Predicting Earthquakes

Whether earthquakes ever will be predictable is increasingly a matter of public concern. In an effort to bring their listeners a rational viewpoint about it, Diane Moye and John Kotick of radio station KPFK recently interviewed three distinguished seismologists from Caltech: Clarence Allen, professor of geology and geophysics; Don Anderson, director of the Seismological Laboratory and professor of geophysics; and Hiroo Kanamori, professor of geophysics. "Predicting Earthquakes" is adapted from that interview.

Gentlemen, our topic is the prediction of earthquakes, and I'd like to ask you to give us an idea of where we stand in relationship to that possibility.

Clarence Allen: First of all, there is a lot of speculation among seismologists as to where we really do stand in this effort. We've already predicted some earthquakes successfully, in this country and elsewhere. We've also failed on a number of occasions. It's clear we are still in a research stage in this whole program, but I am optimistic that we are heading in the direction of successful, routine prediction of earthquakes at some time in the future. It is hard to say how far off that time is; my own guess is that it's at least ten years away.

Don Anderson: I wouldn't disagree with the general assessment of where we are right now. We are really just starting a major research effort in earthquake prediction, and we have very few results so far and very little data. We know what to do, and how, and where. But once we get our instruments in, how long do we have to wait before there is an earthquake? We will have to have a variety of instruments in a variety of places — and then possibly wait for some long period of time.

We are in a particularly complicated position at the moment with regard to the public because we are just learning how to predict earthquakes. And when we find something interesting or anomalous happening, we don't have enough experience to say for sure that it means there will be an earthquake. The public and, in particular, the media — television, radio, and the newspapers — will have to be very patient and sophisticated in this learning period.

What techniques are used for attempting to predict earthquakes at this point? Are there a variety of schools of thought on the applicable techniques?

Hiroo Kanamori: Well, I don't think there are, technically. I don't think there is any major difference among different groups. The difference is more sociological than technical. In Japan they have been doing extensive work in this area for the last 30 years or so, and they are improving the technique. But most of the information they have has been based upon experimental and paper results. There are still many things to be known theoretically. For example, we know that an earthquake is a very complex structural process, but we still don't know at what stress level an earthquake initiates.

Allen: It's rather interesting, if one looks at programs around the world, that many people are doing similar kinds of things. For example, it was suggested in the Soviet Union some years ago that there might be a systematic change in the velocity with which seismic waves — sound waves — travel through the rocks in the area of an earthquake before the earthquake. And even though that was originally a Soviet suggestion, the method is now being tried in many parts of the world, including China.

Anderson: We're still in the middle of a lot of detailed study; we are accumulating a supply of facts regarding the happening of earthquakes, but we aren't yet at the point where we can correlate them to accurately predict the occurrence of earthquakes.

Is there any way of measuring the forces in a fault in an earthquake zone?

Anderson: Several techniques have been tried, but to get an estimate of the actual stresses in the ground is probably one of the hardest branches of seismology. The upper part of the crust, which is available to us by drilling or by other techniques, is very shallow, heterogeneous, and broken up by faults and joints.

It's not clear that a stress measurement, even if we could make an accurate one near the surface of the earth, would be particularly useful. We are, of course, making attempts. But most earthquakes, particularly in California, initiate at a depth on the order of ten kilometers or so, and it is just out of the question to measure the stress at that depth by drilling.

Earthquakes, themselves, by the shapes of the pulses they radiate, give us some indication of the stresses that are involved. Analyzing these is one of the techniques we are using. At the moment, other techniques are very promising — geodetic techniques such as measuring tilts, strain changes, and elevation of the ground, for example.

Allen: Part of the problem is that we not only need very sophisticated instruments, but we need instruments that are cheap enough so that we can put them out in large numbers over wide areas. Yes, we could drill a hole deep into the earth's crust, perhaps, and put an instrument down there, but we presumably have to have instruments in many locations up and down our fault system. That means that the instruments have to be cheap enough for us to afford a number of them, and easily enough interpreted that we can then analyze the results. Those are requirements that make tiltmeters a particularly encouraging area of investigation. Tiltmeters can now be installed fairly quickly. They're fairly cheap; their results can easily be telemetered to central reception points.

