George W. Housner: How It Was

Seismologists are interested from the ground surface down, and engineers are interested from the ground surface up.

George Housner exhibits his shaking machine, which simulates the effect of an earthquake on the model "highrise building" at right. Calculations of how a real building will react when shaken and vibrated have made it possible to develop procedures for designing safer structures. The photo was taken in the early 1960s.

Known as the father of earthquake engineering, George W. Housner first came to Caltech after graduating from the University of Michigan in 1933. He earned his MS here in 1934, then worked for five years as an engineer designing structures in Los Angeles before returning to finish his PhD at Caltech in 1941. He wrote his dissertation on the earthquake behavior of buildings. In 1945 he returned once again as assistant professor, and it was in those early postwar years that he developed spectral analysis, decomposing the complex patterns of an earthquake's ground-motion "signal" into its component frequencies. Housner spent the rest of his distinguished career at Caltech and was named the Carl F Braun Professor of Engineering in 1974. Most recent among his many honors was the 1988 National Medal of Science.

Housner became professor emeritus in 1981, but he never really "retired." And when Gov. Deukmejian needed someone to head an independent inquiry into the collapse of sections of the Nimitz Freeway and the San Francisco Bay Bridge during the October 17 Loma Prieta earthquake, Housner was the perfect choice. His four-decade reputation in making structures safe from shaking had already inspired the Times *of London, two days after that quake, to laud him as "the man who kept Frisco standing."*

The Oral History Project of the Caltech Archives recorded Housner's remembrances in 1984 in three days of interviews with Rachel Prud'homme. The following excerpts from that oral history trace the development of earthquake-safe building standards in California—and probably the rest of the world as well.

Rachel Prud'homme: Can you give me a bit of the background on the difference in the work done here in seismology and in earthquake engineering research?

George Housner: Seismologists primarily study the earth's interior by recording earthquake waves which take various paths through the interior of the earth. Their instruments are very sensitive. I can explain that with an anecdote: For our purposes—we want to measure the very strong shaking that does the damage—but in this case the seismologists' instruments would be off-scale. We had a lot of instruments—when I say "we," I mean the community here in southern California—installed in buildings prior to the 1971 earthquake, and it was sort of an eye opener to the engineers to see what these motions of the ground and of the buildings were. And we had a meeting up in San Francisco to show these records and explain them to the engineers. Afterwards, one of the engineers approached Perry Byerly, who was a famous seismologist and had just become professor emeritus at Cal Berkeley—and said, "Perry, *these* are the kind of records we engineers always wanted. Why haven't you gotten them for us before?" "Oh," he said, "If I had specialized in strong motions, I'd now be *assistant* professor emeritus." And there's a lot of truth to what he said. One way of distinguishing the difference is that seismologists are interested from the ground surface down, and engineers are interested from the ground surface up. The dividing line is maybe 100 feet down. But we're interested in very strong shaking and the nature of strong

A Housner-Hudson shaking machine, the first modern earthquake-simulation device, is hoisted to the top of a 110-foot intake tower at the Encino reservoir in the San Fernando Valley for the first field test of the machine in 1961. Although this tower was scheduled for replacement and could be shaken with the energy equivalent to a fairly strong earthquake, a similar machine on Millikan Library jolts that structure only gently for student projects.

shaking—where it might occur, and so on. Byerly once told me that the only precise definition of an "epicenter" was that it's "a mark made on a map by a man who calls himself a seismologist."

RP: When was earthquake engineering research started at Caltech?

GH: Well, that was started by R. R. Martel, who got very interested. He had gone to Japan to attend a world engineering conference in the late 1920s and had seen what had happened to Tokyo in the '23 earthquake and had noticed that some of the Japanese were interested in earthquake engineering.

RP: The big earthquakes in Tokyo and Santa Barbara, and then Long Beach were precursors in a sense to finding out what potential hazards there were in earthquakes. And then there's a jump to the '64 quake in Alaska.

GH: Well, there were other quakes, but they didn't happen to hit the big cities. An earthquake gets famous for killing people, not for its real size.

RP: So your job is to keep people from getting killed, basically.

GH: Right. There was a very important earthquake at El Centro, California, which for many years held the record for the strongest recorded shaking. It was 7.1 on the Richter scale. So in earthquake engineering circles, worldwide, the El Centro earthquake is well known. We've had Japanese visitors who tell me, "Oh, I'm going down to El Centro and see what it's like there."

