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IN THE MATTER OF:

PACIFIC GAS & ELECTRIC COMPANY

(Diablo Canyon Units 1 and 2)

Docket Nos. 50-275
50-323

Place Avila Beach, California

6472

Date 20 December 1978 **Pages**72 - 6688

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

In the matter of:	
PACIFIC GAS & ELECTRIC COMPANY	Docket Nos. 50-275 50-323
(Diablo Canyon Units 1 and 2)	

Cavalier Room,
San Luis Bay Inn,
Avila Beach, California.

Wednesday, December 20,1978

The hearing in the above-entitled matter was reconvened, pursuant to adjournment, at 8:55 a.m.

BEFORE:

ELIZABETH BOWERS, Esq., Chairman,
Atomic Safety and Licensing Board.

DR. WILLIAM E. MARTIN, Member.

GLENN O. BRIGHT, Member.

APPEARANCES:

On behalf of Applicant, Pacific Gas & Electric Company:

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MALCOLM H. FURBUSH, Esq. and PHILIP CRANE, Esq.,
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On behalf of the Joint Intervenors:

DAVID S. FLEISCHAKER, Esq., Suite 602,
1025 15th Street, N.W., Washington, D.C.

STEPHEN KRISTOVICH, Esq., Center for Law in
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On behalf of the Regulatory Staff:

JAMES R. TOURTELLOTTE, Esq., MARC STAENBERG, Esq.
and EDWARD KETCHEN, Esq., Office of Executive
Legal Director, U.S. Nuclear Regulatory
Commission, Washington, D.C. 20555.

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CONTENTS

P R O C E E D I N G S

MRS. BOWERS: We'd like to begin.

Do you have further direct, Mr. Norton?

MR. NORTON: Yes, Mrs. Bowers.

Whereupon,

JOHN A. BLUME,
H. BOLTON SEED,
GERALD FRAZIER, and
C. ALLIN CORNELL

resumed the stand on behalf of the Applicant and, having been previously duly sworn, were examined and testified further as follows:

MR. NORTON: Unfortunately, the portion of the summary that was given in this matter was done last Saturday afternoon. This is now Wednesday, so I would like at this time for Dr. Blume to very briefly summarize his last Saturday's summary, to kind of get everybody back aboard in just a minute or two, and complete the summary of his direct testimony.

DIRECT TESTIMONY (Resumed)

WITNESS BLUME: Last Saturday I provided some important definitions and terms. I gave an overview of the three sets of design criteria used for Diablo Canyon over the last decade or so. Actually there have been four sets if one looks upon the Newmark curves and the Blume curves as

eb2

independent sets, which they are in practice.

I described the basis for and the criteria of each set. I pointed out that the original plant design provides significant strength for the Hosgri because of two basic factors, among many others, and those two factors are the allowable damping values which were used in the early days during design as compared to what they are today, and the second one had to do with the central hump caused by the postulated non-fault-associated EArthquake D.

I also discussed effective versus instrumental acceleration and reasons for using effective values much less than instrumental peak values.

In this regard I would like to repeat, for emphasis, the four items that applied to the solution of basically all engineering problems:

Number one, observation of what has occurred and has not occurred in actual events and in nature.

Number two, theory and analysis.

Number three, testing and experimentation.

And four, engineering judgment.

Of course there are combinations of these things, and all four have to be reconciled.

The excellent earthquake performance of the major San Francisco buildings close to a fault moving under an 8.3M earthquake some ten miles away is but one example of

eb3

observation. I showed slides of that the other day. Fort Point, only about five miles away from the fault, would, like all the other buildings, fail to pass even the most modern, current seismic building code which, in turn, would be a fraction of the Diablo Canyon design model.

Because of time limitations last Saturday, I showed one Viewgraph that I believe one cannot understand very well without the aid of one that I failed to show. For that reason I would like to show both of these again.

(Slide.)

This Figure 7 from the written testimony I've shown last Saturday briefly, and what it is is a composite drawing consisting of the results from three different probabilistic studies of peak acceleration at the site under the assumption that 7.5M magnitude can be obtained on the Hosgri Fault.

I am now going to switch over to the next slide and then come back to this one.

(Slide.)

MR. NORTON: Excuse me, Dr. Blume. We have to identify those as to where they're from. The record [illegible] indicate-- When you showed it last Saturday, [illegible] indicate which slide it is from the testimony.

WITNESS BLUME: I believe I showed [illegible].

MRS. BOWERS: He identified it.

eb4

MR. NORTON: All right.

WITNESS BLUME: This page is page 36 from the written testimony. It is only part of the page, the tabular portion.

This is a summary of the average return periods we calculated for a 1.15g instrumental acceleration, again all under the assumption that 7.5M can occur on the Hosgri Fault.

Now in Report DL-11 which is Appendix D, I believe, of the documents over there, we used a time span of 45 years. This information was provided by Stewart Smith. We used regression methods and for the 1.15g or greater, we obtained a return period of 54,000 years.

In Report 41 we had two time spans. One was for 10,000 years and the other for 20 million years. Now we have much more faith in the most recent 10,000 years than the other one because of the fact that in 20 million years geologically many things can change. Nevertheless, we ran both of these.

Now the information forthe fault slip used as input for these two studies came from Dr. Douglas Hamilton and was based upon his geologic evidence as to what actual fault slip was either measured or could be reasonably estimated from the rocks and the geology.

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So the 10,000 year period gave 74,000 years as the

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average return period for this 1.15g, and the 20 million years gave 29,000.

Then in a third report, DLL-45, we had several studies, parametric type studies, the two most important of which are shown here. One was to use the plate boundary information, namely taking all of the earthquakes in California over a period of 45 years and then allocating these to the portion of California that could affect the Diablo Canyon site.

In other words, this assumption was that all of the activity known about and measured could be assigned to the plate boundary of the major tectonic plates.

So then assigning the portion that would affect the site, first of all on a diffused basis, which simply means that we assumed there were no faults at all, that an earthquake could pop up anywhere in the area, then on that basis we got a return period of 132,000 years.

On the second assumption where we assigned it to the ten known faults in the area, including the Hosgri, the San Andreas, the Nacimiento and so on, we came up with a 661,000 years average return period.

Now independently of all this and somewhere in about this time period, Ang and Newmark did another report for NRC, and their results I believe I have here. Yes, Ang and Newmark also experimented with certain parameters in.

eb6 one extreme of their results is not shown on this plate but you can visualize it, the 67,000 which falls right about in here somewhere, and the other figure was 83,000 years.

So my conclusion is that based upon these three reports plus the Ang and Newmark report, and assuming that 7.5 is physically possible on the Hosgri Fault which greatly governs all of these calculations, that in very round numbers the average return period for 1.15g is roughly 100,000 years. I say that because I favor this over my solutions, and Ang and Newmark surrounded this one and in bounding it out within 130 their accuracy we call it 100,000 years.

Another subject that was touched upon Saturday was the matter of tau or the averaging of motion over a large foundation. I think later on that we'll probably get into that in more detail.

I would like to point out an analogy that I have found useful in this regard, namely, that those who have been to sea or around boats or ships know that a very large ship or vessel does not rock or move as much as a small rowboat or a small boat in the same sea.

There are six possible degrees of freedom for everything in the world, three translational and three rotational, and if you're in the small boat in a very rough sea, you feel all six, believe me. The thing is popping and bobbing and yawing and doing all those things. But if you're

eb7

in a very large ship, you may feel some motion but most of it is ironed out.

Now that's an analogy that can be applied to the matter of very large foundations as they may be affected by earthquake waves.

Now admittedly there's a great difference between earth or rock and water, but nevertheless the analogy I think is very useful.

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It's a very complex problem, the matter of how to calculate precisely, how do the various waves arriving from various directions are affected by and affect a large foundation especially if it is embedded into the surface of the earth and if it is irregular in shape. It is even more difficult when there are continuous foundations, that is, other structures right alongside.

We have used procedures that will be described and have been described in the written material that are what I call engineering effective methods, very similar to methods that have been used throughout the history of time, including recent years, in engineering design.

For example, wind. In designing buildings and structures for wind, rarely is it done as it really is, it is normally done with equivalent forces per square foot applied statically which tend to represent the wind forces on buildings. Once in a while, aerodynamic procedures are employed but even they contain certain assumptions.

When an engineer designs the live load that will load the floor of an office building, for example, he does not know exactly what that load will be but he is given by code, or he assumes a certain unit pressure, perhaps 100 pounds per square foot, perhaps something else. That is again an example of an engineering equivalent procedure.

The loading and railroad bridges is not an

agb2

exact trainload but it's an equivalent system of loading. The same on highway bridges.

Now the matter of torsion comes up the minute you talk about averaging effects and the effects of waves coming at all angles approaching foundations. I'd like to very briefly discuss the history of torsional design in ordinary building codes, because I believe it bears an important point in this hearing.

I happen to have been one of the engineers involved in the original code development that provides the so-called accidental torsion for buildings. Let me explain accidental torsion.

First of all, if a structure or a building is asymmetric in the sense that the center of mass at each story does not fall exactly upon the center of rigidity of each story, there is what we call an eccentricity, and that eccentricity creates torsion in that story of the building.

Now, it so happens that many building were being designed with real torsion because of the asymmetry of the layout, and this has been in the codes for decades, I'd say 20 or 30 years. But about the last 10 years or so, the concept of accidental torsion was introduced, and this involves a desire on the part of the code designers, including myself, to do something about two problems that we were faced with:

agb3

Number one, many buildings, especially tall buildings were being designed by architects and by others, I guess, where all of the resistance to lateral forces was concentrated at a central core of the building.

You've all seen, I'm sure, many such structures where the bottom story looks like it has tall, spindly columns and the only walls you see are concentrated near the center around the elevators and the stair shafts.

Now a building of this type, even though it may be symmetrical on paper, has what we call a very, very weak torsional moment of inertia, or polar moment of inertia. And the simplest way I can describe that term is to say that this has to do with the resistance of a structure to withstand twisting or torsion.

And the weakness of these buildings was the fact that all of the resisting elements of any consequence were concentrated at a central core away from the boundary. And thus they had very, very weak resistance to twisting or torsion.

Because of this and also because of the fact that we expect all buildings to go into the inelastic range under major earthquakes, there's not one tall building in the United States, even the most modern, that can stand a major earthquake without going way beyond the yield point. We know that when a structure goes beyond the yield point,

it will have to go inelastic in an asymmetric manner.

In other words, the probability of both sides of a structure going inelastic at precisely the same rate is approaching zero. Therefore, we know that even though a building may be symmetric to start with, before the earthquake is over, it's going to be asymmetric and have torsion.

For those two reasons, the code designers of about 10 or 12 years ago wrote a provision into the code that said they had to provide, the designer had to provide for accidental torsion in which he would assume an eccentricity of at least five percent of the longest dimension in the building in plan view, regardless of whether or not there was any asymmetry in the actual structure. I think that was long overdue.

Now, approaching Diablo Canyon, we have designed Diablo Canyon -- or reanalysed it, rather, for the Hosgri, as agreed with NRC at various meetings, with two types of accidental torsion, one is five percent and the other is seven percent. And the only difference between the two is the way they're combined with the other functions.

Now, the structures at Diablo Canyon without exception are entirely different than those other type buildings that I've been talking about. They have large massive walls on the outside periphery, rather than having

all their strength concentrated at a central core. Because of this, they have tremendous moments of polar inertia and have great resistance to torsion.

So when the five percent or the seven percent, as the case turned out to be, was applied to these buildings this was a real bonus, because it was not required at all for the same reason that it is required in a normal building code.

I think I'd like to talk now a little bit about damping, because this came up many times during ACRS hearings and Subcommittee hearings.

First of all, the damping that was employed -- has been employed in the reanalysis has been precisely that allowed by Regulation Guide 1.61 and I know of no variations from that.

But the ACRS Subcommittee especially went so far as to challenge even that, even though it was in the Guide, and they said Well let's prove it all over again and so we proceeded to do so.

Damping is a very, very complex subject. It involves the change of energy--as I mentioned last Saturday, you cannot lose energy, all you can do is change its form -- but the amount of damping is extremely important as to how these spectral diagrams are used and how the structure performs.

Now our reports, DLL-9 in the appendix of the same documents and DLL-49C, outline detailed information on damping tests and damping determinations, many of which were brand-new insofar as the ACRS Subcommittee was concerned.

Damping is a function, to a large extent--that is, the real important damping is a function of friction in a structure. Thus, when you have a bolted joint or a riveted joint, there is far more damping than if you have a welded joint where friction is not possible.

The same is true of concrete, if the concrete is uncracked, if it is one unit, the damping has to be much lower than if the concrete has the tiny, little cracks in it that you expect under normal service.

And when you get to beyond normal service such as for Diablo Canyon loadings and work up close to the yield point the cracking, even though perhaps not obvious, will be larger and the damping will be greater.

So these two things are important. One, the damping is to a large extent friction-dependent and, to a large extent, strain dependent, and these are not mutually exclusive.

Another type of damping is very, very important and that is radiation damping. This normally relates to the fact that some of the energy fed into the building by the moving soil or rock is going to leak out of the building back

agb7

into the soil or rock and away from the structure. It can't all be retained and it can't all be transferred into work done or damage done, so the amount of energy that is lost through going back into the rock is called radiation damping in normal parlance. This is very important, however, we're not taking credit for any of this at Diablo Canyon, it's an extra bonus.

Another concept about damping that was discussed very thoroughly, is the fact that some people were under the impression that damping had to be a matter of high strain throughout an entire structure in order to be effective.

We know this is not so, based upon the actual tests that have been done in the laboratory and in the field, that all you need is high stress in the local joints or somewhere in the structure, such as the bending of the joints of a typical moment-resisting frame, and you can develop the damping values that have been measured. And you may ask, how do we know this? And the answer is by actual tests of similar structures and elements.

I'll now go to some slides and illustrate some of our damping values.

(Slide.)

In the interest of time, I'm only going to show a summary here of the results of one test. This is Table Three, Summary of Damping Values, which is excerpted from

Page 48 of the written testimony.

In this table we have three columns, the left column merely outlines the source of the original data. The second column provides the damping values obtained by these tests or experiments at microlevels of stress and strain. And by micro, I mean extremely low levels.

The farther column on the right outlines the values obtained at or about the yield value of the material. And some of these are blank for the simple reason that the testsdid not extend into that range.

Two small reactors have been tested, and damping measured 6 to 9 percent and 1.5 to 5 percent at the micro level. Several bridge piers in Japan have been measured by pulling the top of the piers over and letting them vibrate. And of course, any such test would involve a considerable amount of radiation damping as well as other types.

So at very micro levels, say, in the range of 3.4 to 16.6 percent, with an average of about 8 percent including the radiation damping -- but remember this is still at the micro level.

Then for the next three series of tests -- these are all independent tests. And by the way, I forgot to mention that there were 22 concrete buildings in Las Vegas that our firm tested under actual motions from ground vibration induced by underground nuclear detonations.

agb9

And at micro levels, we obtained mean readings of 5.6 percent, and this excludes radiation damping because of the method by which the calculations and the measurements were made.

Of course, these buildings do include a lot of walls and partitions, so I would expect that at yield level or micro level, that this would go up tremendously and that's one of the reasons that buildings have survived when they shouldn't.

Getting down to the bottom of the table again, we have two sets or models of shear walls where the damping results at micro levels were extremely small and consistent, 2 to 4 percent and 2 to 3 percent.

Now what accounts for Diablo Canyon is not the mirco level but the macro level, because here we're up around yield or strain because that's the way we're designing for such an unusual loading condition.

It so happens that models of bridge piers were 7 percent at that level. Models of coupled shear walls -- and by coupled, I mean they're connected with a small concrete element -- were about 10 percent at 10 percent above yield level.

Another series tested 8 percent at 9/10ths of yield level. And another set is 7 to 10 percent, and another set is up to 9 percent.

So what you can see here is that in all cases

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We are at or above seven percent of damping at about yield, and we're using seven percent of damping for Diablo Canyon.

(Slide.)

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Now of all the series of tests that we studied, I think this one is perhaps the most pertinent to the problem at hand.

This is a model of a concrete shear wall four inches thick, six feet three inches wide, and 15 feet high. And it has a top slab for applying the force and a very massive bottom slab. And this slab in turn is placed upon another heavy floor slab that is not shown here. And the whole base anchorage was designed and carried out in such a manner that radiation damping was essentially eliminated.

This was done for the purpose of not confusing the data with what energy might be put back into the ground. So I would say that 99 percent or more of the radiation energy was eliminated and kept in the structure.

MRS. BOWERS: Dr. Blume, did you identify the figure number on this one?

WITNESS BLUME: I'm afraid I forgot to do that again. It's Figure 18 from the written testimony. Thank you.

I guess we'll go to the next one.

These tests were conducted by the Portland Cement Association back east, I believe at Skokie, Illinois.

(Slide.)

And this is Figure 19 from the same series, and it shows in plain view the three types of walls that were tested. The wall I just showed you on the prior slide is

a plain wall without flanges. Then there was one with equivalent column sections at each end; finally another one with walls intersecting at each end. All three series of tests were made.

Next one, please .

(slide.)

This is Figure 20 from the written testimony. And it shows the results of the tests on all the walls that I've just shown you. The different symbols, B1, B2, B3, F1, R1, and so on, merely represent the type of wall involved, whether it's the plain wall or the dumbell-shaped wall or the flanged wall. And you can see that at micro levels, down around .02 percent strain on the diagram, the damping is ranging from two to about four percent, the same as I had in the prior table.

But when you get up here to a strain of about .20 to .24 percent inches per inch in the steel reinforcement we find a little more spread of the data, but all three series of walls are testing from 7 to, say, 10 percent, as I also had in the table.

The straight line was drawn by the authors of the test series. I did not do that. But I'll draw the seven percent line, the horizontal line, because that's the line that we're using. And since we're working at this type of strain under the extreme Hosgri conditions and

mpb3

radiation damping has been eliminated, we feel that the test very nicely showed that the seven percent damping is not only adequate, but conservative.

Next one, please.

(Slide.)

I just have one more slide, I believe.

This is Figure 21 from the same series. It's merely the same type of information shown in a different way.

We have on the bottom horizontal scale, of course, the strain in percent, as we had before. But on the vertical scale we have damping in percent of yield stress damping. In other words, that yield, this would be 100 percent. And we have the test values shown in the sets written on here.

You'll excuse this rough writing, but it's the same that I used by hand at one of the ACRS meetings. I didn't want to change that drawing in any bit, because here we have the nine percent at roughly yield. And to answer their questions about what damping we would have at other yields we showed the seven percent at a minor yield, and a five and a four and a three and so on.

Is that the last slide there?

The application of the design spectra and these damping values has been done independently for each and every structure at the plant. This will be described in

mpb4

much more detail by other panels.

The analysis has been done using both the Newmark procedures and the Blume procedures and spectral diagrams. And as you will learn, some strengthening has been required. In fact, when I look at some of it it breaks my heart because I feel it's unnecessary to a large degree.

In overall conclusion regarding my testimony, I feel that the initial Hosgri-E criteria -- you'll remember we called Hosgri E, what PG&E applied to the plant they learned about the problem -- and that was for M equals 7.5 within an effective acceleration of .5g. I feel that those criteria are adequate and proper, and the plant met them without any need for alterations whatsoever.

Number two, even with the assumed 7.5M and 1.15g instrumental acceleration, I personally would consider 0.60g effective acceleration as adequate and proper rather than the .75 that we are now using.

Point number three, I consider the .75g Hosgri basis with the tau reductions as very, very conservative.

Number four, there is, assuming 7.5M can occur on the Hosgri, an average return period of about 100,000 years for 1.15g instrumental, or 0.75g effective acceleration.

And I emphasize most strongly that even if that is reached on an average of every 100,000 years, that is ly

no means a point of failure. That is merely the point at which all the many other reserve values and safety factors and margins that I mentioned Saturday and have in the written testimony and elsewhere start to come into play. By no means would there be failure under those circumstances.

Number five, the damping ratios being used are conservative. They are the same as has been used for many plants all over the United States. And we have rejustified them for this particular plant.

Number six, there are many unrecognized safety factors in the analysis and review system and in the general practice of engineering, I might say, which was never intended to apply to this type of design level. These unrecognized margins could lead to capacity grossly in excess of .75g effective acceleration.

I have described many of these unrecognized margins in my testimony and in my reports.

Number seven, I do not agree with the contentions as written, except one, and that one says that .75g is not appropriate for the plant. I agree, I think it's far too conservative.

Number eight, there is much, much more than a reasonable degree of engineering certainty that the plant can be operated without undue risk to the health and safety of the public from or induced by earthquake motion.

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Thank you.

BY MR. NORTON:

Q Dr. Blume, I would like to ask you a couple of questions before we move on to cross-examination.

You used a couple of phrases during your testimony that I think perhaps the Board might want some further definition of. You used the term "yield level" for example. You talk about on your curves -- you say you get to here and you have a yield level.

What does that mean? What does "yield level" mean?

A (Witness Blume) Yield level applies to the point on a diagram on which is plotted force versus deformation, or stress versus strain. It can be done either way. And the yield point or the yield level is that point at which the force and strain relationships are no longer proportional. In other words, they are no longer a straight line, according to Hook's Law. But the strain begins to increase at a greater rate than the force applied.

Q Does it mean, when you reach the yield level of a piece of steel, that that piece of steel is going to buckle and fall down? Or what does it mean in respect to a piece of steel?

A With regard to a piece of steel, especially of structural steel or structural reinforcement, the steel does

not fail at all. All it does is begin to stretch out. An extreme example might be a taffy pull, where you pull taffy and the longer you extend the taffy the thinner the section gets, but it does not break.

Now steel has a tremendous reserve strength beyond its yield point. In fact, before it finally fails it stretches way, way out, and then gets even stronger due to what we call strain hardening. And before it fails, the actual failure load per square inch or per unit area may double or so what it was at the yield point.

Q All right.

You also talk about elastic and inelastic ranges. I'm sure Dr. Bright understands that very well, being an engineer, but perhaps for Mrs. Bowers, as a lawyer, and myself, could you go into that in a little more detail?

A I'd be happy to, because these are very important considerations.

The elastic range, again, is that level below the yield point where we assume everything is proportional. We call that "elastic"; it's synonomous with being below the yield point.

The inelastic range is that new world beyond the yield point where things start to stretch instead of going on proportionately.

Q All right.

Now you gave some slides, photographs, that were marked as exhibits of the San Francisco earthquake, shown here as buildings that didn't fall during the 1906 earthquake.

Could you describe the importance of what, what it is that that tells the Board other than the fact that the buildings didn't fall down? What is the importance of that as respects these hearings?

A The importance and the relevance is that here we have a model of an 8.2 magnitude earthquake with a moving fault roughly ten miles away and buildings not designed specifically to any earthquake code at all survived. In fact, 50 -- I believe of 52 major structures, all but seven survived, and four of those burned down.

Now you may say why should they survive if they weren't designed for earthquake values? There are several answers to this. One is the good judgment of the engineers of the day. They did design for some wind force. Above all, it's an illustration of how conservative our codes are today, because not one of these structures, whether they survived or not, would pass any modern building code.

