SUMMARY OF OUR PRESENT KNOWLEDGE OF EARTHQUAKE ENGINEERING AND SOME THOUGHTS ON FUTURE RESEARCH

by Lydik S. Jacobsen*

About thirty years ago the National Academy of Sciences, which is made up of a number of highbrow scientists, decided that it was going to have a meeting at Berkeley. That was the first time it had come to the West Coast, and the first time many of its members had seen the wild and woolly West. Naturally, it was decided that the local people ought to put on some type of a show. My old friend and benefactor, Dr. Bailey Willis, who was an eminent geologist and a seismologist of sorts, inveigled me as a young assistant professor to write a paper for this august body of scientists. I did so, made it as highbrow as I thought it should be, came to the Berkeley campus armed with some two or three dozen slides, and presented the paper. When I finished my presentation, I felt quite gratified by the applause, but in the corridor I was met by a young reporter for the Associated Press, Howard Blakeslee, who said, "Very fine, but I did not understand one word of what you said. How can I report it?"

That took me down a peg! But, being a young man and wanting by all means to be on the right side of the press, I said, "Let us get together. I will get a pencil and a piece of paper, and then I will tell you about it."

So we sat down for an hour and I told him about base shear, moment, stress distribution, natural periods, transient disturbances, and resonance. After that I had the feeling that he certainly knew what it was about. I went away becalmed, but he was a reporter, not an engineer.

The next day I saw under fairly large headlines - in the 1920's there were not many things to use headlines for - the following: "EARTH'S HULA HULAS STUDIED AT STANFORD UNIVERSITY." The rest of the reportage was in the same genre.

I know very well that you are not reporters, and consequently I hope you will not get the same impression of what has been done here, namely that this talk is meant to be frivolous. Still your Committee has thought it desirable for someone to try to interpret the many perplexing things that undoubtedly have appeared so to many people in the audience.

A summary can be done in various ways. One would be to start with the first author and point out the good things that he has done and possibly disagree with some of them. There are thirty-four authors here, so I won't do that. I have read Dale Carnegie about how to influence people, and I don't think that is the way to do it.

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CONCLUSIONS

I have made a short outline of how I feel about the whole subject of earthquake resistant construction; moreover, I'll put little notes on the outline, and then I have made lists of the contributors to this Conference who, in my estimation, have added to our knowledge of the various parts of the outline. After that, I will go through the outline and point out what I feel that we do know, and mind you, it is only one person's opinion, obviously a subjective opinion, at that. Perhaps, if it were purely objective, it would be too uninteresting.

So, let us start. First we have the science of seismology, an extremely highbrow science, or it can be very highbrow. For the sake of the foreign guests who may not know what we mean by highbrow, I want to say that highbrow is something that is theoretical, aloof, and, well, sometimes unpractical. Lowbrow, on the contrary, is something that may or may not be practical; it is very seldom theoretical.

Now, seismology, per se, is a highbrow science, but we will put an alpha and omega after it to indicate that everything at this meeting really is based on seismology. If we had no seismology we wouldn't have any earthquakes, and we would have no earthquake resistant problems whatever. So seismology is really the basis of everything. It is up in the clouds perhaps, as far as most of us are concerned, but it deals with underground conditions.

As an offspring of seismology, we have the strong-motion, seismic information, that I have noted here. I will not call it a stepchild of seismology, but it is something that seismologists have not become very much interested in until about thirty or forty years ago. Before that time, they would tell what happened on the other side of the earth, because their instruments would register that; but if something happened very near them, then the instruments got out of range and could not tell much about it. So it's a relatively new offspring of seismology, strong motion, seismic information.

Since I'm a mechanical engineer, I will put after this in parenthesis "prime mover." In mechanical engineering we are quite concerned with prime movers -- is it steam, is it electricity, is it nuclear power? This information that we have noted here is absolutely essential. Nothing can be done without it.

Now, under the prime mover category I would say that we have three large divisions. I have put them here as: soil mechanics, structural mechanics, and the last, but by no means the least, field observations and experience. All three of these must draw information from the prime mover, take whatever that information is, plug it into what those sciences otherwise know, and adapt those applied sciences to what seismology dictates.

I will label soil mechanics by one, structural mechanics by two, and observations and experience by three. Of course, in order to interpret properly the whole field, one should be equally conversant with those three subjects. I think very few people can claim to be so. I certainly do not, and therefore if I make further subdivisions than those shown, they must be subject to criticism.

I know so little about soil mechanics that I'll make no subdivisions. Field observations and experience is so vast that I'll make no subdivisions in that either. When it comes to structural mechanics, I would like to make three subdivisions: 2a) has to do with ground motions, 2b) I will call structural theory, and 2c) I would call structural reconciliation, namely the reconciliation of theoretical predictions with controlled experiments.