Then there was a damaging earthquake in 1935 at Helena, Montana. There was a rather big earthquake in 1952 up by Tehachapi. There was a big earthquake in '49 near Tacoma, Washington, and the one in Alaska in '64. Although the Alaskan quake didn't kill many, it was such a large earthquake, by far the largest in modern times in this country, that it was very important. The National Academy of Sciences put out a big report, and the fattest of all the volumes is the one on engineering. I was chairman of that engineering committee and Paul Jennings was also a member. We put a lot of effort into that; it's a monumental report.

RP: So you're recording and studying ground motion.

GH: We also record and study the motion of buildings during an earthquake. The objective is—given, let's say, the ground shaking—to be able to calculate what a building will do with sufficient accuracy so you can design it properly.

RP: Do you deal with soil condition or is that the seismologist's responsibility?

Housner, shown here in 1958, and Don Hudson designed this compact earthquake recorder, 50 of which were installed in buildings in the Los Angeles area and 50 in San Francisco.

GH: No, that's in engineering. Really, I should not have said from the ground surface but from the rock surface. For instance, here we're sitting on 900 feet of alluvium, so the seismologist's interests would only start 900 feet down. But our interests would be in the behavior of the ground as well as the behavior of buildings. Ground behavior is a matter of soil mechanics. Ron Scott is our expert at Caltech on soil mechanics.

From our research on ground motions and the mathematical analysis of the vibrations of structures, we develop procedures for designing buildings, not with a building code but from a more rational approach. Paul Jennings and I were consultants on the earthquake design of the Arco twin towers, as well as of the Union Bank building, the Security Pacific Bank building, and what used to be called the Crocker National Bank building.

The building code merely says that you should design to resist a certain force pushing on the building. But in reality the building is vibrated. To do it right you need to know how it will be strained. So what we did for these buildings is identify those faults in the general region that might generate strong shaking at the site. This included faults such as the San Andreas, which is about 35 miles from the site and could generate a magnitude 8-plus earthquake. Then there are closer, smaller faults which would generate smaller earthquakes. So, on the basis of earthquakes we had recorded, we were able to develop methods of generating earthquake ground motions that corresponded to these earthquakes at different distances. And we computed for each of them how the building would vibrate and what the forces and stresses would be, and then the engineers designed accordingly. So in a sense those buildings had experienced some four or five earthquakes before they were built.

RP: What was the state of the art of earthquake engineering before, when you started?

GH: Well, for example, when we were doing this work on these high-rise buildings, they were the first ever done. And after the San Fernando earthquake, we took records obtained in some of these buildings and computed from the recorded basement motions the corresponding roof motions. These were then compared with the recorded roof motions and we got very good agreement. The Los Angeles building department then said, "Well, good. From now on, all buildings over 16 stories high must be designed on the basis of dynamic analysis, taking into account realistic ground shaking." So it made a big change in the way things were done.

RP: Do you think that Caltech has pretty much become the leader in this field?

GH: It was the leader for many years. Now some of the other schools have also built up their efforts; notably UC Berkeley and the University of Illinois. Earthquake engineering is an extremely interesting subject, so it has attracted a lot of people now. We're not claiming that right now Caltech is the leader, but I think it's certainly one of the leaders.

RP: Since 1947 you and Professor Martel were on an Advisory Committee of Engineering and Seismology, set up by the Coast and Geodetic Survey. Can you tell me about that?

GH: That only lasted a certain number of years, but it was a precursor to the Earthquake Engineering Research Institute. In the early days those of us interested in earthquakes—we were a very small number—were highly critical of the Coast and Geodetic Survey because they weren't really doing enough. The leader of the group that installed and maintained the strong-motion instruments here on the West Coast, Franklin Ulrich, got the idea that if there were an advisory committee to his operation, then its recommendations might carry more weight in Washington. So that was why it was set up. As it turned out, it didn't carry more weight, and in sort of desperation—frustration—we

formed the Earthquake Engineering Research Institute.

Originally its function was to do research, to develop the instruments and get them installed, and that sort of thing. And in the very early days we actually did some of that. I think we developed the first modern shaking machine that you put on buildings to shake them.

RP: You actually shake the building?