Q Well, why was it, then, that the Veterans' Administration Hospital, which you referred to when showing a slide of the caretaker's cottage, why is it that that building collapsed?

A That building was a building built according to eastern standards, I believe by eastern architects, for the Veteran's Administration. It was built in about 1926. It had absolutely no provision for earthquake resistence. And it did not even have what we would call the design for wind resistence that you would normally have in the San Francisco type area or the Los Angeles area.

It was a three-story building -- in fact two of them were in trouble -- a three-story building designed prior to any codes. They had heavy roofs, and they had tile, hollow tile walls. And we all know from all of our earthquake experience in the field that the worst thing you can possibly use for earthquake resistence is a hollow tiled wall. They are very brittle. They lack the inelastic range, they lack ductility. And if they crack they really fail.

So I would call those buildings completely non-typical for any earthquake region.

MR. NORTON: That's all I have, Mrs. Bowers.

MRS. BOWERS: And that includes the entire panel, Mr. Norton?

MR. NORTON: Yes.

MRS. BOWERS: Mr. Fleischaker?

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CROSS-EXAMINATION

BY MR. FLEISCHAKER:

Q Dr. Blume, later in the cross-examination I am going to question you in more detail about some of the matters you brought up today, damping, tau effect. But I'd like to start out the cross-examination by asking you about some of the basic considerations that you have discussed on Saturday and which are set out in your testimony.

And the purpose of this basically is to provide a framework or a context for the consideration of the more detailed issues.

At page 6058 of your testimony --

A (Witness Blume) Is that page 60?

Q That's page 6058 of the testimony of December 16, 1978.

A Pardon me, I don't have a copy of my testimony as it was taken down.

Q I might be able to find it in your written testimony.

A I think they can get me a copy.

Q Page 6058.

MR. NORTON: That's the transcript for December 16.

(Document handed to the witness Blume.)

WITNESS BLUME: Yes, I have a copy now.

Page 6058.

BY MR. FLEISCHAKER:

Q Correct.

There on that page and on the following page you discussed the derivation of the response spectra for an earthquake. And I believe your testimony there on page 6058, lines 16 through 25 of that page, and on 6059 from lines one through about 20, you define what that is. And I believe that, if I can summarize -- correct me if I'm wrong -- this response spectra represents the maximum amplitudes of the response of single degree of freedom damped oscillators to some representation of ground motion.

my first question is:

Why is that particular device useful in structural engineering?

A (Witness Blume) The response spectrum is one of the most important devices in not structural engineering, but I would say more like dynamic earthquake engineering in that it provides at a glance a representation of how structures of different periods in damping would respond.

When I say "structures", I'm referring to idealized single mass systems, of course, would respond to a given ground motion. It's a very, very important device, as you call it, because in one graph a person can get a very, very good idea of how the destruction, or damage, or lack of damage might follow for a particular structure at a

given frequency or natural period.

Q How do we -- as I understand it, the response spectra constitutes a family of single degree of freedom damped oscillators, is that correct?

A Yes, each line for a given damping value represents -- well, you could say an infinite number of periods or frequencies of oscillators. But in practice the computer is divided into small time scales or period scales so that it represents a continuity of structures of various periods or frequencies.

Q Does the structure itself, a building, respond with a single degree of freedom?

A There are a few structures in this world that do tend to respond to a single degree of freedom, and we're speaking now, of course, in each horizontal direction taken one at a time.

I could give an example of that as the architectural type buildings of five or six stories with solid concrete walls except for the first story, which is nothing but slender columns. A building of that type tends to respond somewhat as a single degree of freedom system if it is symmetric.

Q Would a nuclear power plant tend to respond as a single degree of freedom system?

A No. There would be higher modes involved.

Q What is it, then, that permits us to utilize this representation, or this model, which is one using single degree of freedom oscillators to model the response of a nuclear power plant?

A Now this is done very nicely by mathematical means which bring into account the actual characteristics of the structure, that is the distribution of its mass and of its rigidity, so that all of the natural modes of vibration are computed. And there is a fortunate circumstance in dynamics, that you can treat each mode independently under certain complex mathematical operations, and then you can combine their effects according to certain other mathematical operations.

So even though the response diagram is drawn for a single degree of freedom system, it can be applied to any complex system if it's properly done.

A (Witness Frazier) I'd like to interject here something.

When an engineer does a structural analysis there are a number of steps to doing this dynamic earthquake analysis. Typically the engineer goes to the computer with many, many complex features of the structure, piping, beams, columns, and they have mathematical representations of all of these components. The major approximation the engineer is using here is that these structure behaving linearly --

that is, that the individual members are not being stretched beyond yield. Then, in the interim of doing this analysis the engineer shakes the base of the structure and calculates motions throughout the structure, and this includes all of the higher modes, the fundamental modes of the structure, then the local resonances of floors and columns, and things like this.

And by looking back at the response spectrum, that's the thing we're talking about, the engineer can utilize the response spectrum to, at any period range, to look at how parts of the structure behave. That doesn't mean that the engineer is taking the structure as a single degree of freedom system. Actually there are hundreds and thousands of different waves, different components, different degrees of freedom to which the structure is reacting, and this response spectrum assists the engineer at any frequency range, any part of the building, and so on, to get the dynamic response.

It is not -- the response spectrum does not imply that the engineer is treating the structure as a single degree of freedom system.

A (Witness Blume) I might also add that the response spectrum serves another function, and that is that it very clearly and very definitely sets forth a specification for a design requirement. It is not ambiguous, such

as a peak ground motion. With a peak ground motion you can do most anything with it.

But with a response spectrum you have to follow exactly what it says for the entire period range.

Q Well, if these calculations--mathematical relationships that permit us to model or predict the response of a multi-degree of freedom system structure by use of the single degree of freedom damped oscillator, is this a theory that is generally accepted in the engineering profession and has been accepted for a number of years?

A Yes. It has been accepted for a great many years, I would say at least ten or fifteen in modern structural dynamics.

I've had the pleasure of working with it myself over three decades ago. And there is no doubt that the theory of structural dynamics in the elastic range is thoroughly accepted.

Q Now why do we call this the structural dynamics in the elastic range? Why do we have that particular qualification on the use of this particular modeling, or predictive model?

A Well, to be very clear, first of all the Diablo Canyon Plant is basically being designed in the elastic range. Rarely, if ever, does it go beyond the yield point; and those points are specified.

mpb3

Beyond that, the technology in the elastic range constitutes I would say 95 percent of the literature; and the five percent is in the inelastic range, and there is somewhat less general understanding in the inelastic range as to how to handle it.

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Q Dr. Blume, I got a couple of answers there but let me see if I can repeat my question. I don't think I stated it properly.

As I understand it, this response spectrum is a predictive model. Is that correct?

A No. It can be predictive if it is in the specification form such as the ones I showed on the slide here Saturday, namely, in the sense that here's a requirement that we want you to meet.

Also, you can take an actual earthquake record, any earthquake, and run a response spectrum from that and that is not predictive. That merely shows what the earthquake characteristics were.

Q Okay.

Why is it that we limit the use of this for the elastic range, the use of this particular tool, the response spectra for analysis in the elastic range?

A We don't limit it to that. We have in the Diablo Canyon case because of the fact that we're working in the elastic range, but in the other world there are definite procedures for working in the inelastic range. They are much more complex; they take a vast amount of more computer time, and there are some approximate procedures which can be used in the inelastic range that seem to work out pretty well.

So I did not intend to imply that there is anything

wrong with the analysis in the inelastic [illegible]. There is. It is being done all the time.

Another procedure is to take an inelastic assumption and to modify a response spectrum [illegible] for inelasticity. That's my point. I was [illegible] saying that the spectrum that I have shown and [illegible] in the written testimony are entirely [illegible] spectra. They have not been [illegible] for [illegible] inelastic action.

Q Why, Dr. [illegible] in [illegible] being [illegible] the [illegible]?

A [illegible] project. I would [illegible]. I think it would be [illegible].

Q Does that mean then the [illegible] spectra that you [illegible] essentially that the [illegible] response, upon analysis [illegible] be [illegible] to a certain [illegible]?

A [illegible] I showed one note, [illegible]. [illegible] the Newmark [illegible] already [illegible].

[illegible]

[illegible] allowed [illegible].

in final rulings, it was decided that either the Blume spectra reduced by this ductility factor or the Newmark spectra, unreduced, would govern, whichever one were the stronger, required the most material, would govern.

It has so happened in practice that I think in almost every case the Newmark elastic spectra has governed.

Q Well, does that mean that upon analysis, the components, structures, and systems when subjected to a certain level of ground motion associated with an earthquake, that we must determine that the stress and the strain relationships remain proportional, there is no deformation?

A That's true under the Newmark spectra, yes.

Q And that's the conclusion that we're required to reach upon analysis of the structures, systems and components?

MR. NORTON: Excuse me. This really isn't an objection but this panel I believe is talking about response spectra and structures, not equipment or piping. Those are later panels, and the question could be inferred to include piping, electrical, and so on, and that's not the purpose of this panel. There are panels later that talk about that, the people who did the actual response spectra and so on for those systems.

So that the question may be overly broad for this panel.

MRS. BOWERS: Do I understand this panel is basic

structure?

MR. NORTON: Well, this panel is the response spectra, the .75g response spectra, and it isn't really even structures. Later Dr. Blume will be on a panel with the specific Diablo Canyon structures and what response spectra were used for each individual structure, the results, and all that sort of stuff.

This is really the panel that arrives at the .75g response spectra, the so-called effective ground motion. This is not the panel to talk about individual [illegible] or [illegible] or individual analysis of a wall of a building or [illegible] what-have-you.

Now Dr. Blume of course does get into structures on a later panel, and then some of Dr. Blume's people and PG&E people get into piping and instrumentation and systems and components and that sort of stuff.

So Mr. Fleischaker's question, there's nothing improper about it except from later panels [illegible] that gee, this included things and they are [illegible] consistent. Because I'm not sure this panel [illegible] anything more about the response [illegible] and floor response spectra. [illegible] and that sort of thing.

MR. FLEISCHAKER: [illegible]

MR. NORTON: [illegible]

MR. FLEISCHAKER: Which response spectra?

MR. NORTON: The Blume spectra and the Newmark spectra, the structural response and the floor response.

MR. FLEISCHAKER: Which floor?

MR. NORTON: Dr. Blume, you can tell them what we mean by "floor response spectra" a lot better than I.

WITNESS BLUME: All right, I'll try. This is a rather difficult concept also.

MR. NORTON: Again, I wasn't really objecting to Mr. Fleischaker's question. I just wanted to make it clear that we weren't talking here about piping and electrical equipment and so on unless Mr. Fleischaker wants to ask theoretical type questions. But in terms of the detailed analysis of Diablo Canyon, Dr. Blume didn't do the piping analysis, for example, himself.

MR. FLEISCHAKER: Okay. I understand. I'm not going to talk about the individual analyses that were performed on the piping, the electrical equipment and so on. I'm trying to understand the purpose to which the response spectra is put.

Why don't we get this answer from Dr. Blume on floor response spectra. Then we can go back to the cross-examination, if it would be useful.

WITNESS BLUME: Floor response spectra applies to the response that would be obtained on a higher level in

656

the structure than the base. That's where the word "floor" comes from. Actually it doesn't have to be a floor, it might be at any point at some higher level.

What it really is is a spectrum that describes the motion that would occur or be expected to occur at that elevation or level.

MR. FLEISCHAKER: Okay. I want to get into that but I want to get into it through the response spectra, the basic fundamentals first.

BY MR. FLEISCHAKER:

Q As I understand your testimony, the response spectrum represents the amplitudes for a family of single degree of freedom damped oscillators for each representation of ground motion. How are the various ways that we can develop a response spectra? What are the various ways we can represent a ground motion for development of a response spectra?

A (Witness Blume) I think [illegible] I'd be glad to repeat it again with the [illegible].

Q I read it and I know you [illegible] wanted to go through it and ask you to [illegible] through it.

MR. NORTON: Well, Mrs. [illegible] Mr. Fleischaker ask his questions [illegible] he did it then there's no sense in asking him to do it again.

MR. FLEISCHAKER: I just [illegible]

eb7

BY MR. FLEISCHAKER:

Q What are the various inputs that one would utilize in order to derive a response spectra, inputs representing the ground motion?

A (Witness Blume) Okay. The input representing the ground motion would be the recorded time history of ground motion after it has been corrected for any instrumental adjustments that are always necessary, and that is the basic input.

Then also as input one at a time is fed into the computer the characteristics of a single degree of freedom oscillator with a certain damping and a certain natural frequency. The computation is that the single oscillator is subjected to the entire time history of motion and a single point is obtained.

Then the computer puts in another oscillator with a slightly different natural frequency but the same damping and another point is obtained. And it does this hundreds if not thousands of times.

These points are connected up and that becomes a response spectrum for that particular earthquake motion and for the particular damping of the oscillators that were used.

You can then repeat the whole process for another damping and get another curve for another damping value.

2b

Q This is the time history of an earthquake?

A Yes.

Q Can you use actual time histories and ones that you make up?

A Yes, you can do this for [illegible] [illegible] of time histories.

Q Now this time history [illegible] represents -- or has [illegible] tion and velocity and displacements [illegible]?

A Well, you use one [illegible] to use the acceleration time [illegible] frequency in it to match with certain of the design [illegible] and so on.

I guess I should clarify [illegible] each time the [illegible] time it is called a [illegible] one is to use [illegible]

Q And so what you [illegible] of this [illegible] represents an amplitude, [illegible] a case of dynamic oscillation in respect [illegible] certain accelerations [illegible] through the --

A Yes. [illegible] frequency [illegible]

Q Now I understand you can also do this for velocity, too. Is that correct?

A Yes, although the better procedure is to first do it with acceleration and then, by approximate means, to convert it to what we call pseudo-velocity spectrum, assuming a harmonic relationship, and do the same with displacement.

Q Is that the procedure that you would utilize if you were deriving a design response spectrum?

A Well, I would normally just provide, as we did in the case of Diablo Canyon, I would normally just provide the acceleration spectral diagram although, for other purposes, I would use velocity and displacement.

In fact, we have plots that we put on what we call four-way or tripartite log vapor where we show all of these things at one time for other purposes.

Q Do you have a copy of one of those in your testimony? I believe you do.

A I'm not sure whether I do or not.

Apparently Figure C of the written testimony.

Yes, Figure C of the written testimony is an example of a tripartite plot of several spectral diagrams. This example has nothing to do with Diablo Canyon and appears to be the 1940 El Centro earthquake.

Q Can I go to Figure 1?

A Yes.

Q [illegible] way, this is [illegible] ion of a [illegible] System."

Is [illegible] what the [illegible]

[illegible]

A [illegible]

[illegible] a meal [illegible]

[illegible] inflammation which is [illegible]

[illegible]

[illegible] the [illegible]

Q [illegible]

[illegible] when we [illegible]

A [illegible]

Q [illegible] frequency?

A [illegible] increasing [illegible]

Q [illegible] presents the [illegible]?

A [illegible] each one.

Q [illegible]

[illegible]

A [illegible]

[illegible]

eb11

spectral acceleration on the upper scale and in gravity units. The damping varies. There are five damping values shown on the diagram. The upper one has no damping at all.

The next one is lambda two percent where lambda refers to damping ratio.

The next five percent, the next ten percent, and the lower one is 20 percent damped.

Q Are the damping figures here just selected arbitrarily to show the effect of damping on the amplitudes?

A Yes. That's their only purpose here.

Q Let me go to Figure C. This is the tripartite plot that we mentioned earlier.

Do I understand your method to be to derive a response spectra by plugging in the ground motion from an accelerometer and then to determine the amplitudes in the velocity range and the displacement range by utilizing some kinds of ratios?

A That is correct. This paper that you see here, this plotting paper on Figure C, is specially arranged to allow for the assumption of harmonic motion. So that if you plot any one value against period such as acceleration, spectral acceleration, the plot also automatically gives you what we call a pseudo-velocity reading and a pseudo-displacement reading, meaning that they are approximations of what the velocity and the displacement would correspond to be

[illegible]

This type of pitch [illegible] only the [illegible] purposes.

[illegible]

fingers [illegible]

[illegible] automatically [illegible] the [illegible]

Otherwise on the [illegible]

[illegible] the ground [illegible]

[illegible]

eb13

period or infinite frequency, the law would be exactly true, namely that a rigid body that is accelerated creates a force that is equal to force equals mass times acceleration.

I'd be happy to have any of my panelists who want to expound upon this do so.

HArry?

A (Witness Seed) I can't add much to what you said, but if Mr. Fleischaker would like a little more description of what a response spectrum is, I'll be glad to amplify in that regard.

Q The tripartite?

A No, as to how it is actually determined and what its significance is.

Q Okay. Sure.

A Would you like that?

Q Sure.

A I would like to show a slide to illustrate the point, or two slides.

Q Fine.

Also, Dr. Seed, do you have a slide of a tripartite response spectrum so you could show us how you read the thing?

A No, I don't.

A (Witness Blume) I'll be trying to look for one. I think I may have one.

eb14

MR. FLEISCHAKER: Do you want to take a break while he gets the slides ready?

MRS. BOWERS: Okay, fine. We'll take ten minutes then.

(Recess.)

MRS. BOWERS: We'd like to proceed.

MR. NORTON: Before we proceed further with the cross, Dr. Seed is using two slides that happen to respond to the question but he didn't know the question was coming, so we don't have the appropriate number of slides. But we will provide them, we will provide copies.

MR. FLEISCHAKER: Do you want to mark these?

MR. NORTON: Yes, but we'll have to make the copies, we don't have any copies. Of course, they're slides, everybody can see them, but we will provide copies for the record and the parties.

(Slide.)

BY MR. FLEISCHAKER:

Q Before you start, Dr. Seed, can I ask you to --

MR. FLEISCHAKER: We'd like to mark this Joint Intervenors' Number 53.

BY MR. FLEISCHAKER:

Q Will you give it a name for the record, please?

A (Witness Seed) Yes. I suggest it be called, Example of Determination of Acceleration Response Spectrum.

Q Thank you.

(Whereupon, the document previously referred to as Joint Intervenors' Exhibit 53 was marked for identification.)

WITNESS SEED: I was responding to your question about what is an acceleration response spectrum, and this actually shows a direct determination of one.

This is the response spectrum, and it is the acceleration response spectrum of this particular time history of ground motion.

Now this particular time history of ground motions happens to be the one recorded at El Centro, in the El Centro earthquake of 1940. It was a very famous record at one time and has been used very much for design until more recent records became available.

What I really wanted to point out is the response spectrum that you see down here is the response spectrum only of the El Centro record. It is not a response spectrum for anything else except the El Centro record.

Now the way it is determined is to take a series of what we call single degree of freedom structures. They can be, as Dr. Blume described, simply a single spring with a lump on the top, or they can be represented by simple structures with two springs and a lump on the top. This looks more like a building than Dr. Blume's lollipop.

If we put a series of such buildings --

MR. TOURTELLOTTE: Mrs. Bowers?

MRS. BOWERS: Mr. Tourtellotte.

MR. TOURTELLOTTE: While Dr. Seed is explaining

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this, he's pointing to various things on this slide. It would be nice if he would give us a more accurate description of what he's pointing to for the record, because that's not printing out on the record.

WITNESS SEED: I see.

What is represented up here are --

MRS. BOWERS: Where?

WITNESS SEED: Up near the top of this slide. (Continuing) -- are a series of very simple buildings, and these buildings are depicted as having different natural periods of vibration.

Now I should perhaps explain what is a natural period of vibration. And that is simply the period with which any structure chooses to vibrate of its own accord, every structure has its own natural period of vibration.

And if I could describe that a little more, this for example has its own natural period of vibration.

MRS. BOWERS: You're holding up the pointer.

WITNESS SEED: I'm holding up the pointer.

If I anchor the pointer on the table and leave a long length projecting from the end and then I deform it a little bit and let it go, it vibrates. And the period of vibration is the natural period of vibration of this length of the pointer. And it is a rather long period motion if the length sticking out is rather long.

agb4

And if I take the same pointer and shorten it, hold it here, and then deform the end and then let go, it vibrates with a high frequency of vibration and the inverse of the frequency would be the period, so now it's a short period motion.

Every structure whether it be a pointer or whether it be a building has its own natural period with which it will freely vibrate if it is deformed a little bit and then allowed to vibrate.

That's what we mean by natural period. This building has its own natural period and all other buildings have a natural period of vibration.

The natural period of vibration is a function of the geometry of the structure or thing and the material properties of the structure or object.

So I represent at the top here three different buildings, simple structures having three different natural periods of vibration.

Then we said let us suppose that these three buildings are subjected all at the same time to a base motion, they're all mounted on the same base which has exactly the characteristics of time history recorded at El Centro in the earthquake of 1940.

And if we were to take these three structures and subject them at their bases to this particular time

history, we could either experimentally measure the maximum acceleration developed at the top of each structure or we could calculate the maximum acceleration developed at the top of each structure.

And what we would measure or calculate would depend on how much damping there is in the structure, and that is represented by this little dashed box attached to each structure. And in this particular calculation all damping is given, all structures are given what we call five percent of critical damping, so they all have the same damping for one particular calculation.

Now, if I would subject these three structures which have natural periods of 0.3 seconds, 0.5 seconds and 1.0 second, to this particular earthquake motion and determine the maximum acceleration at the top of the structure, when I do that I would find that the maximum acceleration at the top of a structure having a period of 0.3 seconds would turn out to be 0.75g.

And now I want you to notice that the maximum acceleration of the base motion, as shown here, is about 0.32g.

MR. TOURTELLOTTE: As shown where?

WITNESS SEED: As shown in the middle part of the slide.

So what I'm doing is subjecting the structure to

a base motion having a peak acceleration of 0.32g and what the structure is feeling at the top of the structure turns out to be 0.75g.

If I take a structure, a little different structure with a natural period of 0.5 seconds and subject it to the same motion, then if we determine the peak acceleration at the top experimentally or analytically, it will turn out to be 1.02g. I'm still putting in 0.32g as the base, but this time we're finding that we get 1.02g at the top of the building.

If I take a third structure which --

BY MR. FLEISCHAKER:

Q I'm sorry, you say you're still putting in 0.32g but you're putting it in with all the rest of it?

A (Witness Seed) Peak acceleration input at the base is 0.32g and the whole time history.

Q You're subjecting that --

A -- to this particular time history.

If I take a third structure with a much longer period of one second and subject it to the same time history of motion, the peak acceleration of the motions going into the base is still 0.32g, but the peak acceleration that I would develop, record or compute at the top of the structure would now be 0.48g.

If I make these calculations for structures with

all possible natural periods of vibration starting at zero and going up in increments from zero, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, I would finally get to that one. And these three would be part of the entire set of calculations that I would be making. And then make a graph showing the maximum acceleration developed in the structure when it is subjected to this particular time history of motion recorded in the El Centro earthquake. That graph would have this form.

So we would say this is the acceleration response spectrum for this time history record of the El Centro earthquake.

What I really want to stress is that this is a sort of fingerprint of this motion. Only this motion --

MR. TOURTELLOTTE: Doctor, you're saying this and this. That will not read out in the record.

WITNESS SEED: I will rephrase that.

