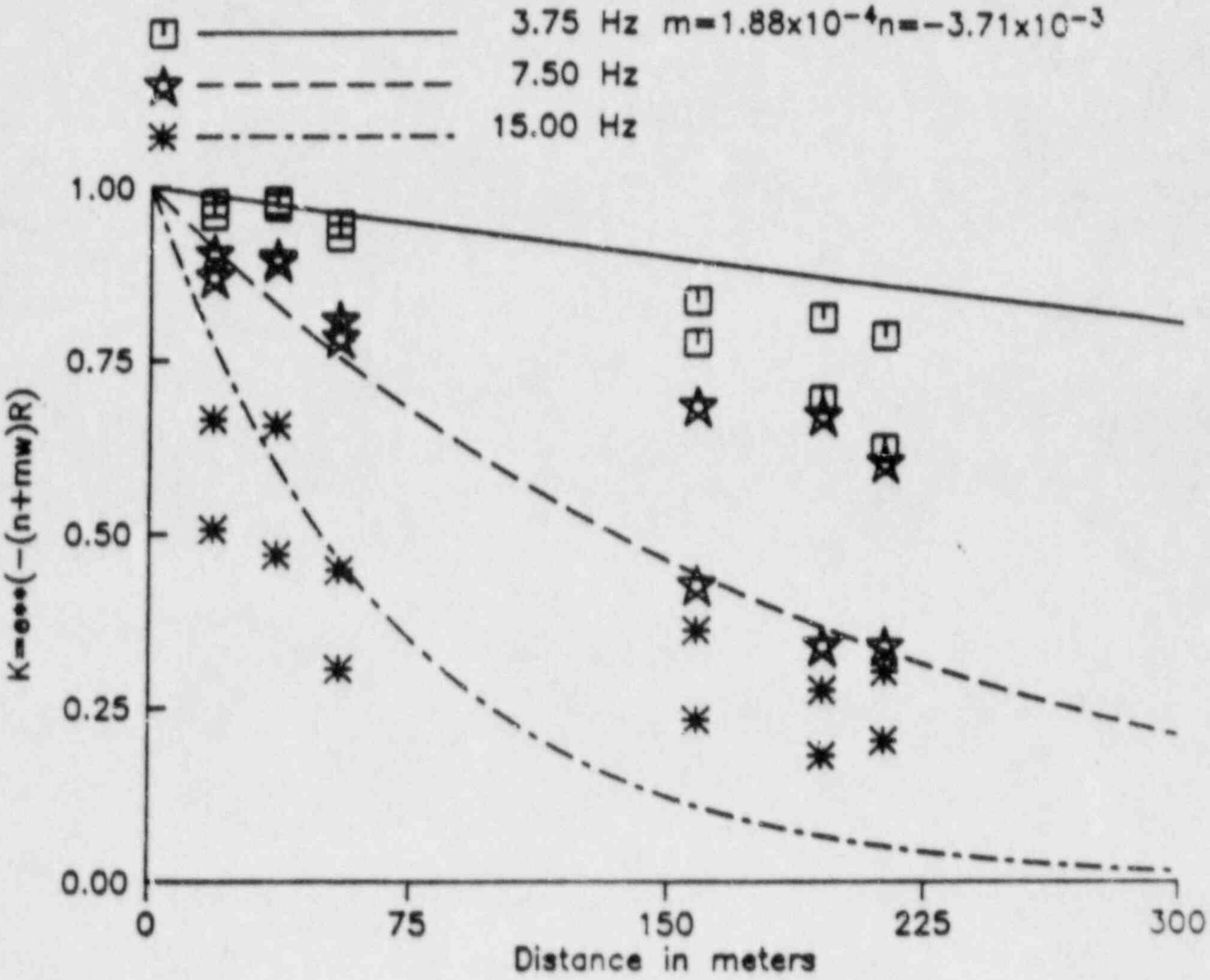


FIGURE 4.19

DCPP location map; scale 1 cm=5 km

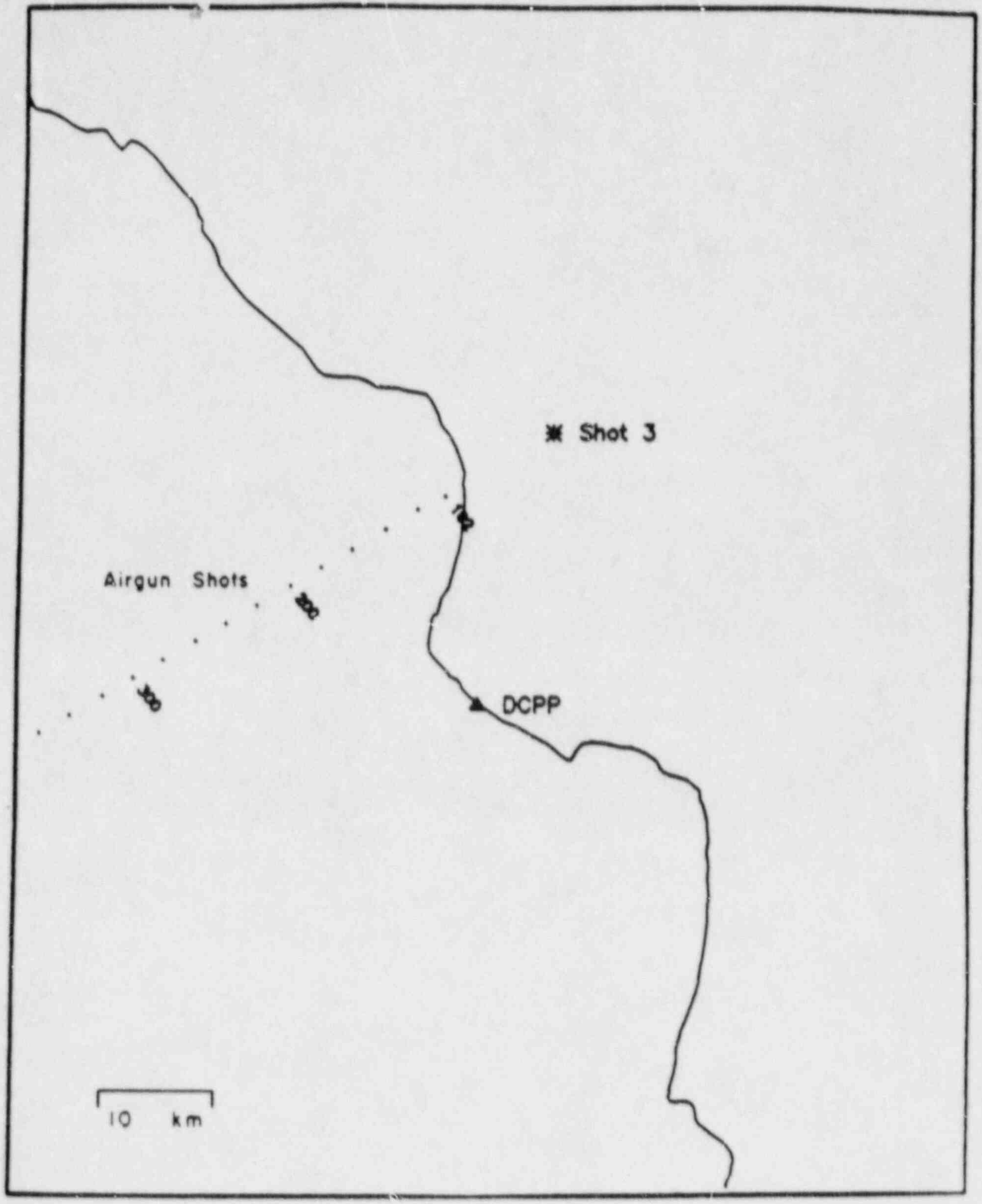
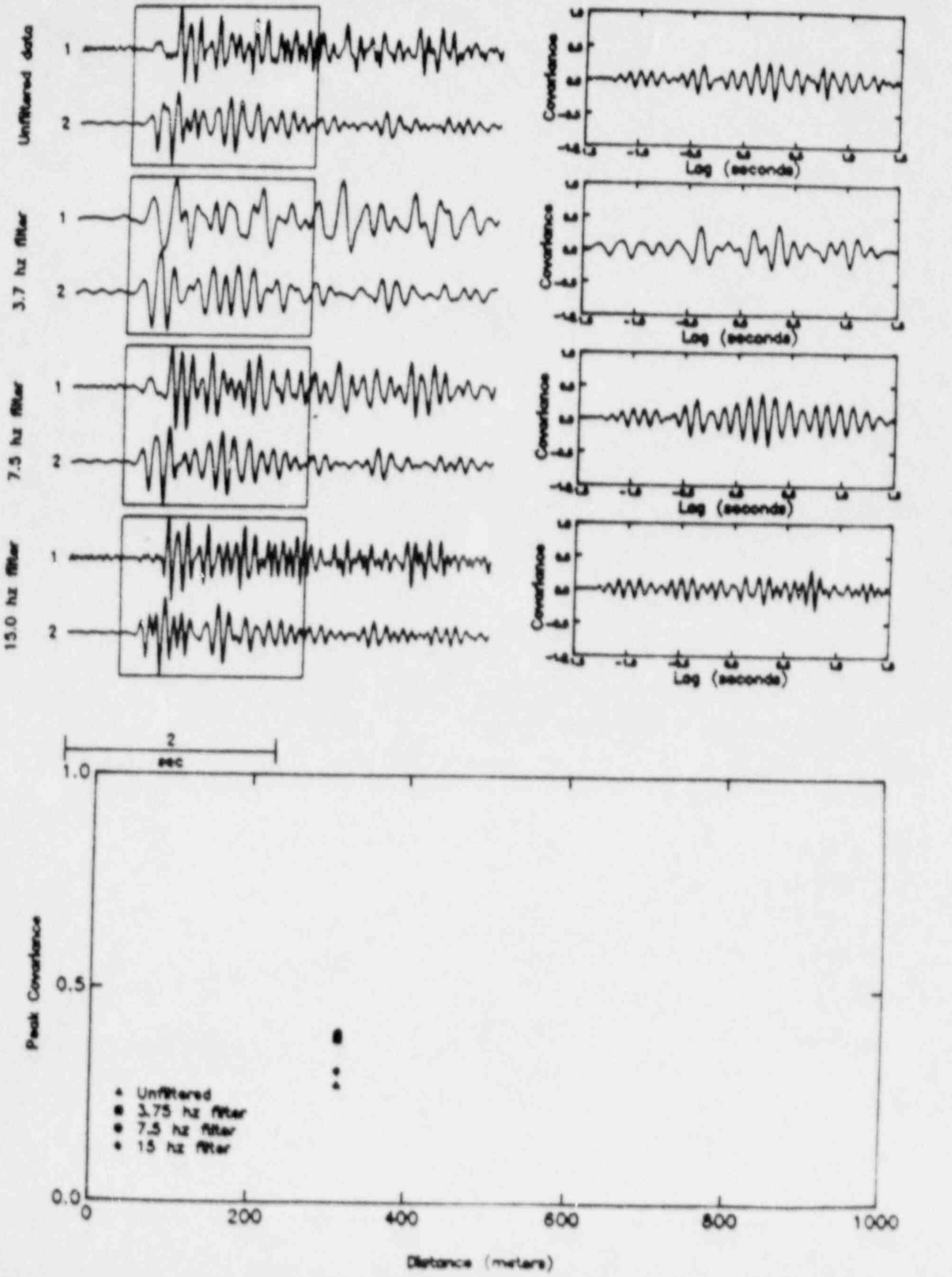


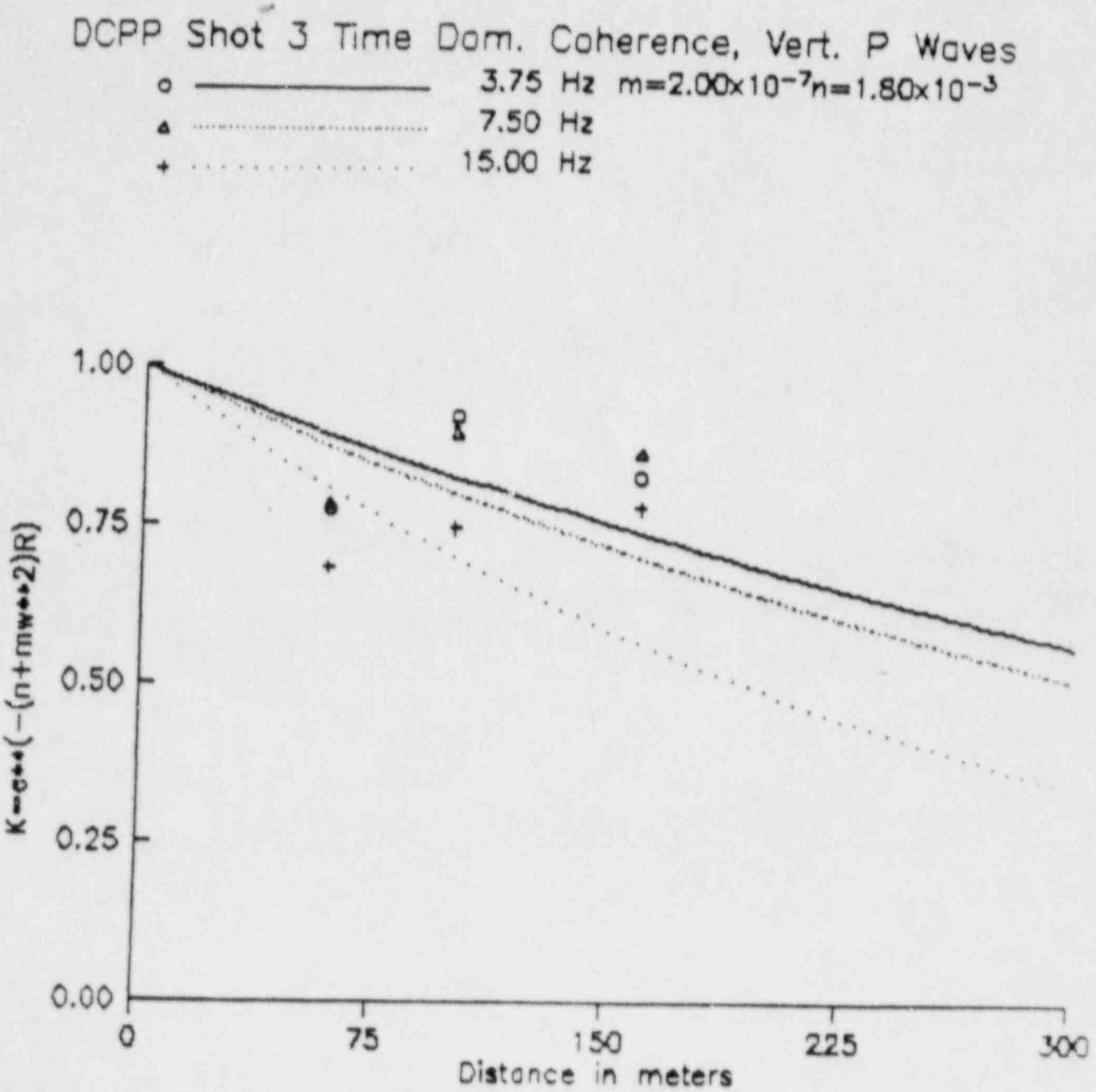
FIGURE 6


Substation
1000
1000
X 914
800
400
200
200
200
200
128
BM
BM 190
Patton
60
23
39
14
84

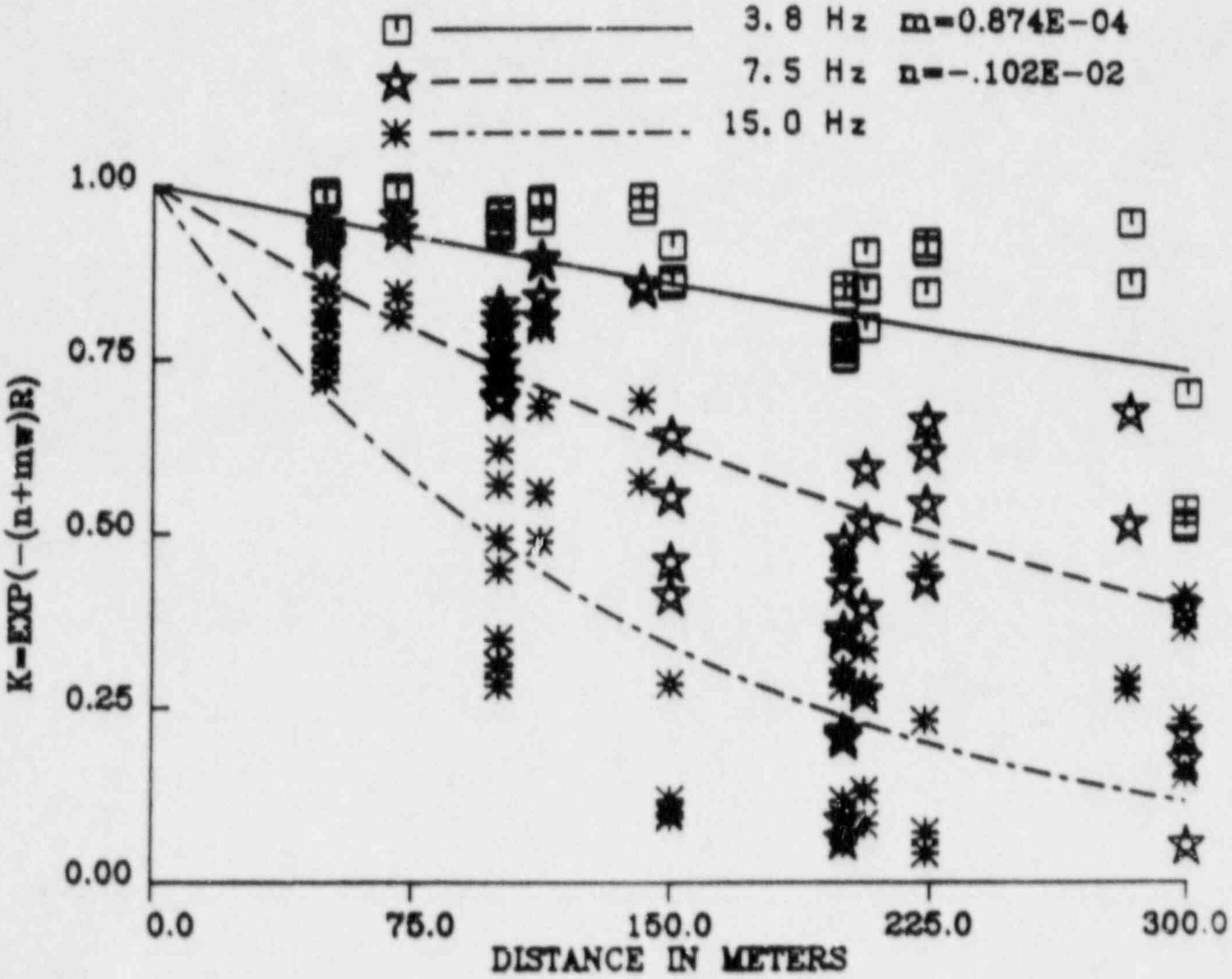

114
115
116
117
118
119
120
B-3
113
101
102
112
111
103
104
105
106
107
108
B-1
B-4
110

Peak covariance vs. Distance
Diablo Canyon Power Plant Site
SHOT3 111, 112 INSTRUMENT VERT
1.75 SEC WINDOW FILTER ORDER 3 PASSBAND=0.5 OF MID FREQUENCY

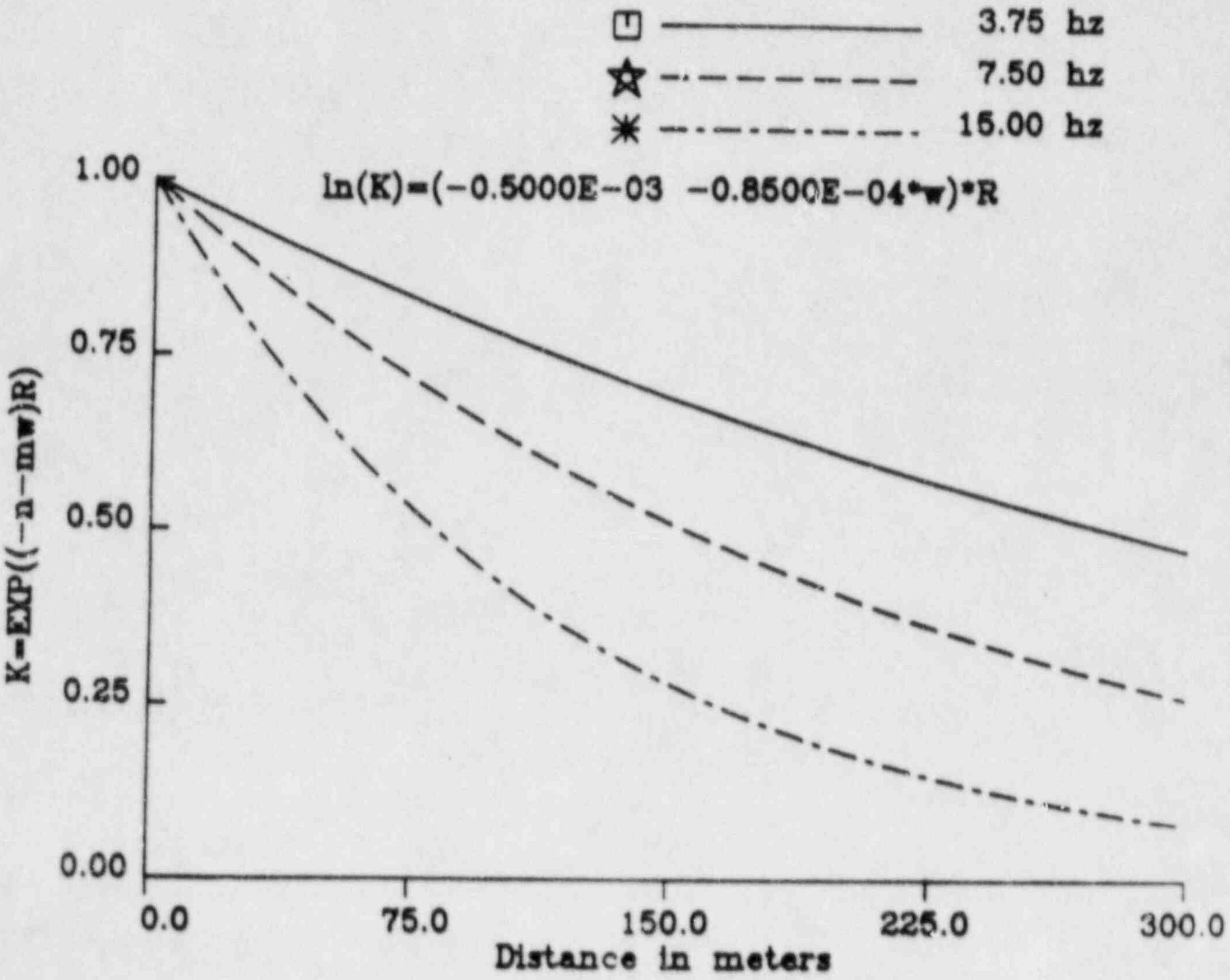


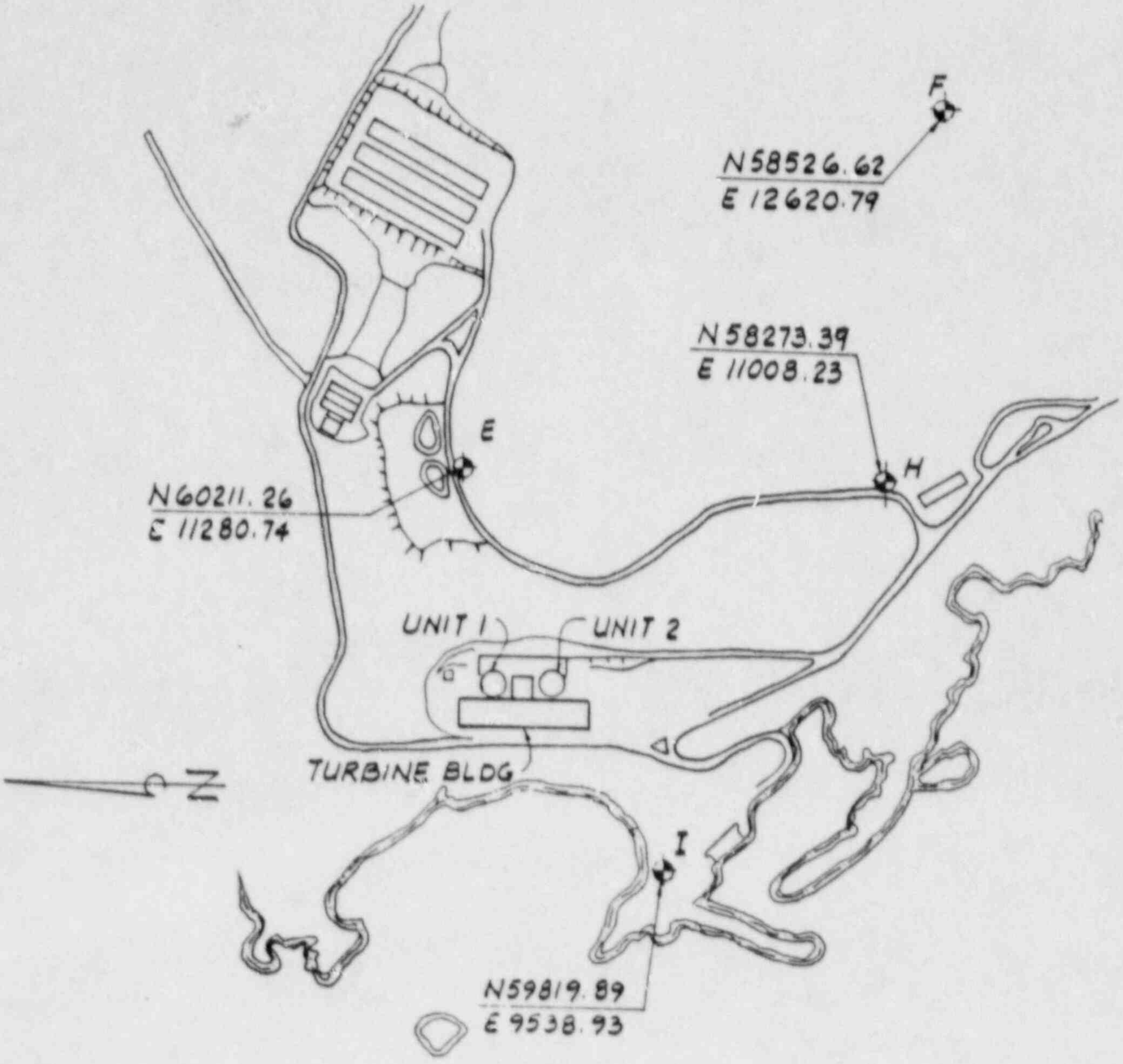

DCPP Shot 3 Time Dom. Coherence, Vert. P Waves
○ 3.75 Hz m=2.00x10⁻⁷n=1.80x10⁻³
▲ 7.50 Hz
+ 15.00 Hz
1.00
0.75
0.50
0.25
0.00
K=e**(-(n+mw**2)R)
0
75
150
225
300
Distance in meters

DCPP SIMULATED ZERO-LAG COHERENCE, HORIZ. S WAVES

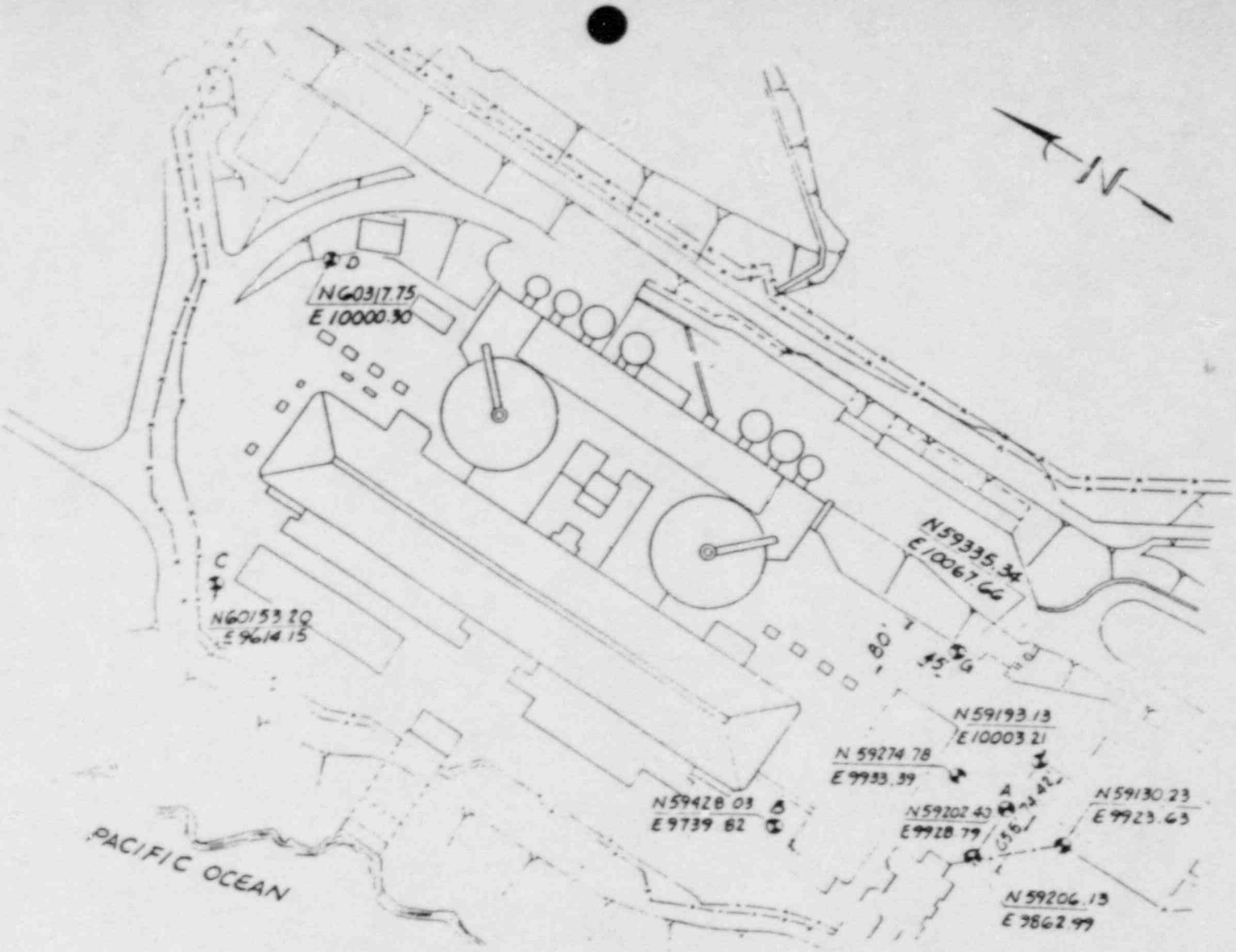


DCPP COHERENCE MODEL, HORIZ. S. WAVES





LOCATION OF INSTRUMENT SITES E, F, H & I



LOCATION OF INSTRUMENT SITES A, B, C, D & G

Ground Motion Data for Fragility Analysis

- 12 Sets of Empirical Time Histories
  - Rock or rock-like sites
  - $R \leq 10$ km
  - $M \geq 6.5$
  - Strike-slip, oblique, and reverse faulting mechanisms