What you see written on the blackboard, those of you who are near enough, are lists of names of the contributors to this Conference. Under strong motion seismic information, I have put five authors in the order of their time of presentation, not in order of whose contribution is of most importance: Professor Byerly, Mr. Cloud, Dr. Takahasi, Dr. Pinar and Dr. Ramirez. Similarly, under soil mechanics I have put another roster that you perhaps can read: Dr. Okamoto, Mr. Blume, Mr. Moore, Dr. Minanni and Dr. Kawasumi. Similarly, we notice the other rosters, but I will not enumerate their names. In my estimation all these authors have contributed to our knowledge of the various divisions that we have on the blackboard.

We might go a bit further in our outline and ask, "What is the final object?" The final object is obviously that of arriving at rational building codes. How can that be done, how should it be done, and how is it done? Information from strong motion records plus information from all three divisions cited and information from all their subdivisions might conceivably lead into something that we will call the practical art of design. I will write that down here. Advisedly I call it an art, definitely not a science. It is an art, and we may say that it is a "fine art," but we cannot say that it is a "free art," because it is definitely hemmed in on all sides by the governing rules that come from **all** the mentioned disciplines.

The art of design, if it is practiced by having a knowledge of these disciplines, with a strong emphasis on experience, should result in earthquake resistant building construction, and this again may result in the formulation of rational building codes. But it would be highly desirable if the practical art of design were given what we may call the "acid test" of an earthquake or close-by earthquake. If a code is given "proof by earthquake" and then revised, we should definitely obtain the end product of the whole business, the Utopia that we are all searching for, namely rational building codes.

Of course, I would not go on record as hoping for an earthquake. That is not a popular wish. If Mr. Blakeslee's successor is here, I definitely do not want him to get the opinion that I have been praying for an earthquake. However, if we have to have an earthquake, and if we can have a discriminating earthquake, one that will make poor construction show that it is poor, and make good construction show that it is strong, then provided we have no loss of life, it would be something that might actually serve a good purpose.

Now, in "proof by earthquake" we are dealing with a precarious matter, and we might prefer to circumvent that test. Indeed that is what we have done in many cases where we have made building codes that are as good as we are able to make them. Of course, the question of getting at the practical art of design through all the mentioned disciplines is still with us, but that's a formidable approach. If a person has to encompass all this before he can engage in the practical art of design, then I'm afraid not very many designs can be made.

There are fortunately other ways of doing it. You can go through one of the disciplines with certain ingredients of others, and if you obtain competent advice, you can design. Obviously, one doesn't stand alone, and the desirability of employing consultants is clear where so many disciplines are intermingled.

There are still other ways of getting at the art of design. One of these I will put down as inspiration. Now I am sure that practical design has a lot of inspiration in it. Some inspiration comes as flash inspiration, but there is another, more sluggish inspiration that has a wonderful Greek name -- it is "omphaloscepsis." If you look it up in the dictionary, you will find that it means "contemplative thinking by looking at one's navel." In other words, it is not the inspiration that you get in a flash, but you sit down and ponder it forth.

Inasmuch as we have a diagram that has a certain amount of symmetry, and since in structural engineering relating to earthquake resistant construction there is only one thing that we have no dissenters about and that is the importance of symmetry, two-fold symmetry, we should have something on the other side of the outline to balance inspiration. Over here I will not write anything down, because it's a little embarrassing, but I will try to make a diagram of it. This is supposed to be an "eye," this is supposed to be an "ear," and then we have an object that is the hardest one to draw, namely a "thumb." So, if you have an eye for, and you have an ear for, and you have the right rule of thumb, you can make a short-cut approach to the practical art of design. I am certainly the last one to say that this is an inferior approach. I know it is used in mechanical engineering, and I have a feeling that is also gives results in structural engineering although I am not licensed to practice as a structural engineer in the State of California.

If we were to say which of these outline divisions are highbrow fields and which are lowbrow, we would say that soil mechanics is a semihighbrow to highbrow field, structural mechanics can be very lowbrow, but it can also be very highbrow. Field observations definitely also range over the whole spectrum of brows. Practical art of design, let us classify that as perhaps normal brow -- one of the best abilities one can have if it includes a lot of common sense. But without rational building codes, the practical art of design is full of trade secrets. If you worked for the Government, it would be termed "confidential," even though we have professional meetings where people are anxious to tell one another how to design. But the restriction that governs design more than anything else must be placed here (writing two dollar signs on blackboard--laughter). Both sides of practical design are hemmed in by costs -- there is no doubt about that. But rational building codes are what we would like to have -- that would be Utopia. If we have them, presumably anyone with a modicum of education can learn to design earthquake resistant buildings. He will still be hemmed in by the dollar signs and the chances are that his fees could not be maintained as high as before we had the building codes.