The acceleration response spectrum shown in the lower part of the figure is a sort of fingerprint of the time history of motion shown in the middle part of the figure. Only the time history that is shown here will produce this response spectrum.

So the response spectrum is a characteristic of a ground motion. It is not something that we invent. Every ground motion that has even been recorded has its own acceleration response spectrum.

agb8

And if we want to, we can take all those acceleration response spectra for all the recorded motions and see how they compare one with another. In general, the motions that have the highest peak accelerations very often tend to have the higher response spectra. And the higher the response spectrum is on this kind of acceleration response spectrum plot, simply says the stronger is the response of the structure, the greater the accelerations produced in the structure and, in fact, in a simple sort of way, the more the structure feels the earthquake.

Now the real value of this is, if we look at the acceleration response spectra for the El Centro record, what we see is that for structures with a natural period of half a second, these simple structures would be feeling about 1g, whereas in the same earthquake, structures with a natural period of 1.5 seconds would only be feeling 0.2g or 1/5th of what the other structures were feeling.

So different structures subjected to the same earthquake motion feel different things. And the acceleration response spectrum is a device, a computed characteristic of a ground motion which tells us quickly which kind of structure will feel the strongest accelerations from any given earthquake motion.

BY MR. FLEISCHAKER:

Q When you use the word "feel," do you mean respond

agb9

Is it actually response that we're talking about?

A (Witness Seed) Yes, response is a way of describing feeling. And there are various ways of characterizing response. Response is an overall name, and we can talk about when a structure feels something it either feels accelerations or it feel velocities or it feels displacements or it feels stresses or it feels strains. All those terms are part of the overall term "response." Response is a overall name for all those particular kinds of feelings.

MRS. BOWERS: Mr. Fleischaker, there are a couple of things about this that I don't understand, could I interrupt you to clear it up?

MR. FLEISCHAKER: That's the reason we're doing it.

MRS. BOWERS: I thought that natural period had a relationship to the height.

WITNESS SEED: In general it does, of a building.

MRS. BOWERS: Yes.

So then you're damping factor remains the same for all three?

WITNESS SEED: Right.

MRS. BOWERS: Then why is there what seems to me not a linear result on the maximum acceleration, you go 0.75 and then 0.102 and then you drop back to 0.048.

WITNESS SEED: That's exactly right.

agb10

As a matter of fact, it's true that, in a very crude kind of way if I may be allowed to be very simple at this stage, a rough way of giving the natural period of an ordinary building is to say it's roughly equal to the number of stories in the building divided by 10 in seconds.

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So very roughly, a 10-story building would have a natural period of one second. Or a one-story building would have a natural period of about 0.1 second. That's a rough rule of thumb.

And if we had 10-story buildings at El Centro at the time that this earthquake was acting in El Centro, then what they would be feeling will be something like the 0.2g that we see down here. Whereas, if we had five-story buildings in the same city during the same earthquake, they would be feeling five times as much.

And when I say feeling five times as much, I mean five times as much acceleration in the same earthquake in the same place.

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So it is very important when we compute the behavior of a structure to determine the natural period of the structure inthe first mode, the second mode, the third mode, and read off the responses from the acceleration response spectrum in these different modes, and then combine them to find the overall effect of the earthquake on the structure.

WITNESS BLUME: May I interrupt to attempt to clarify?

I think Mrs. Bowers may be bothered by the fact that as period goes up, response is going down, and the reason for this is that the energy content in the earthquake motion goes down with period.

MRS. BOWERS: Well, it's the middle structure that bothers me because we'll say a building of three stories gets a certain maximum acceleration; then five stories, if I'm following your theory, would have less.

WITNESS SEED: This represents roughly a three-story building. This represents roughly a five-story building. This represents roughly a ten-story building. So the five-story building feels the most, the three-story building feels a little bit less, and the ten-story building feels only about half of what a five-story building feels.

And if I were to carry this on to a 15-story building, it would feel only about one-fifth of what a five-story building feels.

eb2

MR. NORTON: Excuse me, Mrs. Bowers. I'm not going to try to explain it to you but I think I understand where your question comes from, and maybe if I can state it in layman's terms, then Dr. Seed can explain it.

I think Mrs. Bower's problem in understanding is you're leaving out a step, and that's the record, the accelerogram record. That's the part that breaks up the straight line and that's the part I think that has to be explained to her. I think that's the essence of her question, really.

WITNESS SEED: Well, I think the real answer to Mrs. Bowers' question, if I may say it, is that this is so only for that particular earthquake record.

Now I can make the same calculations for a different earthquake record like the one that was probably developed in Caracas, in the Caracas earthquake of 1967, and that would show a totally different picture than this acceleration response spectrum shows.

In that case I would find that the ten-story building will be the one with the highest point on the response spectrum, and other buildings would show lower points on the response spectrum, so the shape would be totally different from this.

What I'm really trying to say is that every time history of acceleration that we ever record has its own

eb3

characteristic shape of response spectrum, and they don't all look like this.

DR. MARTIN: Excuse me. May I take a crack at it now?

I think it is true, as shown by the numbers below the figures at the top of the slide, that the natural period is more or less proportional to the heights of the structures. The problem is what kind of arithmetic or mathematics goes on to translate the natural period into the acceleration at the top of the structure.

Is there any simple case where you can indicate the mathematical operations that get you from one number to the next?

WITNESS SEED: There's no simple way I can illustrate that calculation. It's a fairly complicated hand calculation. It's a very simple computer calculation.

But in the very early days one might not even have made the calculation. One might do this by putting a lot of models like this on a shaking table and subjecting the shaking table to this particular time history of motion and simply recording the peak acceleration developed, and then plotting them in this form.

Accleration response spectra does not have to be computed. It could be determined purely experimentally. At the present stage we would never do it experimentally because

it's a lot easier to compute it with the aid of a simple computer program.

DR. MARTIN: At the present stage you have enough knowledge to write a program to do this?

WITNESS SEED: That's right.

Now I think the concept of an acceleration response spectrum is extremely important to what we're talking about, so I really think as long as we have the slide on the screen, that if anyone has any uncertainties about it, we ought to try to clear them up.

MR. NORTON: Mrs. Bowers, excuse me. If Mr. Fleischaker has no objection, I really think it is important that we all understand this because it is essential to really the remainder of the case. If we don't understand the basic response spectra and how it is arrived at and the basic concepts, then the next month and a half is going to be very difficult for everybody.

I am not yet satisfied, for example, that Mrs. Bowers understands. Her question I don't think has been answered. And if Mr. Fleischaker would allow me, I would like to make an attempt at asking a question to see if that explains it. I'm obviously not trying to prove a case, I'm trying to make sure we all understand, we who are not structural engineers, about this response spectrum.

I realize it's not proper from a technical, legal

standpoint. If he has an objection I won't do it.

MR. FLEISCHAKER: I have no objection. I mean the reason I'm going through all of this is for precisely that purpose, to try to see if we can get some of the basics out on the record, because I've had the experience of spending a lot of time trying to think about these things and it's not easy. So I have no problems with your asking questions as long as I get to ask the same questions after you.

WITNESS SEED: Can I try to answer Mrs. Bowers' question another way?

MR. NORTON: Let me try to put it in layman's terms and then you can correct me where I'm wrong.

Mrs. Bowers, I think the thing you have to look at is you have to look at the natural frequency of the building in question, whether it be five -- I forgot what Harry said, I think three, five, and ten or 15 stories.

MRS. BOWERS: Ten.

MR. NORTON: The middle one, which is five stories, has a natural frequency period. You have to then look on the accelerogram, the record of the earthquake, and see at that frequency what the maximum g was, and that's what we're going mathematically.

In other words, if the .32g on the accelerogram is not at the natural frequency of that building, it doesn't hurt it. It is only at its natural frequency, so that's why

you run the whole record through there, and the building sees the g's of its natural frequency. And that's why theoretically you have a straight line.

But what you have to keep in mind is when you put any accelerogram up against that building, the building only sees the g's of its natural frequency. The g's of some other frequency don't really affect its response like the g's of its own frequency.

And that's why in fact you don't have a straight line though theoretically you would have.

Now, Harry, I probably have misstated that or over simplified it, but I think that's the problem she was having, is not relating it to each individual accelerogram and looking on there and seeing what the g's are.

Perhaps you could find the frequencies, the natural frequency periods on the accelerogram for those three respective buildings and point out the g levels on that accelerogram and that might help to explain it.

WITNESS SEED: Yes. What really happens is that the buildings that respond strongest are those that have the same natural period as what we call the predominant period of this motion. Now it is hard to look at a time history like this and see what are the predominant periods in that record. It really is hard. Even if you are skilled at the game it's hard to look in there and see what they are.

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But if you look in here you can see that there's a rather long period motion coming in there. And perhaps the period of that is about half a second. Now that strongly affects buildings with a period of half a second, and it is perhaps that motion in this little area which causes this big peak in the acceleration response spectrum.

Now the absolute peak acceleration which occurs here has a very high frequency or very short period. It occurs for a very small instant of time, being so narrow. And that is felt by structures which have that kind of natural period. And that would be essentially structures with a zero period.

So it turns out that always on these spectra the zero period ordinate is numerically equal to the peak acceleration of the response spectrum. That's a very important thing to understand also.

If I had an absolutely rigid body up here, its natural period would be zero seconds. If it were rigid it couldn't move at all, and it wouldn't vibrate, so its natural period would be zero. And what it would feel would indeed be -- as a maximum acceleration, the maximum acceleration at the top would be exactly equal to the maximum acceleration that goes in at the bottom. There would be no change in going up the structure.

MRS. BOWERS: Well, I don't really understand that bottom graph. Does that deal with all three buildings?

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WITNESS SEED: The three buildings for which computations are made at the top of the slide are plotted as points, one here, one there, and one there (indicating) on this bottom graph. And these three computations are merely illustrative of the fact that I can make calculations for these three buildings and plot them as three points on this graph.

Now what we do in reality is make computations not for three buildings but for 300 buildings. And we plot all the points on the graph, and then draw a line through all the points, and the line that we would get is this line down here, and that is called the acceleration response spectrum of the El Centro time history record.

WITNESS BLUME: Nancy, may I say something here on your graph?

WITNESS SEED: Yes.

WITNESS BLUME: In answer to Mrs. Bowers' question, if we can imagine the upper left-hand corner structure were solid, just a massive wall, so that it were completely rigid, it would then have a zero period. This would become zero. And its point would be right down here on the graph on the left, the lower left above the zero period.

This is what I meant exactly when I said [illegible] in Newton's law about force equals mass times acceleration that applies to a completely rigid structure.

But with these structures that Dr. Seed has shown, they are not completely rigid, they have periods and therefore, their points are elsewhere on the diagram.

BY MR. FLEISCHAKER:

Q Can I ask a question?

What's the significance of the value on the veritcal axis of the bottom diagram with respect to the accelerations that you see in the El Centro time history?

A (Witness Seed) Well,the real purpose of this spectrum diagram that we draw is to enable us to calculate the accelerations and stresses in other structures that might be subjected to this particular earthquake motion.

For example, it is a fairly good rule that if I want to know the base shear, which is an important characteristic of what a building feels during an earthquake, the shear force at the base of the structure, if you tell me that you have a structure in El Centro during this earthquake whose natural period were .75 seconds, then I can, with the aid of this diagram, say well, at .75 seconds, the spectrum acceleration is about .5g, and then I can tell you that the base shear for that building would be approximately equal to the weight of the building times the spectral acceleration or W times .5.

Q Let me go back to the selection of the value on the vertical axis of the bottom graph, the zero period limit.

A Yes.

Q That represents a certain-- What does that represent, and how have you selected the zero period limit?

A Well, what we have tried to do, or the object of this exercise is to plot along the bottom axis the natural periods of all structures that might conceivably exist and be subjected to this earthquake, and all possible structures, -- the stiffest possible structure would have a natural period of zero seconds, and perhaps the most flexible of buildings that we would ever build might have a natural period of ten seconds.

So in fact if we wanted to we could extend this plot out to ten seconds. It just happened that I happened to terminate this particular one at two seconds for demonstration purposes.

But very often when spectra are calculated they are calculated for periods ranging from zero up to ten seconds. There are not many buildings with a ten-second period, so that part of the plot is not very interesting to a lot of periods but it can be done that way.

It is just a way of showing on the same plot the potential responses of all conceivable structures.

Again let me stress that the zero period value on here represents that which will be felt by a structure having zero period. Such a structure is an absolutely rigid structure.

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And, being absolutely rigid, the spectral-acceleration will be numerically equal to the peak acceleration at any point in the time history.

MR. NORTON: Excuse me, Mrs. Bowers. I think it has been some time since I believe it was Dr. Smith and perhaps Dr. Bolt described the accelerogram. And I think one thing we may be missing here is for Dr. Seed to point out the period on the accelerogram-- You know, when you start talking about the natural periods of two seconds or one second or a half second, where that comes from on the accelerogram and how-- I don't know....

In other words, it's a time orientation that we're having a problem with.

WITNESS SEED: An accelerogram is simply a record of ground motions. It has no particular structural properties. It has no configuration. It's just a record of ground motion. It does not have a natural period. Only structures have natural periods.

MR. NORTON: But the frequencies?

WITNESS SEED: There are a lot of frequencies all mixed up together in here and what we talk about is the predominant period of this particular accelerogram. And it is very hard to look at the accelerogram and see a predominant period; it all looks like a jiggle of lines.

But in reality when we examine this computationally

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[illegible]

BY MR. [illegible]

Q [illegible]

A [illegible]

Q [illegible] to each of [illegible] arbitrary [illegible] arbitrary criterion or definitive cutoff [illegible] higher [illegible] than low frequencies and haven't [illegible] line and pick out a period?

A That's right.

22

What I really want to stress again, and I've said it several times, is that we all understand that the zero period value on here is numerically equal to the peak acceleration of the motions. And that is why Dr. Blume referred to this in his testimony as the anchoring point for the spectrum shape. That's where we anchor it to.

BY MR. FLEISCHAKER:

Q If there aren't any other questions -- there may be; but let me suggest one thing:-- I think when you read this tonight something may sink in. But let me move on and ask a couple of further questions about the time history.

Can you give us some facts about the time history here? What was the magnitude of the event?

A (Witness Seed) The magnitude of this event was about 6.6, and the record was made about, I think, seven miles away from the source of energy release.

A (Witness Blume) It was on deep alluvium, as compared to rock here.

Q What was the peak acceleration?

A (Witness Seed) .32g roughly.

Q Do you have figures for the next subsequent peaks?

A No, I don't. It's obviously very close to that. The second highest peak would be here, and it would be about .30g.

A (Witness Frazier) I want to make a comment.

The magnitude of this earthquake that Dr. Seed referred to is a local magnitude. The magnitude that we're talking about with regard to the Hosgri 7.5 is not a local magnitude, it's a surface wave magnitude. This earthquake had something closer to a magnitude 7 earthquake in surface wave magnitude.

MR. NORTON: Excuse me, Mrs. Bowers. There's one other thing that I was corrected on during the break, and that's the difference between "spectrum" and "spectra." I didn't even realize there was a distinction between the one. But one is singular and one is plural.

And perhaps, Dr. Seed, you might explain. That's an elemental distinction, but we'd better tell which is which.

WITNESS SEED: This is the acceleration response spectrum for 5 percent damping for this particular accelerogram.

As I said, all earthquake records, all time histories have their own response spectrum for 5 percent damping. And the total body of those would be referred to as the accumulated response spectra for 5 percent damping for all conceivable time histories.

Now because different earthquakes produce different peak accelerations it's difficult to compare all

the response spectra. If you put them all on one plot they would all start at different points on this zero period ordinate. And so you'd be comparing a lot of things starting at different points, and the shape would not become apparent to you.

BY MR. FLEISCHAKER:

Q You called the bottom figure there the response spectrum. That is not the response of the ground.

A (Witness Seed) No.

Q And this is not the response of a building.

A This is the peak acceleration that would be felt by a simple structure, a single degree of freedom structure subjected to this time history of ground motion. What the ground feels is described here. What the structure feels is described here. (Indicating)

A (Witness Cornell) If I may interject:-- It's referred to as a spectrum because it's a spectrum of buildings which are represented by the single graph.

A (Witness Blume) Or a spectrum of simple models; that might be more accurate.

MRS. BOWERS: This may be the same question that Dr. Martin asked:

You take a lot of different things when cyou crank it in to a big computer to come out with your bottom graph; isn't that rgith?

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WITNESS SEED: That's right.

MRS. BOWERS: And you said it was very complicated.

WITNESS SEED: It's only complicated to do it by hand. It's very simple to do with a computer. It might take about, oh, 30 seconds of computer time to make all the computations to plot on this graph, but it would take a lot longer than that to do it by hand.

DR. MARTIN: Could you give us, or refer us to an expression on which the computations are based?

WITNESS BLUME: It's an integration process, sometimes called a convolution integral, where any time disturbance, whether it's an earthquake response -- I mean an earthquake accelerogram or a pulse or a series of pulses or any other disturbances are used to agitate this hypothetical simple oscillator. And the mathematical expression is quite complex. I don't want to get into that here. But it involves a convolution integration over the complete time of the event, whatever it might be. And it's taking the simple oscillator and moving it along from point to point partly in free vibration at times, partly in forced vibration. And whatever the disturbance wants to do to that oscillator it does in the integration process.

As Harry mentioned, this by hand would be an horrendous job, but in the computer it can be done quite readily.

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DR. MARTIN: Well you said the equation was complex. Does it have an analytical solution, or do you use a numerical procedure to achieve integration?

WITNESS BLUME: It can be done either way. It can be done by numerical procedures or it can be done by straight integration, and so on. It can be done either way. It's sometimes called a convolution integral.

The beautiful part of it is it's completely general; it could apply to a single pulse instead of an earthquake.

DR. MARTIN: That's what I was getting at when I said a simple expression.

Suppose you had a single pulse, could you show us a more simple equation that would give a point on the response spectrum for a given pulse?

WITNESS BLUME: I'm afraid I would have to use the same equation, the complex equation, even with a single pulse.

For example, I've used the same type of equation with sonic booms which are merely an N shaped plus pulse followed by a minus pulse. And the equations work equally well: they're quite general.

Now, if you would like, I could prepare a graph showing the equation. But I don't think I'd like to do that just offhand here. It's pretty complex.

WITNESS FRAZIER: I think we can describe the equation perhaps well enough to get your intuition operating.

DR. MARTIN: My feeling is, if we have an equation and can identify the parameters of it then we have some idea of how the response spectrum is a function of the time history, as well as the natural period, which seems to be a simple linear relationship.

WITNESS FRAZIER: The equation that is used to calculate the results for any one of these buildings, if we could just understand how to get the roof, or the acceleration at the top of the building for any one of those buildings, I think we could understand how one could generalize and then do it for other kinds of buildings.

DR. MARTIN: That's what I'm driving at, is the basic element of the computer program that might turn into something very sophisticated and complex.

WITNESS FRAZIER: Well, the equation, to an engineer or a mathematician, is not really a very complex equation, it only involves four terms. It's what in mathematical terms we call a second order ordinary differential equation.

DR. MARTIN: Now we're getting somewhere.

Can you write that on a Vu-graph so we can see what it looks like?

WITNESS FRAZIER: Sure.

DR. MARTIN: I feel like I'm only getting part ofthe story. If I see the input and the output I don't know what goes on in the black box.

WITNESS FRAZIER: Let me describe the equation just a little bit more, and if you still would like it I'd be glad to write it down.

It has four terms. One term involves the acceleration of the structure relative to the ground. And that term tells about the inertia of the structure. The structure is moving. There are forces generated. Newton's second law of motion is dealt with here. There's an inertial term. And the parameter that goes in that acceleration term relative to the base is the mass of the structure. That's one term. So there's one term that involves the mass of the structure and the acceleration of that structure relative to the base.

Another term is the stiffness of the structure, and that simply is a spring constant. And that simply says that if you take the top of a structure and move it over, no inertia involved, just move it over, that there are forces involved due to the stiffness of the structure. So there's another constant here, the stiffness constant. We call it a spring constant. So that's another term.

Another term that has to do with the structure itself involves the damping that has come up several times

already. And what this is, the damping term is a procedure that says the velocity of the structure relative to the ground dissipates energy, or takes energy out of the system and puts it somewhere else.

I was visiting with Dr. Seed, he had his pointer on the edge of the table, and he flipped it, and it went through a resonance, but the resonance died out very quickly. And as I had my hand on the table I noticed that the table was shaking. That's a nice example of radiation damping. He was radiating energy out of that stick into the table. And radiation damping and many other mechanisms of damping turn out to dissipate energy proportionately to the velocity of the structure relative to the ground. So there's a term in this equation that defines damping. And it's proportional to the velocity of the structure.

So we have three terms to describe the structure: one is acceleration, one is velocity; the acceleration has the mass of the structure, the velocity has a damping coefficient; and then there's the displacement relative to the ground, which involves the spring constant. So those are those three terms.

Now I said there was a total of four terms. The fourth term is simply the excitation, which is in the middle of the picture here. Actually the equation is very simple. The complexity is in getting out calculations. The reason so

don't do it on scratch paper and that we need to go to the computer, or go to a shaking table--

DR. MARTIN: The complexity is in the integral.

You're beginning to talk to me in language I can understand. If we have the equation I think it'll all be much clearer.

WITNESS BLUME: I would suggest we provide the equation after the luncheon period.

DR. MARTIN: That'll be fine.

WITNESS BLUME: Or maybe tomorrow morning, something of that sort.

DR. MARTIN: Fine. With an explanation, with a definition of the parameters and their dimensions. --or some dimensions that come out to be consistent.

WITNESS BLUME: We'd be glad to do that.

DR. MARTIN: That'll be excellent.

BY MR. FLEISCHAKER:

Q I have a question for Mr. Frazier on this equation you're using.

For the damping value are you using-- As I understand it, the damping is a measurement of the dissipation of energy in the building as the building is vibrating in a particular mode; is that correct?

A (Witness Frazier) Yes. The damping coefficient that goes into this equation is a catch-all type damping. It's

energy that's dissipated in joints in the structure, it's energy that dissipates even, perhaps, as the structure vibrates back and forth as there are wind loads on the structure, and as it moves back and forth actually some of the energy may go out in the air. I don't think much of it goes out that way.

Some energy is radiated down into the earth.

All of these mechanisms for dissipating energy or getting energy out of the vibrational mode of the structure, all of those terms-- all of those mechanisms join together to form a damping coefficient. And in the type of plot Dr. Seed is dealing with we simply set the damping coefficient and see what the results are.

It's another matter to appraise that for a given structure.

Q Well it seems that damping can come from a bunch of sources. One of them is damping that's due to the dissipation of the energy through the structure itself, without reference to the ground; isn't that correct?

A Yes.

Q Okay.

And then you have another kind of damping which is due to the dissipation of energy due to the soil-structure interaction as the consequence of the non-linearities in the soil, as the building moves through the soil.

A Yes.

Q And then you have radiation damping, which is a third kind of damping; correct?

A No.

Q No?

A The soil-structure interaction, the radiation of energy into the soil is called radiation damping.

Q Well let me ask you about that kind of damping.

Won't you have some kind of damping that results from the refraction of the waves as they move from the soil through the -- to the base, because of the different impedance of the soil and the base?

A No.