GH: That's right. We have a machine on top of Millikan Library now and shake that. But we obviously are under restraint because we can't shake it hard enough to feel. That's part of the student lab work; they shake the building and measure what it does, and so on. Before the library staff moved into the building we shook it real hard once. And we had the top going back and forth about one-eighth of an inch. This was before the San Fernando earthquake. Jennings noticed that the library shelves were not braced properly, so he wrote a memo to the building and grounds people saying, "These bookshelves are not right; you have to strengthen them so that they won't come down during an earthquake." Well, they didn't do anything. So he wrote another memo. They still didn't do anything. And when the earthquake came, down the shelves went. It was a real mess.

Bookshelves on the eighth floor of Millikan Library (below) did not fare well in the 1971 San Fernando earthquake— despite warnings.

RP: And then they did it.

GH: Yes. Now, if you look up, you can see that they're braced. In fact, all the bookshelves on campus are supposed to be fastened to the walls so they don't fall down on the occupants of the room.

RP: Computers must have had an extraordinary effect on your research.

GH: Oh yes, they did—enormous. Without the development of the digital computer, we wouldn't be anywhere near where we are. It's an enormous calculating job to take an earthquake accelerogram and compute the response of a building. One standard kind of calculation we make from an earthquake record is to compute what we call the response spectrum. I first did that for my thesis. And the very first time we calculated it—we did it by pencil and paper, which involved drawing the accelerogram and multiplying and integrating—it took about a day for one point on the spectrum. That was at the very beginning of my thesis research. Then we developed a small mechanical analog computer, and that speeded it up from one day to about 15 minutes, an improvement of about 30 times. But then later we developed an electrical way of doing it, and we'd get a point in maybe 15 seconds. Now we get 500 points in 15 seconds on the digital computer.

RP: You have developed machines to measure ground shaking, and have spread them over a far greater area than before. And you now work with the seismologists who also record data.

GH: Right. Actually, after the San Fernando earthquake, the seismologists saw that our records could also throw light on the fault mechanism, the slip of the fault. So they got interested in our records. When the fault slips, it may slip like the San Andreas fault, which slides horizontally over a depth of six or seven

In the April 1964 Alaska earthquake (magnitude 8.4) a section of bluff near Anchorage (visible in the lower right of the photo at left) slipped into the sea, continuing during the earthquake until damage extended a half-mile inland. About 35 houses were destroyed in this landslide, including those in the picture at right.

miles. Over that fault area, it's jumping and sending out stress waves. And our instruments are close, giving information on this process of slipping. That was of great interest to the seismologists, so they're interested now in our records from that point of view.

This earthquake was the event that got the attention of the government. And the money.

There are some seismologists who work more closely with engineers than others do. Here at Caltech we work in particular with Clarence Allen, Hiroo Kanamori, and Kerry Sieh. For a seismologist the distinction is whether he's interested primarily in seismology or primarily in earthquakes.

RP: In '64 there was the great Alaska quake. And then there was the Niigata in the same year. Would you describe them?

GH: Alaska was the big earthquake with a magnitude of 8.4. We figure that the fault slipped over a length of about 450 miles. If you had the same kind of an earthquake in California, that would go from below Los Angeles to beyond San Francisco, but of course we don't have the same kind of earthquakes. It was a monstrous earthquake. If there had been large cities in the region, it would have been a great disaster. Because of its size it was extremely interesting, and it's really unfortunate that there weren't any instruments to record the ground shaking. The nearest instrument was in Seattle. It was an earthquake well worth studying for the ground behavior and its landslides. One slide was of a size never previously conceived of. The ground at Anchorage extends to the ocean, where there was a bluff of about 100 feet. And during the earthquake the bluff slipped down. Then, as the earthquake continued, additional ground continued slipping until the landslide extended about a half-mile back from the bluff and extended along the coast for a couple of miles. It was on the outskirts of the city, fortunately, but 35 houses were destroyed.

This earthquake was the event that got the attention of the government. And the money. Before that the National Science Foundation didn't have any special earthquake engineering program. But after that they did set up a program with special funding in earthquake engineering.

RP: Isn't it true that after the Alaska quake, President Johnson tried to set up an earthquake research program that would call for extensive surveys of faults and so on?

GH: Yes, he was apparently interested in getting something going, but unfortunately his term came to an end too soon. So the earthquake didn't have a lasting influence in that sense. It was really the 1971 earthquake that finally got Congress to move.