Returning to discussion of what has transpired at this congress, I submit that in the strong motion, seismic information field, we have learned a lot. Dr. Byerly's seismic intensity and magnitude assessments for this area are of great interest. He describes an earthquake by five quantities: intensity, radius at which it is felt, the loss of human life, the loss of money, and then the magnitude. Of course, those five parameters are not independent; they are all tied up. Definitely we must know what the probabilities are that we shall have seismic disturbances. But we must know more than that. We must also have an idea of the character of the ground motion, and to get the character of the ground motion, we must have recording instruments.

Instruments are important, but the whole information on this subject cannot be obtained even if we have an infinite number of instruments in a specific locality, since the recording stretches over a long period. We heard that in Turkey they have records for hundreds of years. On the Pacific Coast we have records for about one hundred years, and I mean by that not seismograms but such information as is obtained from notes written down in church books, newspapers, and what not. All types of records are of importance; we must have a great deal of information about the seismicity of the location where we are going to build, and we must also have some idea of the type of ground motion. To get that we must have instruments. Instruments were described by Mr. Cloud and by Mr. Takahasi. What does an instrument cost? We heard that the people who build the skyscraper in Mexico City couldn't afford to buy even one instrument. As a general rule, we should have one good instrument in a place, because we need time recording. But we should also have instruments of the less expensive type that can supplement information. This is presumably what the Coast Geodetic Survey will try to develop.

In soil mechanics the long-time static settlement problem is a different one from the one we have in earthquakes. For dynamic conditions we should really have soil dynamics instead of soil statics. There is a chance that for soil dynamics the restoration may be linear, whereas for long-time settlement we don't have stress proportional to strain. In general it isn't possible to consider dynamics of a building without taking into account the ground on which it stands. In Naval architecture, which also involves structural dynamics, we consider the dynamic effect of the water that supports the ship.

In structural mechanics we use many methods. First of all, we have to know what the ground motion is, not just what the seismologists tell us, but how we are going to use it. The paper by Professor Hudson described a method originally proposed by Biot, the earthquake specturm that may take the form of either an acceleration spectrum or a velocity spectrum. You may inquire which is the better of those two and which quantity should be recorded by the seismic instruments. As far as recording is concerned, it is relatively unimportant whether we record acceleration, velocity, or displacement, because they are all three simply related. In structural analysis there are strong arguments in favor of utilizing velocity spectra as desiderata for studies and design. One way of looking at it, although it is not an exhaustive way, is that kinetic energy is proportional to velocity squared. Since no damage can occur to a structure unless a certain amount of potential energy is put into it, and since some of that is not elastic, recoverable, potential energy, the energy criterion is a logical one to use; and consequently velocity squared will be involved. On the other hand, if one wants to take an even more unsophisticated point of view, one can say that of the three choices, why not take the middle one?

In my estimation, the invention of the earthquake spectrum stands as one of the great steps forward in the applied science or practical art of designing earthquake-resistant buildings even if sometimes we may choose other types of disturbances for calculations in structural mechanics. In general we can agree that the ground motion must start, and it must stop. What it is to be in between start and stop is debatable. All we can say is that it must be an oscillatory motion; it will presumably have many periods in it; and it will have many intensities. Since it is a complicated, relatively long-time, motion, it is hard to deal with, and that, of course, justifies the earthquake spectrum.

In structural theory, we employ many methods, and at this meeting we have a large roster of people who have contributed to it. The practical design has invaded the field, and as we see, many of the papers presented involve a lot of structural theory.

The simplest and least sophisticated way in which we can make a dynamic analysis is to use pencil and paper and perhaps a compass. We do it that way if we have plenty of time and inclination. Another approach is to do it by mechanical models. This has something to be said for it even though you may feel that they are a little bit passé in regard to frame structures. In regard to dams mechanical models are clearly indicated. Even in regard to some structures it will be of great importance to use mechanical models, because certain properties can be simulated, for instance friction, and plastic behavior, properties that would be very hard to simulate in any other way. Of course, a mechanical model in many cases can also be represented by an electrical one. But there again some limitations come up. As long as you confine yourself to the viscous type of damping the electrical analogy is very straight forward. If a different type of damping is present then it is not so good. If the elastic limit is exceeded and the structure gets into an entirely different region, the plastic one, then it becomes difficult to use electrical models. Mr. Murphy's discussion of the apparatus they are using in New Zealand was an electrical analogy model.