Q You would not?

A No. That would not be damping; that would have to do with how incoming waves -- how effective incoming waves are at getting into the structure. That's not damping.

Q Well what are you talking about?

A Damping is how energy that's in the structure gets out of the structure.

Q So you're defining radiation damping as being equivalent to the dissipation of energy due to the soil-structure interaction effect and the non-linearities in the soil as the building moves through the soil?

DR. MARTIN: The building moves through the soil?

MR. FLEISCHAKER: The base of the building as it interacts with the soil.

WITNESS FRAZIER: That would be part of radiation damping, yes. Often in these hearings we call that radiation damping. There are other types of radiation damping other than energy that gets from the structure down into the foundation. There are other types.

BY MR. FLEISCHAKER:

Q Okay. What are the other types of radiation damping?

A (Witness Frazier) I mentioned one, and that is -- picture a tall building, for example, as vibrating back and forth. And when it moves one way it's got to push on atmospheric air, and when it moves the other way it has to push in the other direction. And that radiates some energy. So that would also perhaps be terms as radiation damping.

A (Witness Blume) The basic type of damping involved here that hasn't been discussed yet is hysteresis, which is present even at very low stages of amplitude or of distortion. That's a conversion of kinetic energy to heat without doing any damage whatsoever. This is present in the damping characteristics.

Q I thought that was the first kind of damping we were discussing; that is, the damping in the structure alone without reference to the soil.

A No, there are many kinds of damping within the structure, and historesis is one of them. Friction is another.

Q In the elastic state?

A In both the elastic and the inelastic.

Q Okay. Let me see if I can separate out one boundary. We have a damping in the building itself without reference to the soil; is that correct?

A You can look at it that way.

Q Okay.

And then you have the kind of damping that relates-- tht results from the soil-structure interaction.

A Yes.

Q Okay.

And then you mentioned a third category which might be the structure-air interaction.

A (Witness Frazier) Yes. I think for purposes-- In general I think it's fair to categorize damping as of two types: one is damping of the structure and all the various components of the structure in any way that might occur, and there are many ways that could occur. Another type of damping would be radiation damping; that is, energy that gets out of the structure into some other -- escapes somehow: we call that radiation damping.

So I think it's fair to categorize damping as of

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two types: radiation damping or structural damping.

Q Okay. Structural damping. What kind of damping do we have for structural damping?

A I think I'll turn this back to John Blume. I'm willing to answer, if you prefer. But I think John Blume has looked more at this.

A (Witness Blume) Take your pick.

Q I'd like to hear from both of you. But, since I'm talking to you, let me talk to you first.

A (Witness Frazier) Well I've been involved in experiments where we've looked at structures and shaken them to get vibrational energy into structure, and backed off and looked at them and, sure enough, the vibrational energy, the resonance; the natural period type phenomena, the resonance of the structure diminishes, it dies out. And this happens at very low vibrational levels. One can be in a structure and have vibrational motions so small that you can't detect the motion.

I remember one time I had instruments on the top storey of a structure, and shifting my body weight --this was a ten-storey structure - and just shifting my body weight back and forth and watching the recording devices, I could actually get the recording device to resonate. So I was exciting the structure. And it was probably a factor of 10 below my ability to detect the motion. I could stand still

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and the structure would go ahead and resonate and the instrument was recording it, and it was well below my ability to detect this.

Now when this dies out there are mechanisms that cause that energy to dissipate. Some of these mechanisms are things like just an elastic member. There's no joint, no friction, just an elastic member. If one could hold that elastic member perfectly rigid on the ends so that no energy could escape from that member and you pluck it like a guitar string or something like that, that procedure, that resonating phenomenon does die out.

And so whatever the mechanism for dying out, that's a type of electric hysteresis, something like a guitar string. The thing doesn't resonate forever. And then in structures, I think --

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Q Can I ask you one question about this?

A Sure.

Q What kind of damping, isn't that the kind of damping that we're talking about when we derive these response spectra?

A When we derive response spectra --

Q In the more formal sense that we're talking about here.

A It is simply a term in an equation that has to do with the structure, and in my opinion when we calculate response spectra we don't identify what kind of damping we're talking about. We merely identify numbers. And we go through a suite of numbers ranging from zero damping, two percent damping, and we carry it out on up to 20 percent damping, so that we get an engineering judgment, a feel for how the response of structures of various periods might respond at various damping levels, and they're not identified what kind of dampings they are, whether they're joints or structural or radiation damping, or whatever they are. They are not identified when we do response spectra.

Q What do you mean "when we do response spectra"?

A When response spectra calculations are performed it's a formal procedure. We merely put a percentage of critical damping in as a parameter and see what the answer turns out to be.

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We don't -- when we do that procedure we don't go in and identify joints or columns or any particular mechanism that's going to provide that damping.

Q Okay.

So we can pick a number out of the air, four percent, five percent, seven percent, we'll say this is damping and it could come from all sources. It could be structural, indirect damping through the air, through the structure, or structural interaction, correct?

A Yes.

A (Witness Blume) No.

A (Witness Seed) I started this. Can I answer this question?

A (Witness Blume) We all want to get into this one because I think it's going off into 17 different directions.

Q Well, let me see if I can narrow it, because I want to talk specifically about the Reg Guide and see when it uses seven percent damping, what is it talking about.

A (Witness Frazier) Well, later one has to come back and justify the number. I mean, when you do the formal procedure you get a response spectrum. Then you have to look at the structure or the mechanisms.

But the procedure of doing the response spectrum is all I'm talking about, how you use it. Then you have to

isolate which type of damping you're talking about so that you can use the appropriate number.

Q Okay. I understand that.

Now do you have Reg Guide 1.61 available?

A (Witness Blume) I've got it in mind --

A (Witness Reed) Yes.

A (Witness Blume) -- as one of the authors.

(Laughter.)

Q We'll come back to that.

A (Witness Blume) I would be happy to describe what the intent was in Reg Guide 1.61.

Q Okay.

Let me get a copy of it so I can get the language.

I saved damping for tomorrow, so I didn't bring Reg Guide 1.61.

MR. NORTON: Excuse me.

Before we go on, I think Dr. Reed had another slide on the response spectra, and I hope we don't lose sight of that. He still hasn't answered your question.

MR. FLEISCHAKER: I know, and I'm keeping that back here.

(Indicating.)

But I thought we might proceed with this damping a little bit and then come back to the response spectrum.

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BY MR. FLEISCHAKER:

Q Instead of waiting -- I don't have the language of 1.61 in front of me -- was it 1.60 or 1.61 which is damping?

A (Witness Blume) 1.61 refers to damping and 1.60 refers to response spectra.

Q Okay.

Now with respect to 1.61, there are figures given here for damping, correct?

A Yes.

Q And you were one of the coauthors of that?

A Well, my work along with Newmark's led to that, yes.

Q Okay.

What work was it that -- specifically was there a publication that you worked on which served as the basis for the numbers?

A Yes. Our firm wrote a report for NRC regarding response spectra and so on, and so did Newmark and Associates. These two efforts were combined into a published paper. I believe it was in the Power Division Journal of the American Society of Civil Engineers. And then finally another document -- two other documents were produced by NRC after review, 1.60 and 1.61

Now 1.61 pertains to damping and only damping.

And I would like to clarify, if I may, a little more about damping. It is a complex subject. I'll try to make it very simple. And I'm speaking now of structural damping.

First of all, there's hysteresis, or the change of energy from kinetic energy to heat. This is due to the friction of molecules internally without damage. You can vibrate a thing forever and pure hysteretic damping will not damage that unit.

Another type involves friction, or [illegible] [illegible]. Frictional damping may occur in minute cracks or dislocations between particles and units so small that we can't see them with the naked eye, but nevertheless it's there.

A third type, the damage you get beyond the elastic point or the yield point, that was quickly talked about today, and I think is the most important one in the whole [illegible] for saving structures, is work done in the inelastic range, and this is simply the product of force times distance, another classical law in mechanics.

This is ignored when you limit your design to elastic -- to the yield point, but it is a [illegible] source of energy throughput.

Now coulomb or frictional damping, [illegible]

hysteresis and the [illegible] are

others that I haven't mentioned -- get very complex mathematically. So it has become universally accepted in the field of earthquake engineering and structural dynamics that the computations involving response spectra and the response of structures and so on that we assume a viscous type damping, v-i-s-c-o-u-s, which is proportional to velocity.

We all know this is another engineering equivalent of the type that I mentioned this morning, where it's not the precise answer, but it is a most convenient and useful method and it yields results that are consistent and standard. So the damping mentioned in Reg Guide 1.61 is assumed to be viscous in nature, even though we all know it isn't. But its value in using that computation is essentially the same as if you went through an extremely complex procedure trying to isolate hysteretic damping from frictional damping, and so on and so forth.

Q Dr. Blume, I'm sorry, you lost me in your description of viscous damping.

A Viscous damping is just what the name implies, but it's a damping that would increase with velocity of motion. Viscosity. In other words, if you visualize a viscous liquid, it has more resistence than water without viscosity, for example.

Q How does this concept relate to the kinds of

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damping that you've listed before hysteretic damping, frictional damping, and damping that is due to structures or materials going into the inelastic range?

A The viscous damping is assumed to be the equivalent of all the structural dampings. It sums them all up into one convenient unit.

Q Now can you have hysteretic damping in the -- strike that.

Would hysteretic damping be appropriate in describing the dimunition of energy as a result of a soil-structure interaction?

A No, because it would only be a small part of the total effort. There would be friction involved and many other things.

Q But would you have hysteretic damping going on?

A In soil-structure interaction?

Q Yes.

A Yes, there would be certainly hysteretic among other things.

Q Would you have frictional damping going on?

A Yes.

Q And would you have damping as a result of materials going into the inelastic range?

A You may or may not have. It depends on the amplitude.

Q How about if the soil around the structure goes into the inelastic range, would we apply the term we would we describe that as the type of damping that you had described earlier, that is the damping that results of a material going into an inelastic range?

A If the soil significantly goes into the inelastic range, yes. But soil is a type of material that is strain-dependent to some degree. I think if you were to get into the details of that I'll turn it over to Harry Seed, who is an expert in soil characteristics.

Q No, I just wanted to pin down that one thing.

This figure seven percent -- or whatever the figures that are given in Reg Guide 1.61, is it your testimony that they are to reflect both the damping that results in the structure without respect to the soil as well as the damping that might go on as a result of soil-structure interaction?

A I would say that Reg Guide 1.61 is an attempt to reflect the energy loss -- or energy change, rather, it can't be lost, that you would normally expect under the given conditions in their tables, regardless of course -- or regardless of the mechanics involved.

I note that in Table 1 of Reg Guide 1.61, footnote three reads in part "includes both material and structural damping". I think the intent of the word "material"

there was hysteresis, and the intent of the word "structural" is probably largely frictional.

Q Well, I don't want to get into this in detail yet. But we'll come back to this 1.61.

Dr. Seed, could we continue with your explanation of the derivation of response spectra? I'm sorry that we had to interrupt that.

A (Witness Seed) Yes.

(Slide.)

Thank you.

That's the slide that we had on before, and I have nothing more to say about that if it's perfectly understandable to everybody concerned what it means. But I will be glad to describe more about it until everybody feels they know enough about it to satisfy their needs.

Q Maybe slide two will provoke questions about slide one.

(Slide.)

A What I really wanted to say next was that this is simply an example of a response spectrum. It is not the same shape as I had on slide one, but it is a drawn -- an artificial -- it's just a diagram I made by drawing some lines on a diagram, and there is some time history of motions that would have this as its response spectrum. I didn't bother to find out what it was.

The important thing that I really wanted to stress in slide one and here is that the zero period ordinates will always be equal to the maximum ground acceleration.

Now if I want to compare spectral shapes, the easiest way to do it -- and when I say "shape" I mean the form of this as distinct from the particular numbers involved -- then the only way to do it is to arrange that all shapes pass through the same point on the vertical axis in the first place. And we do that by drawing what we call a normalized spectrum where all ordinates of the spectrum are divided by the zero period ordinate.

In that way the zero period ordinates will automatically have a value of one, because it will be being divided by itself. And therefore plotted on a normalized spectrum shape it will start at one, and that will be true no matter where I start it up here, the zero period ordinate reporting three, and the spectrum went up there, and I normalize that and plot a normalized spectrum shape, I would have .3 divided by .3, and the starting point over here would always be one.

Using normalized spectra --

Q Excuse me, Dr. Read.

I think that again, for purposes of the record, when you say "here" and "there" could you please identify

which of the graphs you are referring to on the chart so that it gets into the record?

MR. TOURTELLOTTE: I think the record should also indicate that up until the moment he mentioned "normalized acceleration", he was discussing the part of the slide which is simply entitled Acceleration Response Spectrum.

The two representations are entitled Acceleration Response Spectrum on the left, and on the right Normalized Acceleration Response Spectrum.

MRS. BOWERS: Well, and it's entitled Figure 2.

Do you want to read the title?

WITNESS SEED: The figure is entitled Determination of Normalized Acceleration Response Spectrum.

MR. FLEISCHAKER: For the record, could we have this marked as Joint Intervenors' Exhibit number 54?

(Whereupon, the document referred to was marked as Joint Intervenors' 54 for identification.)

BY MR. FLEISCHAKER:

Q Okay. I'm sorry.

A (Witness Seed) The point that I'm really trying to stress in going from an actual response spectrum to a normalized response spectrum is that the shape of the

spectrum is not changed in the normalizing process. The shape of the normalized spectrum will be identical with the shape of the original acceleration response spectrum. The only difference will be that instead of starting at some particular value of maximum ground acceleration as the zero period ordinate, when we plot it in a normalized fashion it will always start at a value of one.

Now if I want to compare a lot of response spectra all together, it is convenient to compare the shapes in this normalized form because then they are standardized to all begin at the same place, at zero period. And I can superimpose on this plot not only one spectrum, but a lot of other spectra all together.

And where this has some valleys, other spectra may have peaks; and where this has peaks, other spectra may have valleys. And that's purely a function of the time history of motions for which the spectra are derived.

So for design purposes, rather than take one particular spectrum from one particular earthquake record, what we do is plot on the same graph perhaps 20 or 30 accelerations response spectra and then find some value which is representative of all of these spectra.

What we may do is take the mean value of all the spectra that are there, or we may take an upper bound value. We could express these spectra in percentiles, and

say I am going to plot 30 spectra on this graph, and then I am going to draw in the mean of all the values that I get on that graph. And in that way I would get a mean acceleration response spectrum representative of 30 different response spectra.

Q Is that what engineers would do in deriving a design response spectra?

A That's what engineers do in deriving a design response spectra, and that's essentially what was done in deriving the response spectrum you referred to in Reg Guide...

Q 1.61.

A 1.61.

A (Witness Blume) 1.60.

A (Witness Seed) 1.60.

Now if we're designing non-critical structures, then we might draw all these spectra on one plot and take the mean of them and say that's an adequate basis for design. If we're designing more critical structures we would put all of the spectra on one plot and then take a near-upper bound because we want to be sure that we're designing for high motions.

And so in the Regulatory Guide 1.61 -- 1.60, the spectrum that was chosen is about an 80 percentile spectrum, often referred to something like mean plus one standard deviation, which happens to make it about an 80 percentile

spectrum shape. That is where conservatism is introduced into the design process. It means that 20 percent of values on spectrum will lie above that, and 80 percent of the values will lie below the value given by the Reg Guide spectra in Reg Guide 1.60.

Q I want to ask you about that.

A Yes.

Q Suppose we only used one earthquake to derive our design response spectra. How could we be assured that the one that took place would have a fingerprint just like the one that we used.

A Well, if we take a spectrum which is the near-upper bound of 33 that have actually happened, all the chances of any earthquake falling outside that spectrum are quite low, very low, the chances are that it will fall well below that spectrum.

A (Witness Blume) In answer to your last question, in the old days one method was to select an earthquake as a model that most typically represented the problem at hand that had to do with selecting a magnitude, an epicentral distance, a type of ground, other characteristics that you would expect to represent the conditions. And then you might possibly obtain your shape -- not the amount, but the shape of the diagram by consideration of that model.

In subsequent years, as more records became

available, and everybody became more knowledgeable, it was decided that a better procedure would be to consider as many earthquakes as possible, but also keeping in mind to select one's that were representative somehow of the site conditions under consideration.

So this can be done and has been done. Other methods involve the characteristics of the ratios of accelerations and velocities and displacements and so on, and by consideration of a great many earthquakes. This is a favorite method of Dr. Newmark.

So there are various ways of taking care of the problem that you mentioned.

Q Well, can we agree that the problem -- you started out, Dr. Blume, by indicating that we're looking for earthquakes that typically represent the problem at hand.

A Yes.

Q Can we agree that the problem at hand is to anticipate a future earthquake?

A Yes.

Q Can we also agree that each earthquake is essentially unique in terms of its time history?

A They are unique; but on the other hand, if you select certain characteristics that are similar, you have a better chance of getting a good model, a much better model.

Q Okay.

Well, we can focus on site conditions, for example, and we can take a look at time histories recorded at a particular site that is similar to the site that we're putting our building on, correct?

A That's one.

Q And we can also estimate or guesstimate at what distance the faults will rupture and look for a record which somewhat is at a similar distance from the fault that ruptured in the case where the record was recorded, correct?

A That's another parameter, yes.

Q But we also have to look at things like the possibility of focusing in the case in the future, isn't that correct, that is the sense of motion on the fault.

A Well, I think the focusing has been taken care of in the records that have been obtained.

Q But the record obtained may not be the record of the future.

MR. NORTON: Object.

I think that's argumentative, number one. I think Dr. Blume said records, and then Mr. Fleischaker wants to argue and say but the record -- singular -- may not be the same.

I think it's argumentative.

MR. FLEISCHAKER: I'll withdraw the question. I agree.

MRS. BOWERS: Mr. Fleischaker, you pointed your finger at the witness.

(Laughter.)

MR. NORTON: Was that verbally or physically? I didn't see.

(Laughter.)

MR. FLEISCHAKER: Too much coffee.

MR. TOURTELLOTTE: Perhaps we should leave our fingers at the door as we come in.

(Laughter.)

WITNESS SEED: Mr. Fleischaker, if I might add one last word on shape, but putting a lot of spectra on one diagram and then taking the mean or the 80 percentile value, the advantage of that is we take out the dips which occur at certain periods, and end up with a rather smooth shape as distinct from the very erratic shape. And that means that we are not arranging -- or there's no way to arrange that your structure falls particularly in one of the valleys. It will have to fall near the upper bound of the peak of some spectrum.

So it is a little more conservative to do that than to take an actual single spectrum.

BY MR. FLEISCHAKER:

Q I understand and agree.

I wanted to focus on the opposite end of the

scale, which is if we took only one earthquake then we would assume the risk that the future earthquake wouldn't look anything like the time history generated in the earthquake that we utilized for response spectra, correct?

MR. NORTON: Mrs. Bowers, excuse me.

Again, Mr. Fleischaker is proceeding on the assumption of one earthquake record, which is totally contrary to the evidence in this case. There is no indication of only one earthquake record as being used for the response spectrum of Diablo Canyon, and that's just totally misleading.

MRS. BOWERS: Well, the slide illustrates one, isn't that correct?

MR. NORTON: That's correct.

But Mr. Fleischaker's questions are not directed at the slide. He's now off into talking about a record as if that's what were used in this proceeding, which is precisely not the case.

MR. FLEISCHAKER: I'm talking about shapes, and I'm talking about the shapes of the response spectra. And I understand, I think the record fairly reflects that with respect to the first design analysis two earthquakes were used. And with respect to the -- for example, Reg Guide 1.60, we had 30 earthquakes that were used, and some mean plus one standard deviation was drawn through those curves. So that was the shape, I believe, that Dr. Newmark utilized.

mpb13

So I'm not trying to mislead. What I'm trying to do is focus on the reason why we take 5, 10, 15 earthquakes, average them, then draw some line in order to envelope or to approximate a mean plus one standard deviation.

MR. NORTON: I withdraw the objection.

MRS. BOWERS: Fine.

BY MR. FLEISCHAKER:

Q Now if we took only one earthquake, then there would be some risk that the one earthquake -- one earthquake in the time history, from that single earthquake to generate a response spectra we would assume a risk that the future earthquake would have a very different time history.

A (Witness Seed) That's right.

Q Even of the same magnitude?

A That's right.

Q Even at the same distance?

A That's right.

Q Even with the same soil conditions?

A That's right.

Q If we take two earthquakes we reduce that risk?

A That's right.

Q And if we take 30 earthquakes we reduce that risk further?

A That's right.

It is debatable how many you need to take to

reduce the risk to acceptable limits; but certainly the more you take the better chance you have of eliminating any values which might accidentally occur at this place in some of the records.

Q Now if we're designing the structure for a 7.5 earthquake at a distance of seven kilometers, hypocentral distance of seven kilometers, on soil conditions that are exactly the same as Diablo Canyon, can you agree that it would be very nice to have 100 time histories of 7.5 earthquakes at seven kilometers on soil conditions similar to Diablo Canyon?

A Yes, I would agree with that.

Q And we would simply superimpose those response spectra on top of one another?

A That's right.

Q And then we would have something that with confidence we could say Yes, this is a good shape for Diablo Canyon.

A Yes.

Q But we don't have it, do we?

A We have something very close to that.

Q Okay.

A It's always debatable whether you need 100 or whether you need 10.

Q Okay. Right.

How many 7.5s do we have?

A We don't have many records from 7.5s.

Q Do we have any?

A Yes, we have a record from the Taft earthquake, maybe to 7.6.

Q Was that one of the eight that was used for the Hosgri reevaluation?

A (Witness Blume) No, not for the Hosgri.

A (Witness Seed) It was one of the ones that was used for the Regulatory Guide spectrums.

A (Witness Blume) It was also used in the original criteria, Criteria 7.

Q What was the distance of that event from the accelerometer from which the time history was taken?

A (Witness Seed) I think it was about 30 miles, if I'm not mistaken.

Q Dr. Frazier?

A (Witness Frazier) Perhaps more directly relevant is we have a record from the Tabaz in Iran, 1978, with a magnitude approximately 7.7 at a distance of five kilometers from the retrosurface.

Q Was that one of the eight that was used?

A No. We only got the record -- the first time I saw it was approximately two weeks ago. And it falls in line with our current thinking.

And the one that Dr. Seed presented earlier, the 1940 El Centro earthquake, I think is a really nice candidate for extrapolating information. It's a very unique situation in which we have a record some five kilometers from a causative rupture, approximately the same distance we're talking about for Hosgri, and it was a large earthquake, approximately a magnitude 7 earthquake, and the peak acceleration was .35g.

Q I'm sorry, what were the parameters that defined that earthquake, the ground motion from that earthquake?

A A recording station at El Centro defined the ground motion.

Q And how far was that from the --

A Approximately five kilometers, six kilometers, something like that.

I can be corrected if anybody knows the distance more exactly.

A (Witness Seed) I always thought it was about six miles, but six miles, six kilometers, something quite close to that.

Q Is that epicentral distance or focal distance?

A (Witness Frazier) That's distance from the causative rupture. That's how far it was from the point -- from the surface that was rupturing.