- 14 Sets of Simulated Time Histories
  - DCPP site
  - Hosgri fault zone
  - $M = 7$
  - Strike-slip, oblique, and reverse faulting
  - Unilateral and bilateral rupture over different segments of Hosgri

EMPIRICAL TIME HISTORIES FOR FRAGILITY ANALYSIS

RECORD	EARTHQUAKE	MAGNITUDE	DISTANCE(km)	FAULT TYPE
TABAS	1978 TABAS	7.4	3	REVERSE
DAYHOOK(MOD.)	1978 TABAS	7.4	17	REVERSE
SITE 1	1985 NAHANNI	6.9	6	REVERSE
KARAKYR POINT	1976 GAZLI	6.8	3	REVERSE
PACOIMA DAM	1971 SAN FERNANDO	6.6	3	REVERSE
LAKE HUGHES #12 (MOD.)	1971 SAN FERNANDO	6.6	20	REVERSE
CASTAIC (MOD.)	1971 SAN FERNANDO	6.6	25	REVERSE
DIFFERENTIAL ARRAY (MOD.)	1979 IMPERIAL VALLEY	6.5	5	STRIKE-SLIP
EL CENTRO #4 (MOD.)	1979 IMPERIAL VALLEY	6.5	4	STRIKE-SLIP
PLEASANT VALLEY PUMP STATION (SWITCHYARD, MOD.)	1983 COALINGA	6.5	10	REVERSE
COYOTE LAKE DAM (MOD.)	1984 MORGAN HILL	6.2	0.1	STRIKE-SLIP
TEMBLOR (MOD.)	1966 PARKFIELD	6.1	10	STRIKE-SLIP

SIMULATED TIME HISTORIES For Fragility Analysis

No.	Mech	Rup Md	Asp #	Ran #	Source	Loc	Comp
1	ss	bil	2	8	CL	2	N E D
2	ss	bil	2	8	IV	3	N E D
3	ss	unin	2	8	IV	9	N E D
4	ss	unis	5	6	CL	6	N E D
5	ss	unis	5	6	IV	6	N E D
6	ob	bil	2	8	CL	4	N E D
7	ob	bil	2	8	CL	5	N E D
8	ob	bil	2	8	IV	7	N E D
9	ob	unin	2	8	CL	5	N E D
10	ob	unin	2	8	IV	6	N E D
11	ob	unis	5	6	CL	4	N E D
12	ob	unis	5	6	IV	1	N E D
13	rv	bil	2	8	CL	1	N E D
14	rv	unin	2	8	CL	2	N E D

SUMMARY OF SPECTRAL ACCELERATION VALUES OF THE TIME HISTORIES FOR FRAGILITY ANALYSIS, AVERAGED OVER THE FREQUENCY RANGE FROM 3 TO 8.5 Hz

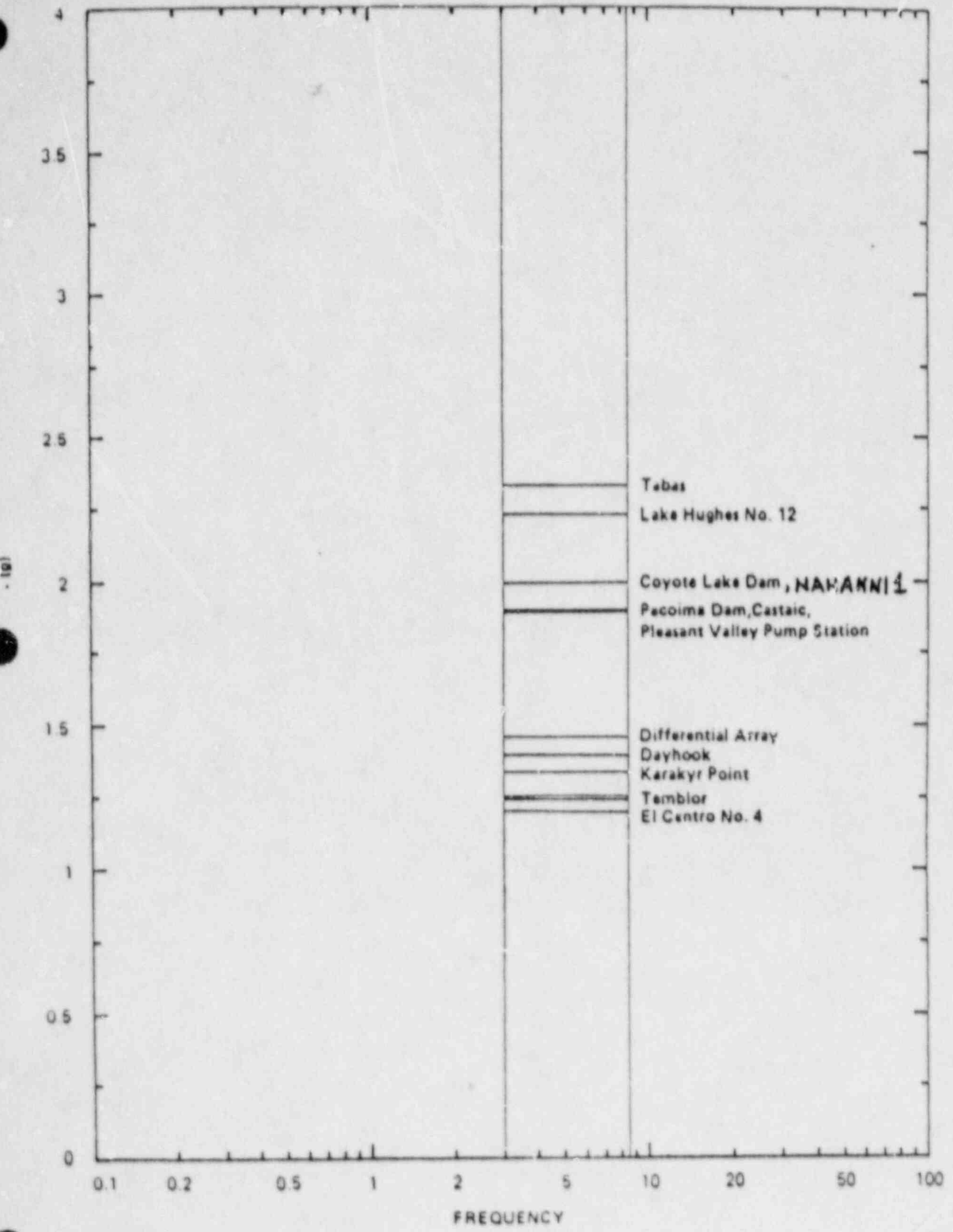


FIGURE 2

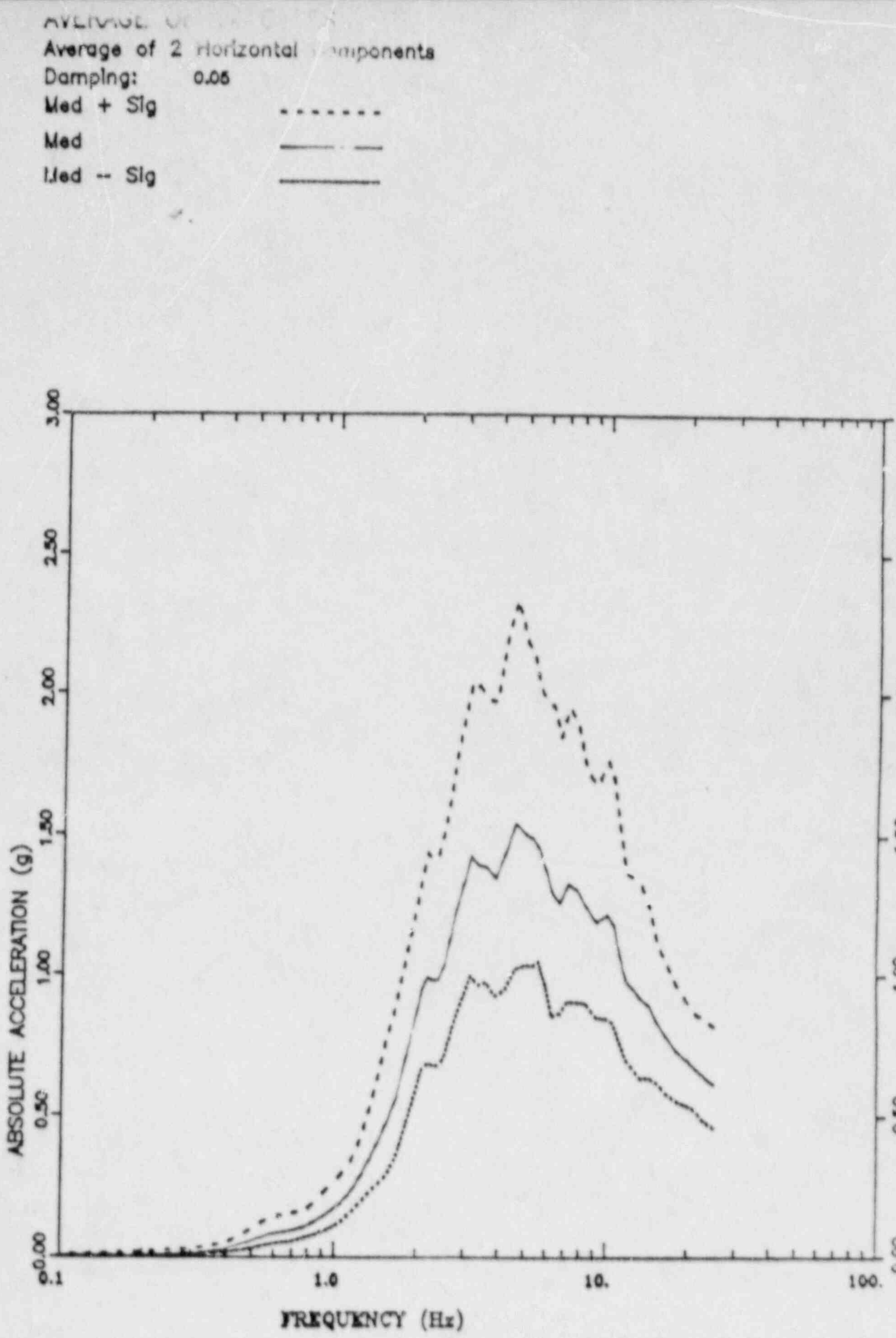

AVERAGE OF
Average of 2 Horizontal Components
Damping: 0.05
Med + Sig
Med
Med -- Sig
ABSOLUTE ACCELERATION (g)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
0.1
1.0
10.
100.
FREQUENCY (Hz)

FIGURE 3.31

Ground Motion Data for Soil/Structure Interaction Analysis

- Site-specific Acceleration Response Spectra
  - $R \sim 4.5$ km
  - $M \sim 7$
  - Site condition: rock
  - faulting type: composite of strike-slip and reverse faulting
  - Components: horizontal and vertical
  - Dampings: 2%, 5%, 10%
  - Level and shape: median

- 3 Sets of Candidate Time Histories
  - Pacoima Dam record of 1971 San Fernando earthquake
  - Tabas record of 1978 Tabas earthquake
  - Adjusted El Centro #4 record of 1979 Imperial Valley Earthquake

- Spatial Incoherence Functions

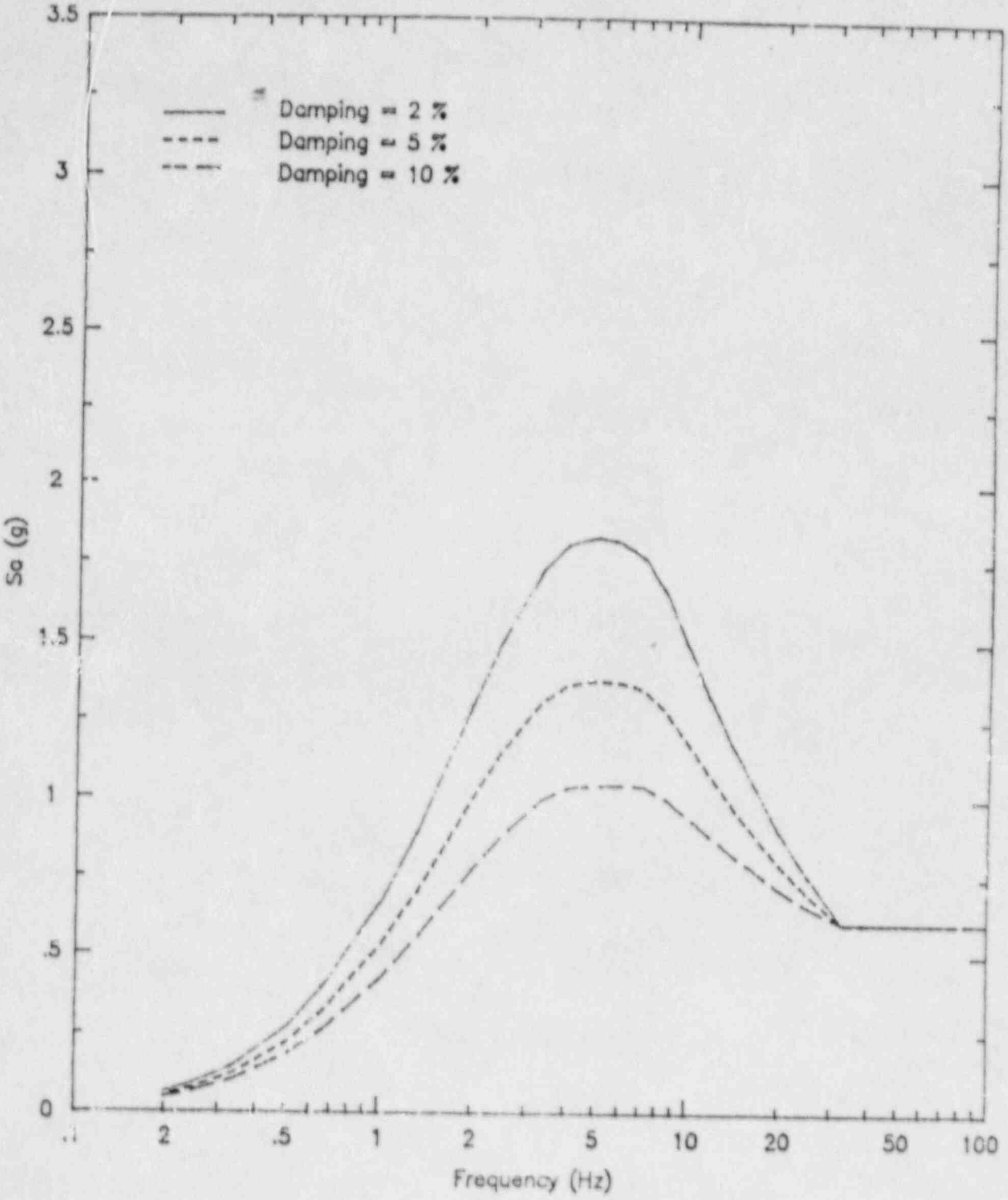


FIGURE 1. Horizontal Response Spectra Used for SSI Analyses

ACCELERATION TIME HISTORIES FROM THE PACOIMA DAM RECORD OF THE SAN FERNANDO EARTHQUAKE, UNMODIFIED

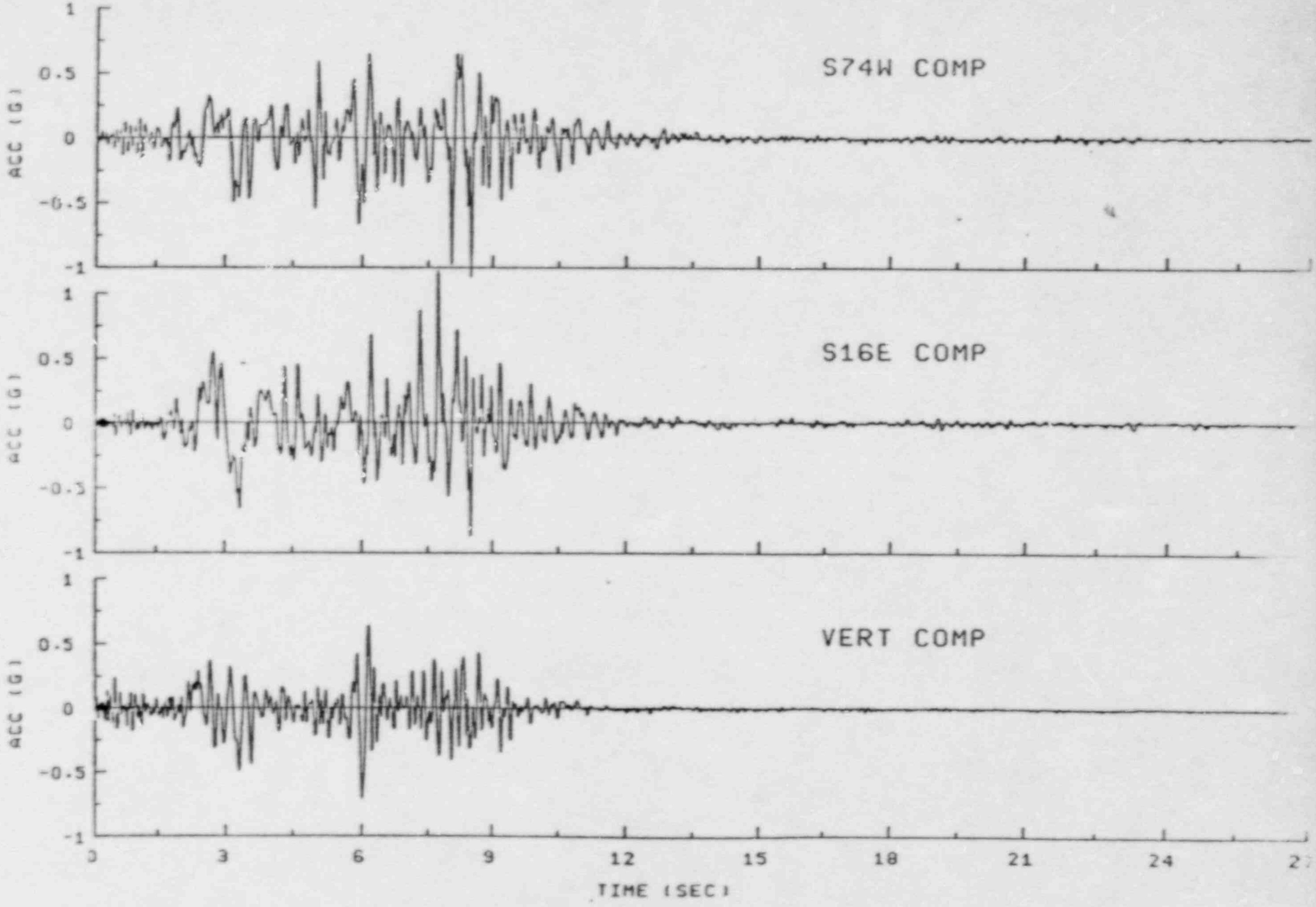


FIGURE 3

ACCELERATION TIME HISTORIES FROM THE TABAS RECORD
OF THE TABAS EARTHQUAKE, UNMODIFIED

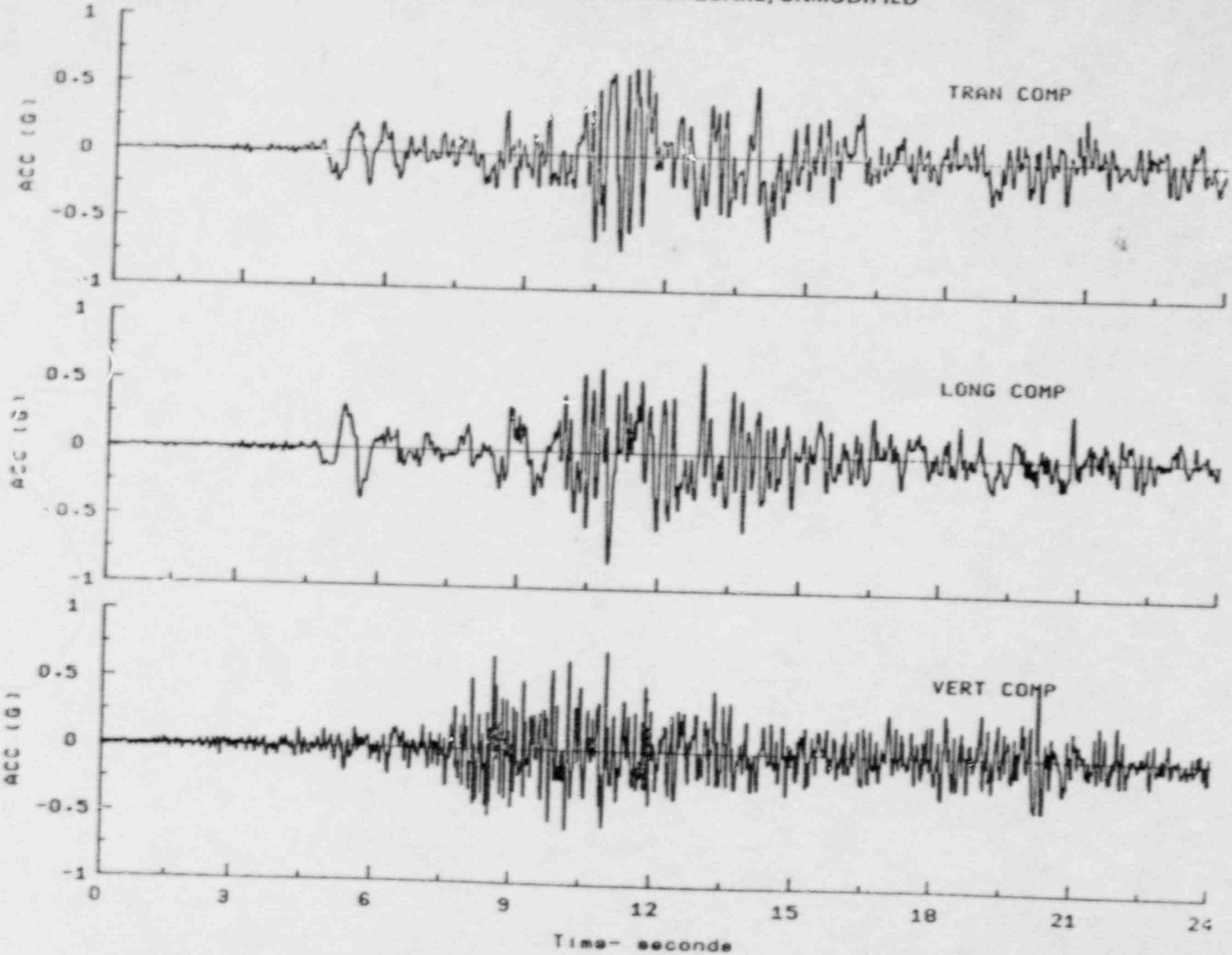


FIGURE 9

ACCELERATION TIME HISTORIES FROM THE EL CENTRO NO. 4 RECORD OF THE IMPERIAL VALLEY EARTHQUAKE, MODIFIED FOR SITE CONDITION

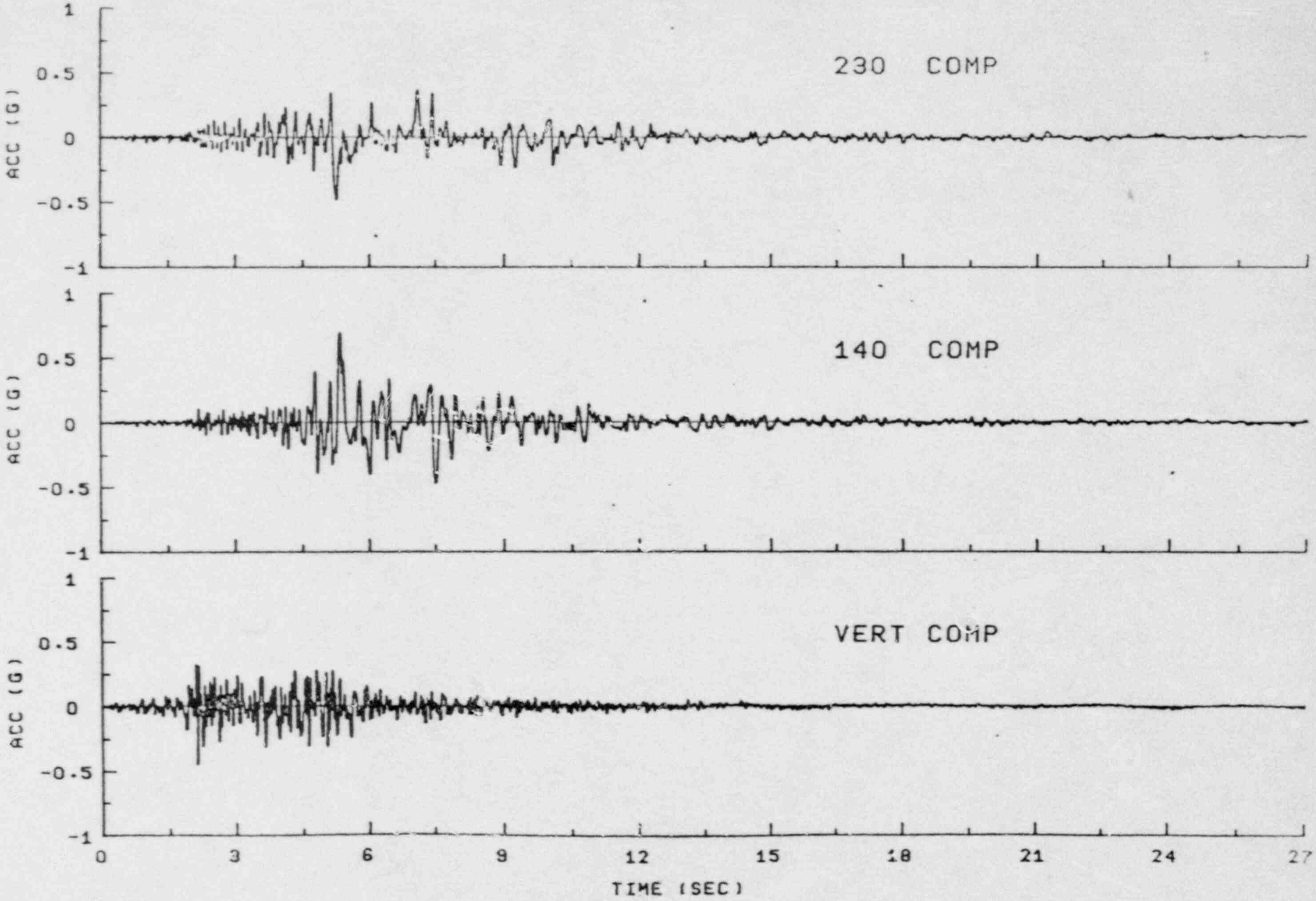
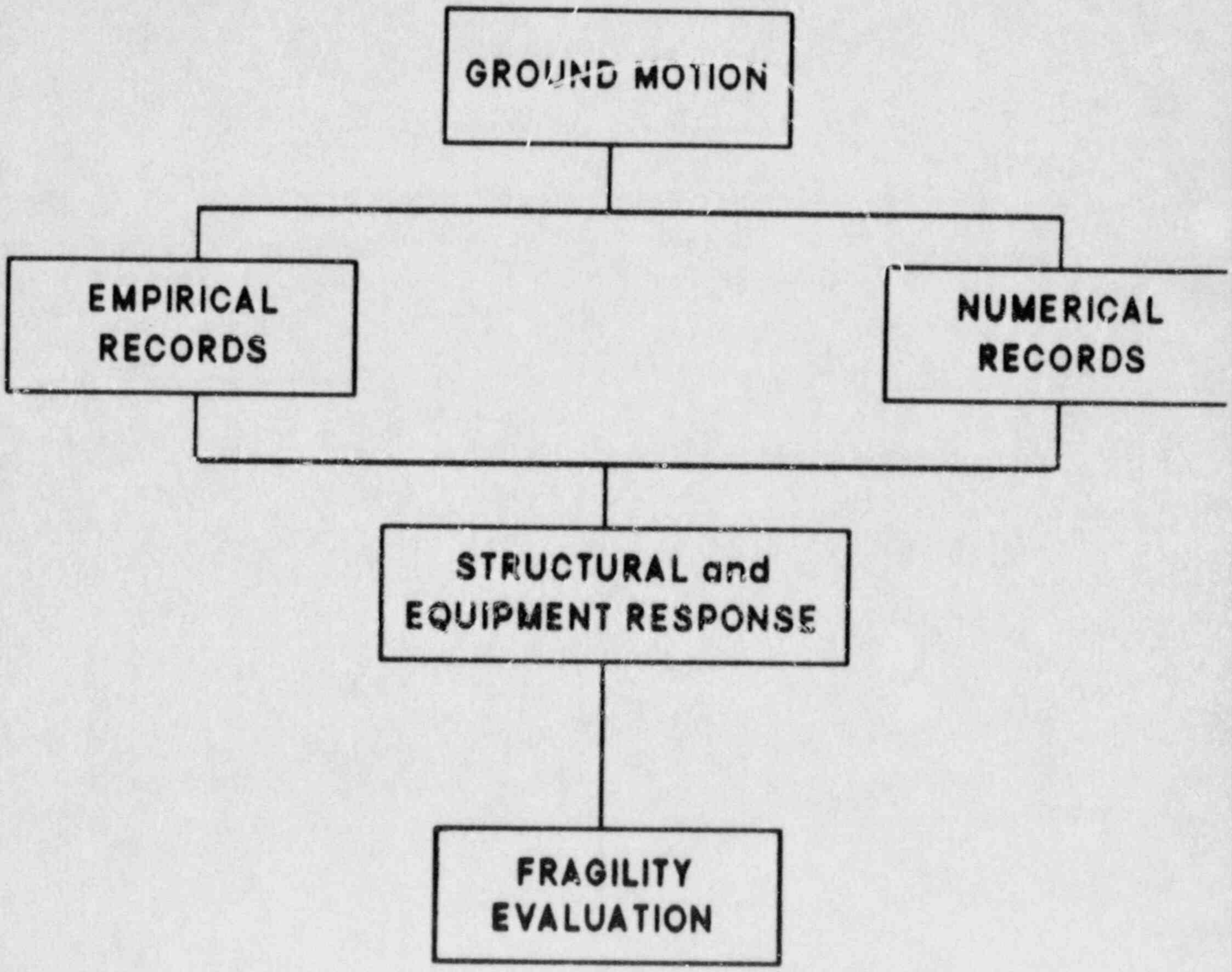


FIGURE 50

Insert #5


GROUND MOTION
EMPIRICAL RECORDS
NUMERICAL RECORDS
STRUCTURAL and EQUIPMENT RESPONSE
FRAGILITY EVALUATION

ANALYSIS HAS BEEN TAILORED TO SUPPORT PRA

REQUIREMENTS:

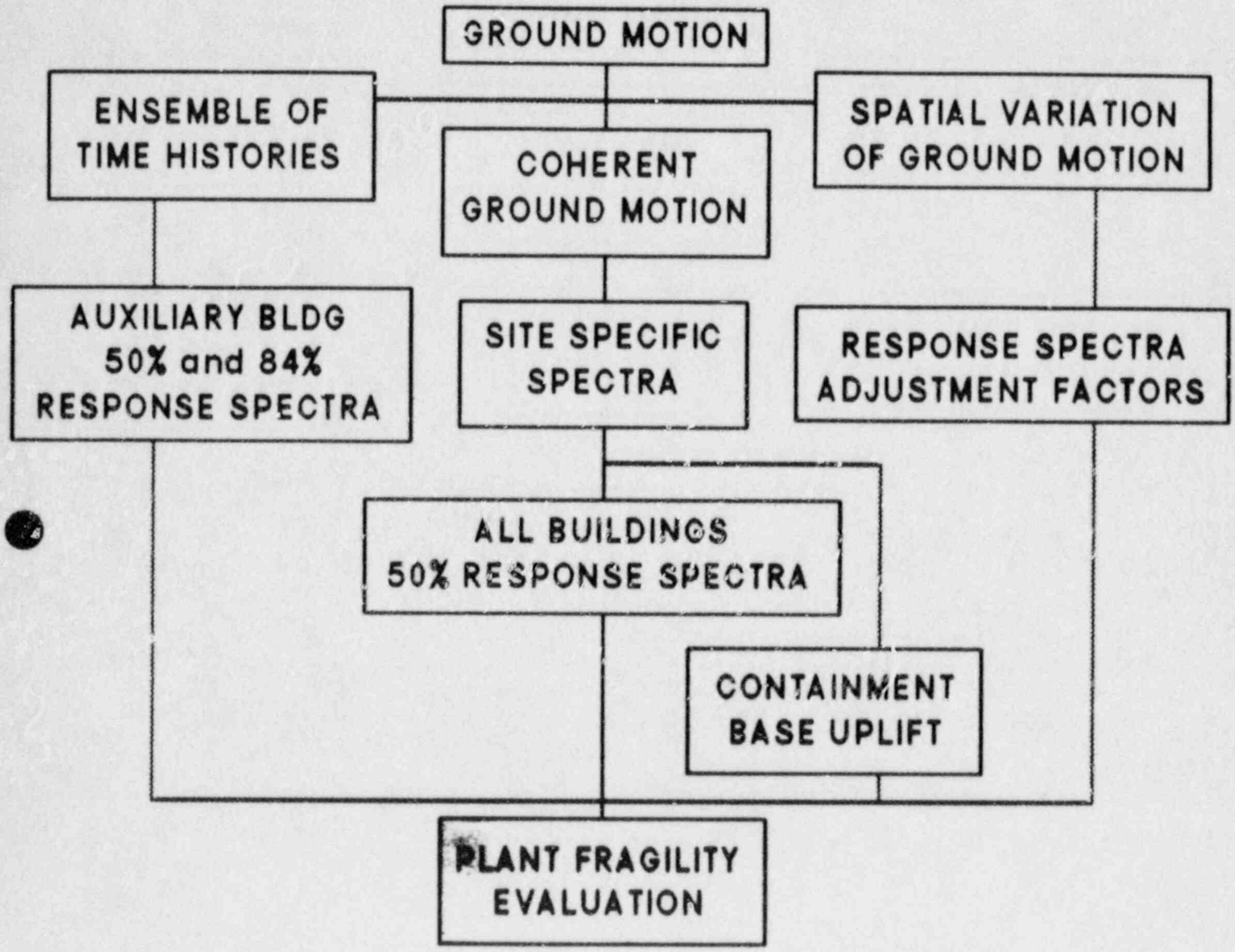
STRUCTURAL RESPONSE
- FORCES IN STRUCTURAL ELEMENTS
- DEFLECTIONS
- ACCELERATIONS
- RESPONSE SPECTRA

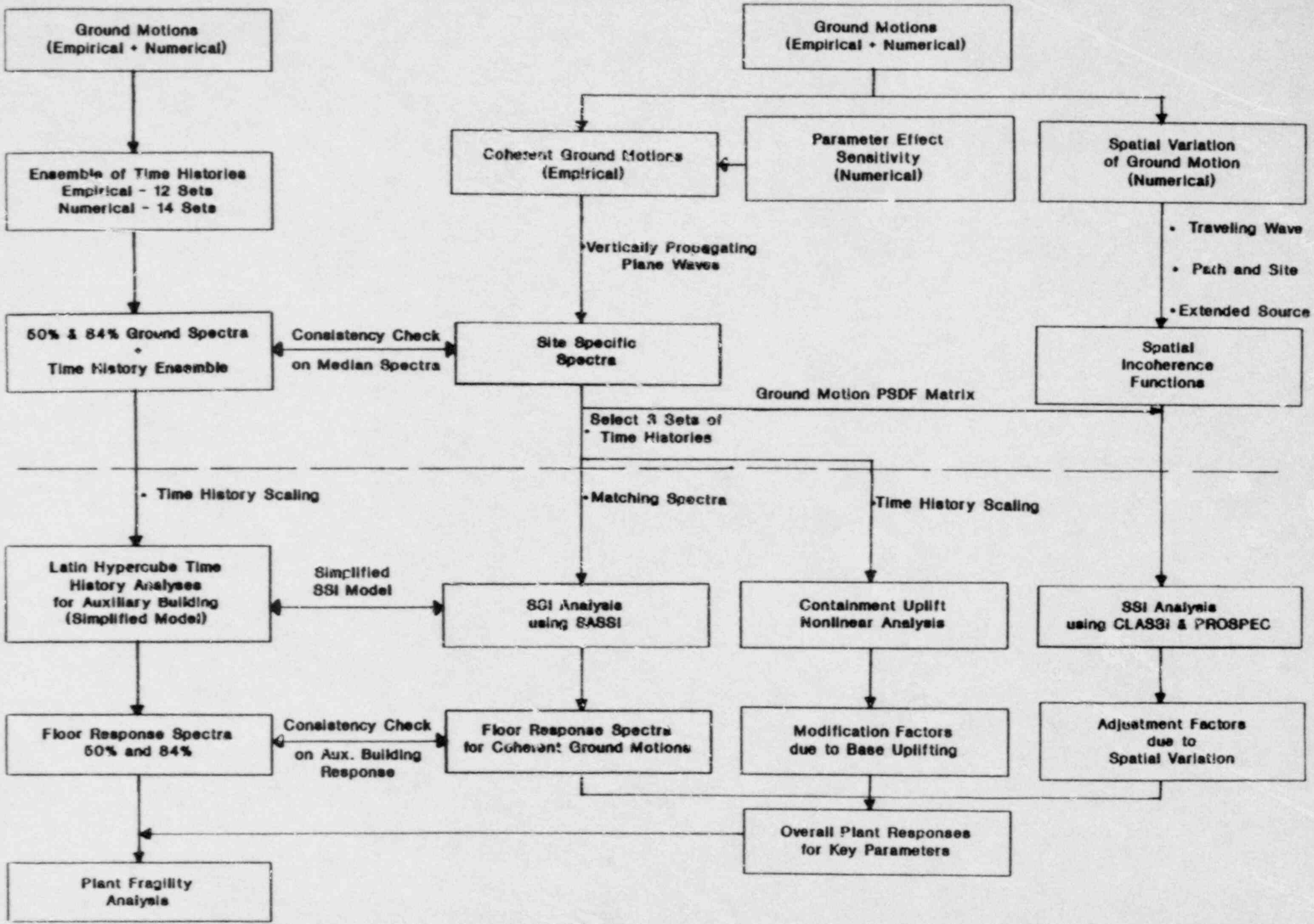
EQUIPMENT RESPONSE
- RESPONSE SPECTRA
- DEFLECTIONS

DISPERSION OF RESPONSE

STUDIES PERFORMED:

- DEVELOPMENT OF MEDIAN and 84% FLOOR RESPONSE SPECTRA-AUXILIARY BUILDING
- DEVELOPMENT OF MEDIAN RESPONSE SPECTRA - ALL BUILDINGS
- EFFECT OF INCOHERENT GROUND MOTION
- EFFECT OF CONTAINMENT BASE UPLIFT


GROUND MOTION
ENSEMBLE OF TIME HISTORIES
COHERENT GROUND MOTION
SPATIAL VARIATION OF GROUND MOTION
AUXILIARY BLDG 50% and 84% RESPONSE SPECTRA
SITE SPECIFIC SPECTRA
RESPONSE SPECTRA ADJUSTMENT FACTORS
ALL BUILDINGS 50% RESPONSE SPECTRA
CONTAINMENT BASE UPLIFT
PLANT FRAGILITY EVALUATION

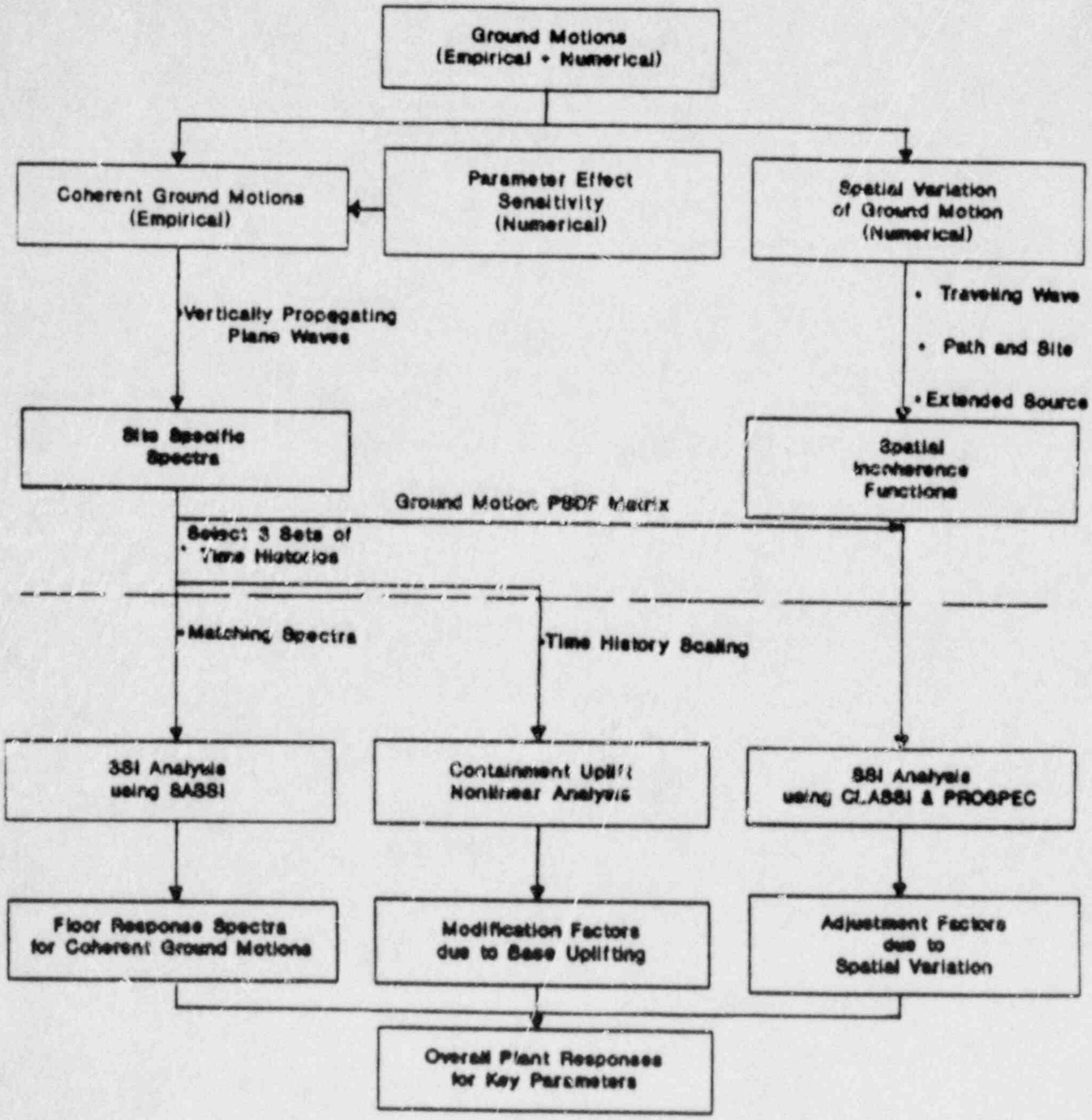

Ground Motions (Empirical + Numerical)
Ensemble of Time Histories Empirical - 12 Sets Numerical - 14 Sets
50% & 84% Ground Spectra + Time History Ensemble
Consistency Check on Median Spectra
• Time History Scaling
Latin Hypercube Time History Analyses for Auxiliary Building (Simplified Model)
Simplified SSI Model
Floor Response Spectra 50% and 84%
Consistency Check on Aux. Building Response
Plant Fragility Analysis
Ground Motions (Empirical + Numerical)
Coherent Ground Motions (Empirical)
Parameter Effect Sensitivity (Numerical)
Spatial Variation of Ground Motion (Numerical)
•Vertically Propagating Plane Waves
• Traveling Wave
• Path and Site
•Extended Source
Site Specific Spectra
Spatial Incoherence Functions
Ground Motion PSDF Matrix
• Select 3 Sets of Time Histories
•Matching Spectra
•Time History Scaling
SSI Analysis using SASSI
Containment Uplift Nonlinear Analysis
SSI Analysis using CLASSI & PROSPEC
Floor Response Spectra for Coherent Ground Motions
Modification Factors due to Base Uplifting
Adjustment Factors due to Spatial Variation
Overall Plant Responses for Key Parameters

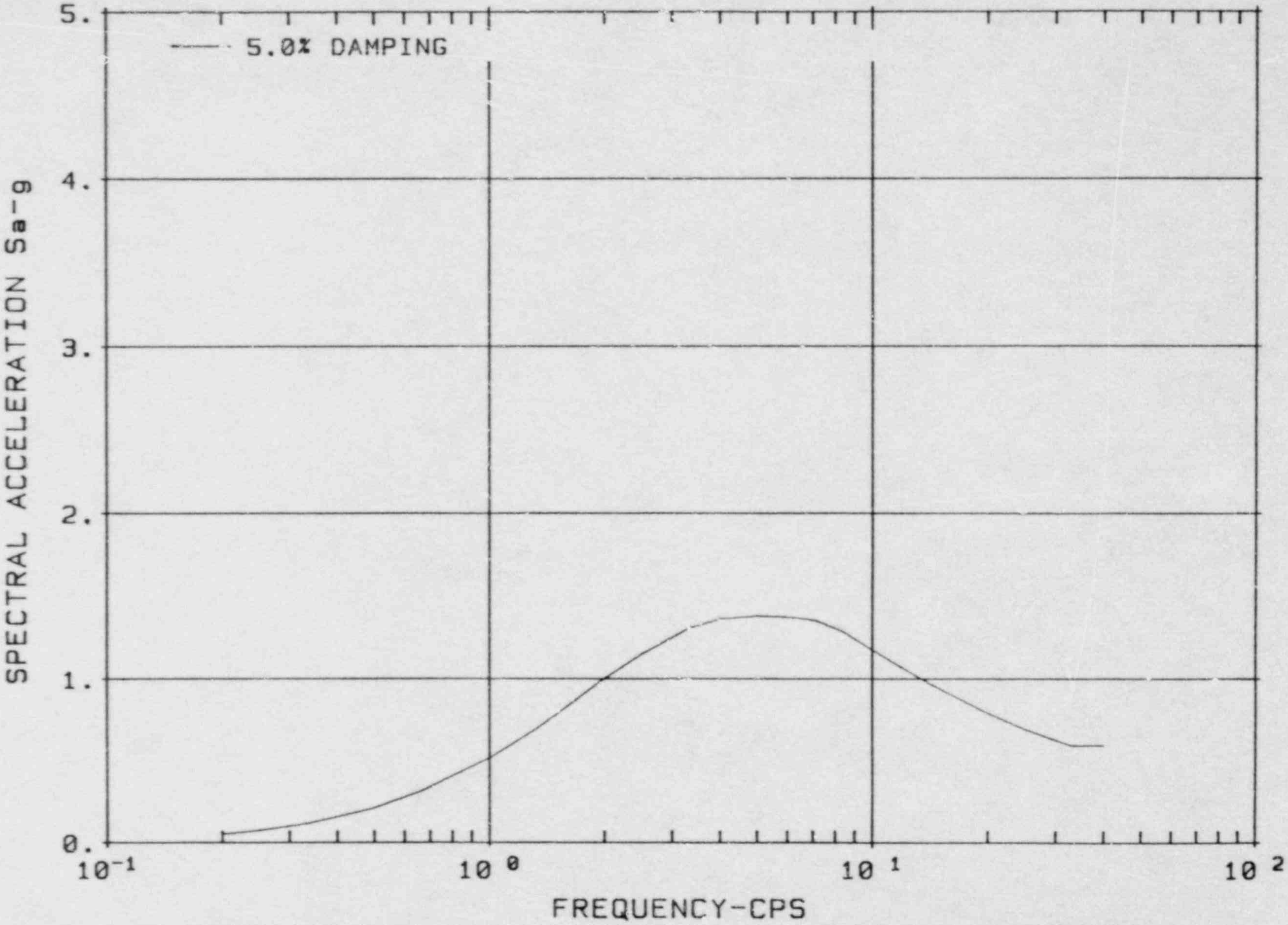
Insert #6

PART I

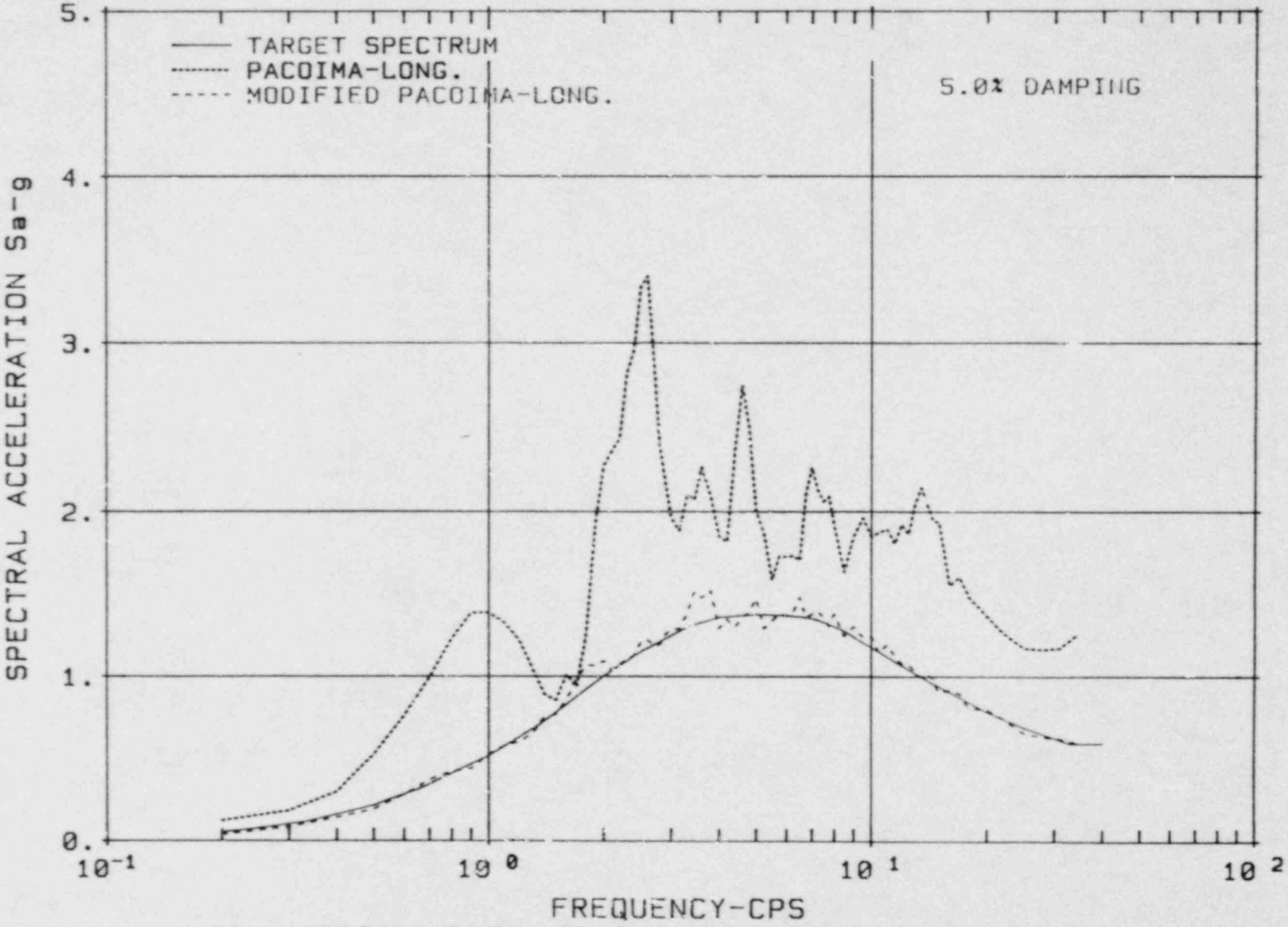
SSI RESPONSES TO COHERENT GROUND MOTION INPUTS (VERTICALLY PROPAGATING PLANE-SEISMIC WAVES)

- CONTAINMENT STRUCTURE
- AUXILIARY BUILDING
- TURBINE BUILDING UNIT 2

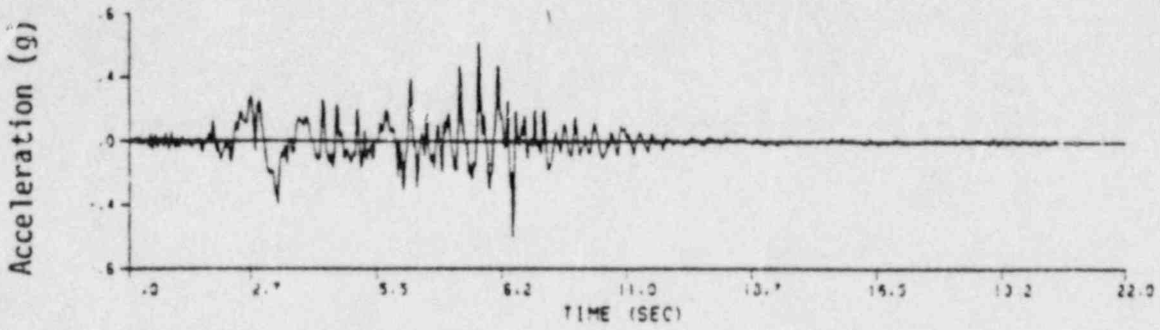

Ground Motions
(Empirical + Numerical)
Coherent Ground Motions
(Empirical)
Parameter Effect
Sensitivity
(Numerical)
Spatial Variation
of Ground Motion
(Numerical)
• Vertically Propagating
Plane Waves
• Traveling Wave
• Path and Site
• Extended Source
Site Specific
Spectra
Spatial
Incoherence
Functions
Ground Motion PSDF Matrix
Select 3 Sets of
Time Histories
• Matching Spectra
• Time History Scaling
SSI Analysis
using SASSI
Containment Uplift
Nonlinear Analysis
SSI Analysis
using CLASSI & PROSPEC
Floor Response Spectra
for Coherent Ground Motions
Modification Factors
due to Base Uplifting
Adjustment Factors
due to
Spatial Variation
Overall Plant Responses
for Key Parameters



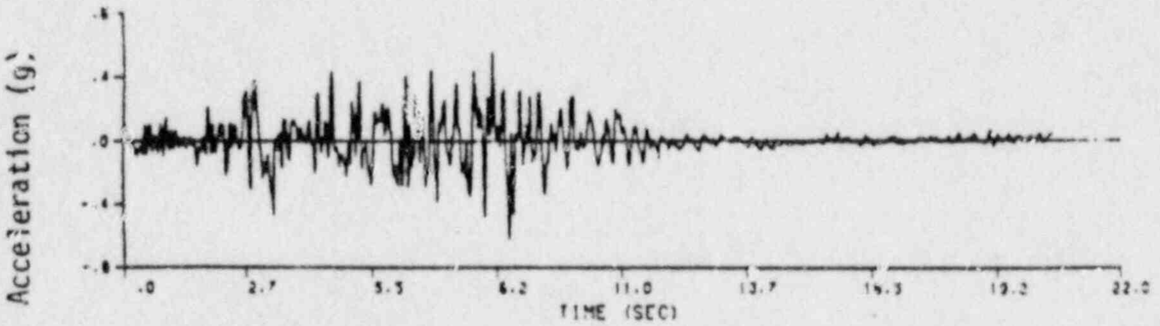
LTSP MEDIAN SITE-SPECIFIC HORIZONTAL SPECTRUM



LTSP MEDIAN SITE-SPECIFIC HORIZONTAL SPECTRUM

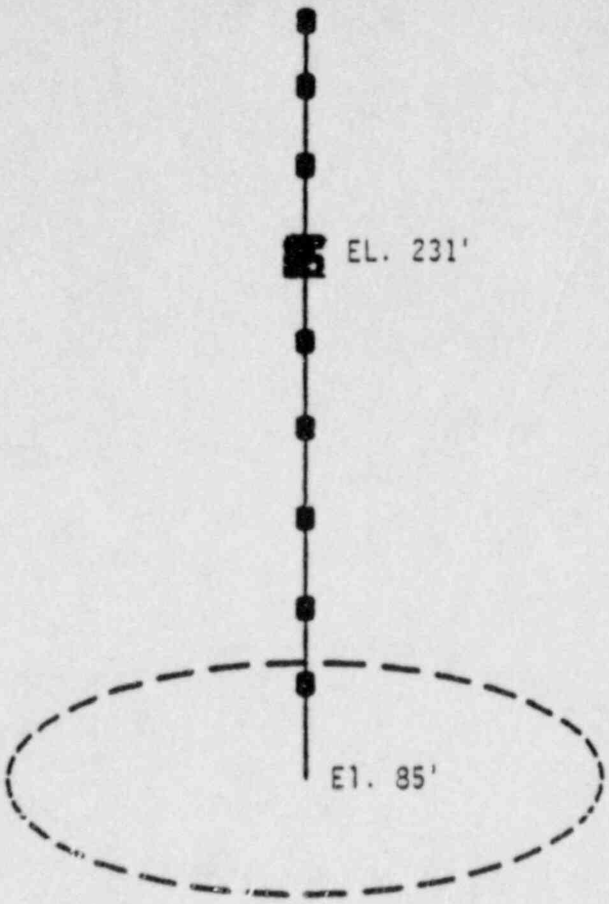


INITIAL PACOIMA-LONGITUDINAL

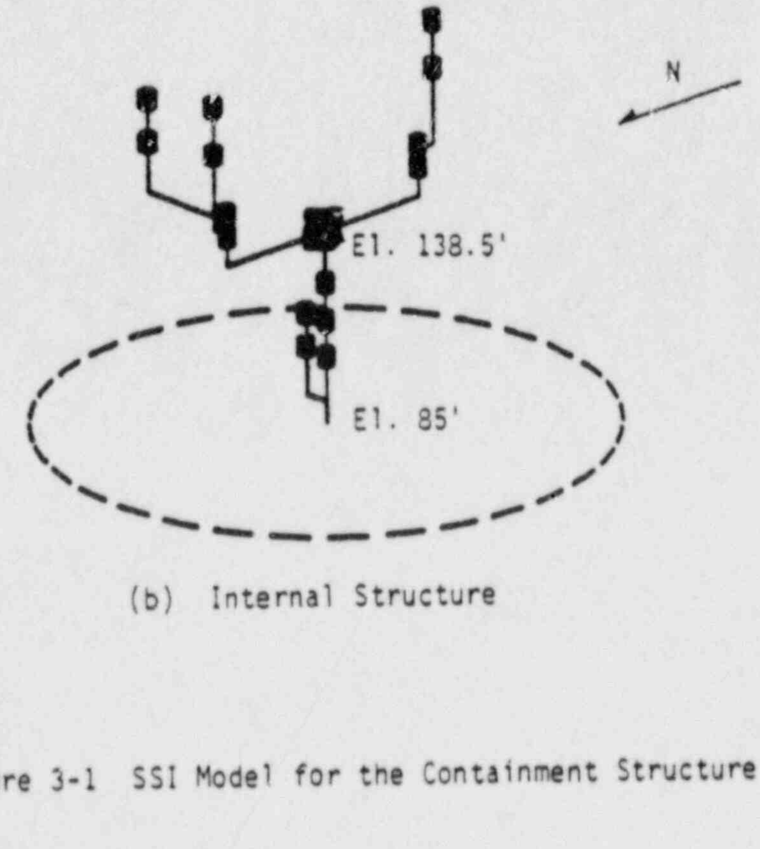


FINAL PACOIMA-LONGITUDINAL

Figure 2-1 Comparison of the Original Recorded Pacoima Longitudinal Acceleration Time History and the Final Modified Spectrum-Compatible Time History