The magnitude-7 Niigata earthquake wasn't such a large earthquake as Alaska, but it had remarkable soil behavior. Like most Japanese cities, it's on an outwash plain of a river. It's so mountainous, and that's about the only place they can build. And the top 100 or 150 feet of ground was sand that had been washed down and deposited, and there was high ground water. When the shaking came, there was a tendency for the sand grains to reorient into closer packing. When that happens (because the spaces are full of water), for a while all the weight on the surface is supported by the water—until it oozes out. During that time the sandy soil has little strength and the damage to their buildings was mainly due to that. Tremendous damage was sustained in Niigata due to settlement and cracking and tilting. This phenomenon, which we call liquefaction—for a while the material is kind of like a liquid, what used to be called quicksand—came to the attention of engineers for the first time as a possible, serious thing. So now it's watched very carefully when putting up buildings or power plants or things of that sort.

At the time of the Niigata earthquake I was a member of the board of directors of the International Institute of Seismology and Earthquake Engineering in Tokyo. It was a school set up cooperatively by UNESCO and the Japanese government, and I was the UNESCO representative on the board of directors to help it get started. Every year we had a meeting over there, and in '64 when I heard about the earthquake I went to visit Niigata. Of course, that isn't my specialty, but when I came back, I told Ron Scott that he would have to go over and see it—he should organize a group and get funding from NSF to go over. So they went over, and I noticed when they came back they were in sort of a state of shock about what could happen.

When the 1971 earthquake came . . . we got more records on that earthquake than out of all the earthquakes in the world before that.

RP: You've done a tremendous amount of work with state and federal governments. How do you work with the government of the state of California? How have you worked with them to help plan for earthquakes?

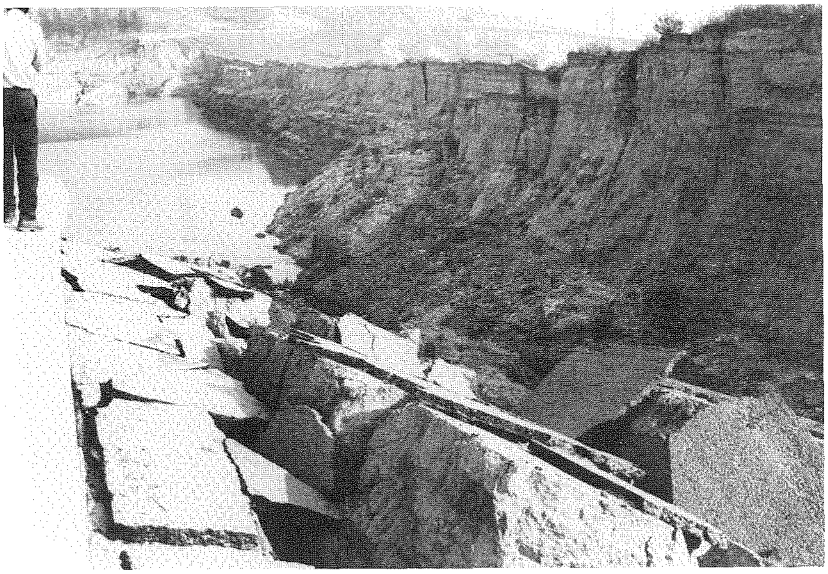
GH: I was president of the Earthquake Engineering Research Institute when the big Feather River project was planned—I think it must have been in the middle or late 1950s—that I first realized there was going to be an earthquake problem. They were going to build this system of dams and aqueducts and pumping plants real close to the San Andreas fault. In fact, the project crosses the fault three times.

The project brings water from the Feather River. North of Sacramento, where the Feather River comes out of the Sierras, a large dam has been built, the Oroville Dam, which provides the main reservoir for the system. From Oroville Dam the water comes down the American River and on through Sacramento and out to the delta region of the bay. Then, at the southern end of the delta region there is a pumping plant which takes water out of the delta and starts it south in the aqueduct—sort of an artificial river—along the western edge of the valley to near Bakersfield. Then about half of it gets pumped up over the mountains into Los Angeles, and the rest skirts around east of the mountains and goes down to San Bernardino. This is an enormous system—some 20 big dams, several big pumping plants, and the aqueduct. At the time it was built, I think it cost about $3 billion, but I think to do it now would be $10 billion. We felt we had to tell them that they were facing big earthquake problems.

As president of the Earthquake Engineering Research Institute, I wrote the letter to Harvey Banks, who was the director of water resources. Then in due course I got a telephone call from Larry James, chief geologist up there, who said that some of them would like to come down and talk to us. So Sam Morris, Don Hudson, and I met here at Caltech with Larry James, Bob Jansen, and Don Thayer. And we explained the problem and how they would have to face up to the risk and so on. They seemed impressed by that, but they couldn't sell it to the boss. They went ahead and built Oroville Dam. Then Banks retired and a new head was appointed, Alfred Golzé, who had been at the Bureau of Reclamation. Apparently these three fellows we'd talked to had gone to Golzé and said, "We think we ought to do something." So they came back here—this was, of course, a number of years later—and said, "We'd like to have you on an advisory committee on earthquakes."