Another way of solving these problems is by mechanical integrators, differentiators, adders, multipliers and subtractors. A machine of that type is located at UCLA. The most sophisticated type of calculating machine is the electronic one mentioned by Professor Newmark. With all those mechanical and electrical aids it would seem that this particular branch of structural engineering with ground motion instilled into it has received a great deal of attention.

The third of the subdivisions, the reconciliation of theory with controlled tests, was exemplified by Mr. Nakagawa from Japan who showed us how to wreck a building under controlled conditions, and by Mr. Blume who showed us how to reconcile with calculations the observed periods of vibration of a building. I think that in this important class we have had perhaps only two contributions here. Professor Newmark's discussion, just before this hour, -- on the effect of several earthquakes recorded by the strain meters in the City of Mexico building falls into this class even if the earthquakes were not under Mr. Newmark's control.

We have a number of people who have contributed to field observation and experience. By that I mean critical observations of what happens to structures after earthquakes have occurred. This type of work can be called lowbrow up to highbrow. It is lowbrow if it is just observed and reported on, it becomes highbrow and sometimes bewildering if fanciful statistics is used on it. In this field we have had many contributors, and it seems to me that in spite of the many contributions it has definitely not been overemphasized because it is an important one.

We have had numerous contributions to building code discussions. I don't mean to say that all of the authors have discussed building codes that might by today's standards be called rational. Some of them are building codes that have just been decided on because somebody had to make decisions, as we well know. We know now what seismic factors are used in the various countries and we have had a glimpse into many parts of the world. The creation of a rational building code must always remain an ultimate goal, but how nearly have we attained this goal so far that is a debatable question. Since I have expressed my own opinion about all these matters and since this is a highly subjective talk I can also say that the San Francisco building code, if not the ultimate in perfection, certainly is on the right track.

In closing this summary of what I have obtained from our International Conference I should make some remarks on indicated future research. If we are statisticians and believe implicitly in statistical analysis then we can say "O. K. we have done enough work on random motion assumptions, but it is my belief that we should do more work in this field, although it might not be of the old fashioned research type." Incidentally, what is meant by research? There are different meanings of that. My young daughter, who is fourteen, said the other day that she was going to the library to do research. I noticed once, perhaps only once, during the conference, a slight sneering at the word "research." Years ago research meant searching for something that has never before been known. Not just looking it up in a book. I don't think that we should retain the old definition. Research can be defined much more generally, namely the coordinating of facts, some of which other people have found. The criterion of an absolutely original idea that never has been discovered before is only one way of defining research.

I don't believe that a great deal of research is necessary from the point of view of analyzing strong-motion seismic information. Obviously if we can get cheaper instruments to record the motions,that is highly desirable. But I think we should do more about the proposal of Mr. Rosenblueth, namely that the spectrum has an equipartition of velocity, so that instead of being a curve it is just a straight line. Whether or not you want to believe that, at the present time, is up to you. I would like to see more spectra of the type that Professor Housner has published before I am willing to accept the Rosenblueth proposal.

In the field of soil mechanics I am quite sure that the soil mechanicists should take into account the dynamic point of view. This important aspect is up to them, and I should say that very gratifying work could be done here. Of course it would be preferable to have it on full scale, but if it cannot be done on full scale, small scale studies are certainly better than nothing. Perhaps in no other field is the question about whether or not the scale is large enough as important as in soil mechanics.

Structural theory -- there will always be many workers in that field, I am quite sure. I have no specific suggestions for future research.

Reconciliation -- that, I think, is the place where we must have more future research. Not just reconciliation with field observations but especially with controlled conditions. And that, of course, has a lot to do with the practical art of design. An undiscriminating earthquake that reduces everything into rubble is not of much use. When you see just a pile of rubble, whatever pet theory you have can perhaps be substantiated. It has to be a discriminating earthquake.

That ends up my summary of what I think I have learned at this Conference and I am extremely happy to have been here. I feel that all the papers have been worthwhile and I hope that the maze of information presented may perhaps be brought a little bit more into proportion by my summary. If you see the blackboard from back in the room then you have a good view of it, then you can see the whole field even though you can't see the individual items. That is perhaps not the best thing to do. But if you see it from a reasonable distance not as close as I am then you might get the proper persepective.

Let me end by saying that the field of earthquake-resistant building construction is necessarily a complicated field. There are many considerations that enter into it. It is no wonder that people are perplexed by it. We are still looking for some practical genius who can bring all this into better focus and give the right weight and attention to each of the fields that I have noted in the outline on the blackboard.

CONCLUSIONS

OUTLINE OF EARTHQUAKE RESISTANT CONSTRUCTION