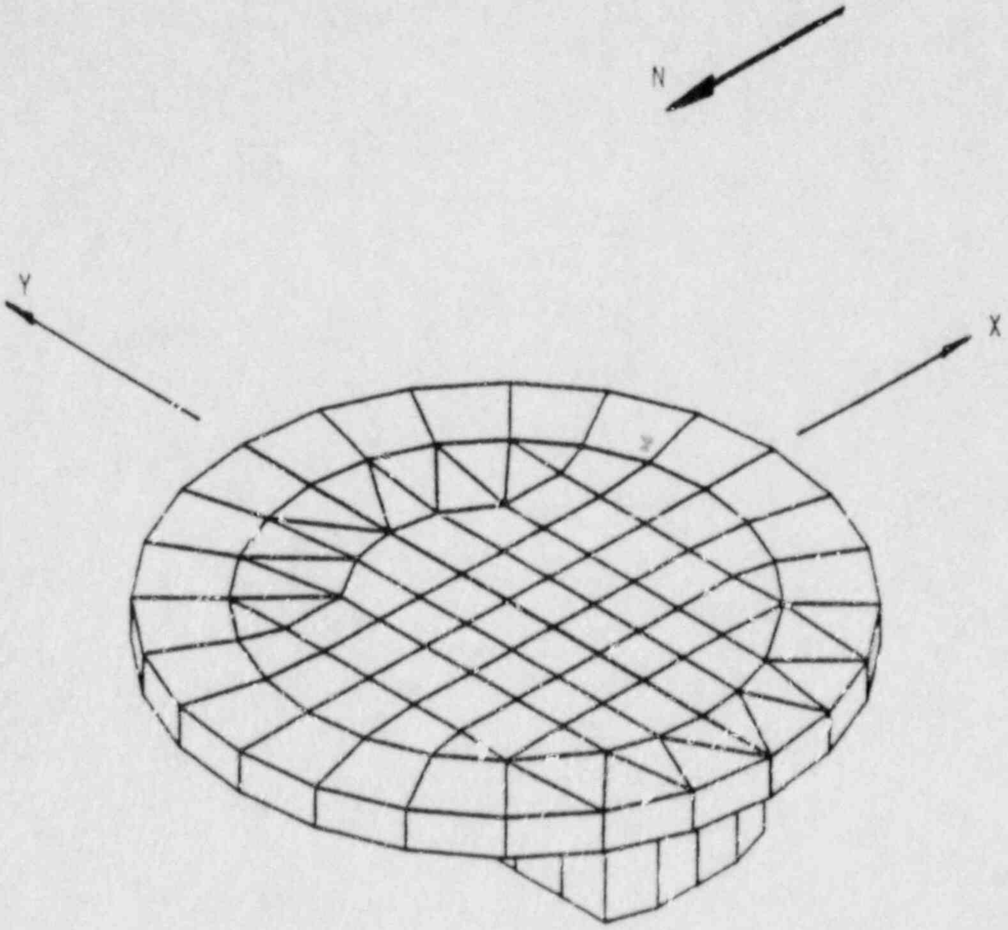


(a) Containment Shell



(b) Internal Structure

Figure 3-1 SSI Model for the Containment Structure



SASSI FOUNDATION MODEL FOR CONTAINMENT

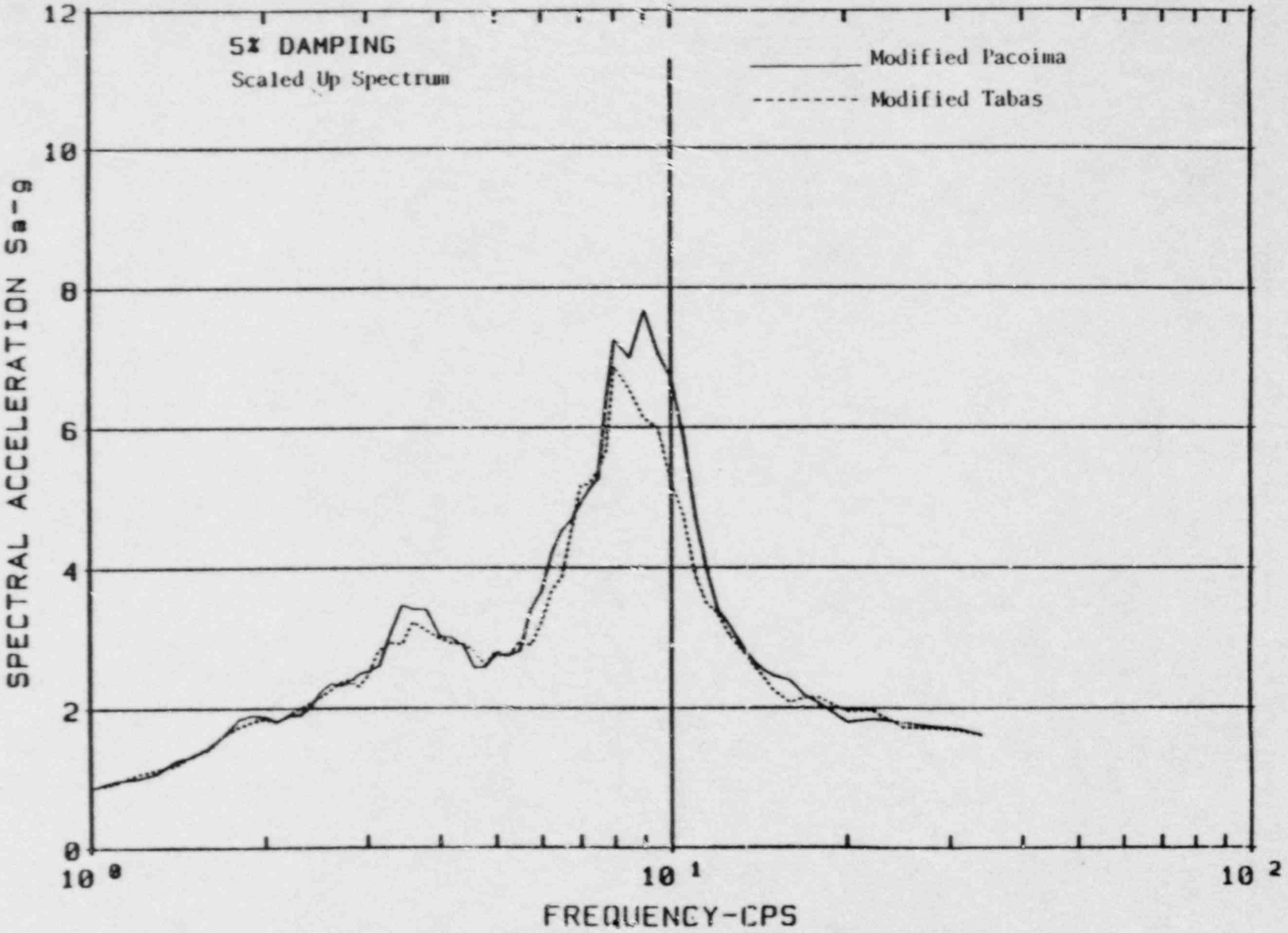


FIGURE 4-3 CONT NS INTERNAL CENTER EL 138'-6"

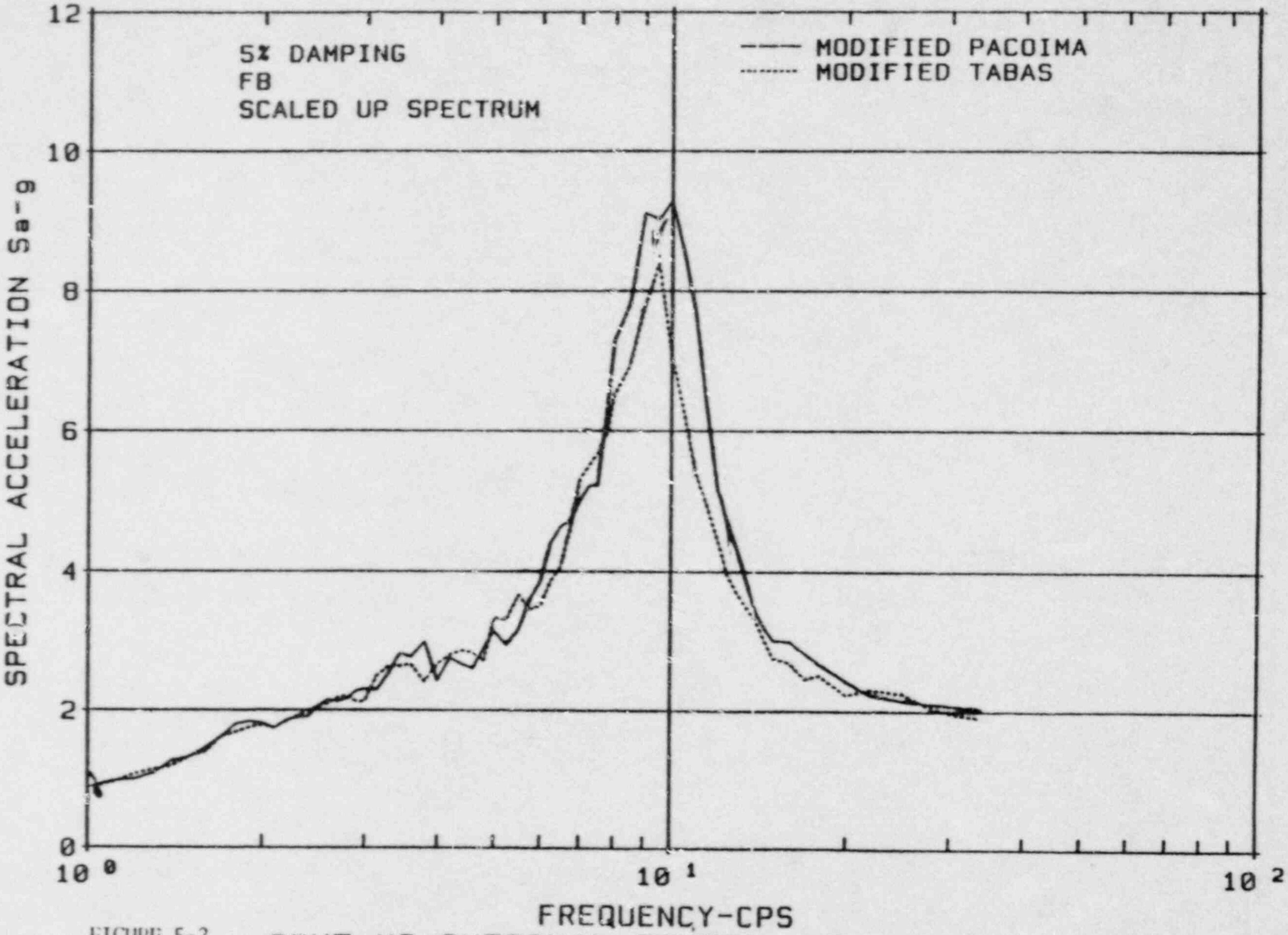


FIGURE 5-2 CONT NS INTERNAL CENTER EL 138'-6"

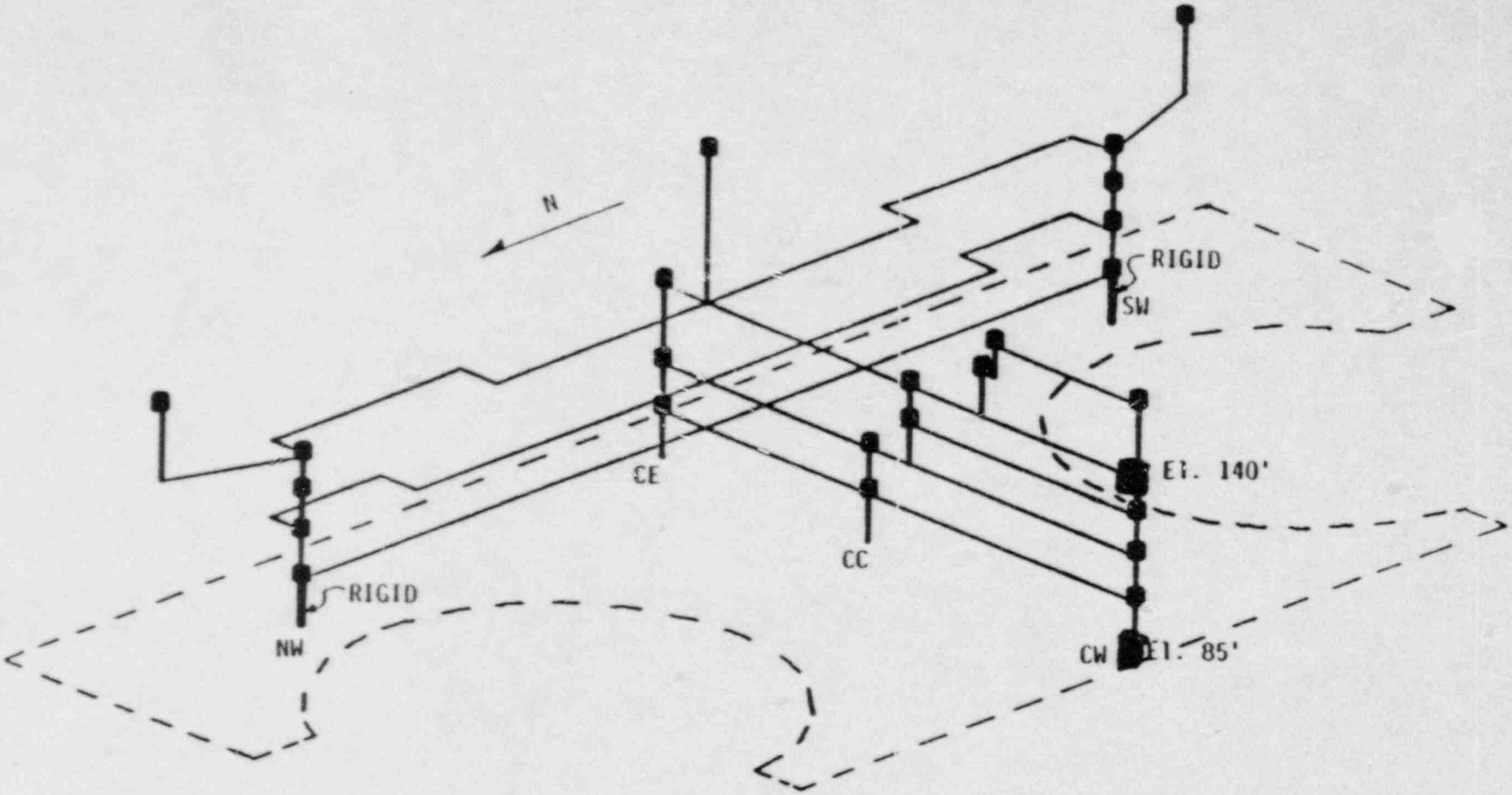
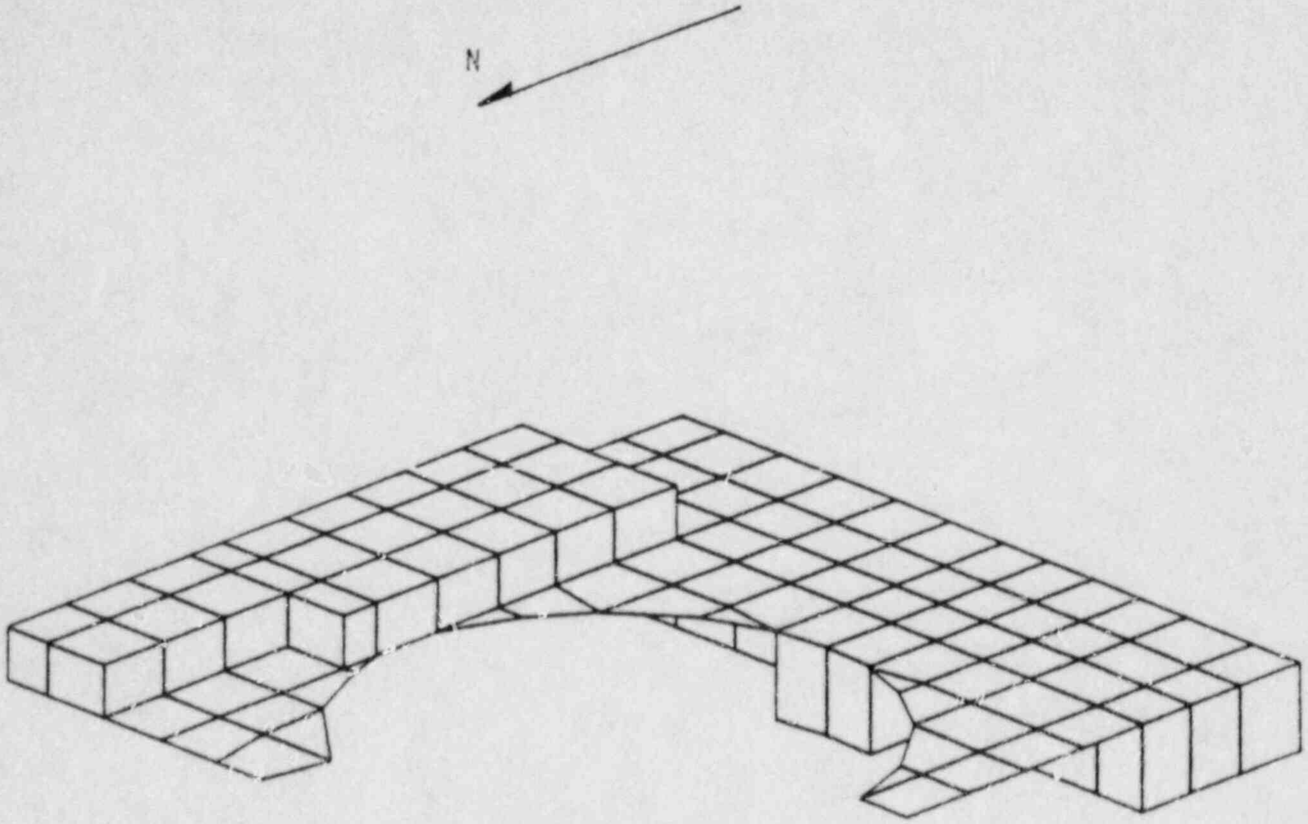


FIGURE 3-2 SSI MODEL FOR AUXILIARY BUILDING



SASSI FOUNDATION HALF-MODEL FOR AUXILIARY BUILDING

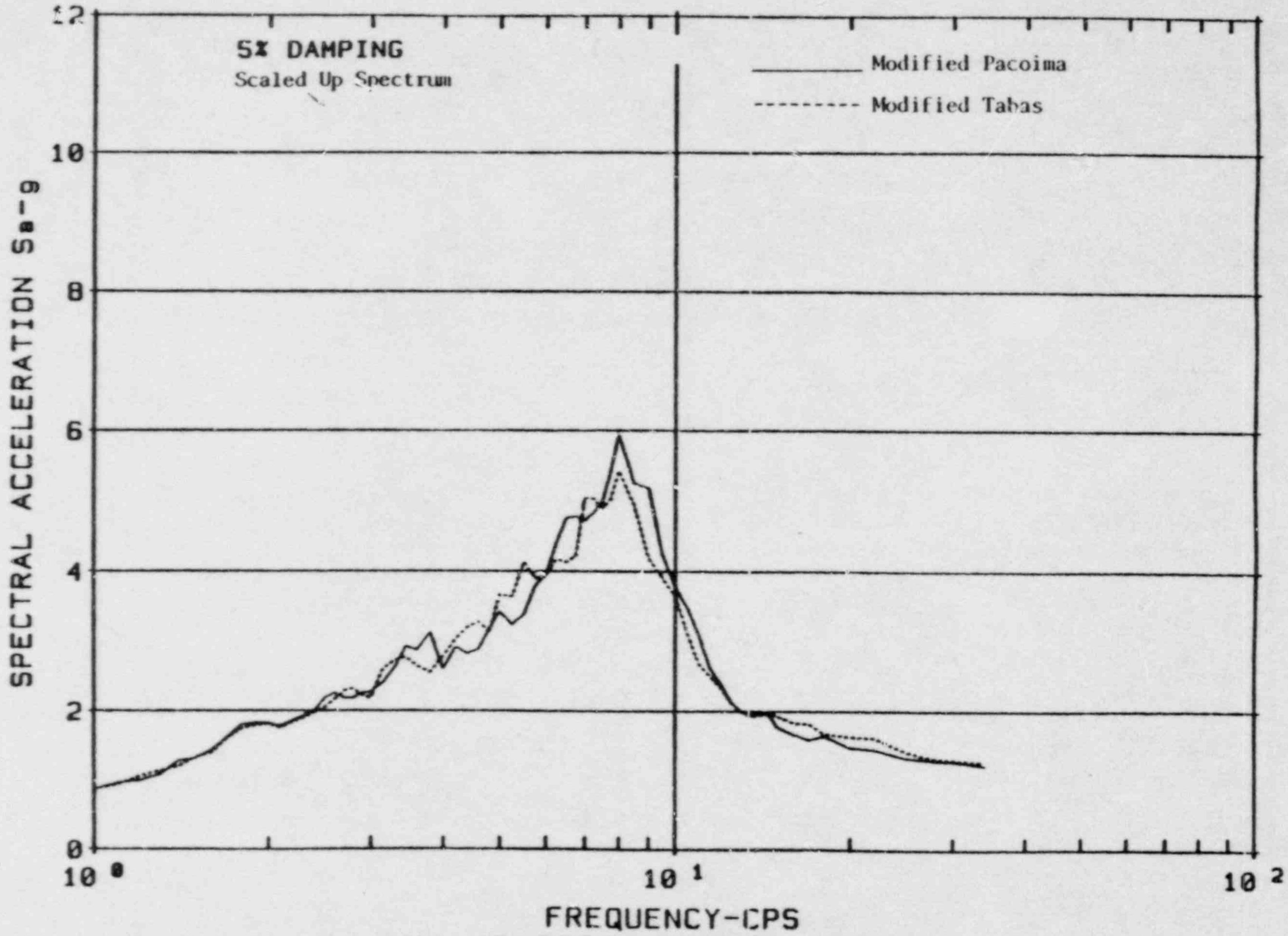


FIGURE 4-7 AUX NS CORE WEST EL 140'-0"

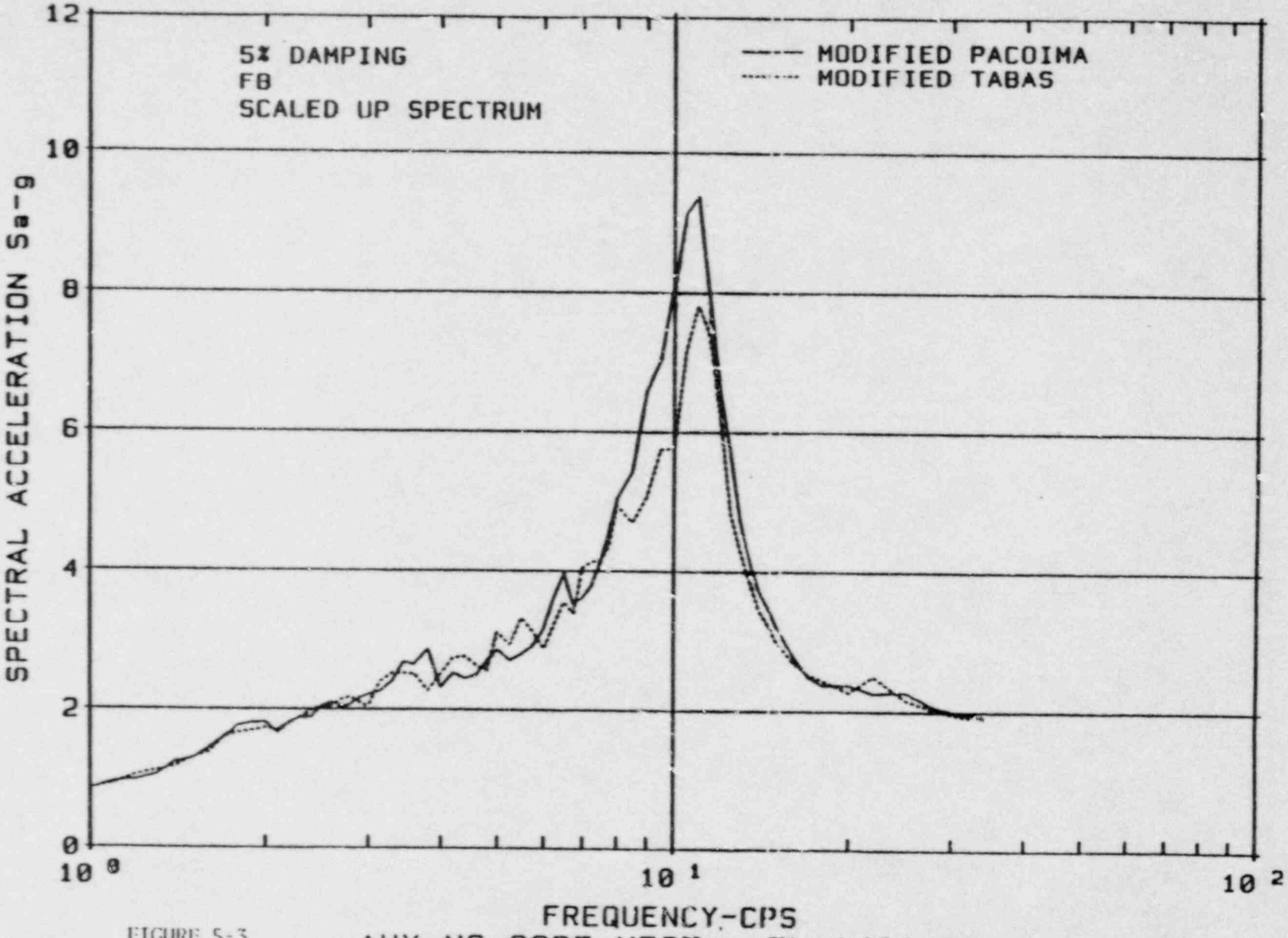


FIGURE 5-3 AUX NS CORE WEST EL 140'-0"

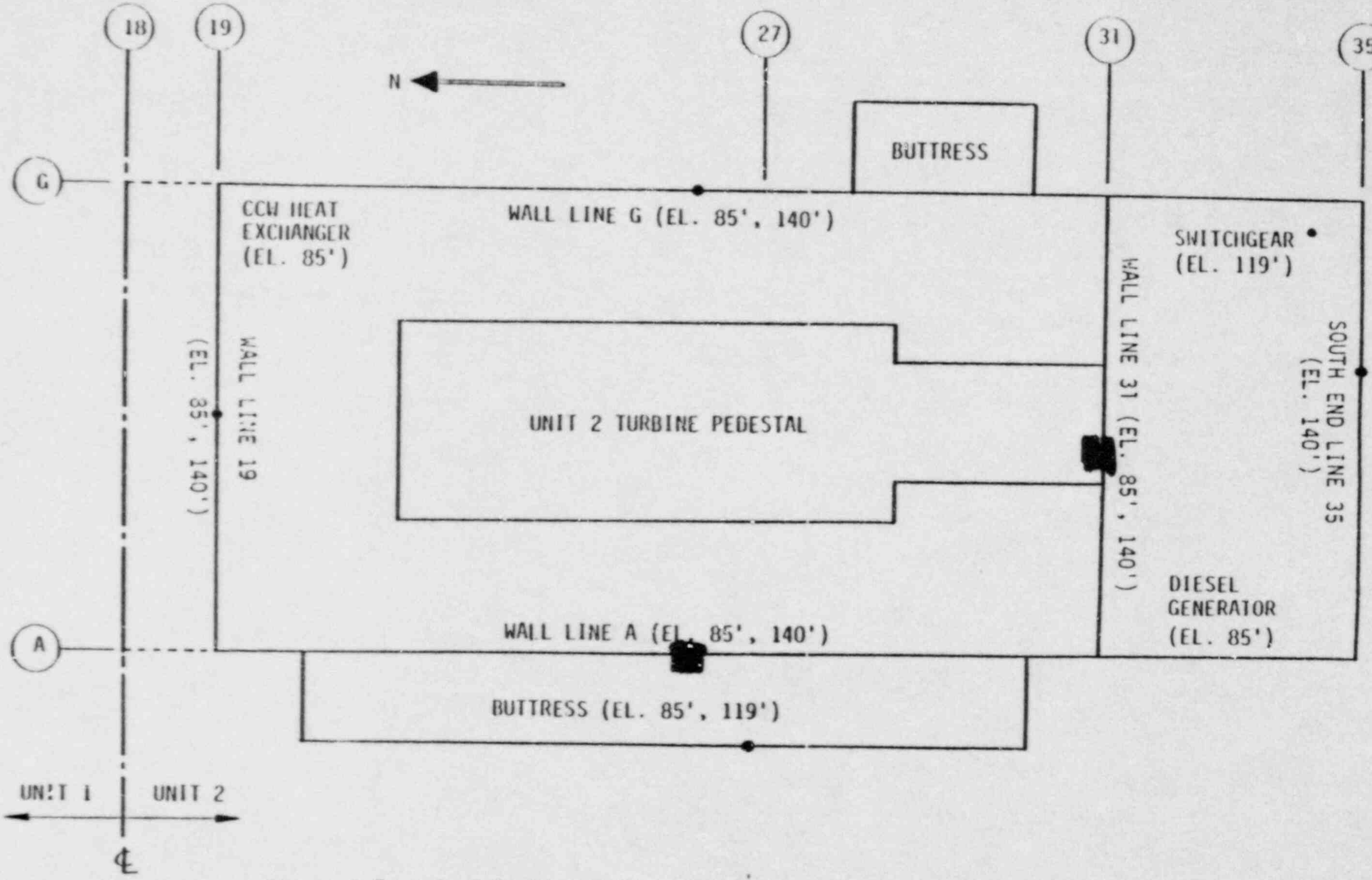


Figure 3-5 Unit 2 Turbine Building Locations where SSI Responses are Provided

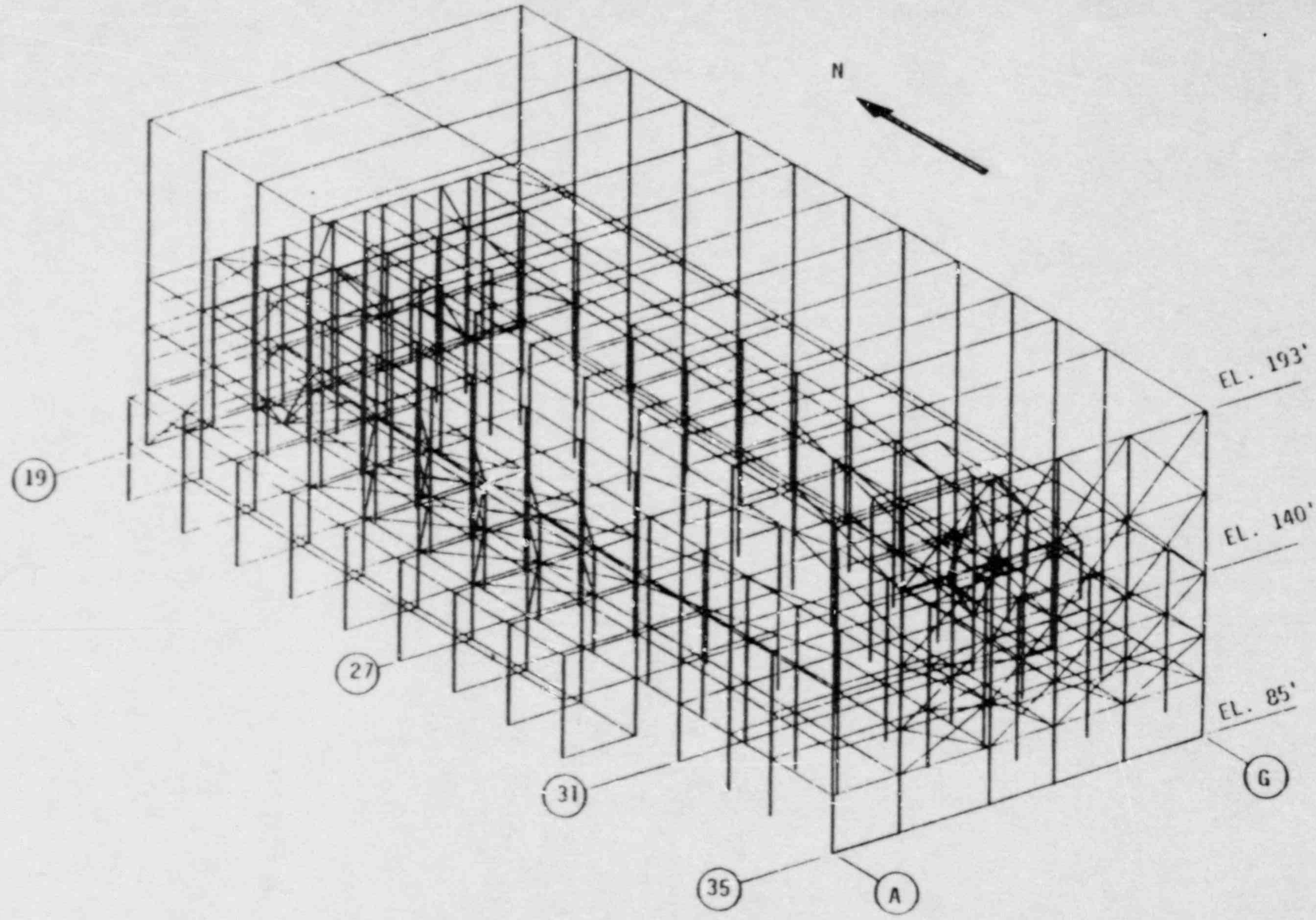
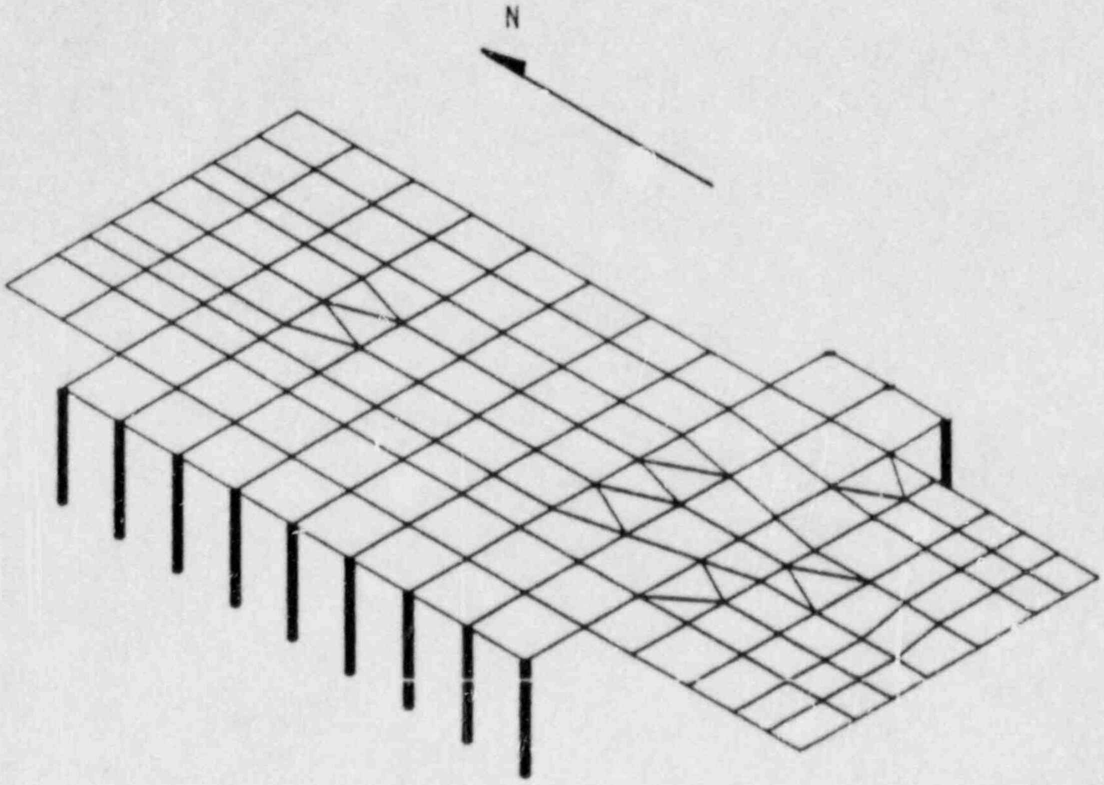
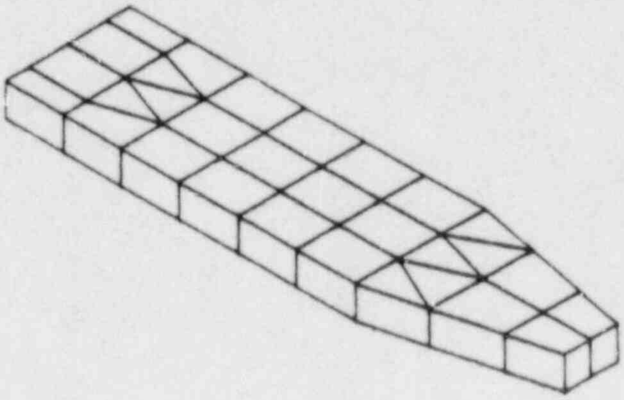