I think we're really fortunate to have these

kinds of records that close to that large an earthquake. That really assists us in appraising these kinds of problems. And then we spend a lot of time -- that was 1940, and a lot of our very important structures were designed based on that particular record because that was a unique event back in 1940.

And then we got more records and refined our understanding, and we were still lacking data from very large earthquakes. And then after drawing conclusions and in doing what we can to appraise ground motions from very large earthquakes, it's very confirming to me personally to get a record -- a high quality instrument record from the Iranian earthquake of the magnitude about 7.7 at a recording station in Tabaz only five kilometers from this very large thrust fault rupture, which we've already testified thrust faults tend to have larger stress drops. We would expect more severe ground shaking from thrust faults.

It was a very large magnitude earthquake record approximately five kilometers away with a .8g. It falls right in line. It's very confirming to not be out on a limb with those large magnitude earthquakes.

Q Well, I think at this time we're not talking about the peak acceleration on the record; we're talking about the shape, we're talking about the shape of the response spectra that would be derived from the time history.

Do we have any idea what the shape of the response spectra looks like devised from the time history of that Iranian earthquake?

A (Witness Blume). I haven't seen one yet, but we expect to get one very soon.

While I'm speaking, may I answer your previous question?

You asked about the Taft distance and on page 10 of my direct testimony it reads:

"The Taft record was for M equals 7.7 recorded about 42 kilometers away from the epicenter. And the San Francisco Golden Gate Park record was for M equals 5.3, about eight kilometers from the epicenter."

MR. FLEISCHAKER: Is this a good time to break?

MRS. BOWERS: I think it is.

But one thing that's been puzzling me, the selection of the word "damping". Now putting a damper on something, this sort of thing has a general meaning. Is that why this was selected, the word "damping"?

WITNESS BLUME: I suspect there may be a connection there. Many people call it "dampening", having to do with wetting something down, and that is not the intent. But putting a damper on something, like damping a fireplace chimney, it reduces the amount of smoke that goes up that chimney.

mpb25

And I would imagine that going back into terms that there is a connection, because damping, structural damping, or whatever type, has to do with the reduction of motion, of vibratory motion.

MRS. BOWERS: Well, we'll break for an hour for our luncheon recess.

(Whereupon, at 12:00 noon, the hearing in the above-entitled matter was recessed, to reconvene at 1:00 p.m., this same day.)

2f flws and

MADELON WRBLOOM flws

AFTERNOON SESSION

(1:15 p.m.)

MRS. BOWERS: We'd like to begin.

Whereupon,

JOHN A. BLUME,

H. BOLTON SEED,

GERALD FRAZIER, and

C. ALLEN CORNELL

resumed the stand on behalf of the Applicant all, having been previously duly sworn, were examined and testified further as follows:

MRS. BOWERS: Are you ready to continue, Mr. Fleischaker?

MR. FLEISCHAKER: Before we begin the cross-examination could we get the second slide back up again? I have some questions about that.

(Slide.)

CROSS-EXAMINATION (Continued)

BY MR. FLEISCHAKER:

Q Let's see. Dr. Seed, you presented this. Let me ask you to make sure I understand what this diagram on the left is.

This is an acceleration response spectrum derived from some specific earthquake at 5 percent damping.

A (Witness Seed) On the left?

Q Yes.

A No, it's just one that I drew in to be representative of what it might look like. It's not a specific-- It is not derived from a specific record.

The purpose of the diagram is purely illustrative and not applicable to any particular record.

Q Now I wanted to ask you something. If I'm using terms that improperly characterize or aren't sufficiently precise I'd appreciate your correcting this, because I'm just trying to get a handle on some concepts that were raised earlier in our discussions.

This acceleration response spectra represents motion or energy that is available to a structure assuming that an earthquake occurs --

MR. NORTON: Excuse me, Mrs. Bowers. I'm going to object to this method of proceeding. What Mr. Felischaker is doing is stating multiples as to his understanding, and with the preface that if it isn't sufficiently precise, correct me. That's not a question; that's him giving his understanding. And I would just as soon he asked a question as opposed to making a speech with a preamble, well, if it isn't sufficiently precise let me know.

MRS. BOWERS: Well, Mr. Norton, in this highly technical field we have all been trying to understand. And Mr. Norton, one of the best ways you can find out if you're

eb3

on the right track is to try to put it in your own words and to see if that's acceptable to the witnesses.

MR. NORTON: I agree. But if the multiples can be held down a little bit, he already had about three or four multiples in there, and if he could just hold the multiples down a little bit, it wouldn't be such a multiple question.

I don't really object to the method of procedure as long as the multiples are held down.

MR. FLEISCHAKER: I'll withdraw the question and see if I can make it more precise.

BY MR. FLEISCHAKER:

Q Again let me emphasize, Dr. Seed or Dr. Blume, that if the concept isn't appropriate, please recast it and refine it and make it more precise.

Does this acceleration response spectra represent, for lack of a better word, a packet of energy that's available to a structure?

A (Witness Seed) No, it represents the maximum acceleration that would develop in a single degree of freedom structure subjected to the time history of ground motions for which that spectrum is derived.

That is the definition of an acceleration response spectra.

Q Can we utilize this spectrum-- in physical

eb4

engineering, for what purpose is this spectrum utilized?

A It is used for a variety of purposes. In the most general sense it is used for evaluating the response of a structure to the ground motions which are represented by the spectrum.

Q If we had a real building out on the ground--
Well, strike that question.

If a structure doesn't have a natural period--
Strike that.

How, if at all, does a structure respond to the amplitudes in the frequency ranges beyond its natural mode?

A Well, Dr. Blume makes those kinds of computations all the time so maybe I should let him answer that question.

Q Okay.

A (Witness Blume) The response of a structure to a response diagram that falls away from its natural modes of vibration or natural periods of vibration is essentially nil. It drops off very rapidly as you get away from what we call the tuning ratio.

And I might define "tuning" as merely that point at which the period of the structure, a fundamental period or a second mode period or whatever, corresponds with the period of the response spectrum that you're looking at.

But away from that peak it drops off fairly rapidly.

[illegible]

[illegible]

[illegible]

Q [illegible]

A [illegible]

Q It's inaccurate then to conceptualize this as the structure with a single natural mode responding to the time history? That is --

A I don't quite understand your question. Could you please repeat it or rephrase it?

Q If I understand your testimony, it is that even for purposes of modeling, we break out-- Strike that.

The Diablo Canyon Nuclear Power Plant has a number of natural modes which can potentially be excited by ground motion.

A That is correct.

Q Can you identify for me the range of frequencies that we're interested in?

A Yes, I believe I can.

I'd rather do it in terms of period and we can convert that to frequency.

Q Whichever is easiest.

A I think period is easiest because we've been working with period on most of the diagrams.

The lowest periods that we have considered have been those that are approaching the point of a rigid mass; in other words, the periods are way down in the order of about .04, .03 seconds which, in terms of hertz, would be 25 or 30 or more. That's the one end of the spectrum.

The other end varies with each structure under

sb7

consideration.

Now the containment structure, as an example, I believe the fundamental mode, which is the longest mode, is in the order of about .20 to .22 seconds, somewhere in there.

Q Can I stop you one second?

You said that the containment has a mode.

A A fundamental mode.

Q To what does that apply, that fundamental mode?

A The fundamental mode of any structure is that mode in which all parts of the structure are moving in the same direction at the same instant of time.

If I might demonstrate with this pointer that Dr. Seed used very effectively: In the fundamental mode, if we assume a straight-line mode shape for the moment, the structure would move all this way to the right, back again all this way to the left, and it would keep oscillating back and forth, maintaining a straight line because we started with an assumed straight-line relationship.

Now I'm not implying that all fundamental modes are straight line; they're not. But in all fundamental modes, every particle is moving in the same direction at the same instant of time.

Q I interrupted you. You were giving us the frequency range of interest for the various structures.

A Well, for the containment structure, the shell,

eb8

the outer shell of the containment structure, the fundamental mode in which it is moving all in one direction at one instant is in the range of .20 to .22 seconds. I'm not giving an exact number because we've had some changes, depending upon which concrete value we are allowed to use.

MR. NORTON: Excuse me, Mrs. Bowers. There are tables that have the exact numbers in them, and perhaps if the witness had those tables in front of him we'd be a lot better off, rather than surmising, because there are an awful lot of numbers.

So if I could have permission of the Board to give these tables to the witness, he could more precisely answer those kinds of questions.

MRS. BOWERS: Well, why don't you show them to Mr. Fleischaker first.

MR. NORTON: He has them, too. They're from the FSAR.

MRS. BOWERS: Oh, okay.

MR. FLEISCHAKER: May I see it for a second, please?

(Document handed to Mr. Fleischaker)

MR. NORTON: I'd like to give this to the panel.

(Handing document to the panel)

2i

MR. [illegible]. [illegible] briefly [illegible] [illegible] [illegible] and [illegible] exhibit.

BY MR. [illegible]:

Q [illegible]

A [illegible]

Q [illegible] something like [illegible] page, in what manner?

A [illegible]

Q [illegible]

A The only one of [illegible]

Q Okay.

[illegible]

A The [illegible] One, and [illegible] everything [illegible] time.

Q [illegible] [illegible]?

A [illegible] [illegible].

agb2

Q Okay.

What are the other 12 figures down there?

A In terms of period?

Q No, in terms of what they represent.

A Well they represent other mode shapes where things are not all moving in the same direction at the same time, they're moving in different directions.

Q And where are those located? Is there any sequence in terms of location along the structure, in terms of height or anything?

A No, all of these modes theoretically apply to the entire system.

Now, it so happens that in some modes, you may find that certain parts of a structure may move very little as compared to other parts, and that is often true. But theoretically, each one of these modes applies to the entire system under consideration.

Q How do you derive those modes?

A These modes are determined, first of all discretizing -- or lumping, as we like to call it -- the mass of the shell, because we're not talking basically about a structure here with an exterior concrete shell in two finite units. Each unit them is called a mass and is connected by springs in what we call the lump mass model, that's the one with the double stars in this table, it's the central

1920. group of the [illegible]. [illegible] [illegible] that there [illegible] some lumps of [illegible] in [illegible] [illegible].

Now in the [illegible] [illegible] [illegible] [illegible] [illegible] though, I [illegible] [illegible] has only [illegible] [illegible] [illegible] you [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] which applies to the [illegible] [illegible] [illegible] [illegible] I'm afraid I can't have Figure [illegible] [illegible].

But an asymmetric model [illegible] [illegible] [illegible] [illegible] into account more of the variability of [illegible] [illegible] [illegible] of the structure. In other words, we would [illegible] [illegible] [illegible] different methods.

Q With respect to [illegible] [illegible] [illegible] [illegible] apparently [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] what are the criteria [illegible] [illegible] [illegible] [illegible] division into five [illegible] [illegible] [illegible] [illegible] [illegible]?

A Usually based upon [illegible] [illegible].

Figure 4-24 that you [illegible] [illegible] [illegible] is the unsymmetric model. [illegible] [illegible] [illegible] I believe, about the lumped mass model. And the [illegible] to your question is that [illegible] generally a [illegible] [illegible] place to assign a mass or a lump, [illegible] [illegible] [illegible] floors are so much [illegible] [illegible] [illegible] [illegible] weight of the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] may be [illegible] [illegible] [illegible]

agb4

Q With respect to the fundamental mode, is that a single period that we assign?

A Yes, the fundamental mode is a single period in each direction under consideration. Generally, a structure is broken into two directions, such as north-south or east-west, and there is a fundamental mode in each direction.

Now there are exceptions to that, where sometimes in a computer operation they may list the modes strictly in accordance with how the numbers fall, the longest mode being called the fundamental and then the next and so on. In fact, that's the way it's done in this table.

In the table, you notice in each column that the period in seconds is dropping off with each mode with one or two exceptions where they happen to be the same.

Q We're talking about Table 4-4A?

A That's correct.

In any one of the three columns, the periods drop off, get smaller as the mode number gets higher.

Q Now, as the containment shell -- that's what we're talking about now?

A Yes.

Q As the containment shell begins to vibrate as a result of ground motion, does that fundamental mode change or shift?

A It does not change radically unless you get beyond

the so-called yield point that I talked about this morning. However, I have found that there are slight [illegible] period in almost any structure, [illegible] the yield point [illegible] these are [illegible] normally neglected [illegible] analysis.

Q Now can you quantify the [illegible] with respect to the Diablo Canyon auxiliary building, you've given us a range of fundamental modes of [illegible] to 3.20 depending on the concrete strengths that you've specified [illegible] in your analysis.

As the containment shell [illegible] move toward the yield point, what kind of [illegible] expect to see in the fundamental mode?

A You wouldn't find very [illegible] until you do get up to the yield point, [illegible] minor variations.

I should correct one thing. [illegible] to you before about the 3.20 [illegible] this table in front of me. And I see, [illegible] that for the axisymmetric model, the [illegible] listed as 0.225, and for the [illegible] it is 0.217. [illegible] corrected.

Q [illegible] the building [illegible]

into the inelastic range, is that what we would call it?

A Yes.

When you get beyond the yield point, we call that the inelastic range. And what happens to a structure that does that varies tremendously with the type of structure and how it's designed and how it's put together. But in general the period lengthens considerably.

Q What would we expect to happen at Diablo Canyon?

A Virtually nothing, it is so rigid and such a strong structure that, first of all, I wouldn't expect it to go beyond the yield point. But if it did, hypothetically, there would be some lengthening of the fundamental mode, that's correct.

Q What is the name that you apply to these other modes that we've attached to -- or that have been computed for the other stories?

A Well we call those higher modes. Anything other than the fundamental is called a higher mode. And in order to determine precisely which stories or which of the lumped masses are most affected, we have to then turn to the mode shape. And I guess I should define mode shape.

Mode shape is the shape of the structure as it is deforming under its modal vibration. Now the mode shape I described for the fundamental mode was everything moving

in one direction. For that [illegible] in different directions. [illegible] on the computer through [illegible] what's going ....

Q [illegible] nodes, then they also [illegible] vibrate and move around this pivot point?

A Yes. If any [illegible] a pivot, the particles [illegible]

[illegible] beneficial in breaking up any [illegible] gration. In fact, I remember [illegible] with reports on that subject.

The main matter of [illegible] fectly constant periods of the [illegible] are not always there. In other words, [illegible] variations which, in my opinion [illegible] the motion.

Q Well, at the moment [illegible] response to [illegible] begins to change, that means [illegible] that it begins to [illegible]

A [illegible]

[illegible] slightly [illegible] as I [illegible]

agb8

move over to that part of the diagram which would then apply to the mode -- to the period then existing.

A (Witness Cornell) Excuse me, I might add that calculations have been made for structures, single mode structures under those conditions, that is, allowing for those small shifts in the mode -- in the fundamental mode periods, and the conclusion is always that the responses are less for models in which that shift of the mode period is permitted.

That is to confirm John Blume's statement that that shifting does tend to reduce structural response.

3A

A (Witness Thaxton) Mr. [illegible], I'm wondering how far we're going to go with these. I'm wondering if it might be helpful to tie the many modes of the structure together [illegible] response spectrum.

Q Okay. Let me [illegible]

Notice [illegible]

A (Witness Conrad) [illegible]

Q Okay.

[illegible] the first mode?

A That's a fair statement.

Q And [illegible] provides the response [illegible]

A There are several [illegible]

Q Why?

A Why? Because [illegible] response spectra which we have [illegible] structures which happen to have natural frequencies [illegible] tend to yield or pick up approximately [illegible] multiples of those [illegible]

[illegible]

the same [illegible]

periods slightly enough to fall off the peaks and back into a neighboring valley. So the tendency is for them to fall toward, on the average, lesser responses.

Q When you say "structures" do you mean masses?

A No, I mean simple, one-mode representations of structures.

Q I see.

A Individual modes, yes.

A (Witness Blume) There's another factor in this, too. What Dr. Cornell has said is exactly right. But in addition, if there is a slight charge of period, the mathematics is so affected that the results are also less because when we go through the mathematics of computing a response spectrum, for example, we're assuming absolutely constant periods which means that any tendency toward resonant build-up which might apply after several cycles tends to be reduced, so you gain in two ways.

Q I didn't understand that because of the word "mathematics." Wouldn't something have to happen to the physics?

A It's the physics, yes.

Q Okay.

Could you explain again what happens to the physics, the second thing that happens to the physics?

A All right.

When we have [illegible] of response, whether it's a response spectrum or the response of an actual structure, then, we take a period such as the periods that were here [illegible]

[illegible]

Q [illegible]

A That's correct, [illegible] linear response below the yield level [illegible] real materials such as concrete under [illegible] certainly [illegible]

Q [illegible]

A Yes.

eb4

Q Okay.

A I would say that's correct.

A (Witness Cornell) The generalization also that you're making is for relatively small changes in the period, that is, near and slightly beyond yield.

Q Well, is it the case --

MR. NORTON: Excuse me, Mrs. Bowers. I have not objected to this line of questioning because I have kind of thought of it as educational or understanding in nature, but there is absolutely no evidence in the record that the Hosgri analysis for structures deals with the inelastic to the elastic modes. To the contrary, the analysis shows that the structures remain inelastic below yield-- I'm sorry, I'm switching the two words around, inelastic and elastic. Excuse me, I'll use yield, below yield.

So all this line of questioning, while it may help everyone here understand what happens when we go beyond yield, it's not relevant to this proceeding. And I've let it go on for nearly half an hour now because I guess it does add to our understanding, but it doesn't have anything to do with Diablo Canyon. It doesn't have anything to do with the Hosgri evaluation which is below yield.

And I would object to backing it any further -- you know, asking any more questions about it unless Mr. Fleischaker can avow to the court that he has got a

witness that high is not, the Bechtel analysis shows the structure is beyond yield.

MR. [illegible]: I think that the analysis [illegible] show that particularly the auxiliary building [illegible] from the [illegible] turbine building and the core [illegible] they go into the inelastic range of response. [illegible] the point of this questioning.

What I am exploring [illegible] as it moves from an elastic response [illegible] and the relevance of this is that [illegible] of regular structures which go inelastic [illegible] have the structure as much as [illegible] whereas Diablo Canyon is going [illegible] response range for a long time and therefore [illegible], this testimony is to the point. [illegible] that range of elastic response it's going [illegible] going to benefit from moving to the longer periods. [illegible] response will remain high during the elastic range.

And that's the purpose of this cross-examination.

MR. [illegible]: Well, [illegible] pointed out the purpose. I [illegible] we've heard of the purpose that [illegible] purpose than I [illegible] [illegible] witness [illegible].

MRS. BOWERS: Does the Staff have a position?

MR. TOURTELLOTTE: Well, he's withdrawn the objection, but we thought it was relevant.

MRS. BOWERS: I knew you were getting your big guns ready and I didn't know what was coming.

(Laughter.)

MR. TOURTELLOTTE: We found no place to check our fingers at the door when we came in.

MRS. BOWERS: Do you want to continue, Mr. Fleischaker?

MR. FLEISCHAKER: No. I think I'll move to another line of questioning right now.

BY MR. FLEISCHAKER:

Q I would like to go to page 9 of the testimony and there, Dr. Blume, you --

A (Witness Blume) Is that the written testimony?

Q The written testimony, yes. I'm sorry.

Before we begin this, Dr. Frazier, you had some equations I believe you indicated might be useful in pulling together the response spectra that you mentioned earlier.

Could you show us those, please?

Was this in response to Dr. Martin's question?

A (Witness Frazier) Yes.

What is on this transparency that I drew up while we were sitting here just a minute ago is the governing

eb7

equations that we used to calculate response spectra.

(Slide.)

MR. FLEISCHAKER: Let me give this an exhibit number, please, and ask you to name it. Hold on one second, please, Dr. Frazier.

This is Joint Intervenors' Exhibit Number 55.

(Whereupon, the document referred to was marked as Joint Intervenors' 55 for identification.)

MR. FLEISCHAKER: Could you give it a name?

WITNESS FRAZIER: I've called it "Response Spectrum Equation."

3B wbl

BY MR. FLEISCHAKER:

Q Will you go ahead, please?

A (Witness Frazier) As I was describing before lunch, there are four terms in the equation that we used to calculate response spectra. And I refer to these four terms in this equation here.

Before I describe the four terms let me give a physical feel for what it is we're doing, for what it is we're calculating.

Here's a picture in the middle of the slide of a simple depiction of a one degree of freedom structure. At the base of the structure we have ground shaking, which I've depicted as B for the base. And I put two dots on top of the B. This is a conventional form for denoting acceleration. When I put one dot I denote velocity, and no dots denotes deformation.

So this is the base acceleration. These are the things that the strong motion records record, base acceleration at the base of the structure.

The structure is depicted by a mass up at the top here and some column -- some symbolic representation of columns. And they have a stiffness that we denote as K. The mass we denote as M. The displacement, or deflection of the structure at the top with respect to the base -- you see the base is moving, and the top is moving with respect

to the base. We denote the deformation of the top with respect to the base as X.

The only other term we have that enters the equation is a damping coefficient which we -- this is conventional in vibrational analysis to denote that with some sort of a dashpot arrangement. I think other branches of physics have similar denotions. And I've used the symbol D to denote the damping coefficient.

So let me step up to the equation that we used to calculate response spectrum.

The input to the equation is over here on the righthand side of the equation. And that involves acceleration and mass of the structure. The base acceleration is a function of time. And it's kind of complicated; it's too complicated typically to be able to do in ten minutes. It looks something like this. I've just drawn it by hand, an acceleration record. So there's where the complexity comes from, is the base acceleration.

The equation as a whole is derived from the principle of conservation of linear momentum. It simply says that all the forces acting on the structure must sum together to equal the mass times the acceleration of the structure. That's basically what this equation says.

The first term is the inertial forces of the structure, it's the mass of the structure times the

wb3

acceleration of the relative deformation of the top of the structure with respect to the base. And the acceleration term, or the inertia term, the first term in the equation, can be thought of as-- When you get something moving... It's hard to get something moving. It takes a lot of force to get something moving. Conversely, once you get something moving it's hard to stop it from moving.

Like an automobile. You're pushing an automobile by hand, and it's hard to get it going. Once it gets going a little bit it isn't too hard to push it. And then if you decide to stop it's very difficult to stop it. That's because of the momentum of the -- the inertia of the automobile.

So this is the inertia term.

The third term in the equation contains the stiffness of the structure. And this term simply says that if you deform the top of the structure with respect to its base that takes some force to do that. So this is the stiffness coefficient of the structure, denoting how stiff the structure is.

So we have two force terms here. And in the middle -- the middle term is the damping term. And the damping term merely says that there is energy going out of the structure proportional to the velocity, the relative velocity of the top of the structure with respect to the base.

Now that's what the governing equation looks like. It's an ordinary second order differential equation.

To solve this equation is a very simple procedure. We can get analytic solutions to the equation provided the ground shaking is very simple. As soon as you complicate up the ground acceleration we have to add together analytic solutions. But the solution is really quite simple.

We simply program this-- There are two ways to do it, two different ways to solve it. And both of them we solve on the computer. And we can get any order accuracy we want with very little difficulty from the equation. So we just basically solve this equation.

Now I'd like to add something here to help clarify the importance of this equation.

A structure,say-- This is a general statement about the use of this equation.