They had designed the dam and were building it, and were just getting ready to start designing the rest of the system—it took maybe six years to build the dam and fill the reservoir. I remember talking with Larry James, who decided who the advisory committee members should be. Hugo Benioff, a Caltech seismologist, was chairman; I was on; Nathan Whitman, a Caltech graduate and practicing engineer in the local area; and Harry Seed of UC Berkeley. We prepared a recommendation based on my research and told them what the strong shaking would likely be and what they should do. And they adopted that procedure. That was the first time such modern procedures had been used on dams and pumping plants. We set a precedent; now all over the world they do it the way we had recommended.

It's kind of ironic. This project is sort of a leader in earthquake safety; it's being held up as a model all over the world. Yet, after the project was essentially completed, Ralph Nader's group came out with a report denouncing the whole project, saying particularly that it hadn't been designed for earthquakes and wasn't safe! It turns out, apparently, that's standard practice,



Dams hold a great potential for destruction and loss of life in an earthquake. Although a large section of the Van Norman dam (built in 1916) failed and slid into the reservoir during the 1971 San Fernando earthquake, the dam itself survived. This was not part of the Feather River project, whose earthquake engineering standards, developed by Housner, set a precedent eventually adopted worldwide.

and when Nader's been asked why he does this, he says, "Well, that's the way to make an impact." He doesn't *want* to check, you see; he wants to make the impact. I'm really annoyed at that.

RP: You were chairman of the Geologic Hazards Advisory Committee for the organization of the California State Resources Agency in the late 1960s. And you were chairman of the Panel on Aseismic Design and Testing of Nuclear Facilities for the International Atomic Energy Agency.

GH: Yes, we drew up reports. I suppose these reports on geologic hazards and atomic energy circulate around and people see them; and maybe they don't do anything immediately, but in the long run something comes out of it.

RP: And of course we had the San Fernando earthquake in February 1971.

GH: Yes, there we were, with an earthquake in our backyard. We prepared a report at Caltech. A number of us were on the Los Angeles County Earthquake Commission; Harold Brown, president of Caltech, was the chairman, and there were Charlie Richter, Don Hudson, Hardy Martel, and myself.

RP: What changes in engineering came out as a result of that earthquake? You said before that the old structures are still unsafe in spite of the 1933 building codes and so on.

GH: Even at that date it wasn't enough to move people to do anything about the old buildings. But the thing simmered on the back burner. All the other cities looked to Los Angeles. Los Angeles was the only city big enough to have a good building department with competent people, and so they always looked to LA for leadership. Well, we recommended to the city council that they should do something about hazardous old buildings. And it was kind of a hot potato; they always had some reason for not taking action—more studies, and this and that. And it kept on that way but it didn't die, which you might have expected. And finally, 10 years after the earthquake, they passed an ordinance to get rid of the old hazardous buildings. Of course, they don't try to get rid of them all at once. At that time they estimated there were about 8,000. Well, if you try to tear them all down at once, that would be worse than an earthquake economically. So what they're doing is to identify the most hazardous, and each year notify maybe 50 people that their buildings must be strengthened or torn down. Of course, they don't want to notify too many at once, because they don't want 500 or 1,000 irate building owners coming at them. So the building department people were somewhat nervous; they didn't know if they could get away with it. If there were a big outcry, they would have to back off. But so far, there hasn't been; they've been doing this and the owners have been cooperating. One building owner did bring suit a year or so ago and asked for an injunction against it, and the judge said, "No, you can't have an injunction against this." So that has sort of settled it now. (The 1985 Mexico earthquake

President Ronald Reagan presents the National Medal of Science to George Housner in 1988 at the White House.

speeded up the process, and by 1989 about two-thirds of the buildings had been taken care of.)

RP: What can you do about the hidden hazards—the water mains, the gas lines?