Figure 3-4 Unit 2 Turbine Building Finite Element Model of Structure Above EL. 85'



UNIT 2 TURBINE BUILDING FOUNDATION MODEL



UNIT 2 TURBINE PEDESTAL FOUNDATION MODEL

SASSI FOUNDATION MODEL FOR UNIT 2 TURBINE BUILDING

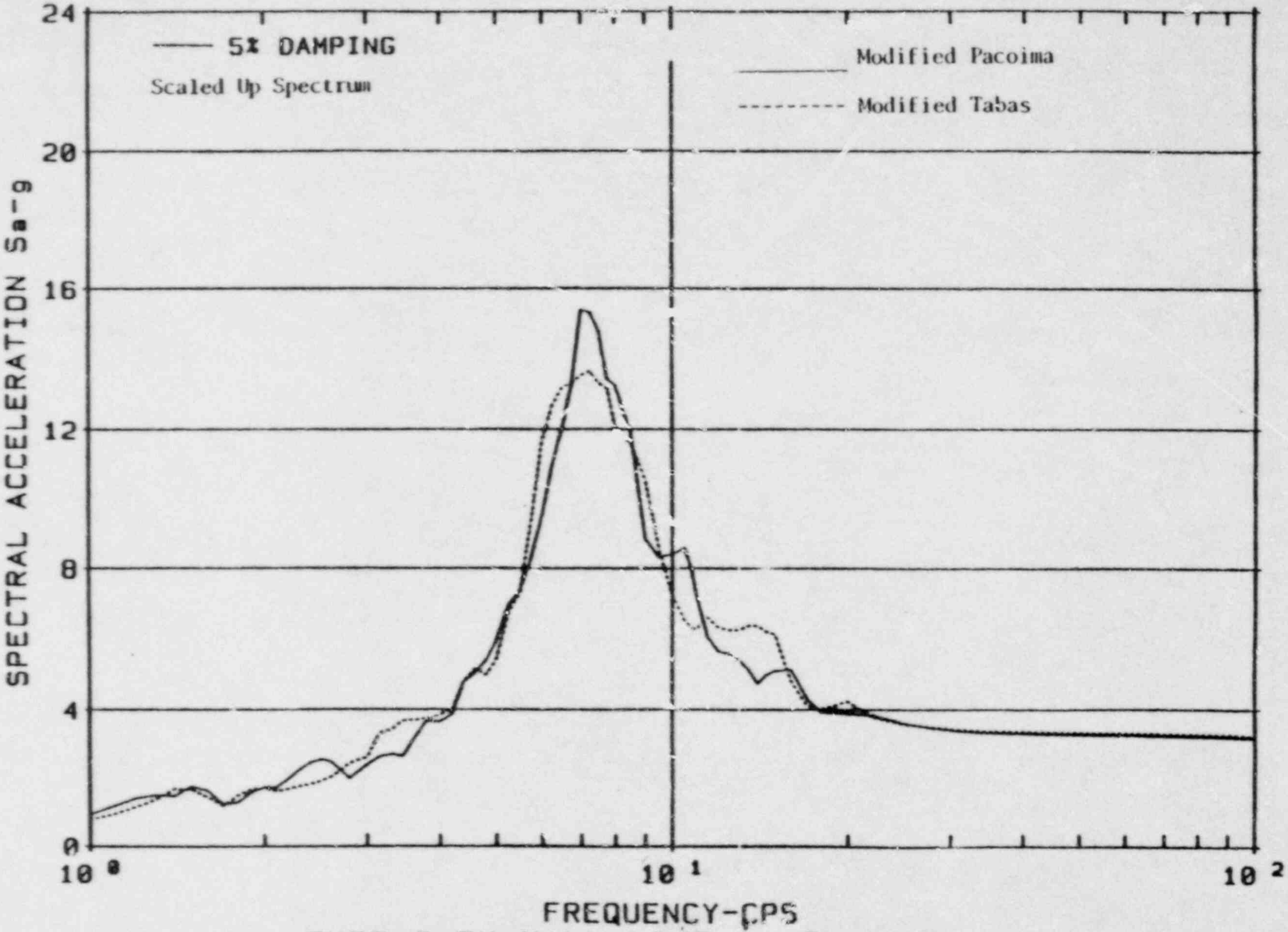


FIGURE 4-18 TURB-2 EW WALL LINE A EL 140'-0"

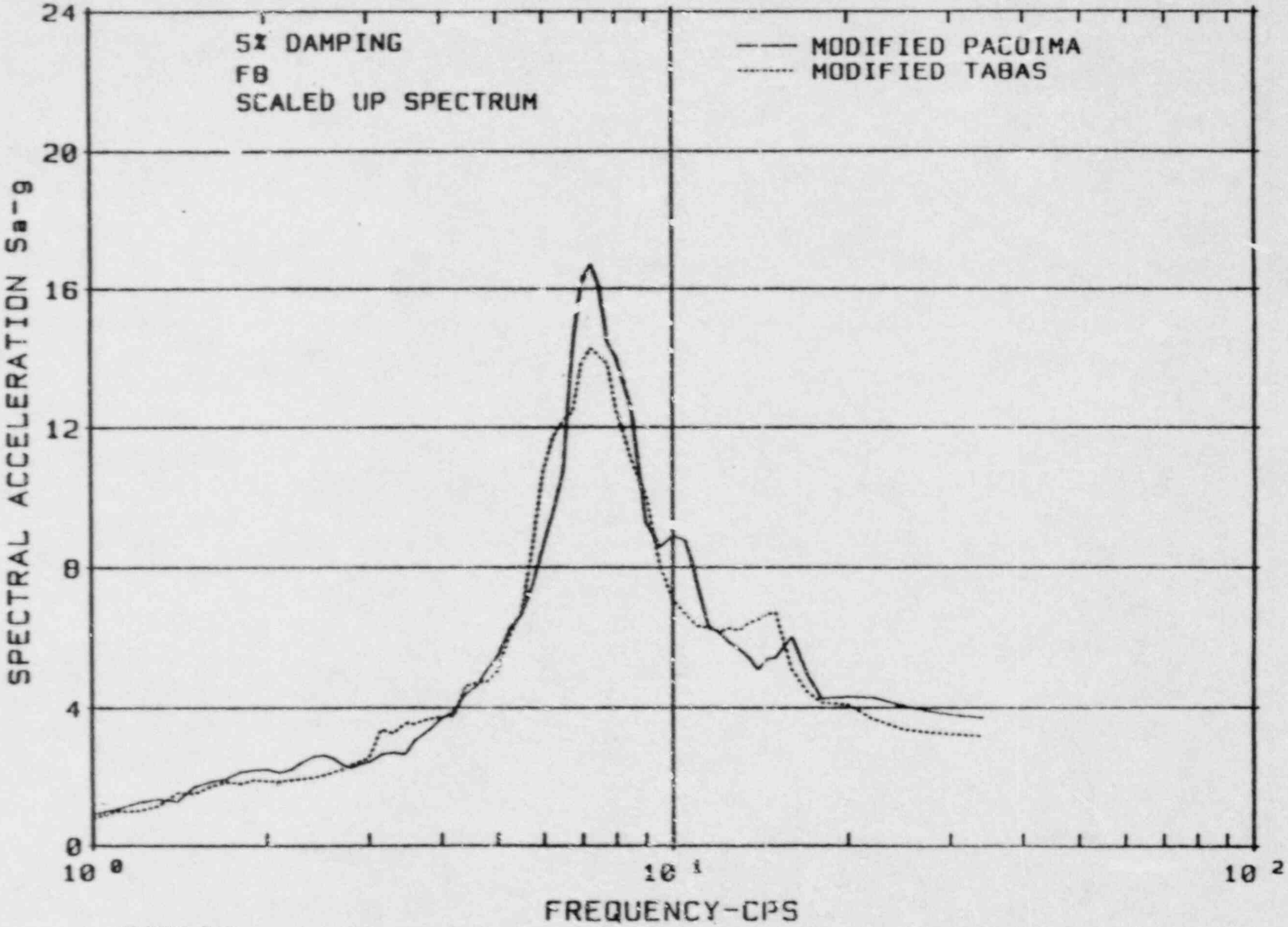
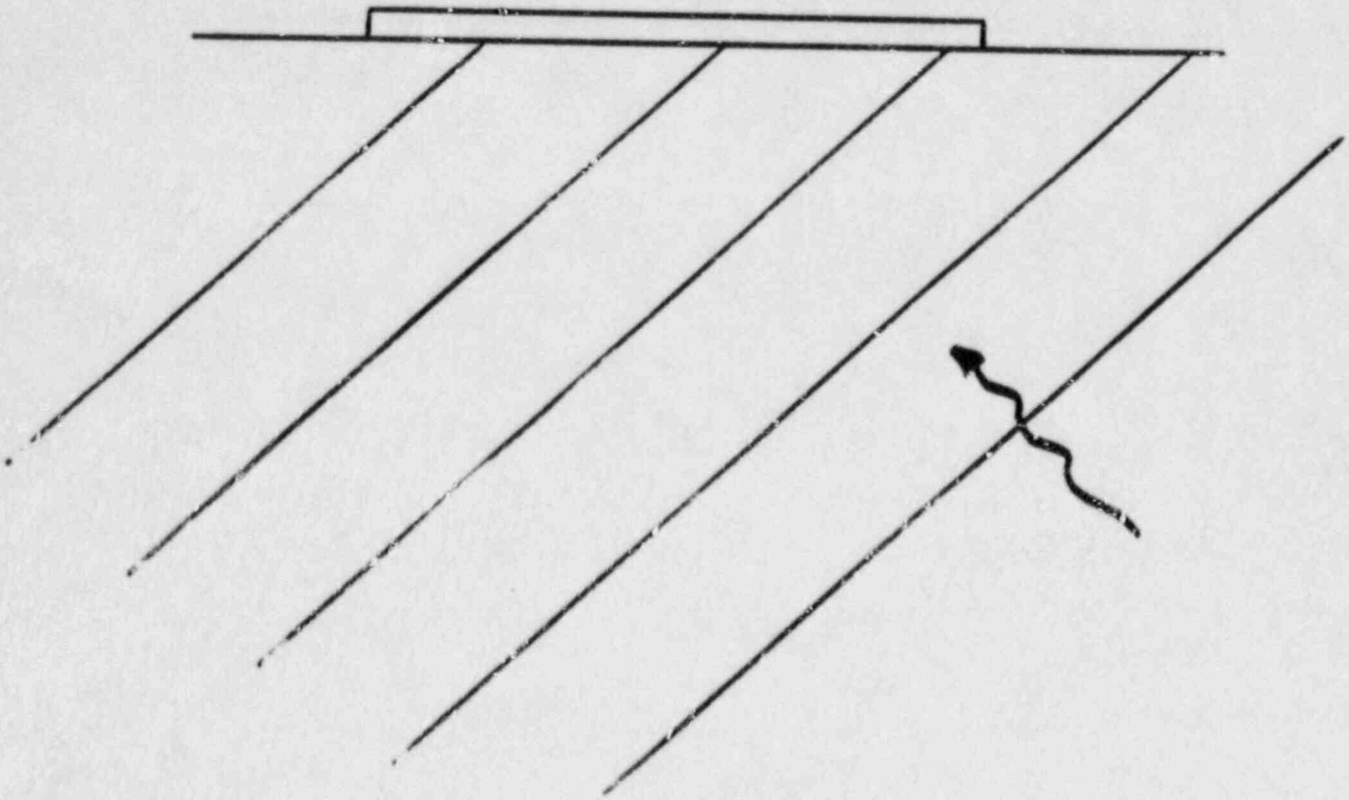


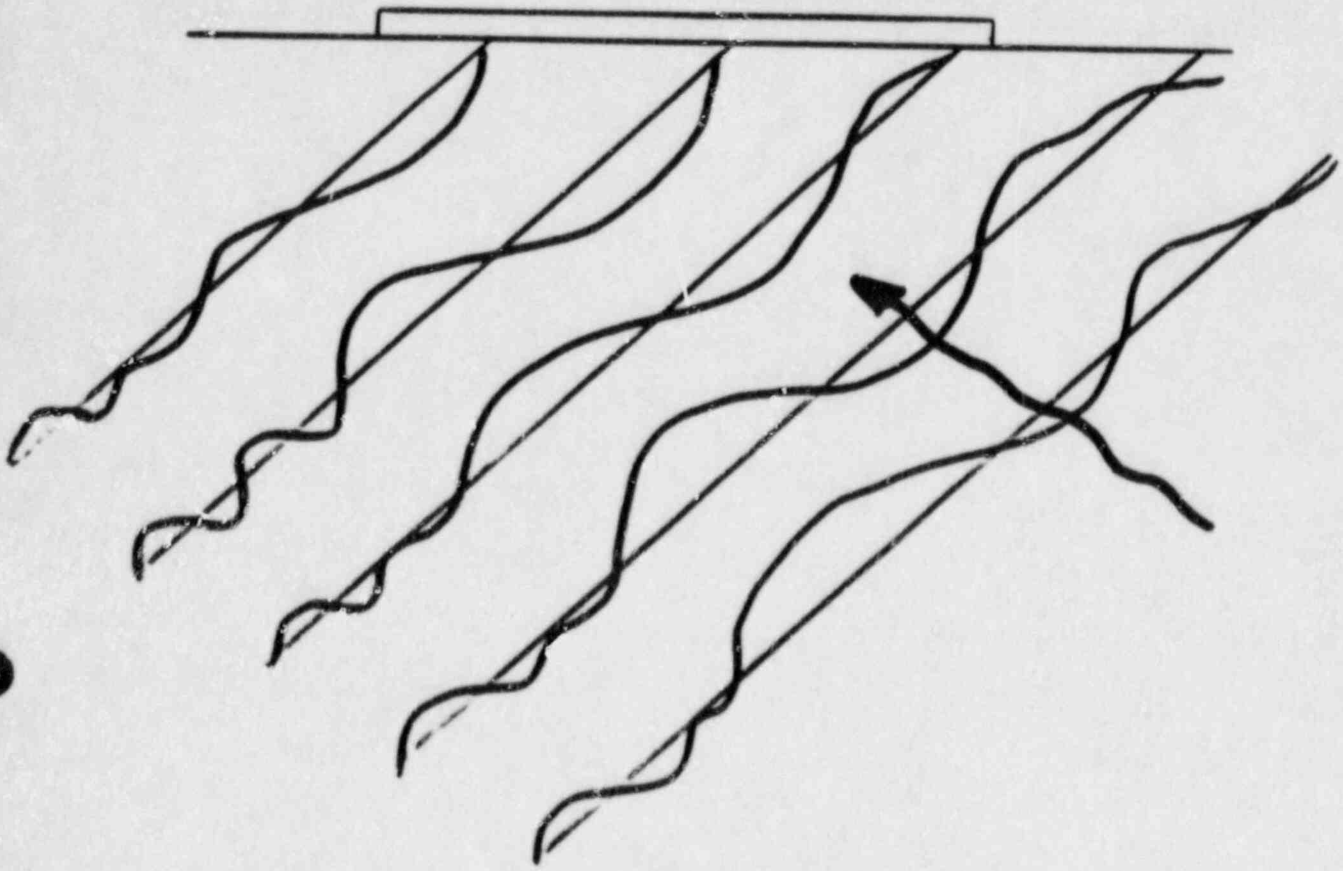
FIGURE 5-9 TURB-2 EW WALL LINE A EL 140'-0"

PART 2

SSI RESPONSE ADJUSTMENT FACTORS DUE TO SPATIAL INCOHERENCE OF GROUND MOTION

- Containment Structure
- Auxiliary Building
- Turbine Building Unit 2





INCOHERENT GROUND MOTION CHARACTERIZATION MODEL

$$S_{u_g}^{ij}(\omega, |x-x'|) = S_{u_g}^{ij}(\omega, o)\, C^{ij}(\omega, R) \quad ; i,j = 1, 2, 3$$

$S_{u_g}^{ij}(\omega, o)$ = GROUND MOTION CONVARIANCE MATRIX AT REFERENCE POINT 0

$C^{ij}(\omega.R)$ = SPATIAL INCOHERENCE FUNCTIONS

$R = |x-x_o|$

SPATIAL INCOHERENCE FUNCTION FOR LTSP-SSI

$$C(\omega, R) = A(\omega, R) \, \mathrm{Exp} \, [i \phi(\omega, R)]$$

WHERE

$$A(\omega, R) = \mathrm{Exp} \, [-(N+M\omega) R]$$

$$\phi(\omega, R) = C R\omega + D R \sin(F\omega)\sin(G\omega)$$

N, M, C, D, F, G, ARE CONSTANTS

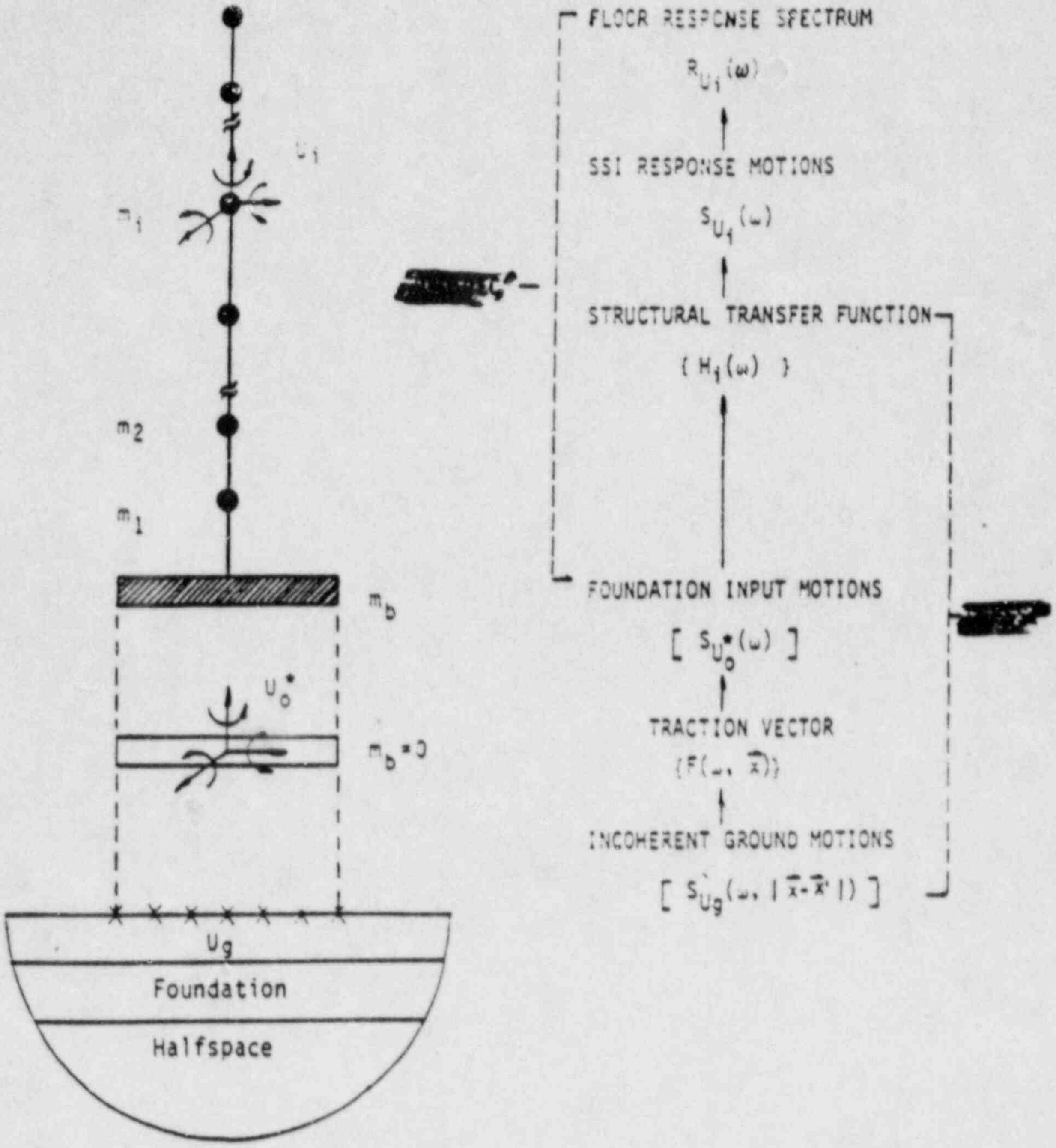


Figure 2-1 Schematic Diagram of Probabilistic Approach of SSI Analysis for Incoherent Ground Motion Input

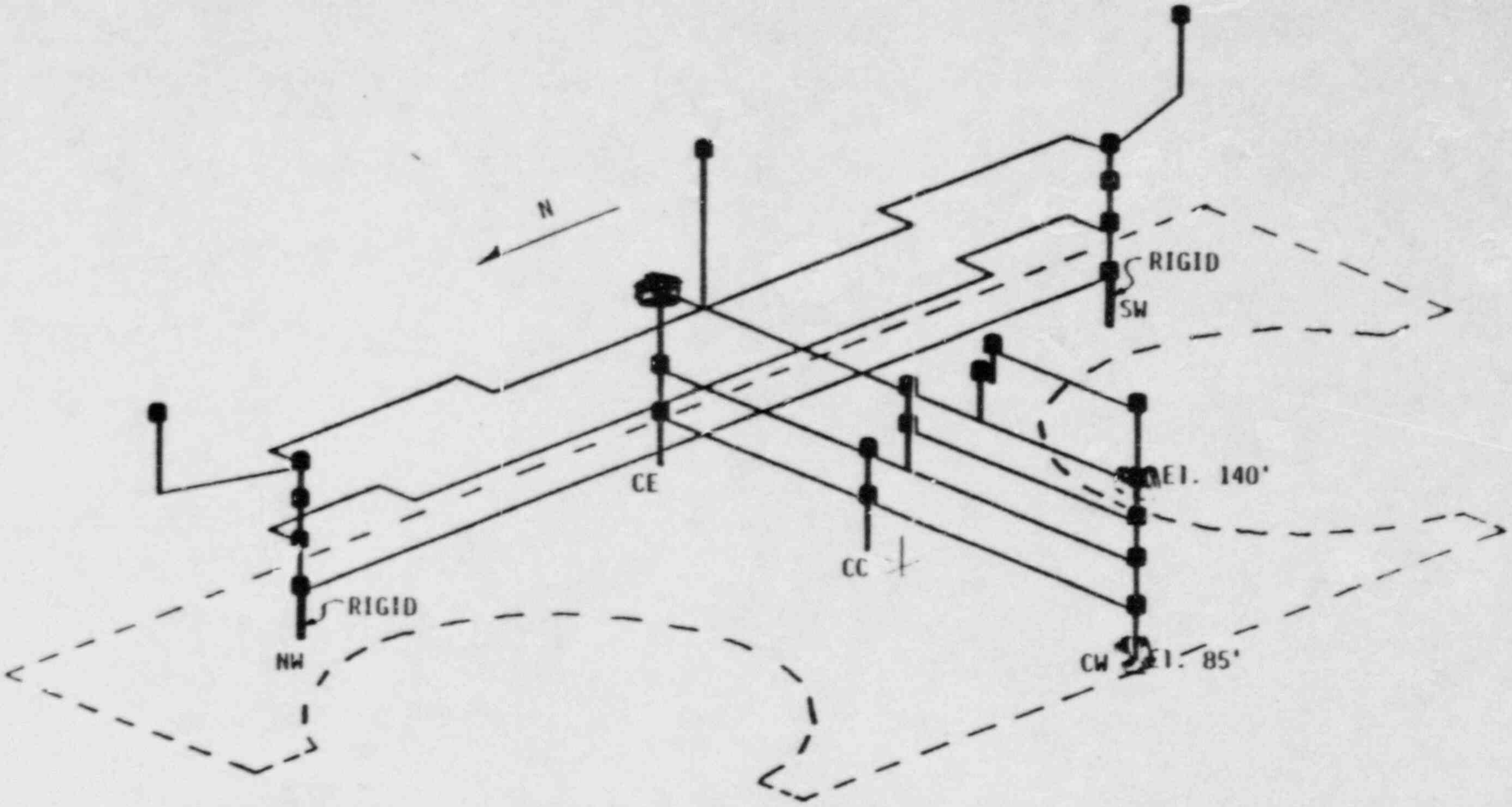


Figure 4-2 SSI Model for Auxiliary Building

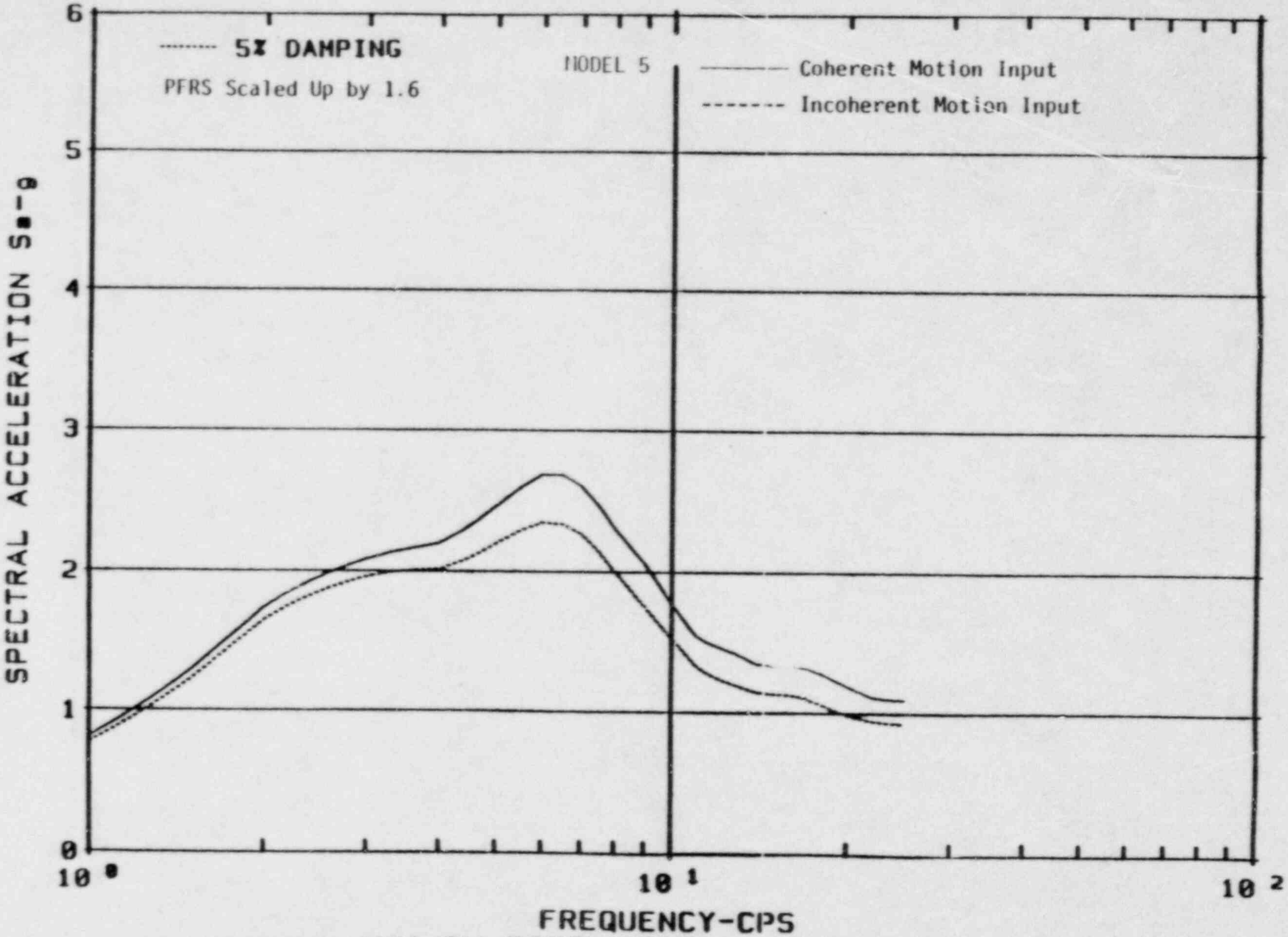


Figure A-29 AUX EW CORE WEST EL 85'-0"