Say we have a ten-storey structure. The response ofthat ten-storey structure might be well represented in terms of the first ten modes of vibration. The fundamental mode has been described in terms of shaking of this pointer. I'd like to describe what a higher mode is.

If one could picture holding onto the base of a fishing rod and you shake it slowly, the tip of the fishing rod whips back and forth. That's the fundamental mode of the fishing rod. If you speed that up a little bit, what will

wb5

happen is that your hand is moving one way and the tip of the rod is moving the other direction. And you can keep that up. That's a second mode. And so forth. If you go a little faster you get into the third mode.

The key to the use of this equation is that any elastic system can be represented -- the response of that elastic system can be represented as a combination; its reponse is a combination of all the modes.

Now this equation here turns out to be a description of how any one mode responds. In other words, this is not restricted to a single degree of freedom system. This is the response of one mode, be it the third, fundamental mode or the ninth mode so an engineer can actually take this equation and appraise how the ninth mode might respond.

At the bottom of the slide I jotted down the relationship between the various terms used to describe the little symbolic structure, the resonant period called "T" has units of seconds. It's related to the square root of the mass over the stiffness and the damping ratio is proportional to the damping divided by the square root of the mass and the stiffness.

cl

DR. MARTIN: Your drawing looks very nice.

By its definitions most everything-- I assume the dots and the double dots are Newtonian notations for first and second differential.

ebl
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WITNESS FRAZIER: Let me just repeat that. The "X" is relative displacement relative to the base. We have to be careful. This is not absolute, it's relative to the base.

The "X" dot in the equation is relative velocity of the top of the structure with respect to the base.

And the "X" double-dot is relative acceleration of the top of the structure with respect to the base.

DR. MARTIN: Okay, right out of Newton.

WITNESS FRAZIER: Yes.

DR. MARTIN: Thank you.

WITNESS BLUME: I think it might be worth noting while that's on the board that with regard to our previous conversation about damping, the letter "D" up there represents damping and you'll notice it is tagged onto the velocity, so that "D" is an effective viscous damping coefficient corresponding to what I said before, that that is a convention in the whole profession to use that system.

004

MR. NORTON: Excuse me. I believe Dr. Bright had some questions.

MR. BRIGHT: I just wanted to state as a matter of interest the response record seems to me to be a real beast to try to do anything with. I assume it's your forcing function up there. Actually do you break that down, like do a Fourier analysis on it, try to separate out the various

eb2

components and then put them back together again?

WITNESS FRAZIER: No. With modern computing devices this presents very little difficulty. The acceleration record is typically digitized at 50 points per second; that is, this is time coming across this way, and the second-- If I were to think this were an acceleration record -- I told you I made it up -- an acceleration would be approximately-- Well, this entire record would be approximately 30 seconds.

We go to great pains-- Engineers go to great pains to digitize these records moving across in time at 50 points per second which is an ample description of the very minute or the very narrow spikes on this acceleration record. And so this would be 50 times 30 is whatever-- 1500 points would describe this particular record.

And it is not difficult to calculate the response of this system to 1500 points.

One thing I did not mention a minute ago is that if we want the acceleration response spectrum we solve this equation numerically and record the peak acceleration in the equation.

If we want the velocity response spectrum we do the same thing only this time we record relative velocity and so forth.

So the solution of theequation gives us whatever we want.

MR. BRIGHT: Thank you.

WITNESS CORNELL: I might amplify that answer, Dr. Bright.

Another method to solve the problem is, as you began to suggest, to do a Fourier decomposition of that complicated record and then for each term in that decompositio you have simply a sinusoid on the right-hand side of that forcing function, and then those sinusoids are superimposed. That's the so-called frequency-domain approach solution.

MR. BRIGHT: The only reason I asked was because that was the way we had to do it a long time ago, and I'm happy to see that things have progressed.

WITNESS CORNELL: We still do it that way. In fact it's considered a sophisticated way to do it.

DR. MARTIN: Is it considered in any way superior, or just more sophisticated?

(Laughter.)

I'm serious. Since computers have lots of fingers to count on and they count very fast, you could just take the record straight without making any Fourier analysis.

WITNESS FRAZIER: The question is really one of speed. Engineering firms that do these kinds of calculations are trying to minimize their computer costs, and it is not a matter of accuracy. All the different methods we use are equally accurate. We get the accuracy to whatever degree we

eb 4

want, one percent accuracy or something like that, or less than one percent, by any of the methods we use.

DR. MARTIN: So if somebody has time to work out the sophisticated solution, you might save a little time on the computer?

WITNESS FRAZIER: Well, everybody on the panel or a couple of people on the panel said the equation was complicated and I said I don't think it's so complicated. I don't think the solutions are complicated. THey're really very simple.

WITNESS BLUME: I think I said that. It's complicated to me. It depends on whether you're going to do it in a computer or not. Of course when you have a massive computer and all sorts of computer time, why nothing is complicated if you have it properly programmed. But we used to do some of these things by hand.

DR. MARTIN: That was complicated.

WITNESS BLUME: That was complicated, I agree, because we're dealing here with --

DR. MARTIN: -- too many points.

WITNESS BLUME: When we get down to the high frequency range, we have to be very, very careful that we digitize close enough. You will occasionally see response spectra with the tail sort of taking off as you approach zero and right away we know that the digitization integral was

eb 5

inadequate to do the job.

DR. MARTIN: Thank you very much. This makes it much clearer to me than anything I've seen heretofore.

3C agbl

BY MR. FLEISCHAKER:

Q I have a question on the damping ratio down there I still want to pursue that.

You have a damping lambda equal to D over the square root of something, it looks like.

A (Witness Frazier) For the record, it's D divided by two times the square root of the stiffness times the mass term.

Q Okay.

Now, what is the D? What is the D equivalent to?

A The D is merely the term used in describing the equation, to give physical significance -- to give significance to D, we turn to lambda. Lambda has more meaning to me than D does.

So what I do is, I put in values of D that will cause lambda to be what I want it to be, namely, five percent, two percent or ten percent of critical damping. So it's the lambda that is the percentage of critical damping.

Q And what does the K stand for, I'm sorry?

A The stiffness.

Q Of what?

A (Witness Blume) Of the structure.

Q And how about the M, that's the mass of the structure?

A (Witness Frazier) Yes.

agb2

A (Witness Blume) K is the stiffness. M is the mass.

Q There was one last thing that we were going to do before we moved on, and that was examine a tripartite plot.

Dr. Blume, you said you might have one of those available to show?

A (Witness Blume) I've searched for one during the noon hour and I have no plot except in the literature. So, if we turn to --

A (Witness Frazier) There's one in your written testimony.

A (Witness Blume) Yes. Figure C in the written testimony.

Did you have a question on this?

Q Yes, I wanted to know how you read this Figure C.

A All right.

Let's start with a period of one second. That'll be right in the middle of the diagram at the bottom. You see the Number One?

Q Yes, I do.

A And let's assume that we have a damping of 20 percent, just for fun, that'll be the lower diagram of the group.

So we follow Figure One up until it intersects that lambda equals 0.20. We put a little dot there, at least

agb3

mentally, and we then are able to read off three quantities. If you turn to the scale that's reading diagonally from the upper left-hand corner down to the bottom right-hand corner, that scale is labeled Acceleration, g..

So we take the point that we've previously made, run parallel to the lines that are actually normal to this scale that I just mentioned, and we will read a value of about 0.22g. So that's the acceleration that we have for the one second period at 20 percent damping.

MRS. BOWERS: When you say "normal," you mean we move over to the left where they intersect?

WITNESS BLUME: Yes, at right angles to that line, and we read 0.22 approximately.

That's the acceleration.

Now suppose we were interested in the velocity instead of acceleration. We then simply take the same point and run a line horizontally to the left-hand scale.

And I'm not going to attempt to do this exactly, but it looks to me like it might turn out to be about 14 inches per second on the left-hand scale, so that gives us the velocity of this same point.

Now that's a pseudo-velocity. By that I mean it's not precise, but it is very close to being an exact number.

Now suppose we're also interested in displacement,

agb4

which, as you'll recall, is the relative displacement of the system. We then turn to the scale that's running from the bottom left-hand side up to the top on the right-hand side, and it's labeled Displacement in Inches.

And you go normal to that line again, as we did before, and we read about, I would say, that's about 2.2 inches.

So what we've done then for this example problem is to read off acceleration, velocity and displacement, all spectral values. They're not ground motion, these are all spectral for this El Centro earthquake in Figure C.

MRS. BOWERS: I still don't know what you mean by "going normal."

WITNESS BLUME: At right angles, normal is the same as going at 90 degrees or right angles.

MRS. BOWERS: But not horizontal, is that right?

WITNESS FRAZIER: If you want to read acceleration, you read it 45 degrees coming down to the left. If you want to read displacement, you move it 45 degrees going down to the right.

And the difficulty is you have to find the scale in order to know how to read the number, that's one of the many difficulties.

WITNESS BLUME: Now the basis for the whole thing and the trick in it is the way the paper is plotted.

You see, these are printed forms. And the computer, or whatever, simply draws these diagrams right on these printed forms. And they're designed to solve these simple equations for harmonic or sinusoidal motion.

Now I might say that the error in using the harmonic assumption for a vibrating system is some but not nearly as great as it would be for ground motion, you just can't do that for ground motion.

I'll rest my case unless you have another question on this tripartite.

MR. FLEISCHAKER: No, I don't. There were a couple of concepts that you mentioned that I want to explore with you, though.

BY MR. FLEISCHAKER:

Q You mentioned pseudo-velocity. What is pseudo-velocity?

A (Witness Blume) Well, pseudo, of course, means false. It's not really that false. It's used -- it's not on this particular scale, by the way, on this page, but it's often used to describe the fact that this is not an exact spectral velocity but a velocity derived from acceleration or displacement in such a way that it is approximate. The error is usually very slight, maybe a matter of a few percent.

Q Is acceleration a real value that we use to plot on here? I mean -- how do we derive the acceleration

agb6

value that we plot on here?

A Well the acceleration values are derived according to the equations that were just illustrated on the Board, the solution of that second-order deferential equation. And that is an exact figure for the given situation. And that starts out with the time history of the recorded acceleration.

Q And do we apply some constant or some ratio to that to derive the velocity and the displacement?

A Well I can give you the harmonic equations, I think I have them jotted down here. Yes.

A (Witness Frazier) I want to put this into context a little bit that tt's equally easy for the engineer to calculate any displacement velocity or acceleration. The reason engineers use the word, "pseudo," is so we in fact can plot another trilog paper. It's a matter of convenience, the use of the term.

Q I'm not bothered by the term, I'm just wondering where you get the number.

I'm trying to determine whether there's some ratio that you apply to your acceleration value to get your velocity and displacements.

A When an oscillator is responding -- Say we have a one hertz oscillator number and we're trying to build a response spectrum, and the oscillator has a fundamental period of one hertz. If we put the complicated 1940 El Centro

agb7

record through that, at the base of the one degree of freedom system, and plot the results of the top of the single degree of freedom system, what that looks like when you plot it is very simple compared to the ground motion. It looks like a -- what we call a sine wave, it's a wave action just like this, and it's very steady and it beats, it goes up and then it comes back down again and then it goes back up again and coming back down and so forth.

If it were a pure sine wave, if it had no undulations about it then we could, from acceleration, exactly calculate the velocity and the displacement without doing any additional calculations by merely to go from acceleration to velocity simply divide by the resonant requency to go from acceleration to velocity, just divide by the resonant frequency of the oscillator.

Now that's an approximation, because the oscillations of the single degree of freedom system, when you plot it looks very sinusoidal. But it isn't perfectly sinusoidal. And so it really should be divided by the natural frequency plus or minus epsilon where epsilon is a small number.

MRS. BOWERS: Somehow I think the record should show that Dr. Frazier just casually waved his pen up and down in a freeform --

WITNESS BLUME: A sinusoid is like a corrugation

on a pipe that goes under a roadway. A corrugated metal is like a sinusoid. And the response of the single degree of freedom system when you plot, it looks very much like a corrugated steel, however, it does vary in amplitude somewhat.

BY MR. FLEISCHAKER:

Q Do you derive some constant, have some constant you apply to the acceleration value in order to derive your velocity?

A (Witness Blume) Yes. I will give you the equation, it's very simple.

The spectral velocity is equal to the spectral acceleration times the period divided by 2 pi.

Now I trust everybody knows what pi is. It's not something you eat, but a fraction of a circle. In fact, 2 pi revolutions make a circle in radians.

Q Does this relationship hold true for all -- throughout the magnitude range?

A Well magnitude really is not a function here. We're just dealing with the ground motion.

Q Okay.

Does this function then hold true for the universe of time histories that we might observe?

A Yes, it's true for any ground motion situation that you're dealing with. Or, I should say, spectral response situation due to ground motion, I think that would

aqb9

be more accurate.

Q And is there some, like constant that we can apply to derive the displacement?

1.240

A Yes. The displacement can be described by the spectral velocity times the period divided by 2 pi.

Q And likewise this relationship holds true for the universe of time histories that we might observe?

A Yes, for these given assumptions.

Q Dr. Blume, let me clarify one thing.

What period are you referencing in these equations that you've just given me?

A The period of any mode under consideration of any structure.

However, I must put in a word of caution, that there's another thing we haven't talked about that may be very important in your application of such modes, and that is the participation factor.

I hate to complicate things unnecessarily. But you enter the spectral diagrams with different modes having different weights.

In other words, each mode is not assigned the same weight in the spectral diagram. Its weight is described by what's often called participation factor, and that in turn is a function of the distribution of the mass and the stiffness throughout the structure of the whole system.

agb10

I apologize for brining this up, but I have to for completeness.

Q Okay, now let's go to Page Nine of your testimony. And at Page Nine of your testimony you describe -- Pages 9 and 10 of your testimony, you describe how the design response spectra, the original response spectra was derived for Diablo Canyon, is that correct?

A Yes.

end3C

3d ebl

Q As I understand your testimony you basically selected two earthquakes to represent condition B and condition D which you decided were controlling for this facility. Is that correct?

A Yes. We tried four earthquakes but we found that B and D controlled the design. In other words, adding A and C would not have accomplished anything more.

Q Now by what method did you determine -- did you select among these four earthquakes? How did you decide which was controlling?

A We determined the acceleration at the site of the power plant under the given magnitudes and distances by equations of attenuation.

Q What attenuation function did you utilize?

A As I recall, for this one I used one of my earlier versions of SAM, and SAM stands for-- It's an acronym for site acceleration magnitude.

I subsequently updated that version but as I recall I used possibly version 2 or 3, somewhere in there.

Q Is that version set out in the FSAR anywhere?

A I think it must be. I haven't looked at it in years but I think it must be.

MR. NORTON: Excuse me. Would that possibly be the PSAR as opposed to the FSAR?

WITNESS BLUME: Yes, it would be the PSAR if it

eb2

is in there at all.

BY MR. FLEISCHAKER:

Q Before I ask you about these accelerations, could you explain briefly what an attenuation function is?

A (Witness Blume) An attenuation function is an equation that takes into account the decrease in ground motion as one gets farther and farther away from a source such as an earthquake hypocenter or epicenter.

The attenuation again is due to -- I hate to say the word again, but damping or, as it is often called, Q in the underground circles, but it's still damping or energy loss, transfer of one from kinetic motion to something else. And the farther and farther you get away from a site, assuming there is no resonant condition that's encountered along the route, why the smaller become the amplitudes of the ground motion.

MR. NORTON: Perhaps Dr. Seed, being from Berkeley and being the soils expert, would be the one to talk about underground circles.

(Laughter.)

WITNESS SEED: I'll pass that up.

340

BY MR. FLEISCHAKER:

Q In your testimony you describe -- you discuss the SAM-5 model. Is this an attenuation function?

A (Witness Blume) Yes.

eb3

Q Do you have available to you the LL report or the appendix that has the equation for the SAM-5 in it?

A I think I do, yes.

Q Can we take a look at that so you can describe the parameters of that attenuation function?

MR. NORTON: Excuse me. I know the Board hasn't been hauling around its FSAR with it, but for this panel I suppose I should have warned you yesterday that the LLs are contained in just two volumes, Appendix D, Volume 4 and 5, and I suspect that you may want to bring those here for the remainder of the hearing because it would be impossible of course for-- I assume when we start jumping around it is going to be impossible for Mr. Fleischaker or anyone else to get copies of these up to you so that you can follow along in them. But for the remainder of the hearing it might be well to have these here because, as you can see, there's a tremendous amount of material in these volumes.

These are the LLs that you will continually hear reference to. For today, I guess we're stuck without them but....We can store them here at the hotel for you so you don't have to carry them back and forth each day.

MRS. BOWERS: Well, we'll just leave them here when we didn't need them at home.

MR. NORTON: Sure.

MR. FLEISCHAKER: Does the Board have these volumes

4 and 5 available here --

MRS. BOWERS: Not here.

MR. FLEISCHAKER: -- at San Luis Obispo?

MR. NORTON: Oh, you don't even have them here in San Luis Obispo?

MRS. BOWERS: No. That's not my department.

(Laughter.)

MR. NORTON: Perhaps when we come back January 3rd, though, a lot of the stuff gets into the structure and I don't know whether Mr. Fleischaker intends to use the LLs that much but I suspect he might want to. He may well. So perhaps when you come back the 3rd you can arrange to have these two volumes shipped out here for the use of the Board because-- I'm sure we have two copies here but not enough for everyone.

MR. FLEISCHAKER: I can tell you what I'm going to try to do. I'm going to be going into one or two of the LLs, hopefully tomorrow, in some detail, so maybe I can get those particular ones xeroxed tonight, and the Board can have copies to follow the cross-examination.

Does the Staff have copies of the LLs here?

MR. TOURTELLOTTE: No.

MR. FLEISCHAKER: We'll xerox copies of the LLs that we'll be discussing in detail tomorrow.

But I thought while we were discussing the

eb5

attenuation function, Dr. Blume could at least get that function up on the board perhaps so we would have the equation and perhaps the Board could look at it overnight and sort of digest what the parameters of that equation are.

MR. NORTON: Which LL are you talking about?

MR. FLEISCHAKER: I'm not sure. Is it Number 45 that contains SAM-5 in it?

WITNESS BLUME: Well, the original paper for SAM-4 and SAM 5 is contained as an appendix.

MR. NORTON: LL-11?

WITNESS BLUME: It's in LL-11 and it's Appendix B, 11-B. That's the actual paper given at the Sixth World Earthquake Conference. It was necessarily a limited paper because of their space requirements, but it is given in there.

MR. NORTON: That's actually a fairly short paper. It consists of perhaps six or seven pages total.

Perhaps, Mr. Fleischaker, if you intend to spend any time on this, we could take it upstairs and have it xeroxed on the Viewgraph paper and it can be shown on the Viewgraph, and therefore, the Board will be able to see it.

MR. FLEISCHAKER: I don't intend to spend a lot of time on it this afternoon, but I wanted to get the parameters out. I can get it xeroxed this evening.

BY MR. FLEISCHAKER:

Q Do you have a copy of --

eb6

MRS. BOWERS: Is this going to be a long, continuous examination? Maybe we should take a break now.

MR. FLEISCHAKER: Okay. Why don't we do that?

MRS. BOWERS: All right. Ten minutes.

End 3d

(Recess.)

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MRS. BOWERS: Can we resume?

MR. NORTON: Mrs. Bowers, before we get started, perhaps Mr. Fleischaker could tell us which LLs are going to be in use tomorrow so that we can have them prepared for the witnesses to have copies of them, because we just have this one volume here.

MR. FLEISCHAKER: I don't know yet, but I'll have copies xeroxed for everybody.

MR. NORTON: I thought you said earlier there were two LLs you were going to go into tomorrow.

MR. FLEISCHAKER: This would be one of them.

(Indicating.)

11, and --

MR. NORTON: The one you're pointing your finger at?

(Laughter.)

MR. FLEISCHAKER: At the paper, not the witness.

I'll have to take a look at the list in the testimony. I think Dr. Blume listed a bunch of them in his testimony here, and at the end of the proceeding I'll take a look at them for you.

MR. NORTON: Fine.

BY MR. FLEISCHAKER:

Q Dr. Blume, can we get a copy of the first page from your report on SAM 5 and SAM 6 on the viewgraph so the

Board and all the other Counsel can take a look at the terms that have been utilized in your attenuation functions, which I think you've given the name SAM 4 and SAM 5?

(Slide.)

A (Witness Blume) I notice that page 2-87. I don't quite know the reference to that page number.

Q I'm not sure whether that's out of the FSAR -- that is one of the copies I have and I can't tell you.

A I do know that this page appears to be the first page of Appendix 11B of Report DLL11, which is contained in those brown and red volumes, and that may be where the page number is from, I don't know.

MR. TOURTELLOTTE: The Sixth World Conference, could that be it?

MR. NORTON: It is not the same at the bottom as the report that I have, which is not to say the content isn't the same because I haven't made that comparison. But the bottom of my page says D11B.1, and that says 2-87. So it came from a different source.

Perhaps Mr. Fleischaker can tell us where it came from.

MR. FLEISCHAKER: It may have come from the Sixth World Conference. I think so.

BY MR. FLEISCHAKER:

Q Dr. Blume, so that we'll have no confusion on

the record, can you quickly scan that and see whether that is in fact the document you've written for application in the FSAR?

A (Witness Blume) Well, it seems to be the same, except for that page number.

Q Okay.

Well, the primary purpose for putting it on the screen was to identify the glossary of terms, I believe some of which are later used in the equations.

So could you proceed with an explanation of the various terms up there?

A Yes.

The letter a refers to peak ground acceleration in gals, and gals is another word for centimeters per second squared.

Incidentally, 981 gals equals one gravity.

a_y is the peak ground acceleration associated with probability level y, also in gals.

b_1, b_2, b_3 are constants determined from the data in regression and in other analyses.

$\bar{b}$, with a bar over the top of a small b, is the Blume site factor per equation four, which will come up later.

G is the standard geometric deviation used in the log normal distribution.

mpb4

ln is the natural logarithm to the base e.

M is Richter magnitude as given in <u>United States Earthquakes</u>. That's a publication.

R equals hypocentral distance in kilometers.

And I presume everyone knows that hypocentral is the distance from the point under consideration to the focus of the earthquake.

SAM is merely the acronym for Site-Acceleration-Magnitude.

V_s is the site shear velocity in feet per second.

Rho is the site specific density, dimensionless.

y is the standard normal variable with zero mean and unit standard deviation. That is used, of course, in probabilistic operations.

Q Could we turn to the second transparency and take a look at the two equations -- one question.

In your magnitudes there we've had some discussion about local magnitude and surface wave magnitude. Have you discriminated in those two in your two SAM equations?

A I have made no discrimination. I simply took whatever was listed in <u>United States Earthquakes</u>. I believe for the earlier years those would be MLs, or locals, and in later years they might be MS or ML. I took whatever was in that document, an official document.

Q Okay.

mpb5

MR. BRIGHT: Dr. Blume, the dimensionless site specific density, does that refer to a particular density, a ratio or....

WITNESS BLUME: We used densities. We plugged densities into the equations.

But this is referring to a particular site which has to do with the weight of the density divided by the weight of the water, of course. And that's the way we get the specific value, divide by the weight of the water.

(Slide.)