Tell us a little bit about a tiltmeter.

Kanamori: A tiltmeter is an instrument that measures change in the tilt of the ground. If a stress or a force builds up within the earth's crust, the crust deforms, and a part of it might tilt.

Anderson: The simplest way to think of a tiltmeter is to think of the bubble of a carpenter's level. A carpenter's level measures the tilt of the ground. If you build a wall, of course you use a carpenter's level to make sure it's level. If you keep the carpenter's level there, eventually you'll see a change in the tilt.

How do you know whether the tilt is significant in the indication of an impending earthquake?

Allen: That's the whole problem, of course. There are many ways in which you can get tilts. Most obvious of all is some sort of settling of the instrument itself. As a matter of fact, for the first few months — or sometimes even years — after you put any instrument into the ground, it sort of settles and gives you signals that might not have any real significance. And so the problem we face is how to distinguish between the noise and the signals, so to speak. But there have been a sufficient number of rather encouraging results for us to be optimistic. For example, the recent prediction by the U.S. Geological Survey of an earthquake up in the Hollister area — as I understand it — was based upon prior tiltmeter records.

What do you take as the starting level for a tiltmeter? You look at the variation in the angle of the earth's surface in relationship to what? To the position of the earth at the time the tiltmeter is placed? Or to some absolute measuring standard?

Anderson: Actually, you're measuring relative tilts. You install an array of tiltmeters along a fault, and then you look at the changes that occur. Now, if you have a very sensitive tiltmeter and it's installed deep underground, you'll see a daily periodicity of tilt just due to the attraction of the moon and the sun, the tidal variations. You'll also see variations due to changes in weather, such as rainfall and barometric pressure fluctuations. However, if you have a string of these tiltmeters along a fault and three or four of them start to behave erratically or to shift in a common direction — and those that are some distance away do not show any perceptible change — and if you can rule out weather influences, then you're probably seeing something that's truly a tilt in the ground.

Clarence brought up a point that's common not only to tiltmeter observations but to all methods of prediction. There are many phenomena that have been reported as seen before earthquakes. We don't have statistics, however, to know how often these things happen without an earthquake following them.

Allen: As we look back at the record, particularly in places with long histories, such as Japan and China, it's very clear that there are well-documented examples of major earthquakes being preceded by peculiar events that were noted by people at the scene and reliably reported. The changes in ground level, the islands that came up out of the water, say, a few hours or days before an earthquake — there's no question that there have been physical precursors to earthquakes. The whole problem is whether they happen consistently enough so that we can use them as a tool that will allow us to make relatively reliable predictions. Will the tilts that precede one earthquake, for example, be the same kind of tilts that precede another in some other part of the world? And will the effects that precede small earthquakes also precede big earthquakes? After all, it's the big earthquakes that we're really concerned about in terms of saving lives and reducing damage.

Anderson: It's further complicated by the variation in geological strata from place to place. For example, a tilt in southern California, similar perhaps to one in Japan, might not be indicative of the same condition because of the different structure of the earth there.

Kanamori: Actually, there is a fairly large difference in the mechanism of earthquakes in different parts of the world. Some of the earthquakes in Japan are very different from those in California or in South America, and even in Japan there are different kinds of earthquakes. We know there is a difference, but we still don't really understand what it is. The question of what precursory phenomena occur before an earthquake can be answered only if we really understand the physical mechanism of an earthquake.

Anderson: This is where the theoretical studies also come in. Coming from observations, data are, of course, empirical. It's the interpretation of the data and building up a physical model of the earthquake that are absolutely essential. The more data we accumulate on the way the earth changes its tilt before an earthquake, the closer we are to being able to build up a theoretical model for what's happening in the ground. Once we can do that, we can take information from one area and, we hope, utilize it in a different area.