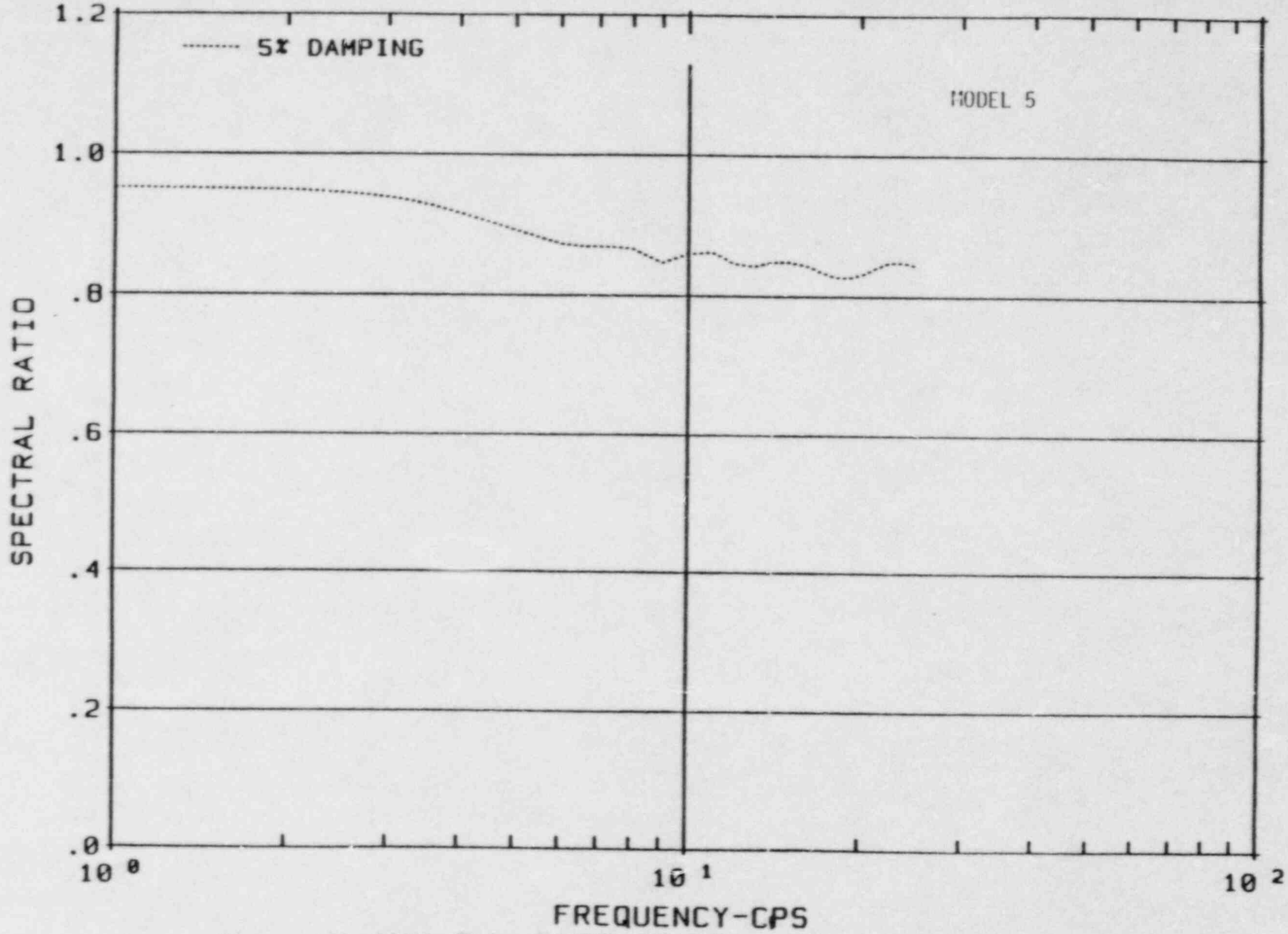


Figure 5-29 AUX EW CORE WEST EL 85'-0"

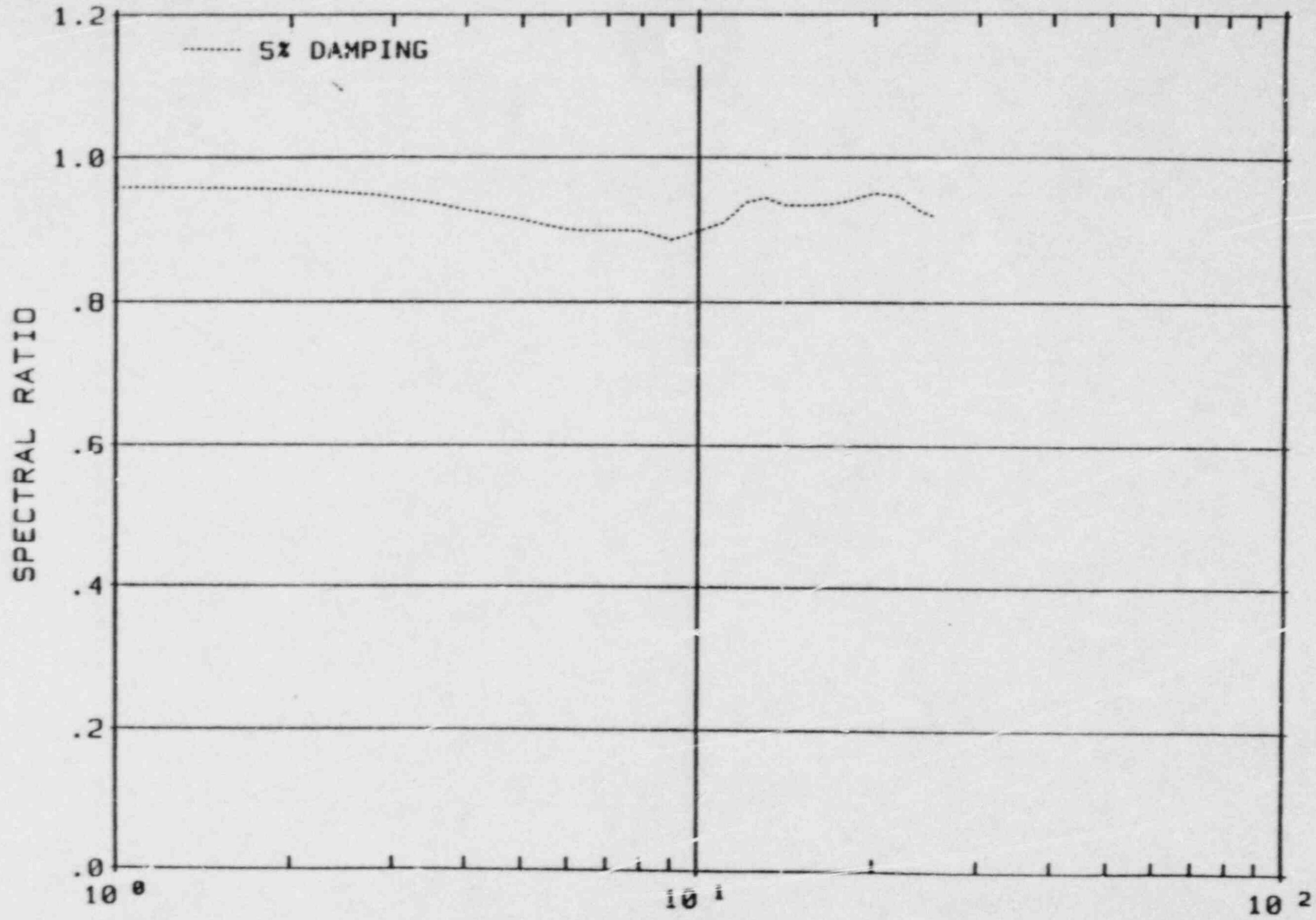


Figure 5-7 AUX NS CORE WEST EL 140'-0"

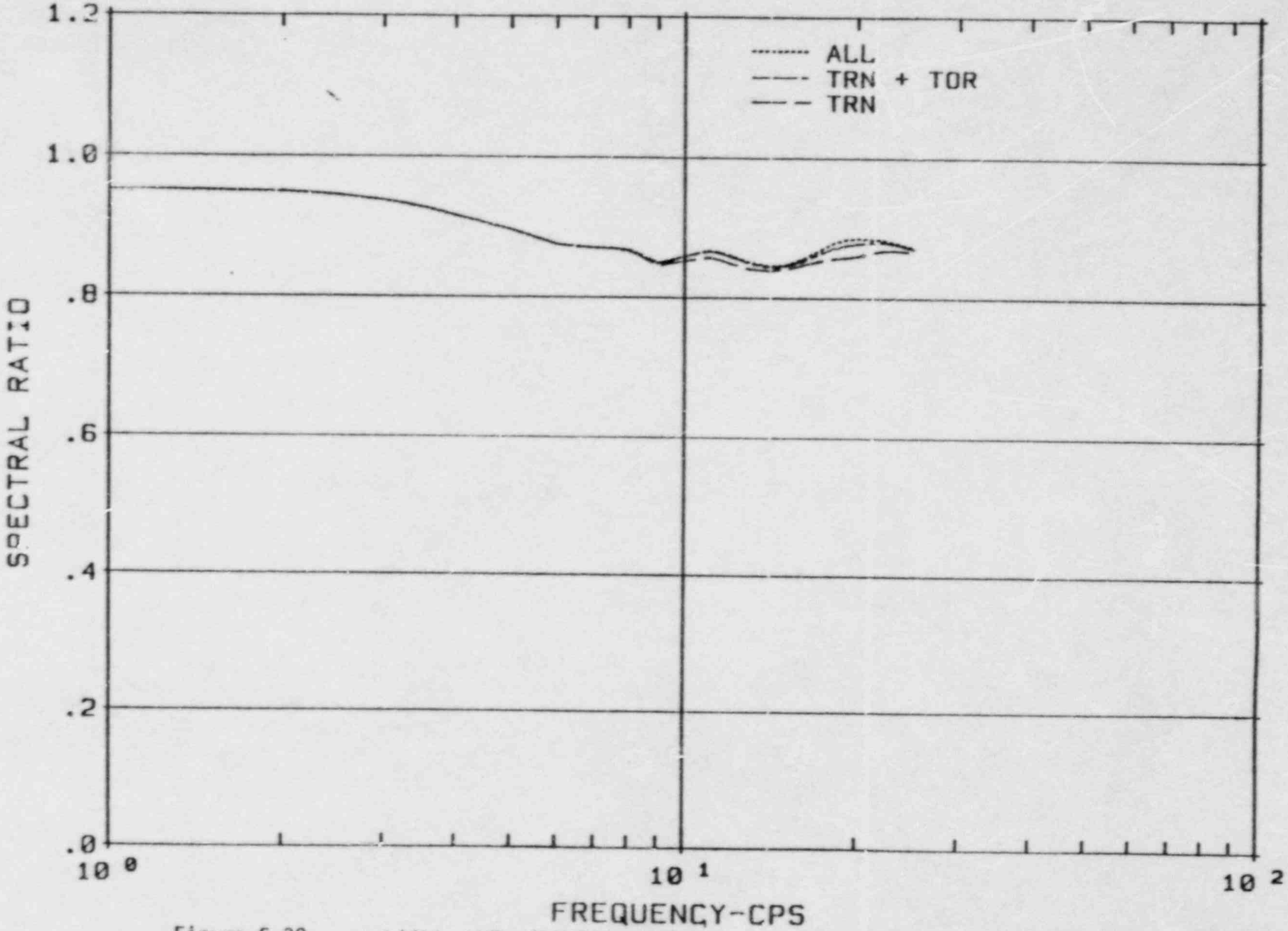


Figure 5-32 AUX NS CORE WEST EL 85'-0"

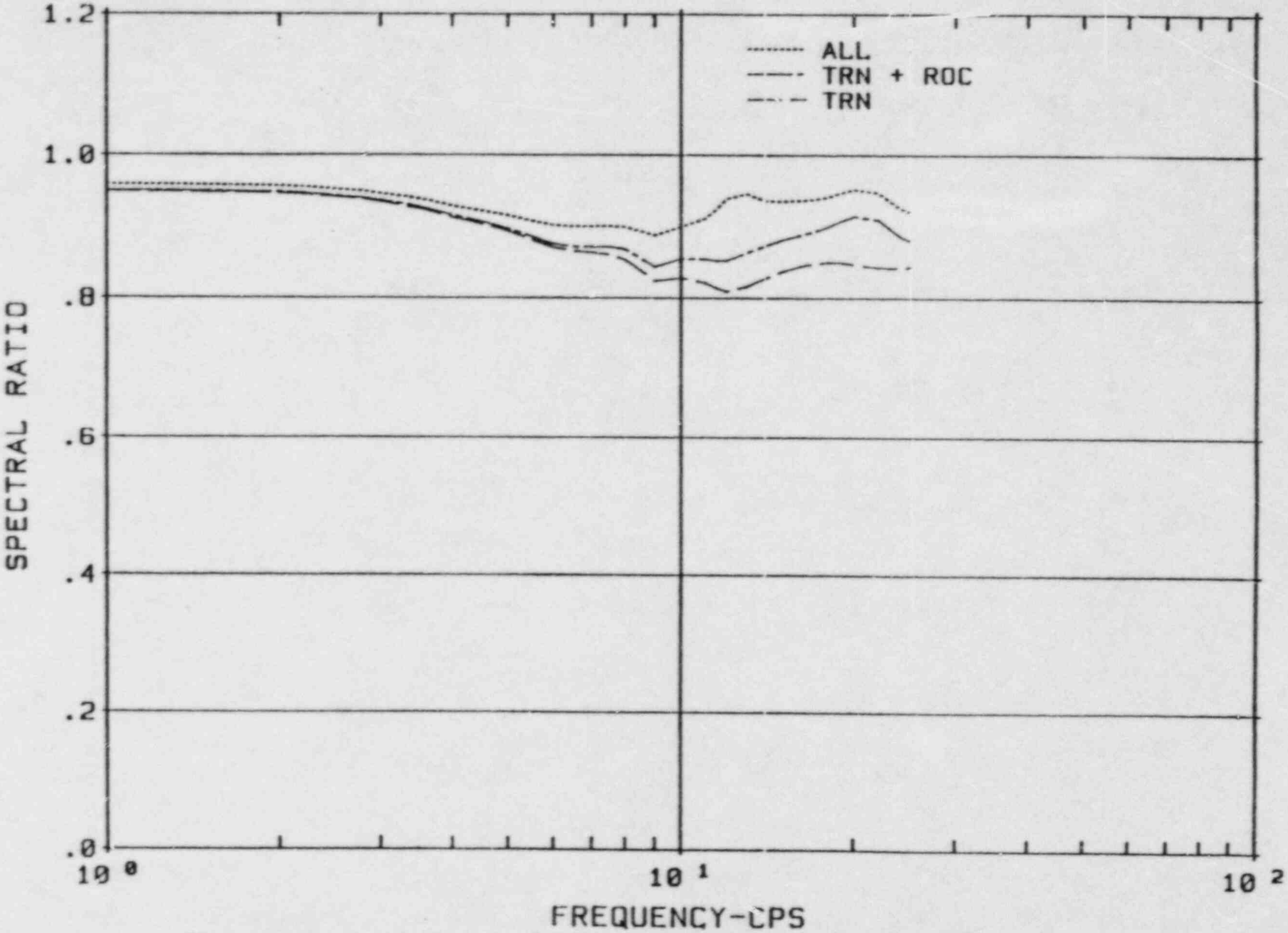
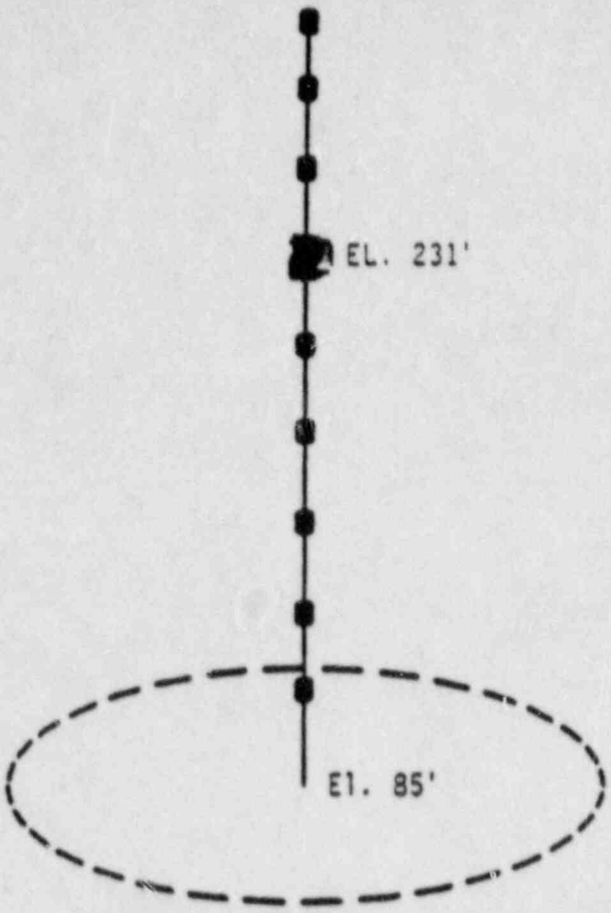
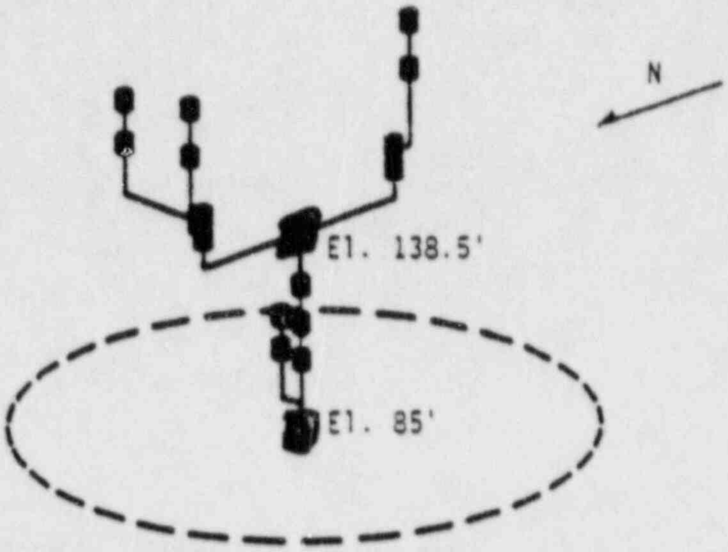


Figure 5-31 AUX NS CORE WEST EL 140'-0"



(a) Containment Shell



(b) Internal Structure

Figure 4-1 SSI Model for the Containment Structure

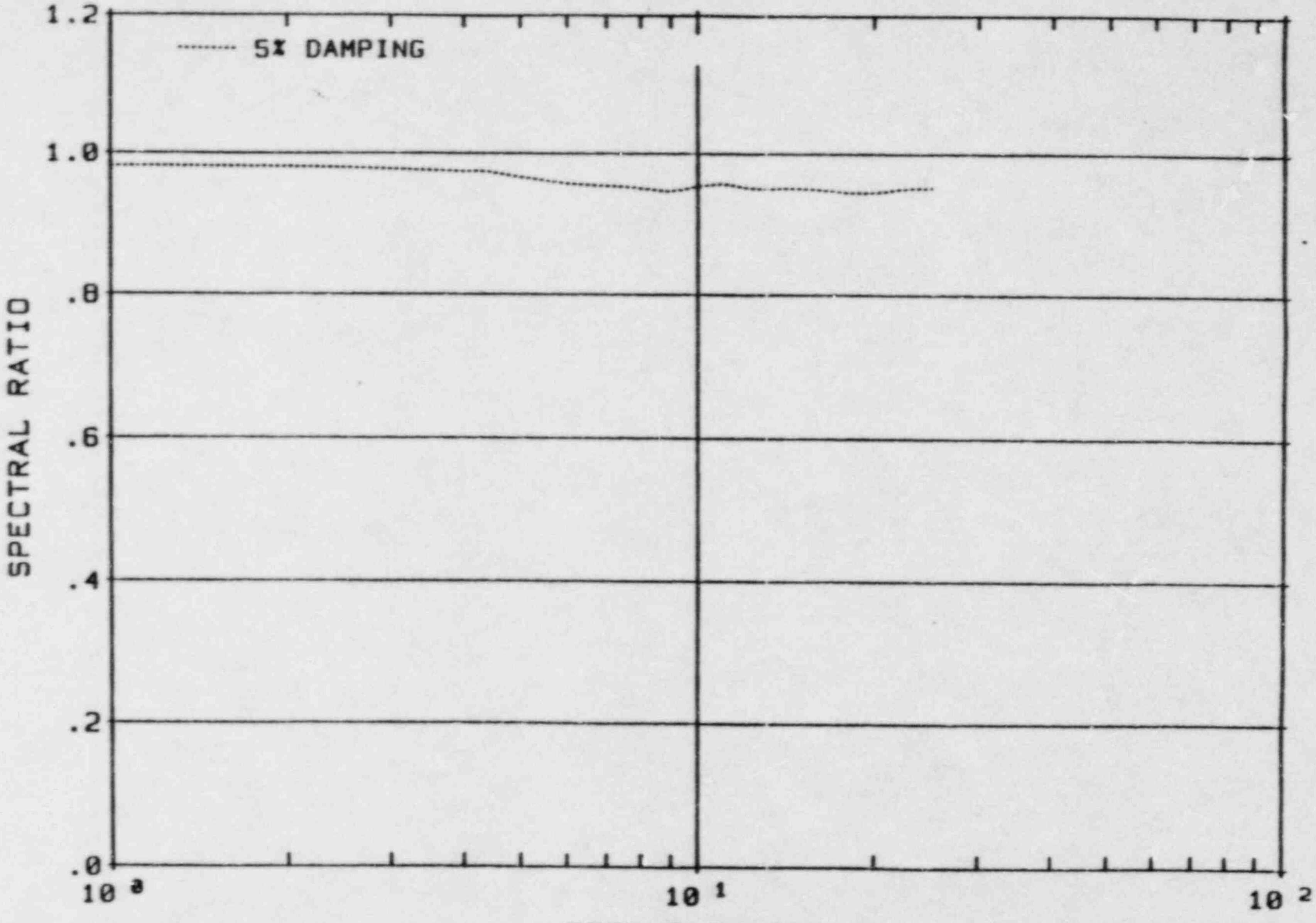


Figure 5-2 CONT EW BASE CENTER EL 85'-0"

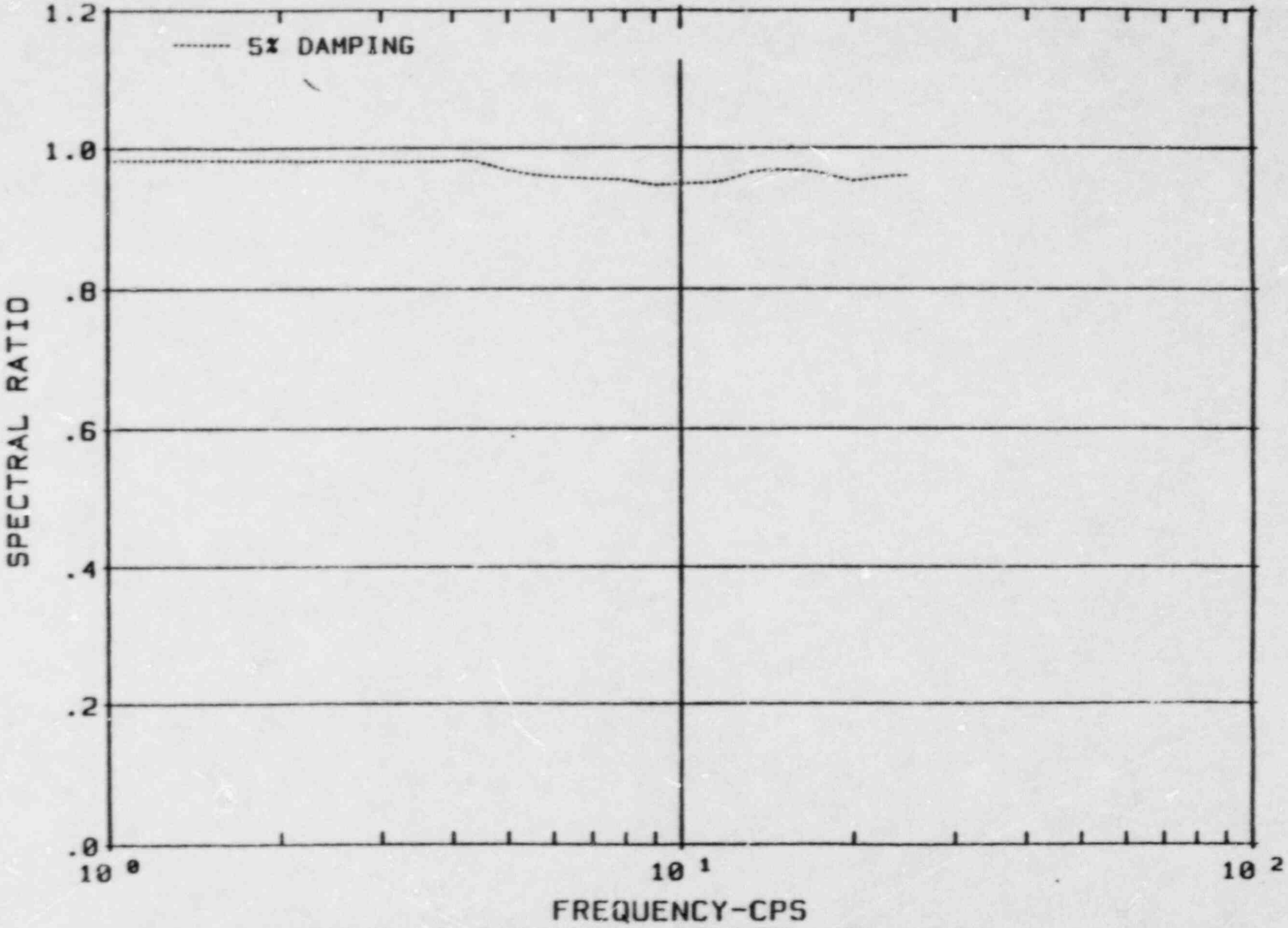


Figure 5-3 CONT NS INTERNAL CENTER EL 138'-6"