GH: Those are all problems. The governor of California has some advisory committees, which I presume are still in effect—this was before Deukmejian's time—to look at various aspects. On the water supply for southern California, there was a committee of people who were involved with water supply systems. They came over to talk to us about the general problem. Several were Caltech alumni. They were to size up the situation should the big earthquake occur on the San Andreas fault: what would happen to the water supply to the homes? A big amount of our water comes from outside—the *majority* of our water comes from the other side of the San Andreas fault. And then the question of what happens to the distribution system has to be considered. So they're looking at these things. I myself think it isn't too hazardous a situation. There'll be some damage and interruption with the distribution but not anything in the nature of a crisis.

For many years people interested in earthquakes have pushed the idea that more instruments should be out there to record what's happening. And it was very difficult in the early days to get any money or get anything done. We saw one problem was that there weren't any instruments commercially available. So in the 1960s Hudson and I got hold of one of the instrument companies—Teledyne, a local company making geophysical instruments—and convinced them they should build a strong-motion earthquake recorder, which they did. We advised the company on what kind of instrument it ought to be and the kind of cost it should have and so on. After that, you could recommend to people, "You ought to have one; you can *buy* one right here." We thought that perhaps 100 instruments could be sold, but now Kinemetrics, the successor to Teledyne Seismic Instruments, has sold 5,000 worldwide.

Then a Caltech graduate, John Monning, became chief of the Los Angeles building department in the 1950s. He was a very able man, and it was clear that he had the confidence of the city council, the mayor, everybody. He saw that our recommendation for more instruments, especially in buildings, was very important. So he talked to the councilmen and got their approval, and they put in the code that all new buildings over 10 stories high should have three recording instruments in them—at the roof, at mid-height, and in the basement. With Monning getting it into the code, many buildings got these instruments, and when the 1971 earthquake came, we were able to get all sorts of records. We got more records on that earthquake than out of all the earthquakes in the world before that. And new computer technology made it possible to do something with the records. It was because these instruments were there and we got the records that we were able to show that it was possible to compute what buildings do.

RP: Your implication is that, in earthquake

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matters, Los Angeles is the leading city in the world, over and above San Francisco.

GH: For earthquakes, yes. I'm sure that the Los Angeles building department is one of the most competent in the country and, as far as earthquakes go, *the* most competent. Usually what happens is that Los Angeles puts something in their code on earthquakes, and then a few years later, it goes into the Uniform Building Code. Monning tried to get this instrument thing into the Uniform Building Code right away. It's the function of what is called the International Conference of Building Officials. But when Monning made his proposal, he was voted down. But I think that now, while the Uniform Building Code doesn't require it, it recommends it. And quite a number of cities have done something.

RP: You received a large grant in '74 from the National Science Foundation for a new research program.

GH: Yes. That's, of course, the result of the 1971 earthquake. We had thought that the NSF ought to be putting more money into earthquake engineering research, but it's very difficult to pry money loose when it's already allocated to somebody else. And while they did have a little to put into earthquake engineering, it wasn't much. Then—I think it was just a little before the '71 earthquake—I got a call from one of the assistants in Sen. Alan Cranston's office who said that Sen. Cranston was interested in leading a bill through Congress on natural disasters and wanted advice. We were just finishing a report on earthquake engineering research, funded by NSF, on what the problem was, what you ought to do, and so on. Fortunately, I had a copy and sent it to this assistant, and in due course she got back to me and said, "Well, that's just what we want. And we'll try to put through a bill on it." Of course, you can't keep anything secret there, and the Geological Survey got hold of it and said, "Well, you have to also put in seismology."

So Cranston's office drew up a bill which had two parts: one for funding research in seismology and one for funding research in earthquake engineering. The scheme they use is that when the Senate draws up a bill the House does too, and vice versa. Well, Cranston got his bill approved by the Senate, and then they had the corresponding House committee work one up, and it went to the House. And who should get up and denounce it on the grounds that they didn't need to do anything about earthquakes in California but the representative from Palmdale—sitting right on the fault! And that killed it; they didn't get enough votes. So then they had to put it away and start again.

Well, in between came the San Fernando earthquake. And Sen. Cranston—I guess he wanted a little publicity—called and said he'd like Clarence Allen and me to meet him at such and such a place and show him around. So we did. Of course, by "coincidence," wherever we went there were TV people waiting for us. So Sen. Cranston made hay on that. Then he went back and got the bill through both houses, got it approved and implemented. So that's where the big grant came from, because the bill directed the National Science Foundation to put a certain amount of money into earthquake engineering research. I think it was at that time something like $6 million. It's been a very important thing because it funds earthquake engineering research at many universities, and it's had a reinvigorating effect on civil engineering because it suddenly brought them all into the 20th century. □