Allen: One question we still haven't resolved is whether — even in a given area — different earthquakes give the same kind of precursors for use in earthquake prediction. For example, we know that the San Fernando earthquake in 1971 was caused by movement on what we call a thrust fault. The mountain block to the north was thrust up and over the valley block of the south. That's very different from the kind of movements that give rise to the earthquakes on the San Andreas fault, where the two blocks move horizontally. And because the mechanisms of these two kinds of earthquakes are very different, it's not yet clear that the precursors will turn out to be the same.

What other techniques are being explored in the prediction of earthquakes? You mentioned the Soviet technique of analyzing the speed of sound waves through particular geological strata. How does that function?

Kanamori: All of these techniques are basically measuring a change in the physical properties of the crust before an earthquake. If the rocks are compressed or squeezed, then the hardness of the rock might change as a function of time. And that change may be reflected in a change in the seismic-wave velocity propagating through the rock. So by measuring seismic-wave velocity very accurately, we may be able to detect a possible change in the stress in the crust. Of course, there are many other techniques, like measuring electrical resistivity, ground water level, and some geochemical properties.

Allen: This change in velocity in seismic waves is not easy to measure accurately, but Hiroo is doing a very interesting experiment on that right here in southern California.

Kanamori: Well, rather extensive earthquake prediction studies were initiated in southern California after the San Fernando earthquake, so it's only five or six years since we started. We are using the many large quarry blasts in southern California as a seismic source. We set up many stations to monitor them. The wave velocity from these blasts, measured very accurately, can vary up to 1/100 of a second along various paths from the point of the blast to the stations. Since we started this experiment, there has been no large earthquake, say exceeding 5.5, so we haven't had any definitive example of the way in which velocity changes preceded an earthquake. But by accumulating precise data from blasts, we can trace a change in the crustal condition as a function of time, and these data might be very useful for predicting an earthquake in the future.

Allen: As a result of Hiroo's studies, we now realize how many quarry blasts there are in southern California every day — something we never really appreciated before. In fact, we find it a little embarrassing to go back and look at some of our old records and discover that we actually thought some of these events in past years were earthquakes.

Anderson: This particular experiment brings up another point. You have to be patient in this kind of science because if there's no earthquake, you're not going to learn anything about precursors, no matter what you measure.

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Allen: That's only part of the problem. Even if we're successful in predicting small earthquakes (and I think we have been in a few instances), will those same techniques work for large earthquakes? We'll never know until we have a chance to observe a large earthquake, and that may not happen in the next ten years. That's one reason why we would really love to do experiments not only in California but in other areas where the seismicity is even higher, such as parts of Turkey, perhaps, or in China, where we could instrument an area with a greater probability of seeing a large earthquake during the period of the experiment.

Is there any international cooperation on the measurement of earthquakes?

Allen: There is a worldwide network of seismographic stations that has been established for a number of years, and it has given rise to a lot of data that are shared. But I think the most significant thing is that in the field of earthquake prediction itself there are a number of joint research projects between different countries — for example, between the Soviet Union and the United States. Some of our people are in the Soviet Union right now with seismic equipment in the field. Some of their people are in this country; one of their scientists has recently visited Caltech. There are also cooperative programs between the United States and Japan.

Anderson: There have also been several exchange visits between Chinese seismologists and American seismologists. Clarence has been to China on one of these exchanges.

Allen: We don't yet have any cooperative research programs with the Chinese, but there's been a fair amount of communication.

Kanamori: In terms of flow of information, there has been a very extensive exchange. Through the scientific literature, we know what is happening in other countries, and by reading many journals they know what is happening in this country.

Allen: I was amazed in China by how up to date their scientists were on what is going on in this country. They knew a whale of a lot more about what we're doing than we have taken the pains to find out about what they're doing. One result of what was apparently a successful prediction of a major earthquake in 1975 has been a great deal more interest in this country in finding out what the Chinese are doing.