Now this is page 2-89, which means we've jumped a page, but it doesn't matter, I guess, for this purpose.

MR. NORTON: For the record, this is the same as page D11B.13, as contained in Volume 4 of the Hosgri analysis.

WITNESS BLUME: Yes, that seems to be the same except for that page number.

I'll move it up. I presume you're not interested in all that wording. If you are, let me know.

BY MR. FLEISCHAKER:

Q Okay.

I notice we have two equations there.

A (Witness Blume) Yes.

Q May we begin at the two equations that have the number 5 and 6 on them? If you could, explain what those

equations are for?

A Well, equation 5, also called SAM IV, is for cases where the magnitude is equal to or less than 6.5. And equation 6 is called SAM V, is for magnitudes greater than 6.5.

I would have preferred to have many more divisions. But there simply weren't enough data to divide the equations into finer increments.

The reason for varying with magnitude is that there is definite indication -- and it's also my strong opinion that acceleration does not go up directly with magnitude.

Q What is the purpose of magnitude -- excuse me, of equation number 5?

A Equation number 5 is used for magnitudes 6.5 or less to compute the acceleration at the site due to any probability y, due to any magnitude M, and due to any hypocentral distance R. The $\bar{b}$, of course, has to be obtained by equation 4.

I might give a brief explanation of that equation. My first published paper on this attenuation method was published a long time ago. I think it was the SEcond World Conference on Earthquake Engineering, possibly the third. I think it was the first one. And I then had empirical curves for $\bar{b}$, partly upon the work of Gutenberg and

Richter.

And I have since found in doing this over -- I have done this over many times over the years. As new data were obtained, I simply plugged in more data to get a sounder base for the equations. But I also found that I could greatly simplify 5 by this simple equation which has to do with the impedance of a site. And I'm deciding impedance right now as the product of specific density Rho times the site shear velocity.

The shear velocity has to be determined locally by field tests. And also Rho, of course, is simply determined by weighing samples of the material.

Q What is the shear velocity, not number, but what does it apply to?

A The shear velocity applies to the speed with which a shear wave travels through a medium, soil or rock.

In this case I'm using the units feet per second, but it can be given various units.

Q Are there two kinds of shear waves that generally propagate from earthquakes, body shear waves and surface shear waves?

A Yes. Some people call a Love wave, which is a surface wave, a type of shear wave.

Q Does this velocity apply to both types of shear waves, that is the body wave, the S wave, and the Love wave,

mpb8

which is the --

A Yes, this is the velocity that would be obtained by site experimentation. I would say generally speaking it's a body wave shear velocity going from trench to trench or from old hole or down-hole or up-hole. There are various ways it can be determined.

Q So this is applicable to the S wave.

A Yes, the S wave.

Q Now, how about equation number 6?

A Equation 6 does exactly the same thing except it's limited to magnitude over 6.5.

Both of these equations are derived by using all available earthquake strong motion data for California and western Nevada for a period -- well, ever since they started recording, and I think it goes up to 1970. And I don't recall the exact number, but I believe I'm dealing in these equation derivations with approximately 800 points.

I may be slightly off on that; we've made so many different combinations. But about 800.

Q Now isn't the purpose of these equations to relate the site characteristics and earthquake magnitudes to expected accelerations?

A That is correct. And also to estimated confidence levels or probability values which come out of the y.

The last term, by the way, in both equations

in parenthesis with the y exponent has solely to do with deviations from the median. As you can see, if y were zero, this number becomes one. And we are then dealing with the median value.

This is a log normal type distribution, by the way.

Q I think you indicated that the hypocenter rather than the epicenter distances are used, is that correct?

A Yes. R is hypocentral.

Q What was the assumed focal depth?

A Well, for this equation it could be anything. But as far as Diablo Canyon is concerned, in all of our calculations we have assumed a focal depth as five kilometers.

Q Well, for these equations in the various -- did you have an assumption regarding the average focal depth?

A Oh, in the data?

Q Yes.

A Yes. I believe we used either 8 or 10. I'd have to check that to be positive, but in that order, which, I might say, contrasts with other investigators, some of whom have used very great depths as published in some of the earlier reports, depths that would be considered abnormal today. They might show up in the reading here, actually.

Q In the 800 or so horizontal strong motion records that were utilized, do you recall whether the

mpb10

San Fernando record was utilized?

A No, it was not in that group. There were two reasons for that:

One was when we did this they had not been published officially. The second is, even if they had been published we would not want to have such a mass of data from one earthquake to bias the statistical study.

We feel that there were so many records obtained from one earthquake that it would abnormally bias the results. But at the time we did it they were not available anyway.

Q How many records were available from the San Fernando event?

A Ground motion records or total records?

Q Total horizontal ground motion records.

A I think I'll ask my panel, and put them to work.

How many ground motion records were there for the San Fernando earthquake?

A (Witness Frazier) I'm not quite clear on the question.

When you say "ground motion" -- I mean, most of the records were in buildings.

What's the question?

Q The question is -- let me see if I can put it into context.

Dr. Blume has utilized 7-, 800 strong motion,

horizontal records, I think, as his data base. And I asked him whether he used Pacoima; he said no -- excuse me, the San Fernando, and he said no, there were a lot of -- too many records or something. And I was wondering how many there were.

A (Witness Blume) I also said they weren't available at the time.

Q Oh.

A I have that in other documents that I could look up, but I don't know whether you want to take the time now or not; probably in LL46.

A (Witness Frazier) I think we know the answer. We don't know the question.

A (Witness Blume) The question is how many ground motion records, and I think he would mean to include basement records or first floor records.

Q Let me ask you this:

Did you include basement records in this data set?

A Yes, whatever was published in _United States Earthquakes_.

Q Okay.

A (Witness Seed) When you say "records", you mean north-south-east-west counted separately, or as part of one record?

Q How did you do it for purposes of this computation of 800?

A (Witness Blume) I took both horizontal components, if they were published. Otherwise I used which ever one was published.

Q Did you count them separately?

A Separately, yes.

Q Okay.

A They're good separate data points.

Q Okay.

Utilizing the same methods of identification and counting as were applied in counting up the 800 odd strong motion records, how many -- do you know how many San Fernando records there are available?

A (Witness Seed) I could guess, if that would be useful.

Q Okay.

A 150 to 200, something like that.

A (Witness Cornell) I would guess 216.

(Laughter.)

A (Witness Blume) I was going to guess around 200, but I guess I shouldn't.

A (Witness Seed) Well, it all depends on how small an acceleration you want to go down to.

Q I was just noticing, Dr. Blume, that in your

mpb13

study you've made a distinction between the statistical study, you have 1911 records on alluvium and 802 records on rock.

A (Witness Blume) In this paper? That must be another record.

Q This is on page D1183 -- I think it would be in the text above. I can't see.

A Well, now, let me explain that.

That refers to another source of data.

In order to clarify this whole thing I think I have to give a little more explanation.

As far as I know this is the only attenuation procedure that allows for the impedance of the site, number one. Number two, that brings in probabilistic variations in a formal manner, that's the y factor. And number three, it varies the motion as you go out from the source depending upon whether you're dealing with hard soil or soft soil. That's this $\bar{b}$ factor.

Now in order to get the data to develop the variation between alluvium and rock as you go out from the source, I turn then to another source of data because there wasn't near enough available in the earthquake field. I simply went to the thousands of records available mostly in Nevada and some in California, but mostly in Nevada from the underground nuclear testing program in which we've been

involved for many years. And the numbers you see up here -- I'll read this:

"This plot is based on a statistical study"--

No, pardon me. I should have started sooner.

"Figure 1 shows the ratio of peak acceleration in alluvium to that on rock plotted against hypocentral distance. This plot is based on a statistical study of 1911 records on alluvium and 802 on rock (Reference 3). Most of the records were taken in Nevada as part of the seismic effects monitoring program associated with underground nuclear detonations at the Nevada Test Site."

Now that data was used solely for the purpose of distinguishing between rock and alluvium and how the motion varied between the two. The basic earthquake data that I had referred to in using the regression analyses for these equations was the 800 or so, plus or minus, that I talked about.

Figure 1 of the actual paper which is in the appendix of Report 11 gives a plot of the ratio of acceleration in alluvium to rock acceleration versus hypocentral distance based upon all of this data from the Nuclear Test program.

Q We don't have this page on the transparency,

unfortunately. I believe it's page D11B.2. But I believe you have a term there by which you describe the attenuation with distance.

Okay. That's it.

(Indicating.)

Could you explain where you got that from?

A Well, the exponent of the thing in parenthesis, R plus 25, has an exponent of -1.135 for equation SAM IV, and -1.225 for equation SAM V.

Now that exponent -- those exponents were determined in association with this information I've just mentioned that came out of the Nevada Test Site. I matched the decay depending upon the relative decay between rock and alluvium with the information from some almost 2000 -- in fact it's 2700 records, which is a very large data sample.

Q What is the significance of that term? What is the purpose of that term in the equation?

A The purpose of that term is to not only attenuate -- and this again is a unique feature of these equations. It not only attenuates the motion with distance from the source, but it further considers in the attenuation process whether you are passing into rock or alluvium or what your site conditions are.

Now close-in, very close-in, you'll find that these things practically drop out, and it makes no difference.

mpb16

But far-out it makes a very great difference whether it's on rock or alluvium.

Q What is that difference?

A Far-out?

Q Yes. Qualitatively what is the difference?

A Well, the difference is that due to the --

MR. NORTON: Excuse me.

May we have a definition of "far-out"?

(Laughter.)

MR. FLEISCHAKER: He asked the question.

MRS. BOWERS: And I believe you used the term.

Dr. Blume, did you use that term first?

WITNESS BLUME: I'm afraid I am perhaps guilty of using it first.

What I meant mathematically is when the difference between these equations starts to become significant. But if you want me to take a guess at distance, I would say that beyond 30, 40 kilometers for R, I begin to think of it as being far-out.

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BY MR. FLEISCHAKER:

Q Would that distance have any relationship to the length of the fault rupture?

A (Witness Blume) No, because in these equations we are assuming all the energy concentrated at the focal point, which is an extremely conservative assumption, therefore fault rupture length does not enter into this at all. It should, but that will be SAM VI or VII, I hope.

Q So the physical thing that you're describing would be a function -- in the real world, would be a function of the length of fault rupture, is that correct?

A Yes. I would say very definitely so, because if energy is assumed to be released along the entire fault rupture, that would affect the way you select the term R, and it would also have some bearing on how the attenuation proceeds.

Q You sort of backed into this. What is this physical thing you're describing? You were going to describe it qualitatively. What happens far out?

A What happens far out?

Well I think normally, if it were not for the fact that soil deposits have their own natural periods of vibration or tend to amplify motion that, if it were not for that fact, that their motion would decay faster than that of the rock.

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However, based upon empirical data -- and it's quite consistent for these hundreds and hundreds of records -- the real effect is just the opposite, that due to -- probably due to local amplification of soil deposits over the bedrock, the motion is amplified.

So far out, the equations find, and I have found in all this work that far out alluvial motion is considerably greater than it would be on rock, based upon empirical evidence.

Q Is that reflected in these two functions here?

A Yes, it is.

Q What about close in?

A Close in, it works out with very short Rs, that the difference is negligible. In fact, very close in, you'll find as much motion on rock as you will on alluvium and vice versa.

Q Does the data support that conclusion?

A The data in Nevada certainly did.

In fact, I'm looking at the Nevada curve now, Figure 1 in Appendix 11B, and I find that at 10 kilometers hypocentral distance, the ratio of acceleration on alluvium to that on rock is only about 1.25. And at four kilometers, it would be one.

In other words, based upon that data extrapolated on only four kilometers, the rock and the alluvium would have

agb3

the same peak instrumental ground motion.

Q Would you conclude then that you're likely to experience the same peak acceleration at Diablo Canyon -- excuse me, if we were within say seven kilometers of a 7.5 magnitude event, we would experience the same peak acceleration for rock sites that we would be likely to experience for alluvium sites?

A I would say that, in accordance with the equations and the empirical data, that would generally be true.

The exception might be if you had an abnormal alluvial site, such as very deep or very soft, something that might amplify the motion. But barring that, the empirical data would indicate that that is the case.

Q Again, this is the empirical data from Nevada?

A No, that would be the empirical data from -- well, yes, Nevada and also the earthquake data from California and Western Nevada.

Q Do the San Fernando records support that conclusion?

A I have not -- yes, I have plugged San Fernando in, come to think of it, but I don't have the data here and I think I shouldn't try to guess as to what the results were. But in general, I think it did support that conclusion.

Q Dr. Seed, do you know anything about that?

agb4

MR. NORTON: Excuse me, may I have a definition of what "that" is?

BY MR. FLEISCHAKER:

Q The conclusion that --

MR. NORTON: Excuse me, I still have an objection. I don't know what he means by "conclusion" either. The last conclusion I heard was the one that Mr. Fleischaker drew three or four questions ago.

MRS. BOWERS: Well I thought the witness, Dr. Blume, just said to the best of his recollection, that he cranked in the San Fernando data into this kind of an equation, that it proved out.

MR. NORTON: I think he said it was generally true.

I don't know if Mr. Fleischaker is asking Dr. Seed if what Dr. Blume said was true. If that's the question, I will object on the lack of foundation, there's no foundation that Dr. Seed knows what Dr. Blume did. But I don't think that's really what Mr. Fleischaker was asking.

MRS. BOWERS: I thought Mr. Fleischaker was going to go down the panel to see if other members of the panel had more specific information or memory.

Is that correct?

MR. NORTON: Regarding the plugging of the San Fernando earthquake into the formula, SAM V?

agb5

Because, if so, there's no foundation that they've done that, and that would be my objection. But I don't know what was in his mind. I don't think it was, but if it were, I would object insufficient foundation that they haven't done that exercise.

WITNESS BLUME: I think I should emphasize --

MRS. BOWERS: Just a minute, please.

Mr. Fleischaker?

MR. FLEISCHAKER: I think I would have to read the record, but I think Mr. Norton's objection may be well taken and let me restate my question to Dr. Blume to see if I can get -- if I can separate out the thing I'm interested in.

BY MR. FLEISCHAKER:

Q Dr. Blume, do you know whether the San Fernando records tend to support the correlation that in the near field or near to an event we would expect to see the same peak accelerations on rock and alluvium?

MR. NORTON: Excuse me, Mrs. Bowers.

I don't want to seem to be an obstructionist, but again I've just heard testimony there are 216 -- a guesstimate -- records on the San Fernando.

Now is this question directed at all 216 records or I suspect -- in fact, Mr. Fleischaker is concerned about one record, the so-called Pacoima record.

And if that is indeed his question, I would prefer

agb6

that it be asked as the Pacoima record rather than the records, which are, I guess, 216 in number.

MR. FLEISCHAKER: I'm asking about all numbers.

MR. NORTON: Each and every record? Okay.

MRS. BOWERS: Well one problem we would have with that. I think a little dialogue between Dr. Seed and Dr. Cornell, the number would depend on how far down you went or how low you went in considering records.

MR. NORTON: Mrs. Bowers, the problem I have with that is because a record -- I assume the 216 records, let's say the 216 in terms of distance is many, many, many miles away perhaps thousands, I don't know, but I don't know how that would bear on the question of rock versus alluvium in close.

So when he says Do all records bear on it, that's what my objection was as to which records he was talking about. Some may not bear on the question at all.

MRS. BOWERS: Mr. Tourtellotte?

MR. TOURTELLOTTE: I'm not sure I understand the objection. I thought Mr. Fleischaker was asking a question that was directed simply toward whether you get a difference response for rock than you get for alluvium. Maybe I didn't understand the question either.

MRS. BOWERS: Well he's trying to find out, if I understood the question, does the equation hold up when you

agb7

crank in the San Fernando data.

MR. NORTON: Yes, and my objection is which San Fernando data, the Pacoima record or all 216 records?

MRS. BOWERS: I think another problem here, I don't know that the witness has the information with him, the way he spoke it was as if he were trying to recall from memory.

MR. FLEISCHAKER: Let me do this: I understand that Dr. Seed has published on this matter. We have an article which we can review tonight to make these questions more specific.

The name of the article is, "Relationships of Maximum Acceleration, Maximum Velocity, Distance from Source and Local Site Conditions for Moderately Strong Earthquakes," which appears in the Bulletin of Seismological Society of America, Volume 66, Number Four, Pages 1323 to 1342, August, 1976.

I believe Dr. Seed was one of four authors on that. So that, rather than probe around in some imprecise manner at this time, we'll reserve this line of questioning and come back to it tomorrow.

BY MR. FLEISCHAKER:

Q That's all for that.

I believe, Dr. Blume, we got off on this in talking about the selection of the earthquakes which would govern the response spectra selected for Diablo Canyon in the initial response spectra, and I believe you testified that you selected-- Let me get your testimony. Hold on, please. I believe it's at page 9.

Listed on page 9 you have four possible earthquakes: Earthquake A, apparently occurring on the San Andreas FAult 48 miles away, maximum magnitude 8.5.

Earthquake B on the Nacimiento Fault 20 miles away, maximum magnitude 7.25.

Earthquake C on the Santa Ynez Fault extended 50 miles away, maximum magnitude 7.5.

And Earthquake D, a local earthquake unassociated with any known fault, with the focus 12 miles away in any direction including down, maximum magnitude equal to 6.75.

My understanding of your testimony was that the earthquakes that were selected were B and D, and that those were selected on the basis of calculations of the peak acceleration at the site for each -- assuming the occurrence of each one of these earthquakes A through D. Is that correct?

A (Witness Blume) That's correct.

Q Okay.

eb2

Now did you utilize some model, computer model as we just discussed here, SAM 4 and SAM 5, in order to predict the peak acceleration at the site, given site conditions, distance, and magnitude for each of these four?

A I used predecessor SAM procedures that were done some many years before SAM 4 and SAM 5. They differed in the input. Naturally there weren't as many earthquakes recorded then, and they differed somewhat in the technique. But in general it was the same type of operation.

Another thing that was different about it was that the probabilistic aspect was not so formalized.

Q What value peak acceleration did you calculate for the Earthquake A occurring at the site?

A I don't think I have Earthquake A here since it didn't govern. It was very low.

MR. NORTON: Excuse me. I believe that information may well be in Dr. Smith's direct testimony. I believe the table of the four earthquakes with the maximum acceleration was there, if I'm not mistaken. Let us pull it out and I'll check.

Dr. Frazier, do you recall whether it's there or not? I think it is in Stewart Smith's testimony.

WITNESS FRAZIER: No, I'm afraid not.

MR. FLEISCHAKER: How about Mr. Bettinger's testimony at page 5?

eb3

MR. NORTON: Maybe that's it. I know I saw it someplace.

Yes, it's in Mr. Bettinger's testimony which was placed in the record yesterday as though read. So if you have a copy of yesterday's transcript, there's the place it can be found.

BY MR. FLEISCHAKER:

Q So can you just read those values off for us for each of those earthquakes, please?

A (Witness Blume) Yes.

I am handed sheet 5 and there's a table on that sheet which shows the San Andreas 48 miles away and it shows here the maximum ground acceleration at .10g. I think that was from our calculation in those days. The magnitude was 8.5.

Q How about for Earthquake B?

A Earthquake B, which would be the Nacimiento, 20 miles distance, magnitude 7.25, maximum ground acceleration .15g.

Q How about for Earthquake C?

A C was the Santa Ynez, and it was 50 miles away, 7.5 magnitude, acceleration .05g.

Q And how about D?

A D is the one not associated with any faults, 6.75 magnitude, acceleration .20g.

eb4

Those sound correct to me, although I believe the Nacimiento was originally .12 and through negotiations in various meetings it was increased a little before we formalized it.

Q Now did you derive all of these accelerations through application of some kind of function that we've been discussing here like the SAM-5?

A Yes, similar procedures, only different ones of course.

Q Well, then, on page 10 you describe the use of two earthquakes, --

A Yes.

Q -- one which was the Taft earthquake in 1952, and one the Golden Gate Park. For what purposes were those two earthquakes used in deriving the design response spectra, the initial design response spectra?

A The Taft earthquake of 1952, north 69 west, was used as a model for Earthquake B which is the Nacimiento Fault. The record was-- The shape of the record was used and it was scaled up to or down to, whichever it may be, to .15g.

Now this shows very clearly on one of the figures in my direct testimony. I believe it's Figure 1.

In Figure 1, the lower curve, at least the lower curve at zero period, comes in to .15g which corresponds exactly with the 15g that we were talking about here on this

table.

And that curve swinging up, the one without the tallest hump, is the Nacimiento earthquake B shape scaled from the -- scaled and smoothed from the Taft earthquake.

Q So you used the time history of the Nacimiento to derive this response spectra here that's depicted on Figure 1?

A No, we used the time history of the Taft earthquake.

Q I'm sorry, yes, of the Taft earthquake to derive --

A To develop a response spectrum which naturally had peaks and valleys in it like they all do, and then we smoothed that.

Q And that was the exercise we went through this morning, hypothetically, the same exercise applied to this earthquake and it gives us this curve here on Figure 1?

A Well, we went through many exercises this morning. I think I know the one you mean but I'm not sure.

In any event we did smooth the spectrum for the Taft earthquake and that's the one you see in Figure 1.

Q Was the peak acceleration for the Taft earthquake .15g?

A I have that elsewhere in my testimony I believe. I'd rather look than go by memory.

No, apparently that did not get into the written

eb6

testimony, but it was about .17g, very close to the value we used.

Q So this was an earthquake of surface wave magnitude 7.7?

A Yes.

Q And the accelerometer upon which the time history was recorded was 42 kilometers from the fault?

A Yes, I recall reading that a little earlier in the day.

Q And it is your testimony that the time history of that accelerometer had an instrumental peak acceleration of approximately .17?

A To the best of my recollection. I don't have those numbers in front of me. And I've literally got thousands of earthquakes in my head, so I don't want to be pinned down too closely.

Q Is there any way you can obtain the information on the actual peak instrumental acceleration for that particular time history?

A Oh, yes, that's easy to obtain.

Q Okay. Could we do that for the record, please?

A For tomorrow?

Q If you can do that.

MR. NORTON: Well, perhaps it can be done right now so we don't have to go back and go over all these things

eb7

tomorrow.

Dr. Frazier is pulling out a stack of papers that may have it.

Mrs. Bowers, as a matter of fact, this, as no one can dispute, is a very, very difficult area and I would suggest that we take two breaks in the afternoon. Dr. Blume has been discussing a great many technical things now for a long time, and I'm sure while he wouldn't admit it, is probably tiring, and I would like to take a break around four o'clock each afternoon to give Dr. Blume a chance to catch his breath and have a glass of water.

MRS. BOWERS: My watch had stopped. I thought it was a quarter past three.

(Laughter.)

MR. FLEISCHAKER: Can we take a break now and I can ask for another piece of information and maybe during the break they can look for it instead of breaking up the continuity of the cross-examination.

MR. NORTON: Yes, except I don't want Dr. Blume to spend the entire break doing calculations.

MR. FLEISCHAKER: This isn't a calculation.

MR. NORTON: Well, I want him to rest instead of work during the break is all I'm saying, Mr. Fleischaker.

MR. FLEISCHAKER: However you want to do it, let me tell you what the piece of information is and you can

eb8

allocate your resources any way you want.