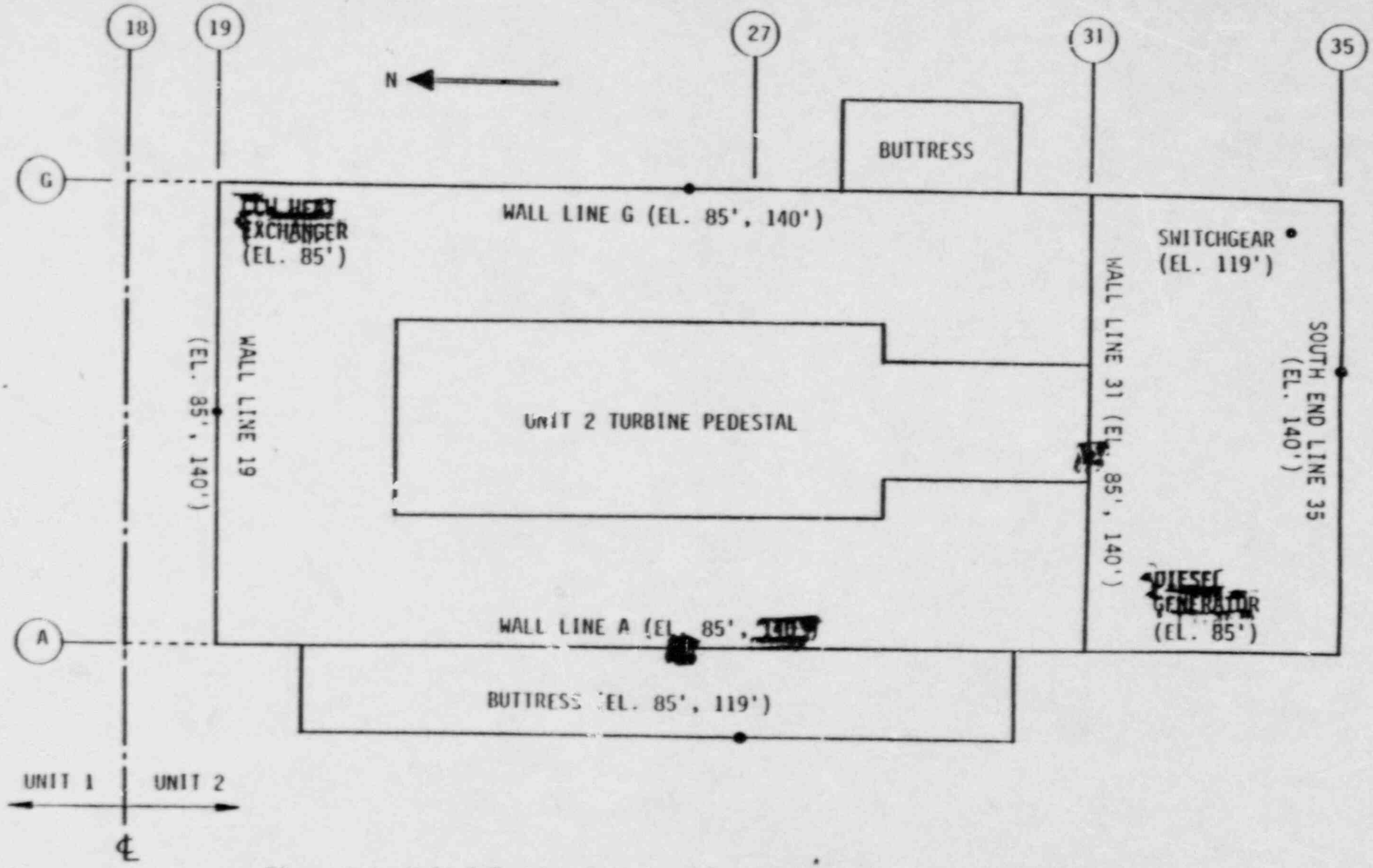


Figure 5-2 Unit 2 Turbine Building Locations where SSI Responses are Provided

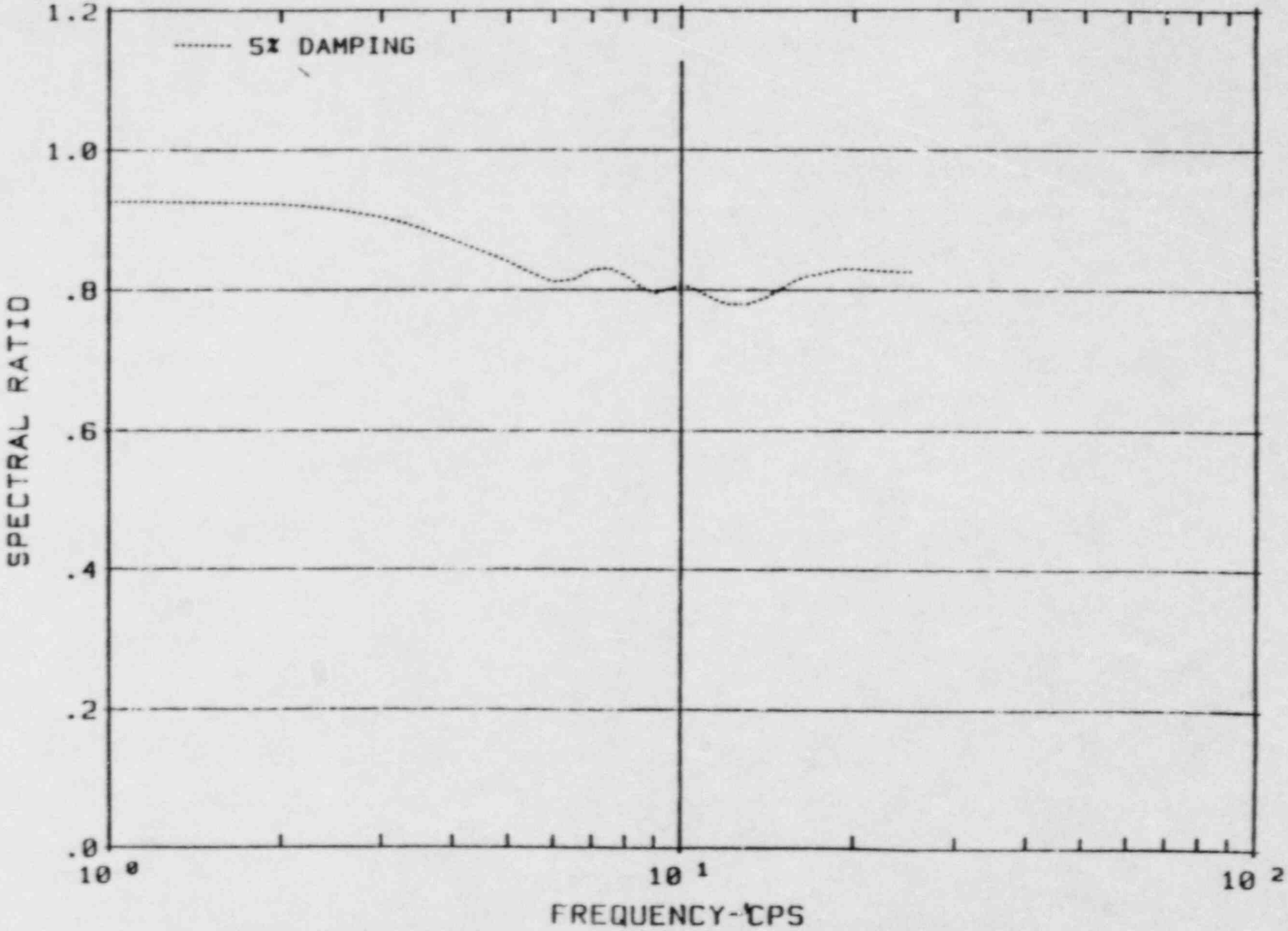


Figure 5-21 TURB-2 NS WALL LINE 31 EL 140'-0"

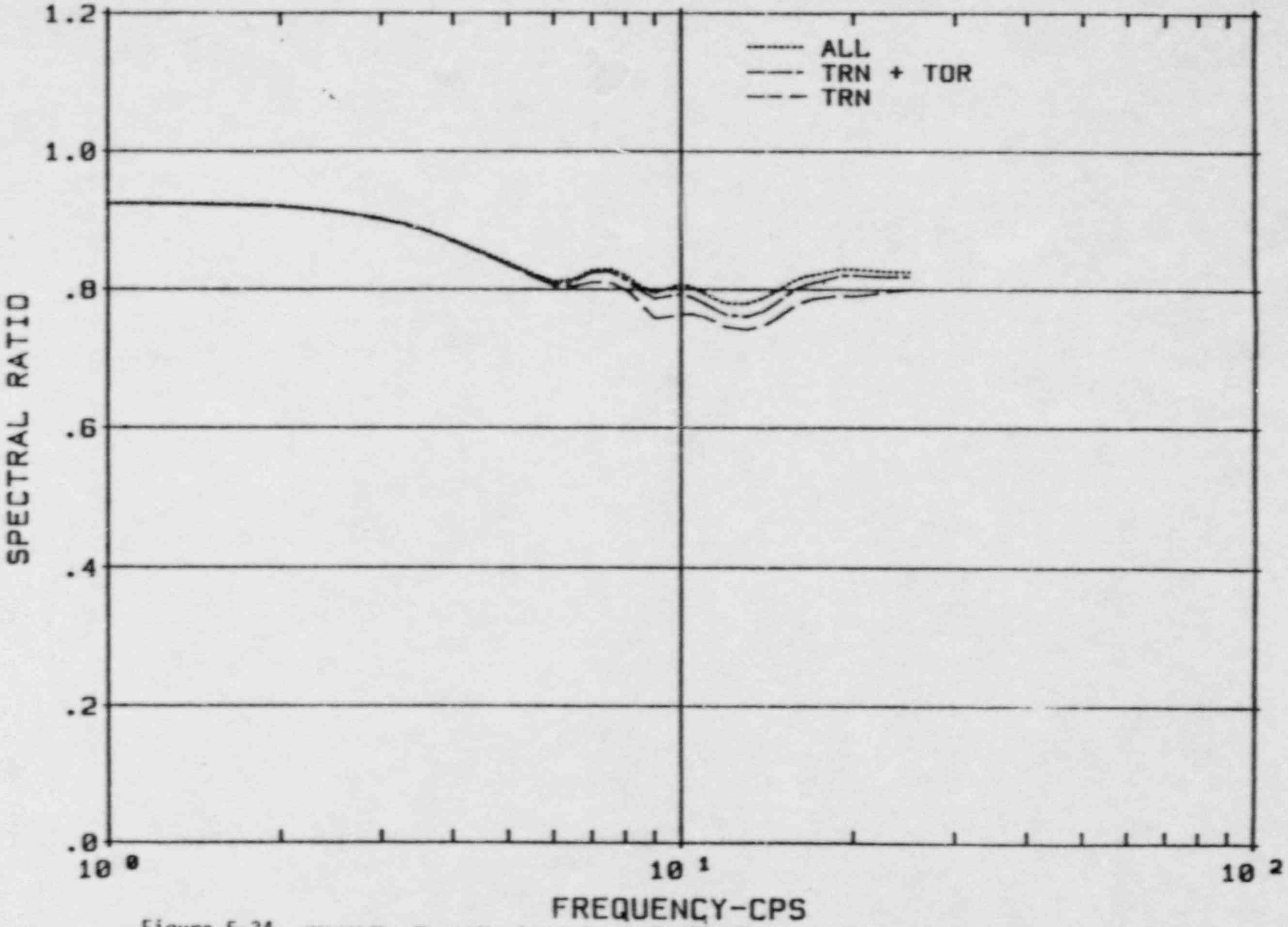


Figure 5-34 TURB-2 NS WALL LINE 31 EL 140'-0"

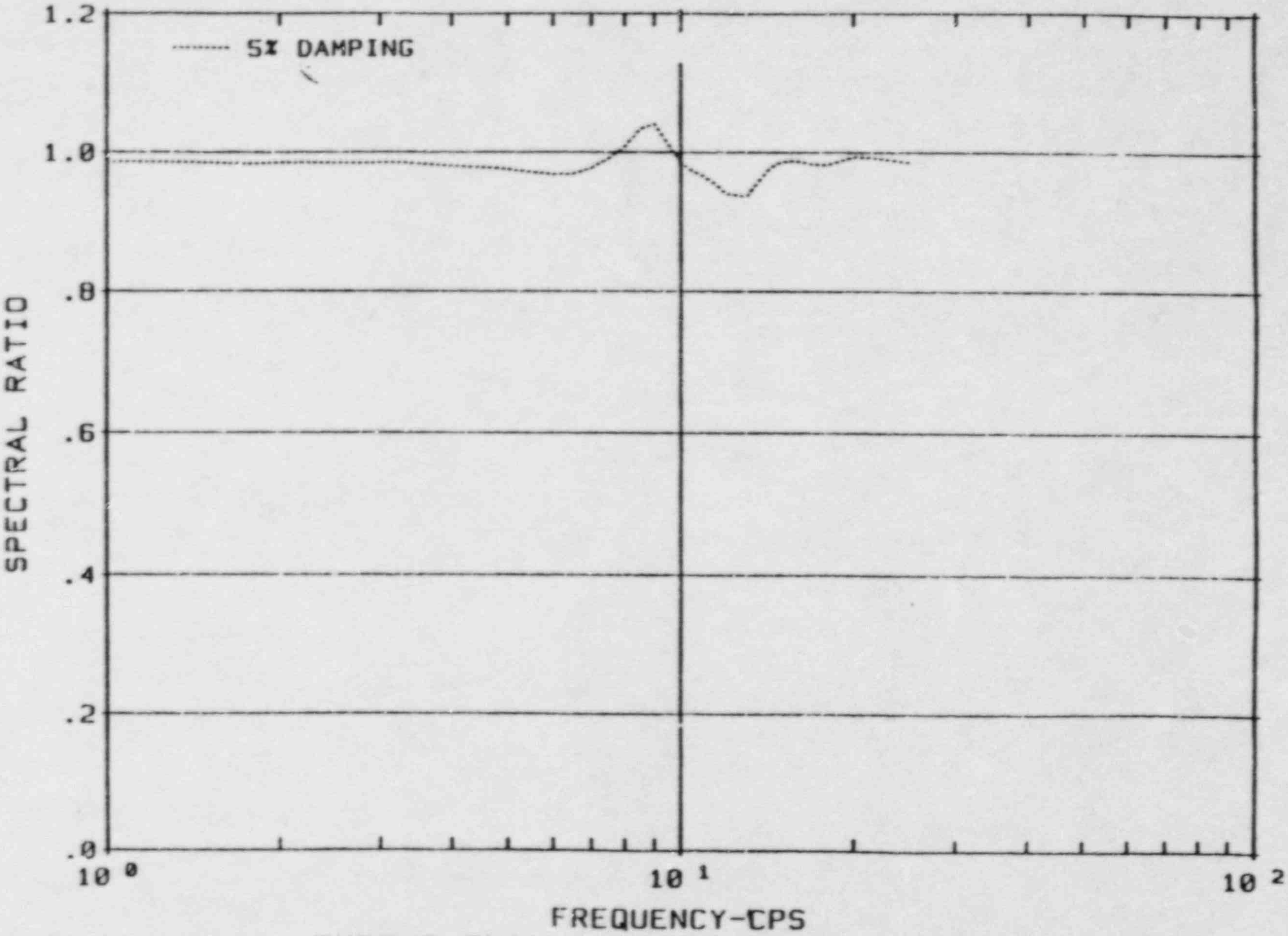


Figure 5-22 TURB-2 EW WALL LINE 31 EL 140'-0"

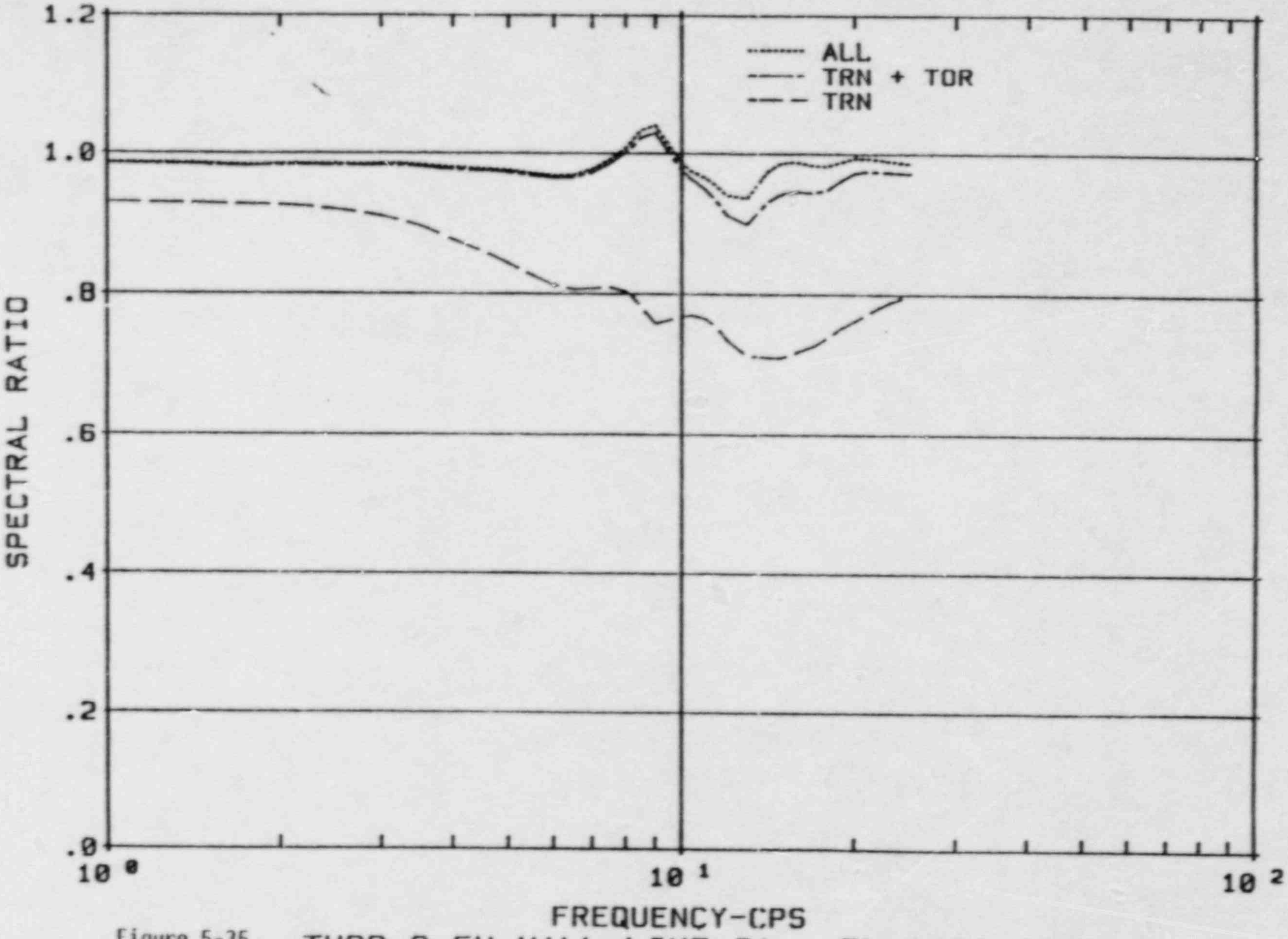


Figure 5-35 TURB-2 EW WALL LINE 31 EL 140'-0"

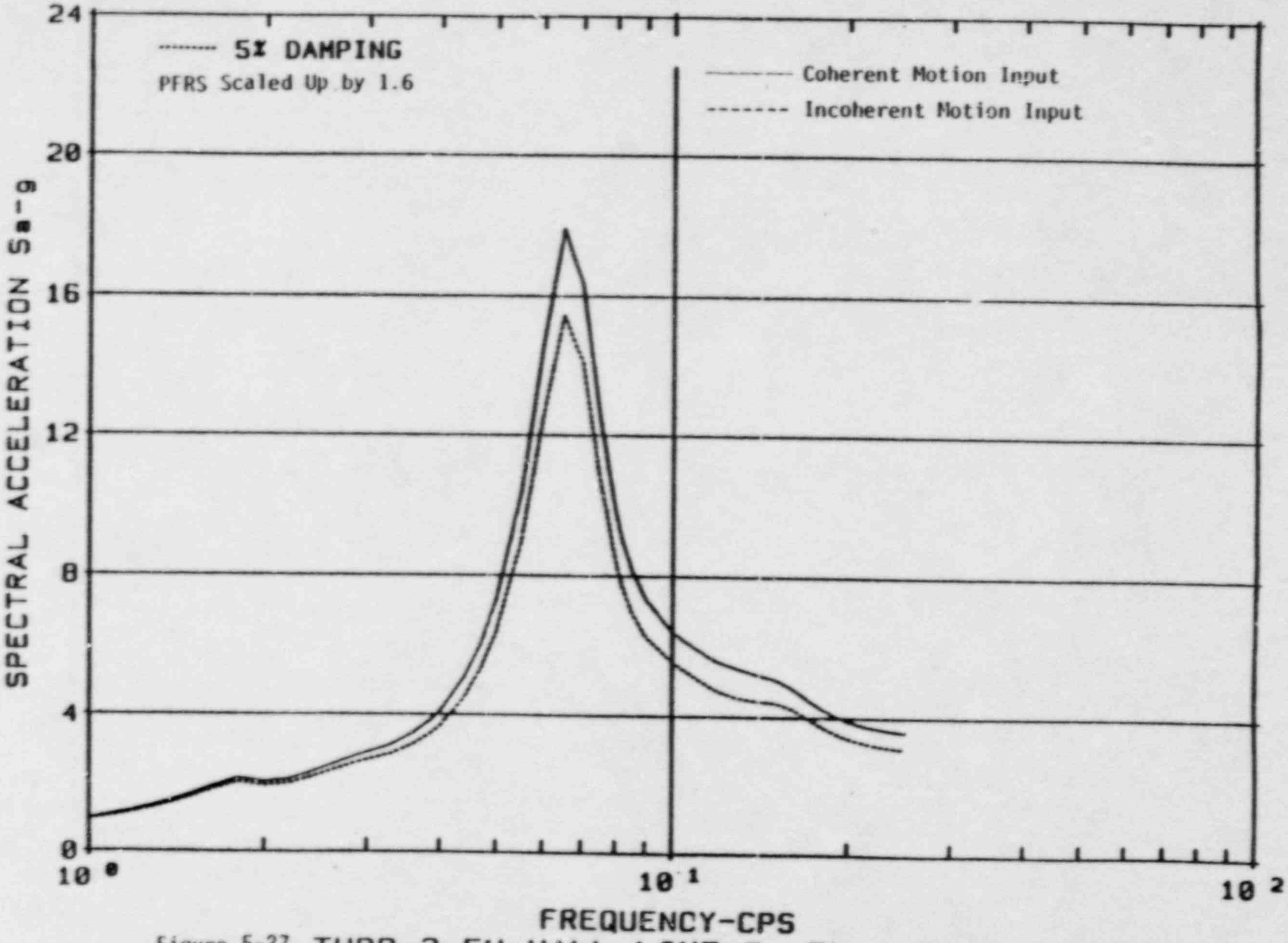


Figure 5-27 TURB-2 EW WALL LINE G EL 140'-0"

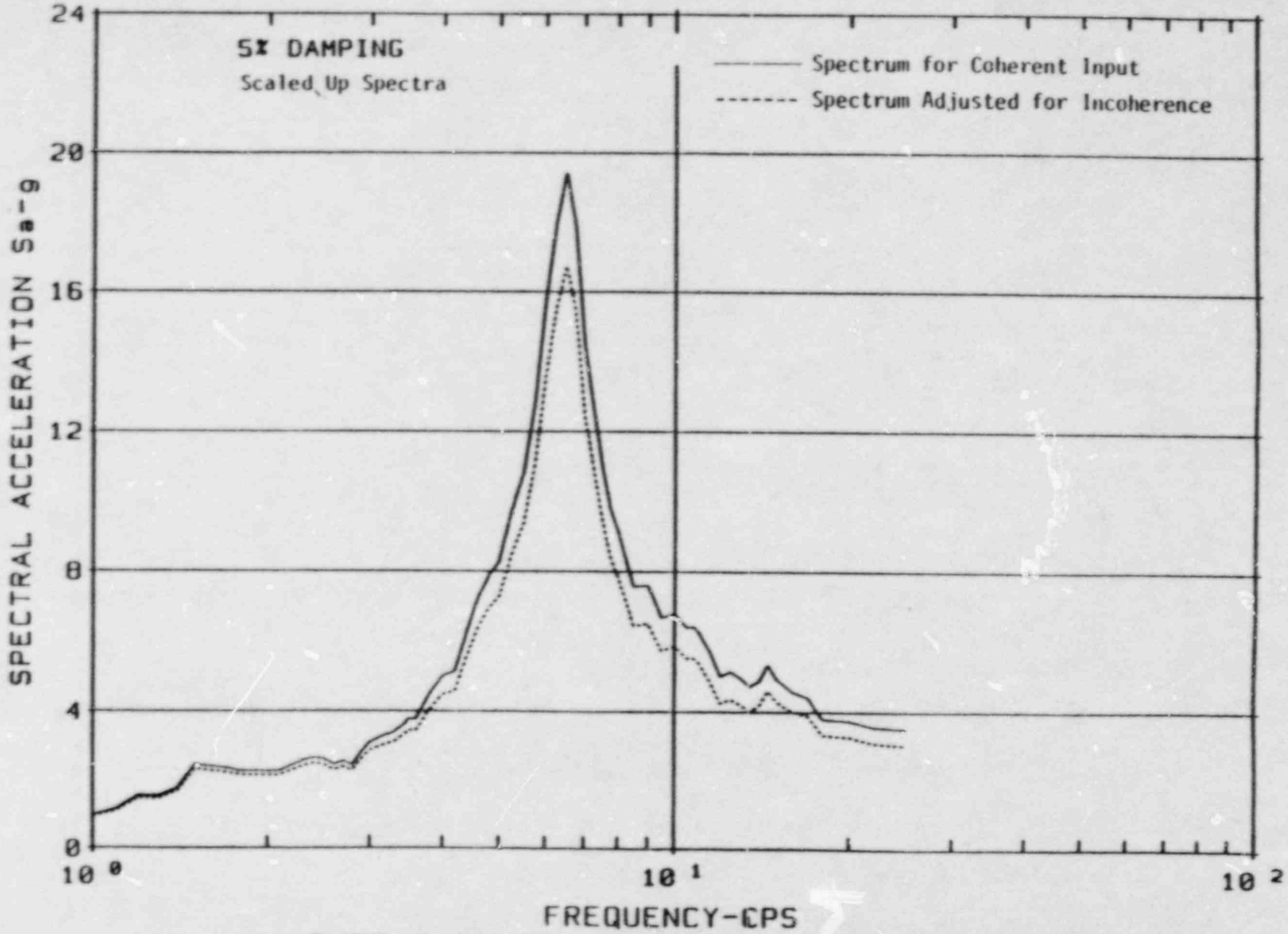
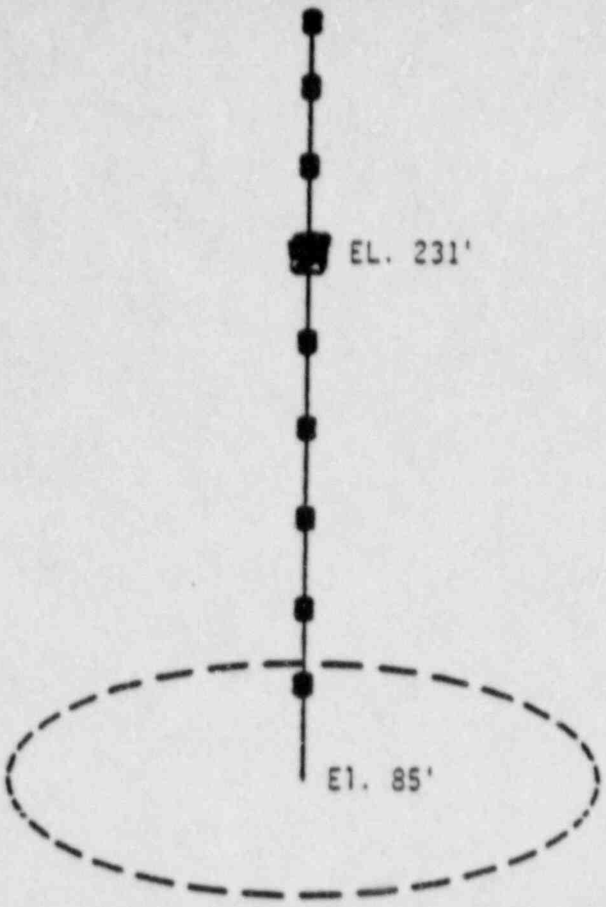


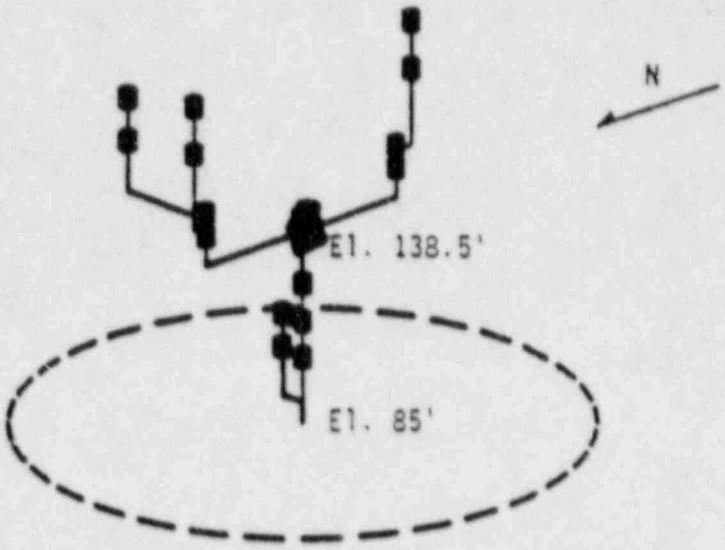
Figure 6-3 TURB-2 EW WALL LINE G EL 140'-0"

PART 3

NONLINEAR ANALYSES FOR CONTAINMENT BASE UPLIFT RESPONSE FOR DEVELOPING THE RESPONSE ADJUSTMENT FACTOR



(a) Containment Shell



(b) Internal Structure

Figure 3-1 SSI Model for the Containment Structure

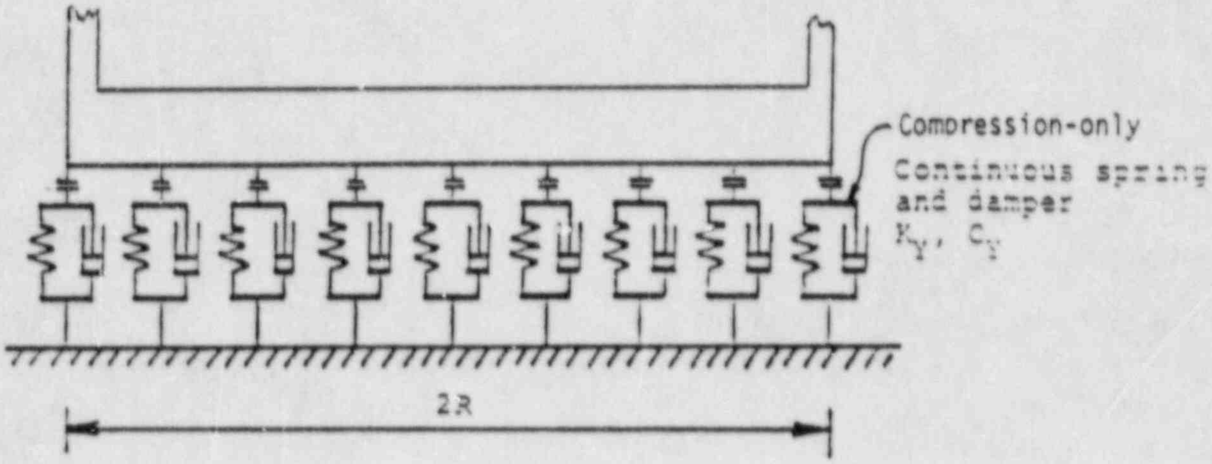
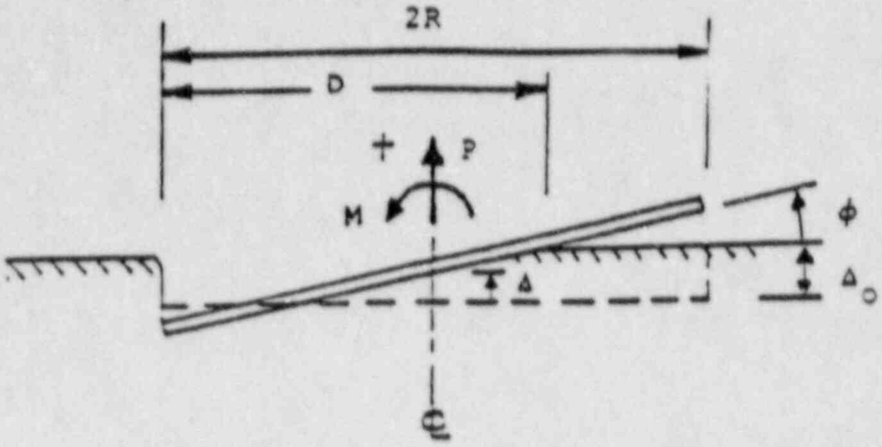
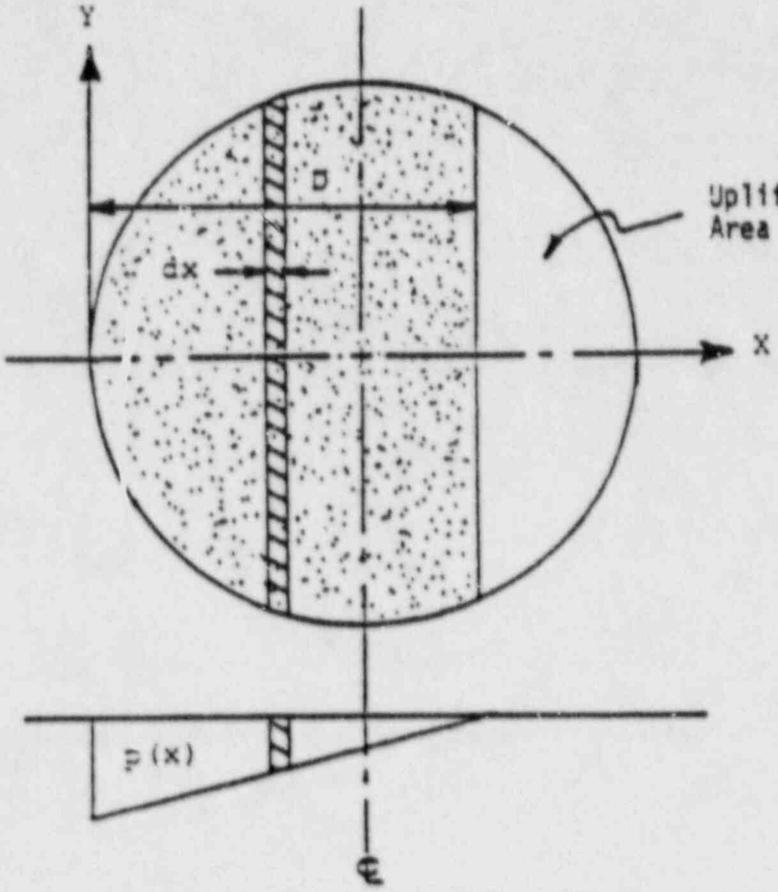