Kanamori: Clarence mentioned this worldwide seismographic network system, which now has nearly 120 stations. Those stations all have the same type of instruments, and they gather similar information. So we can study in detail earthquakes that occur in other parts of the world. For example, we have collected all of the records of the Chinese earthquake in July of last year. By studying those records, we can acquire information that may be relevant to future California earthquakes.

Allen: It's rather interesting that this particular Chinese earthquake was a really major disaster, no question about it. The loss of life, reportedly, may have been as much as 600,000 to 700,000, which would make it among the major disasters in world history. That earthquake, insofar as we can tell, was not predicted by the Chinese, and they do not claim to have predicted it. This is rather interesting because they have made claims of some 10 to 15 successful predictions of previous large earthquakes, some of which are no doubt valid claims. We don't yet know the full meaning of this lack of prediction because we have not heard reports directly from China, and no American groups have been in China since that earthquake.

That would seem to be an indication of the difficulty of predicting different types of earthquakes in different circumstances. What techniques are being utilized by the Chinese? Do they differ from those used, say, by the Soviet Union?

Allen: Well, many of the techniques are the same kinds of things we're trying here, and the Japanese and the Soviets are trying. They involve such things as velocity changes, tilts, and measurements of radon, which is a radioactive gas that sometimes seems to increase in ground waters before earthquakes. But I think the one unique aspect of the Chinese earthquake prediction effort is the great dependence upon observations — by amateurs in the countryside — of such things as animal behavior before earthquakes.

Anomalous animal behavior has been subject to a great deal of joking, even in China. It's not clear that they really believe it in every respect, and yet they are not willing to dismiss it. And I don't think we should either. At any rate, in China there are hundreds of thousands of people in the countryside who are making various kinds of observations of, say, the level of water in their backyard wells, or the behavior of their animals, or of any other sorts of anomalies that could be observed by amateurs. I don't know of any other place in the world where there is this kind of dependence upon local people.

Apparently these observations have played a fairly large part in their predictions, and they may well have been significant. Even if 95 percent of what they're doing is not scientifically meaningful, that other 5 percent still represents a more massive effort than is going on anywhere else in the world. I think we have a good deal to learn from that effort.

Is any research like that being done here at Caltech?

Allen: Not that I'm aware of — though there is some interest in animal behavior in this country. I think it's important to note that there's a great difference between our country and China. We have the opportunity to put out sophisticated instruments, we have the funds (at least, I hope we will have the funds), and we have a smaller area to work in here in California. In China the situation is quite different. They have a tremendous resource in peasants out in the countryside.

Anderson: The Chinese farmers routinely monitor water-well activity. With lots of small farmers it is possible for them to monitor unusual animal behavior in a much more systematic way than we can. Also, the government can tell people to observe things — and to get out of their houses.

Allen: In China, Mao's philosophy espouses the wisdom of the broad masses of people. The Chinese are convinced that the people have been predicting earthquakes for 3000 years, and this is something you don't question.

What could you ask people in Los Angeles to monitor?

Allen: There are probably things we could do that we haven't been doing. This problem of the level of water in wells may be very important among events happening before earthquakes. We're not making many observations on this sort of thing, and perhaps we should be. We might also try to enlist the aid of a relatively sophisticated group of people — like the radio ham operators, who have a good deal of experience with sophisticated instrumentation.

One of the peculiar aspects of your occupations is that part of the success of your research depends upon the existence of earthquakes. You probably look forward to earthquakes as a research tool, but how do you feel personally about living in an earthquake area?

Anderson: Earthquakes are fascinating things, and the more you understand about a subject, the less you fear it. A great deal of beauty goes along with earthquakes — such as the rugged coastlines we have in California and New Zealand, beautiful mountains and valleys. These are all part of the on-going geological process.

Allen: You *are* an optimist, aren't you?

Anderson: Of course, if you are right in the center of an earthquake, there's a great amount of fear when it does strike. It's one of those natural phenomena that will never be predicted to the precise moment, so it's quite a thrill when it happens. As soon as you get over the initial shock, you, as a scientist, start analyzing the vibrations you're feeling. Naturally, we immediately come down to the laboratory to go to work.