The second piece of information is the instrumental peak acceleration from the time history used for the Golden Gate Park record, magnitude 5.3 at 8 kilometers.

MRS. BOWERS: We'll be in recess.

(Recess.)

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MRS. BOWERS: Are you ready to begin?

BY MR. FLEISCHAKER:

Q. Dr. Blume, have you had an opportunity to obtain the value for the instrumental peak acceleration from the time history of the Taft earthquake?

A (Witness Blume) Yes, we have determined that. The value I offered is very close to being right. It's somewhere between .17 and .18g.

Q How about the peak acceleration on the time history on the Golden Gate Park record?

A That was .13g.

Q Okay.

I'd like to direct your attention to page 10 of your testimony, lines 18 through 20. There you state as follows:

> "The zero period acceleration or the effective acceleration for these earthquakes was taken as .15g and .20g for earthquakes B and D respectively."

Now, according to your prior testimony the -- we have a cat on the floor.

MR. NORTON: We listed him in our prefilings as a witness.

MR. FLEISCHAKER: I didn't see his sworn testimony.

mpb2

(Laughter.)

BY MR. FLEISCHAKER:

Q Now the instrumental peak, the instrumentally recorded peak for the earthquake B I believe was between .17 and .18, correct?

A (Witness Blume) For earthquake B.

Q And the instrumentally determined peak for earthquake D was .13, correct?

A As recorded, yes.

Q The corresponding effective acceleration for earthquake B, according to your testimony, was 0.15g, and the corresponding effective acceleration for earthquake D was .20g.

How did you get from -- let's take them one at a time.

How did you get from .17 for earthquake B to .15g, by what calculation did you get from the instrumentally determined peak to the effective acceleration?

A That was, I would say, not exactly a calculation. That was a matter determined by various means including judgments. The numbers you have referred to in lines 18, 19, and 20, namely these effective accelerations, are for what was in those days called an OBE. I guess they still are, an operating basis earthquake.

And the figure 1 that corresponds with this is

mpb3

plotted the same way. That is also for an operating basis earthquake.

In those days it was customary to design first on that basis and then consider a double design earthquake called a DDE.

So I actually worked backwards. I started with the DDE and worked back to this. And the DDE would be respectively .30 and .40g.

Q Where is that listed in the testimony, those two figures, .30 and .40?

A On page 11, on the bottom, line 20:

> "It is to be noted that the peak effective accelerations for the original plant were 0.20g for the operating basis earthquake and .40g for the double design earthquake, or the DDE. These values spring from the unassociated earthquake D."

So the actual spectra used in the original design of the plant should be figure 1 multiplied by two all across the scale, speaking onow of the severe earthquake motion.

Q At the top of page 11, lines 3 to 5, you state:

> "Two times these accelerations were used for the safe shutdown condition, then termed the "double design earthquake" (DDE)."

In that sentence to what accelerations are you

mpb4

referring when you say "these accelerations"?

A The antecedent of "these" is figure 1 shown on line one.

I'll read from line one. It says:

"Figure 1 shows these operating basis design curves for two percent damping based on earthquakes B and D."

So figure 1 is the antecedent.

Q And for earthquake B, the acceleration, figure 1, is .15, is that correct?

A Yes, for B, as in boy?

Q That's right.

And for earthquake D the acceleration is .20g.

A That's right.

Q Now, how did you get those two figures from the peak in the time histories for earthquakes B and D?

A There is no relationship. We selected the time history from Taft and Golden Gate Park on the basis of their modeling similarities. Golden Gate Park was fairly close-in on rock, which modeled earthquake D very nicely. And the Taft earthquake was farther away on alluvium, which modeled the Nacimiento situation fairly well, at least the magnitude and the distance part of it.

So there is no mathematical connection between the peak recorded accelerations for those two earthquakes.

We were interested in their shapes, the spectral shape, which was described on a figure by Dr. Seed earlier in the day, the fact that shape is often of great interest to us.

The determination of the .20 and the .40 for the zero period was by other procedures. That had to do with the computation of what accelerations we might expect from those earthquakes B and D, and it had nothing to do with Taft, per se, or Golden Gate Park, per se.

Q So you just used these two time histories because of the shapes they gave you?

A The shape and and the fact that we felt they modeled the conditions as well as any other earthquakes then available.

Q Specifically what conditions?

A The proximity to the source, the fact that Golden Gate was on rock, was on a sandstone type material, and the available records.

Golden Gate Park was known to us as having a very high amplification in the high frequency range which we felt was indicated for this site in view of the reports by the seismologists and the geologists.

MR. FLEISCHAKER: Mrs. Bowers, may I have a moment?

MRS. BOWERS: Surely.

mpb6

(Pause.)

BY MR. FLEISCHAKER:

Q Let me see, Dr. Blume, if I can understand the methodology that was utilized.

You went out and selected two time histories. You derived a response spectra for those two time histories. You normalized those two time histories and you got a shape.

A (Witness Blume) And then we smoothed those shapes.

Q Right.

And that's represented here on Figure 1?

A On Figure 1, yes, for the operating basis conditions.

Q Now you considered those shapes to be representative or useful -- why did you consider those shapes to be useful in the design of Diablo Canyon?

A In view of the reports of Dr. Benioff and Dr. Smith that there would be a nonassociated earthquake D without any known fault being there in close proximity, we felt there would be a richness in high frequency motion at the site under those conditions. So we searched all available earthquake records until we found one on rock recorded close-in that we felt would best represent this high frequency amplification.

And that accounted for this big hump you see in

mpb7

Figure 1 due to earthquake D, but it still did not account for the Nacimiento far waway.

You'll notice how fast the earthquake D curve decays in Figure 1. We felt there was, then, a sparsity of information to cover the Nacimiento exposure. So we turned to the Taft earthquake and its shape to cover that condition.

Q Okay.

Now let me direct your attention to page 10, lines 18 through 20. And there again coming back to our earlier point of departure, you state that:

> "The zero period acceleration or the effective acceleration for these earthquakes was taken as 0.15g and 0.20g for earthquakes B and D respectively."

A Yes.

Q How did you derive those two figures?

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A In consideration of our computation of the accelerations that would obtain at the site from all four earthquakes, A, B, C, and D. And as we mentioned before, B and D by far governed the others. So we knew the type of exposure we had from B and D, and we went through and obtained these values.

Now as I also said before, the .15g for the B earthquake we originally had .12g, but in negotiations with AEC at that time we were forced up to .15g.

3g

Q Earlier you gave us the accelerations for those five earthquakes -- those four earthquakes, and I believe that the acceleration for Earthquake A was .10, the acceleration for Earthquake B was .15, the acceleration for Earthquake C was .05. Now we find that the acceleration for Earthquake D was .20.

A Yes.

Q You've got a figure here for Earthquake B as .15g on page 10. And you have an earlier figure -- excuse me; that also was .15.

Now did you get that figure?

A The .15?

Q Correct.

A I think we've been through that.

MR. NORTON: Yes. Excuse me, Dr. Blume.

We've been through it three, if not four times. And I'm going to object as asked and answered again and again.

MR. FLEISCHAKER: I don't think I got an answer yet. I don't know where he got this .15.

MR. NORTON: Mrs. Bowers, I would only say the understanding of counsel is not the test, but whether the question has been asked and answered. Whether he understands the answer or not-- If he doesn't understand it then he can ask different questions to broaden his base of understanding.

But he can't keep asking the question over and over and over until he does understand it. It's been asked and answered on more than one occasion.

MRS. BOWERS: Does the Staff have a position on this?

MR. TOURTELLOTTE: No.

MR. FLEISCHAKER: Could I speak to that?

MRS. BOWERS: Go ahead.

MR. FLEISCHAKER: According to Dr. Blume's testimony he has an earthquake which was representative of Earthquake B, which was the Taft record, which had an acceleration -- time history peak acceleraton of .17 to .18. That isn't the same as .15. And I have yet to understand where he has gotten this .15 figure from.

MR. NORTON: Mrs. Bowers, that may be that he has yet to understand it. But he has asked that question and it has been answered on more than one occasion.

If the test is the lawyer's understanding, believe me, there have been some questions here that I haven't understood the answers to, and I can probably ask them for a year and I won't understand the answer. Because it's a very technical subject.

But you're not allowed to just sit here and ask the question over and over again. The way I guess you attempt to understand it is to ask different questions.

MRS. BOWERS: Well it appears to us the same question has been asked several times.

Let me ask a very basic question, and I guess I shoulddirect this to Mr. Norton.

I can understand the reason for the historical recitation in the direct testimony of the application, telling what happend back through the years, and all that sort of thing. But aren't we today faced with entirely different considerations, and that's when you get back into the direct testimony on the revised criteria for Hosgri?

MR. NORTON: Absolutely. But the one thing you must keep in mind, and a point Dr. Blume made in his opening statement, that the hump in Earthquake D, that assumption of an earthquake occurring within 12 kilometers, I believe, of the site, including directly underneath to, due to an unknown earthquake, that assumption gave the original design the beef that is there that makes it withstand the Hosgri analysis. I believe that was Dr. Jahns' testimony in different words. --excuse me; Dr. Blume's testimony in different words. That's why it's there, is to show the Board, or to show anyone who wants to look at the facts, that this original beef was put in the design.

So it is not surprising that it withstands the Hosgri re-analysis.

So that's why it's there.

wb4

But actually the Hosgri analysis is the meat of why we're here. But this history does have import in that area.

MRS. BOWERS: Well, we're here -- if I understand why I'm here -- to consider whether Diablo Canyon should get an operating license or not. Now isn't the present design whether it's agreed to or considered necessary by PG&E, isn't that the thing we should be considering?

MR. NORTON: The thing we should be considering is whether the plant as designed can withstand the postulated Hosgri event. Some of the postulations which PG&E considers are way over-conservative, such as magnitude and acceleration. But that's precisely why we're here, to determine whether or not Diablo Canyon can withstand the postulated Hosgri event.

Somehow I guess this is where Mr. Fleischaker is going to get to eventually.

MRS. BOWERS: And is part of the purpose of developing the historical background and full data information on what was done prior to the revision to show not only that that was considered adequate but, if that's adequate, why, then, what is there now must be adequate?

MR. NORTON: Well I hate to be a witness and say I'm not sure I understand your question. But I'm afraid I'm not sure that I understand your question.

wb5

MRS. BOWERS: Well I'm trying to figure out why we're spending so much time on what to me is not a part of today's real world.

MR. NORTON: Well I tend to agree with that. I don't know why we are either. We're at page 9 of the testimony, and I forget how many pages there are. But it's a long ways to go.

MRS. BOWERS: Well I'll repeat an earlier question. Isn't the problem, the matter before this Board, whether the present design of Diablo Canyon is proper?

MR. NORTON: That's right. Is it adequate to withstand the postulated Hosgri event. That's the question. And all the contentions boil right down to that question.

MRS. BOWERS: And, like it or not, PG&E has been told it's 7.5g; isn't that correct?

MR. NORTON: Not like it. That's correct. 7.5 magnitude, .75g.

MRS. BOWERS: Yes.

But you see, I'm just sitting here listening. And it seems to me we're spending a lot of time on the various considerations that were done in past years that are no longer the consideration before us; except that you're trying to establish through the direct testimony -- and, of course, from that flows the cross -- that they were so great that a higher seismic design must be little more than perfect.

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MR. FLEISCHAKER: Can I respond to that because I've been sitting here and I think that I'd like to respond to that.

MRS. BOWERS: Fine.

MR. FLEISCHAKER: What I hear Mr. Norton saying is that one of the reasons this is in the testimony is to demonstrate that there was such a great margin of safety in the original design that the facility can withstand an even greater earthquake than that to which it was built, and they have --

MR. NORTON: Excuse me, Mr. Fleischaker. That's not what I said. But you can go ahead with your speech.

MR. FLEISCHAKER: Okay.

MRS. BOWERS: I may have said it.

MR. FLEISCHAKER: Okay.

Well, I have no reason to make a speech. The testimony is here, and if the Applicant wants to withdraw the testimony I'll be happy not to cross it. Mr. Norton can explain the reasons he put it in there but I think as long as it's there, we are going to cross it, and I think we have counterarguments to develop from the cross-examination and the information that we'll develop through the cross-examination.

MRS. BOWERS: Well, I'm really just trying to understand.

eb2

Now if the single purpose is for this Board and various review levels to determine whether the present design is a proper design for Diablo Canyon to operate, then I'm somewhat puzzled at so much concentration on earlier designs that are now out of the picture unless somebody is going to sue somebody else.

MR. NORTON: Mrs. Bowers, the thing that you have to remember is that the plant was built on the earlier design. The plant wasn't built on the postulated Hosgri design. So it is important to look at that to see how much strength the plant has.

As a layman as I look back at it, to me it's rather a nice thing that Dr. Smith postulated the 6.75 magnitude earthquake 12 kilometers underneath the site. Had he not done that, had EArthquake D not existed, there wouldn't have been the added strength.

If you look at Figure 1 you see that big hump in it, and that's from Earthquake D. If Earthquake D hadn't existed in the original design, then there may have been problems with the Hosgri re-evaluation. But fortunately Dr. Smith, as he testified in his testimony, envisioned Sure, there must be faults continuing out there in the ocean, we're not so stupid as to think that they stop at the shoreline, and so on that sense it is important to look at it only to show the margins of safety in the facility.

eb3

MRS. BOWERS: Well, then, we'll later get into the modification, the engineering part of the modification?

MR. NORTON: That's certainly in the written testimony.

MR. FLEISCHAKER: I'd like to make a couple of corrections to the statement of fact.

The 6.75 was postulated 12 miles underneath the plant which is about 20 kilometers, and I think that from our point of view, the important thing is what are the characteristics of ground motion that were utilized in the derivation of the design response spectra.

And then let's look at the characteristics of ground motion that one would expect given a 7.5 earthquake 5 kilometers, and then determine whether there is an adequate margin of safety.

MRS. BOWERS: Well, back to where we were before I made a speech, the Board does think that this witness has been asked repetitive questions and --

MR. FLEISCHAKER: I'll withdraw the question and move on; rather than beat that to death, I would rather read the transcript.

BY MR. FLEISCHAKER:

Q We've got these two values, .15g for earthquake B, and .20g for earthquake D.

Now how did you arrive at the selection of .40g

to govern the zero period limit for the design response spectra for the structures, systems and components critical to safety?

A (Witness Blume) We first calculated earthquake D, the local earthquake, and came up with the most probable shaking at the site of .20g which, after many meetings and discussions with AEC as it was then called, was agreed to as an operating basis earthquake anchor point or zero period value.

We then doubled that in order to provide much more added resistance for extreme possible earthquake conditions called the DDE or the double design earthquake.

31 agbl

The Golden Gate Park record was used solely for the shape of the spectral curve and its peak value had no connection with the 20 or the 40 just mentioned.

Q On what basis did you decide to double 0.20g?

A That was pretty much common practice in those days which is, I guess, over 10 years ago now. There were not the more formalistic procedures and probabilistics that we are sometimes using today.

And besides, it was a matter of judgment. It was a matter of concensus after many discussions mainly between Dr. Newmark and I at official meetings back east in Bethesda.

Q That figure, 0.40g, is that taken to represent the occurrence of any particular earthquake?

A No, just twice what earthquake D might do in the way of ground shaking. It was a conservative margin or safety factor type conduit we thought I might do.

Q Could you state for me, Dr. Blume, how you developed the initial Hosgri criteria?

A Yes, that was done in a different manner than the pre-Hosgri criteria.

Our new information was that there was a Hosgri Fault offshore. And I decided then to try another procedure that I thought would be quite effective and modeled conditions very well, namely, to consider all of the available strong motion records worldwide that represented rather large

earthquakes recorded close to the source and on a rocky site.

My judgment and intuition, as well as many other considerations, led me to believe that this would be one very good way to model the situation.

So I considered 10 earthquake components first. Two of which were the Pacoima Dam earthquakes, and I found out subsequently that the Pacoima Dam earthquake records had been altered in some manner unknown, so we decided to discard those for that reason only.

And the eight records left are shown o Page 14 of the written testimony at the top of the page: two components from Helena earthquake, 1935, which was on granite; two components from Daly City, which is really the same Golden Gate Park earthquake we've been talking about, we did not throw that out we continued to use it. The reason it said Daly City is that was close to the epicenter, but the motion was recorded in Golden Gate Park about eight kilometers away.

Then we used the two Parkfield earthquakes from Temblor Station Number Two, that was on rock recorded only seven kilometers away. And then the final two were the Pacoima Dam records, recorded three kilometers away on rock and on a rocky ridge.

Now I thought very deeply about modifying the Pacoima Dam record because of the rocky ridge, which I feel

agb3

grossly exaggerates its motion, that plus the dam right next to it. But I decided that I would use them unaltered for the purpose of determining shape, not for determining ground motion but for determining shape factor.

So these eight earthquake records were processed. We got the very latest corrected records from Cal. Tech., the official records, we ran them through the big response spectra, we divided these response spectra into very narrow period bands across the period scale, and then within each band we treated the data statistically. That is, we computed the means, the medians, the standard deviations and the coefficients of variations, et cetera.

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From this, we were able to plot. First of all, we plotted the mean curve and it, of course, had some little unevenness to it, naturally. So that was smoothed.

We then started to reason this way: that these earthquakes recorded close in were not all of probably sufficient energy in the longer period range because two of them fell below the magnitude -- in fact, three of them fell below the magnitude level.

Now I should state at this point that, in conjunction with the geologists and the seismologists of PG&E, all of us got together and it was decided that the maximum magnitude that we could give to the Hosgri Fault, which we then called Earthquake E, was 6-1/4 to 6-1/2 M.

agb4

And so we used that in our operations and we also determined that the maximum shutdown-type acceleration that we saw for the same earthquake was 0.50g.

The procedure then was to take these eight earthquake records with its statistical data, scale them into 0.50, and then to make allowances for going above the average value or the mean value, median value, and this was done.

The next step was a whole series of meetings with NRC Staff and their consultants. And there was getting to be some general feeling that we were on the right track here.

And I believe Figure -- Let me get the figure number, please, excuse me a moment.

MR. NORTON: Figure Two, I believe.

WITNESS BLUME: Figure Two of the written testimony shows the following situations: it shows the original B and D that we've been talking about this afternoon.

It then shows, on the top curve, Hosgri, E for five percent damping, which would correspond with the damping used for B and D, they were also five percent damping. And then below the Hosgri five percent curve, I show a Hosgri seven percent curve.

And I mentioned Saturday that this is all plotted on the same curve because, in the interim time, it had been

agb5

found within the profession that, where we formerly considered five percent as a valid number to use, seven percent was then allowable -- had become allowable. So it's entirely feasible then and proper to compare the lower Hosgri curve in Figure Two with B and D.

You'll notice on the far left at the zero period value, that we're now up to 0.5g instead of 0.4 where we were. As we get up in the range of 1/10th to 2/10ths second period, we find that the seven percent damped Hosgri B falls below the prior Earthquake D, which is one of the points we've been making, that this is one of the strong reasons why this plant is able to stand this very severe present criterion with modifications, of course.

The balance of the curve is simply self-explanatory. In places it's above B and D, in places it's below.

We did enough calculations at this time on the main structures to find that they would meet this E curve seven percent damped without modification.

My frank opinion is today, that would make an excellent design and an excellent plant just the way you see E seven percent plotted on this curve.

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BY MR. FLEISCHAKER:

Q You used these eight earthquakes, I guess, to get the shape of this curve here, E, that is reflected on Figure 2; is that correct?

A (Witness Blume) Yes.

Q Okay.

And where did this figure .50g come from?

A That was arrived at, again, by some calculation--

MR. NORTON: Excuse me, Mrs. Bowers. He just answered that. He just said that. I don't think that Mr. Fleischaker was listening to the answer. He not only just said it, it's right in the testimony that Mr.Fleischaker is referring to. It says it there.

C-6

I don't know what we're trying to do here, whether we're trying to run these hearings out in 1980 or not. But, you know, objection: asked and answered.

MR. FLEISCHAKER: Well, sown at the bottom of page-- I think I understand the testimony; I just want to make sure. He says,

> "These results were scaled to .50g which, after much study and analysis in accordance with modern attenuation procedures, was considered by PG&E and its consultants to be a conservative peak acceleration."

And I think on the next page he tells me what

wb2

those conservative procedures were, and I think it's SAM IV and SAM V. But I want to make sure with this witness.

I think this isn't at all repetitious.

BY MR. FLEISCHAKER:

Q Dr. Blume, from where did the .50g figure come?

A (Witness Blume) The .50g came from SAM-like calculations: that's part of it--

MR. TOURTELLOTTE: Mrs. Bowers, I don't believe the Board ever ruled on the objection. And, if you want to rule, I'd like to speak to that, too.

MRS. BOWERS: Well it wasn't really in the form of an objection, it was a lament.

(Laughter)

MR. NORTON: Mrs. Bowers,--

MR. TOURTELLOTTE: He specifically said he objected because the question had been asked and answered.

MR. NORTON: Mrs. Bowers, it was a lament. Andatthe end I said: Object: asked and answered. He didn't ask the same question before, but Dr. Blume supplied the answer to the question he just now asked in his previous answer.

MRS. BOWERS: Mr. Tourtellotte?

MR. TOURTELLOTTE: That's correct. And it seems to me that this is also in the testimony. And if Mr. Fleischaker wants to ask if there is any other information,

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other than that already presented in his testimony, he may do . But he can't ask him to repeat what is in the testimony. That's cumulative. It's unnecessary, whether it's even been asked and answered or not. And consequently I think the question should be reframed so that Dr. Blume can either say yes, or no he considered something else. And if he considered something else, then that's worth exploring. Otherwise we're just getting cumulative evidence.

MR. NORTON: Excuse me, Mrs. Bowers. The problem was that Mr. Fleischaker was talking with his consultant during the answer. They were busily talking about something else, and Mr. Fleischaker didn't listen to the answer at all.

MRS. BOWERS: Well but you do agree, don't you, just because a statement is set out in the direct testimony that questions can be asked for a fuller explanation?

MR. NORTON: Oh, absolutely. But that specific question had just been answered by the witness. And Mr. Fleischaker was talking to Mr. Hubbard and never even heard it. And then he turned around and asked the question that had just been answered.

MR. TOURTELLOTTE: Moreover, the question should not be a question that's directed to elicit from the witness what is in the testimony. But it should be a question that is directed toward whether there is any other information other than in the testimony, and, if so, what

wb4

that is. Or, if there is some explanation that is required by reason of incompleteness of the testimony, that can be done. But you just can't ask a flat question so that Dr. Blume can sit over here and enlighten us by reading from his testimony.

MRS. BOWERS: Well that's what he has been doing, a number of times, just simply reading aloud to us what's in the direct testimony.

The objection is sustained. And hopefully, Mr. Fleischaker, you'll have an opportunity to review today's cross-examination and we can proceed tomorrow without these kind of questions.

Well, I think we should adjourn.

MR. FLEISCHAKER: I agree.

MRS. BOWERS: We'll be in recess until eight-thirty in the morning.

(Whereupon, at 5:00 p.m., the hearing in the above-entitled matter was recessed, to reconvene at 8:30 a.m., the following day.)