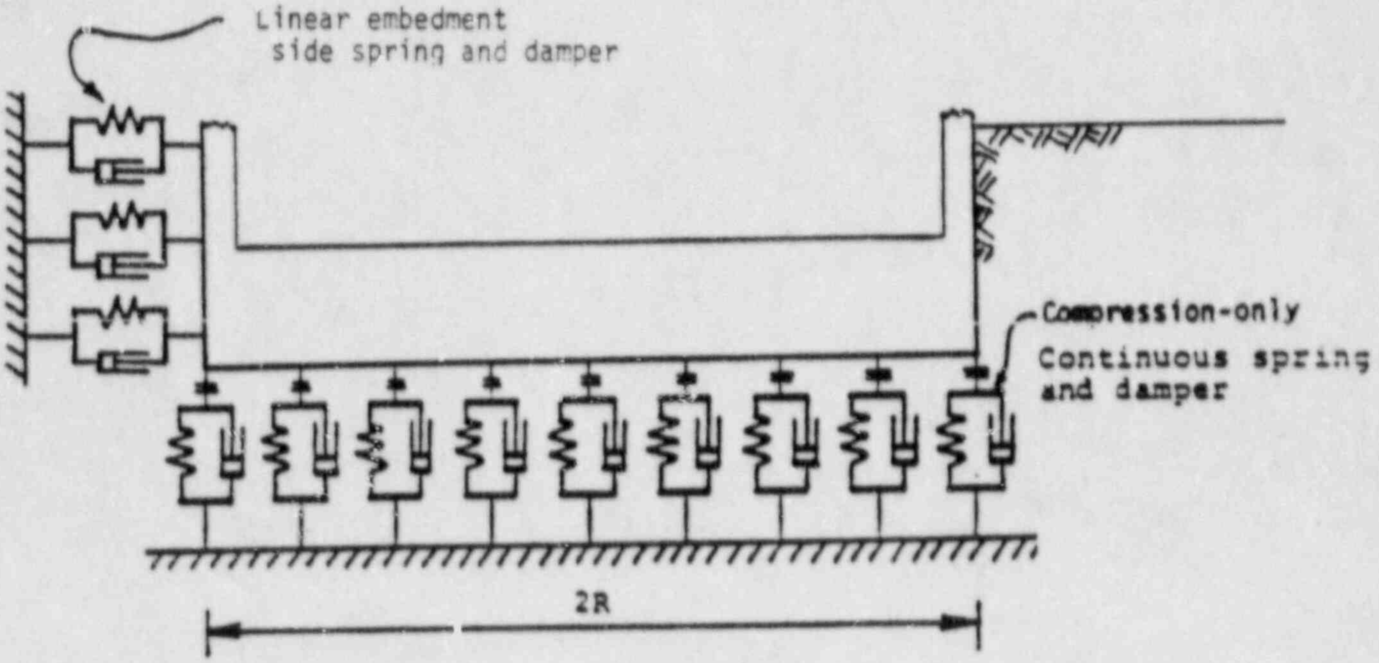
Figure 2-1 Winkler Foundation Model for Surface-Supported Basemat



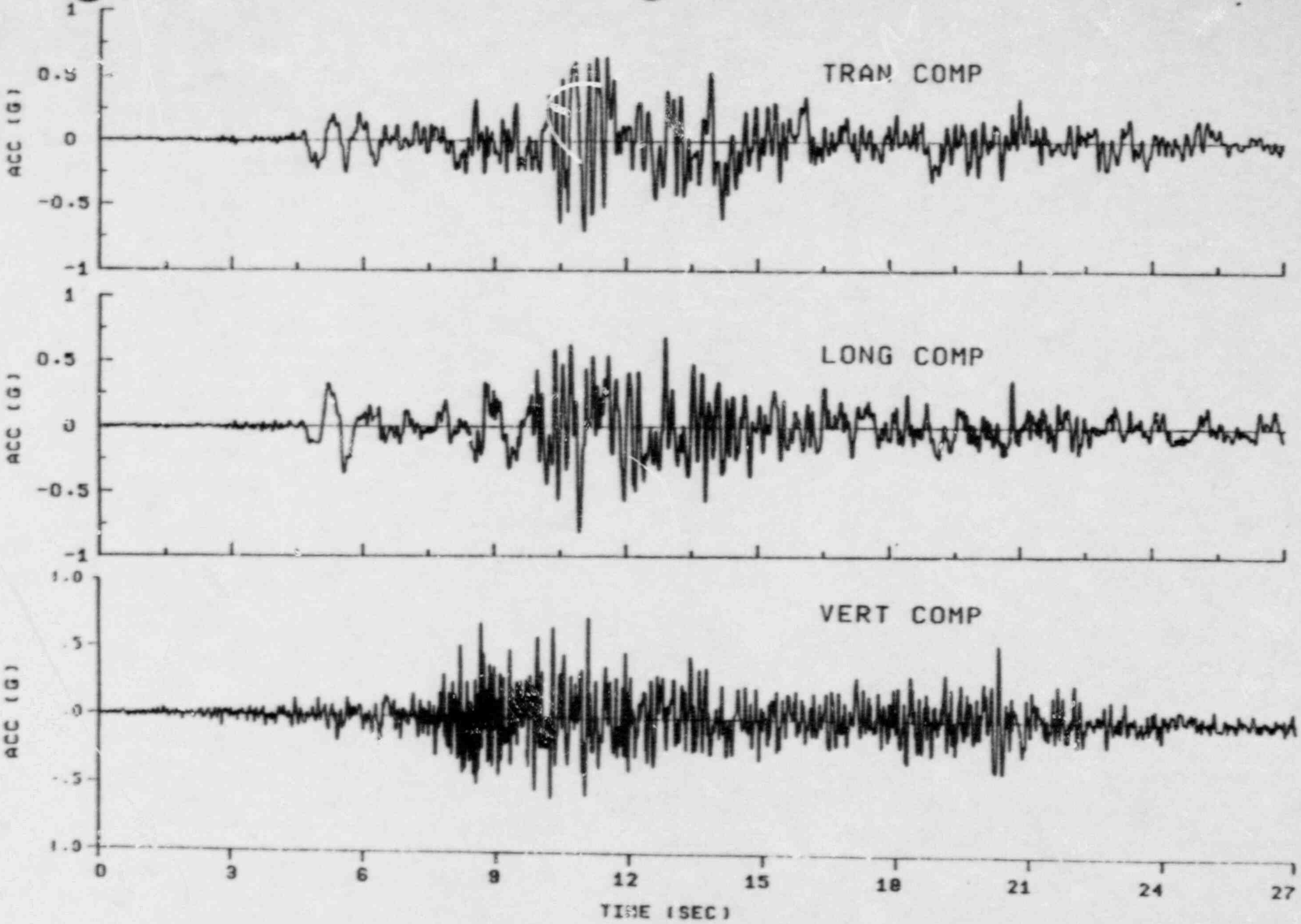
Configuration of circular basemat at uplifted position



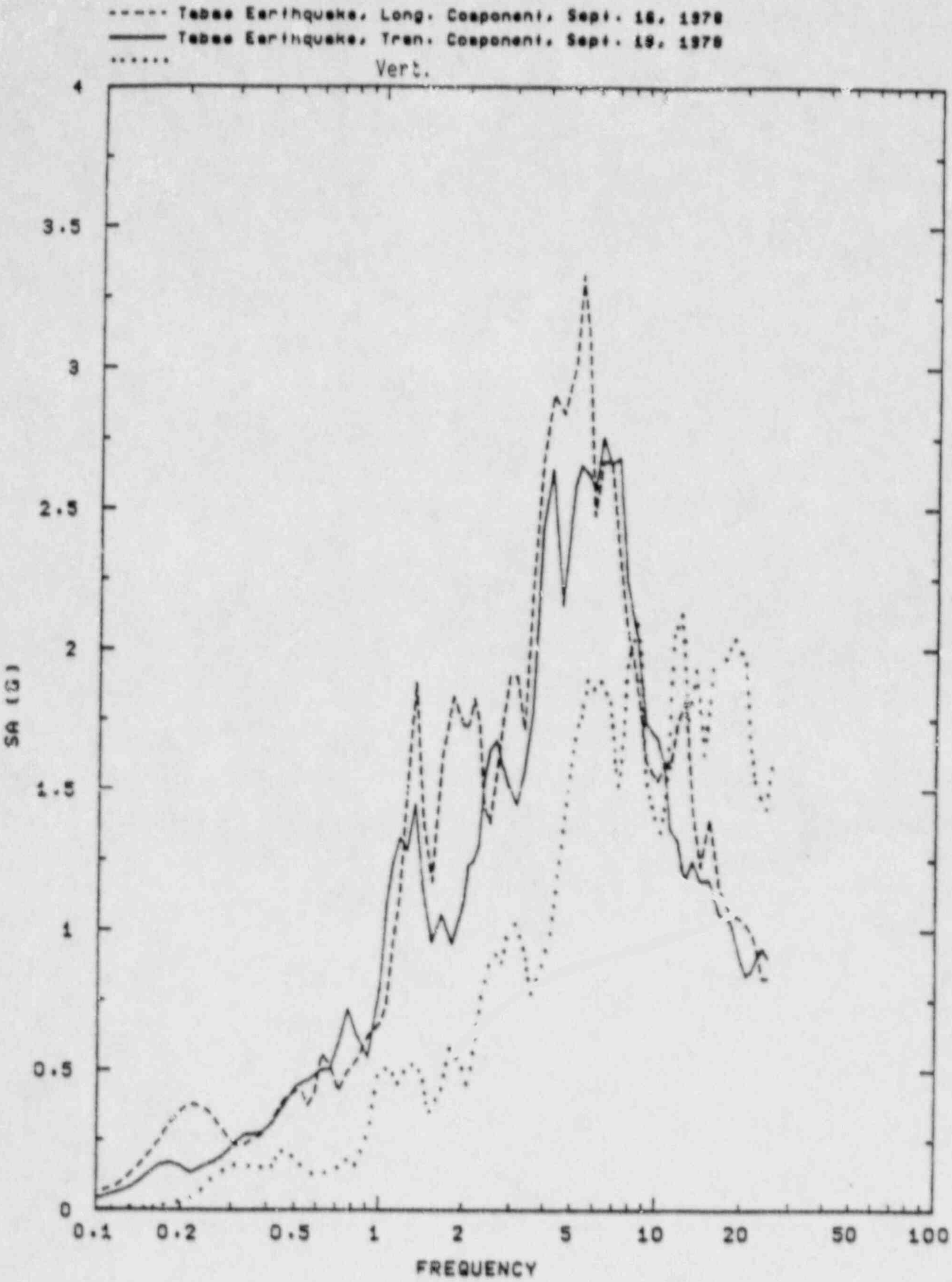
Pressure diagram for circular basemat at uplifted position



Winkler Foundation Model for Uplift Analysis



Acceration Time Histories of the Tabas Recording of the Tabas Earthquake



5% Damping Response Spectra of Tabas Records of Tabas Earthquake

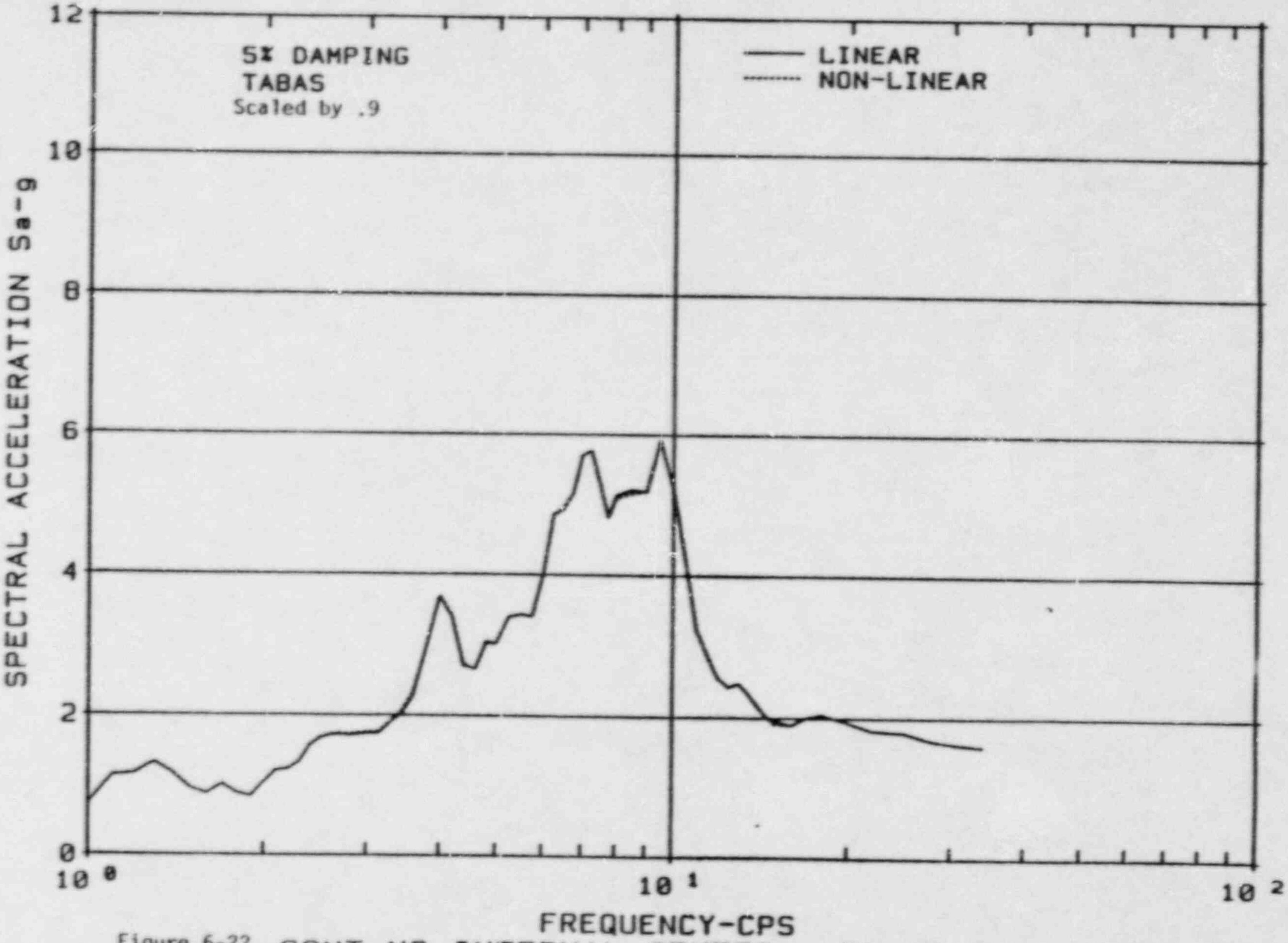


Figure 6-22 CONT NS INTERNAL CENTER EL 138'-6"

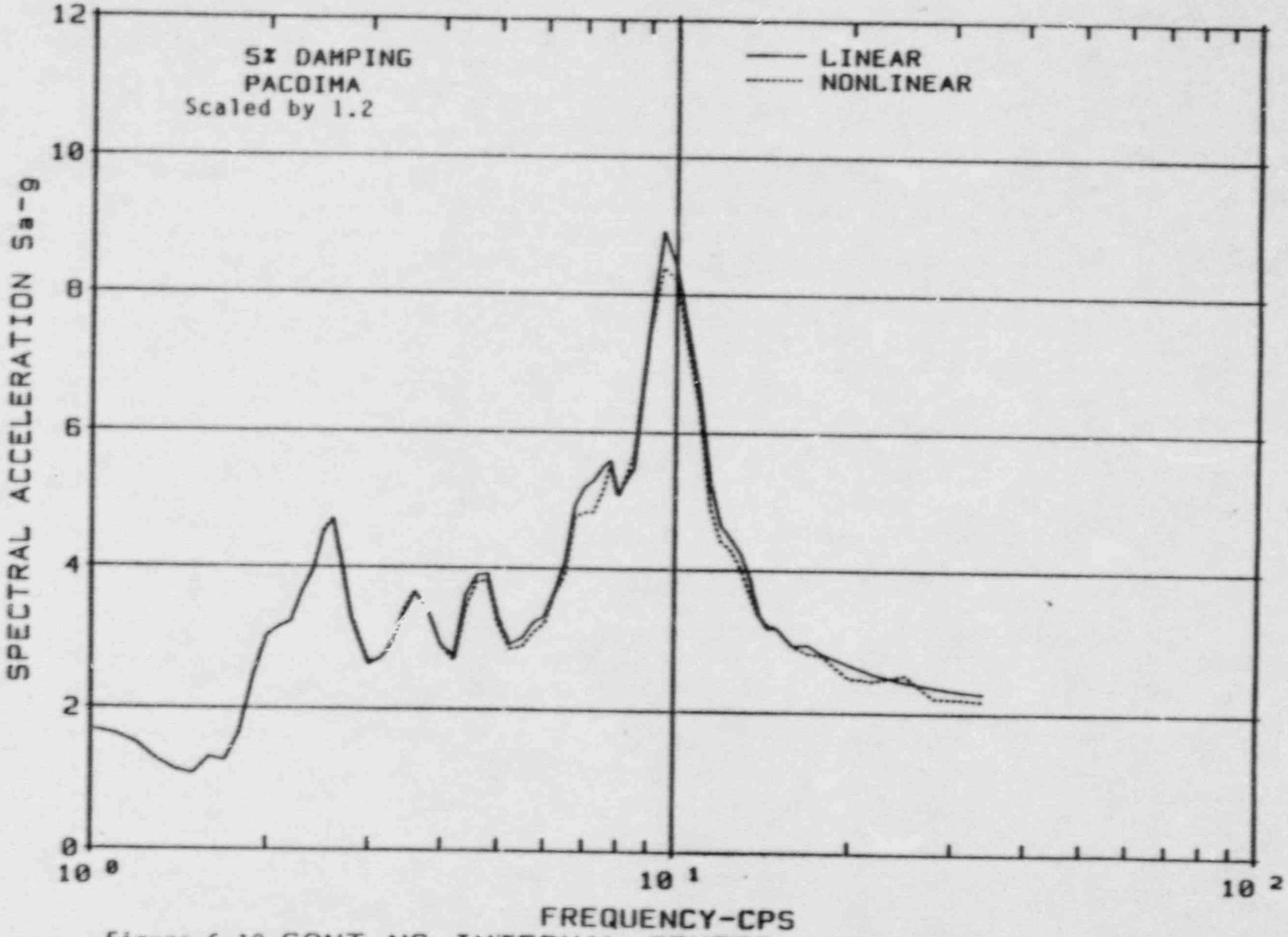


Figure 6-10 CONT NS INTERNAL CENTER EL 138'-6"

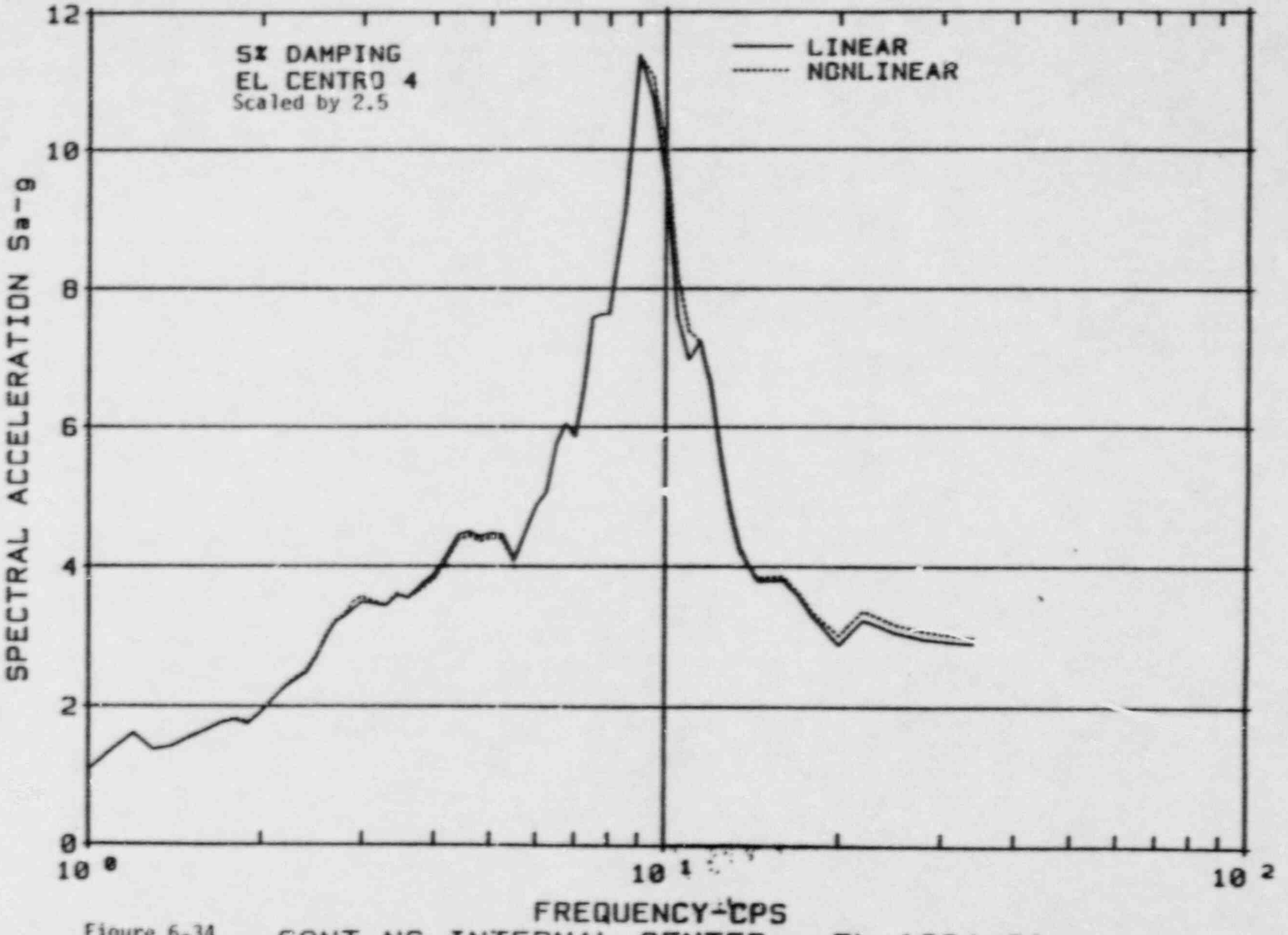


Figure 6-34 CONT NS INTERNAL CENTER EL 138'-6"

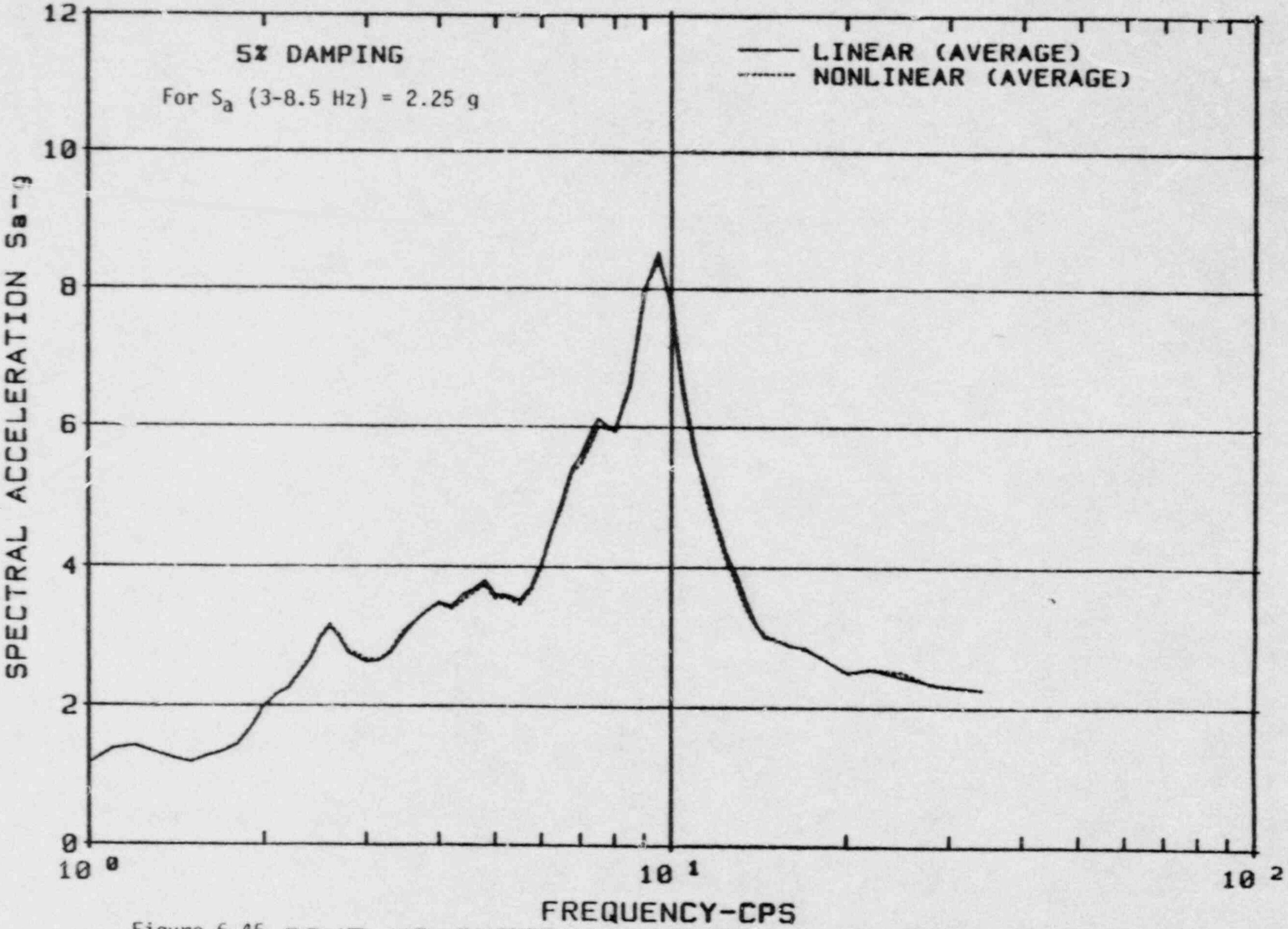


Figure 6-45 CONT NS INTERNAL CENTER EL 138'-6"

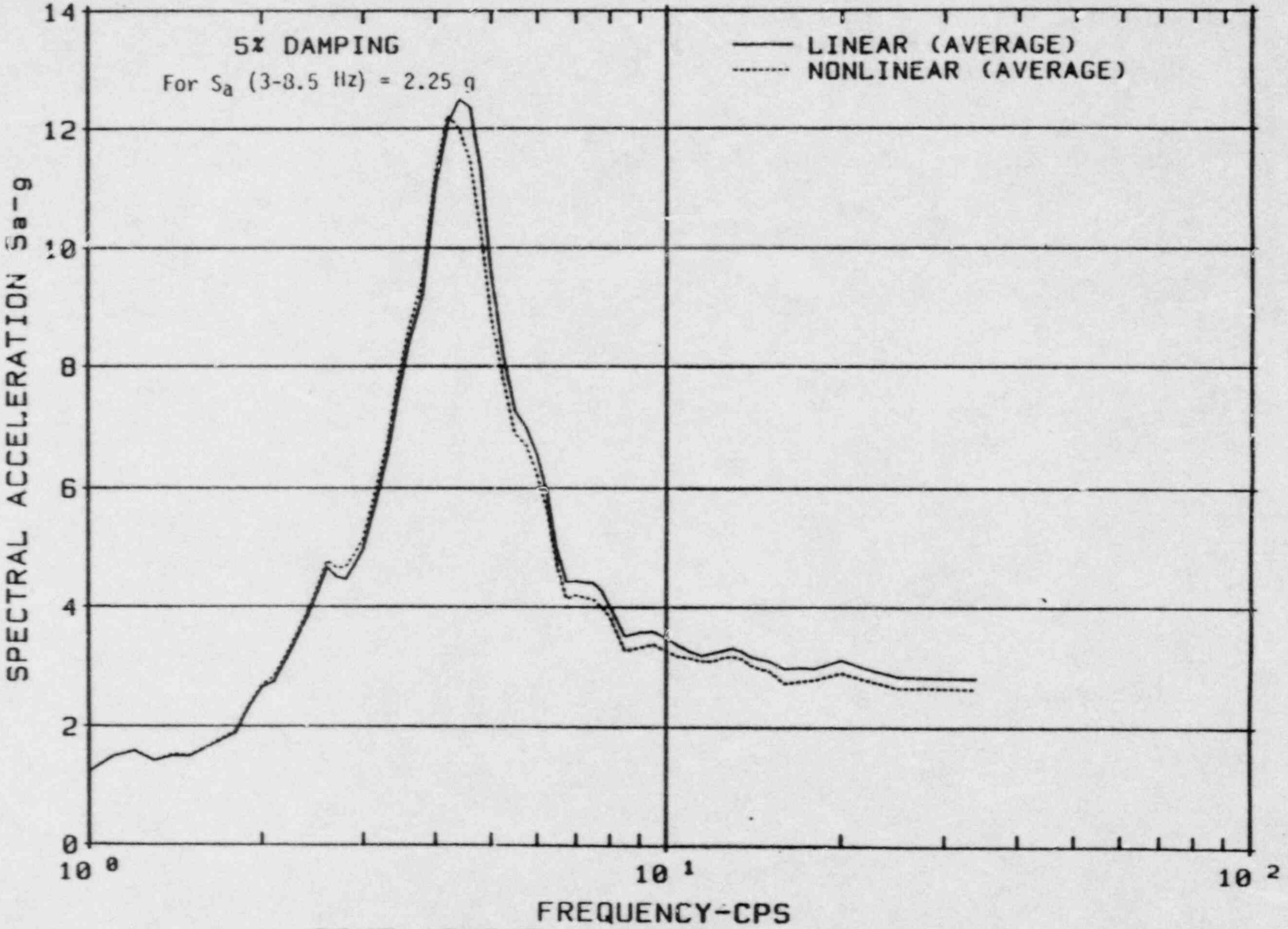


Figure 6-42 CONT NS SHELL CENTER EL 231'-0"