Allen: I can assure you, though, that during the San Fernando earthquake at six o'clock in the morning, we were experiencing the same kind of fright and trauma that other people were. We weren't jumping out of bed saying, "Great! We're going to have another scientific experiment." Now, admittedly, it did provide an opportunity for us to try to understand earthquakes better, and we tried to take advantage of it. But at the time of the shaking, our reactions were probably not grossly different from those of anyone else.

I think it's also true, though, that those of us who study earthquakes don't have the blind fear that many other people do. People tend to fear what they don't understand. I think we realize that, yes, the next great earthquake will be a disaster, but it will not be a cataclysmic kind of thing. Parts of California are not going to slide out into the Pacific. This is ridiculous.

What is the Palmdale bulge?

Kanamori: The U.S. Geological Survey studied geodetic data in the past, and they discovered that the ground in the Palmdale area was uplifted about 25 centimeters, or about 10 inches, sometime in 1962. Then during the subsequent period of time, this uplift spread out into the Mojave Desert.

Of course, there are many examples of uplift in the past. Probably the most famous is the uplift prior to the 1964 Niigata earthquake in Japan. About five years before that earthquake there was a rather extensive uplift in the epicentral area, and in 1964 a magnitude 7.4 earthquake happened. In this particular case, the uplift was a precursor to this rather disastrous earthquake. Obviously, there is some concern that this Palmdale bulge may be one of the precursory phenomena prior to the next major California earthquake. However, there are some other cases in which uplifts happened, but no earthquakes.

When we talk of earthquake predictability, are we talking in terms of predicting for a range of time or for a certain date? How accurate could earthquake predictability ultimately be?

Allen: Well, since we don't know what the finest point could be, I think the important thing right now is that anyone who is offering a prediction should specify a bracket of time, over which he thinks the earthquake will occur.

There are, of course, all kinds of predictions; for example, we have said a major earthquake is likely to occur in the San Andreas fault in the next 100 years. In a sense that is a prediction, but it's not a very meaningful one in terms of doing anything other than work on building codes.

The Chinese prediction of the earthquake in 1975 started out five years before the earthquake. At first it was merely a prediction that that area was of some concern, and it had no time limit at all. Then about a year before the earthquake the Chinese specified that they expected an earthquake with a certain magnitude within about a year. As the time got closer, they successively refined that prediction, and, finally, 5½ hours before the earthquake, they announced that it was so imminent that people should get out of their houses. In China, when they say that, people get out.

Will we, at some point, be able to predict magnitude?

Anderson: Yes. There are several ways. One is the duration of the precursor, the length of time it takes between the onset of something that appears anomalous and the actual event. It now seems that the longer the time the anomaly builds up, the greater will be the earthquake. Also, in the area that is being affected by the anomaly — such as a tilt anomaly or a radon gas anomaly, or a ground uplift anomaly — the larger the area involved, the more likely it is that the earthquake will be large. The trouble is we have limited data before large earthquakes. Most of our information has been obtained on very small earthquakes, and it might be dangerous to extrapolate to larger earthquakes.

As for the time of earthquakes, there are what we call long-term precursors and short-term precursors. The long-term precursors might start years before the earthquake. As the stresses continue to go up and we get closer and closer to the earthquake, we anticipate that more dramatic things will happen, such as an increased number of foreshocks or, perhaps, an increased squeezing out of radon in the ground, or an increased activity of the ground deformation. This might allow us to say it's now getting much closer, and we might be within a week.

As far as southern California is concerned, a prediction won't really be very useful if it says in the next year we're going to have an earthquake. That doesn't tell us to do anything more than we should have been doing all along anyway — just by the simple fact that we live in an area of the world that is prone to earthquakes. However, when we get the prediction down to the point where we can say there will be an earthquake within, say, the next two days, then you can take such emergency preparations as the evacuation of people, or at least having people leave their dwellings and sleep outside. This is what the Chinese did. If the prediction is vague to the extent of even a month, you're not going to be able to save many lives. In the case of China, perhaps, they could have ordered people out of their houses for a whole month, but that would clearly not be possible in Los Angeles.

Allen: It is not even clear that 5½ hours would do it here.

What does earthquake predictability mean to the people of Los Angeles? If we could predict an earthquake accurately, what would we then do in any major city? Is it best to evacuate people? Or should we take preventive measures regardless of prediction of earthquakes?

Anderson: There's a wide variety of opinion on the social implications of earthquake prediction. Since we live in earthquake-prone country, all schools and emergency facilities, such as hospitals, should be built up to earthquake standards. These are things we should do regardless, because there *will* be an earthquake during the life of these particular buildings.

My personal opinion as to what to do when we can predict an earthquake within a very narrow time and space limit is that all emergency people should be notified — the police, the hospitals, the civil defense, and the National Guard. These organizations should be on alert; their vehicles should be parked in such places that they won't have their garages collapse around them. People should be told to stock emergency supplies, particularly food and water (because there will be water interruptions), and medical supplies. Every family should be relatively self-contained. I'm not sure how much further one should go.

Allen: Well, of course, we've identified 14,000 buildings in Los Angeles alone that are basically deficient in terms of earthquake design. The City Council is now trying to find some way of bringing these buildings up to standard or getting rid of them. We know darn well those 14,000 buildings are dangerous.

One obvious thing to do is at least to try to get people out of those particular buildings because that's clearly where there is going to be major loss of life. But I don't think that applies to most people in their own homes. Single-family dwellings as we know them in southern California are relatively safe places to be. That's not true in China, where most people have been killed in their own homes because of the way the homes are built.

What activity is government — city, county, or state — engaging in as far as the analysis of fault structures prior to housing development? Is there any effort to look at existing fault systems and prohibit developments along fault lines?

Allen: There's a fair amount of effort in this. Over the years we have gotten progressively better in our land-use planning with regard to earthquake hazards. Just about three years ago a bill was passed in Sacramento that identified special study zones along our active faults, and if you propose to put in a housing development or a subdivision within that special study zone, you must satisfy the authorities that you have taken into adequate account the active faults that exist within that zone. Many of our cities have been relatively progressive in terms of land-use planning in regard to landslide hazards that may be related to earthquakes. We are making progress.

Is there something you feel is essential for people to understand in relationship to earthquakes?

Allen: I would just re-emphasize what Don said; that is, that the next ten years are going to be rather rough ones for us in this area. I'm firmly convinced that earthquake prediction in the long run will be beneficial to people, save lives, save property loss. But nevertheless, in the process of achieving that prediction capability we are possibly going to have some false alarms, and it is going to be a rough ten years for us all. I hope the public is going to be a bit patient and recognize that this is a scientific development, a research development, that's going to have many problems as we develop our capability.

Anderson: And it's going to be particularly rough for the media, because a lot of people are going to be coming out of the woodwork, predicting earthquakes with no scientific basis whatsoever — just to gain publicity. If the media don't become very sophisticated in dealing with this kind of phenomena, they are tampering unfairly with the fears of the public.

You are suggesting that the media should take earthquake predictions with a grain of salt unless they come from reliable sources.

Anderson: Yes. This is one case where selling newspapers and getting prime-time TV just for the sake of sensationalism is not in the public interest at all. Because of the fear of earthquakes, this particular kind of sensationalism is extremely dangerous.

Allen: Many of us are rather unhappy with some of the TV coverage of unfounded predictions. It is almost like crying, "Fire!" in a crowded theater. I think a certain amount of discrimination has to be used by the media in the treatment of these stories.

To large numbers of people, the concept of an earthquake is very threatening. Perhaps we need to stop looking at the earth as a solid, static object and start seeing it as a constantly changing one.

Anderson: That is exactly right, because the earth *is* in constant motion. We are always going to have earthquakes — many of them damaging to people and property — but knowledge of the real risks and judgment about safety measures can reduce that damage. Scientifically responsible earthquake prediction may help all of us to live more comfortably with our shifting planet. □