on the moss, and I fell to the chute floor. I just couldn't gain my footing, and I was sitting there on my rump, sliding on that moss down the chute.

That was about a 300-foot fall, and, luckily, they had drained the plunge pool. I thought, "By God, I hope there's not more than about three or four feet of water in the plunge pool." While sliding down the chute, I had enough sense to keep my feet ahead of me and my elbows spread out so I wouldn't be tumbling every which way. When I hit the plunge pool water, my feet hit first. The water depth was about three feet with a couple of feet of mud on the bottom, which gradually stopped me. I stood up covered with mud, but wasn't hurt at all, except a little scratch on my left elbow.

Some men were working with a large crane over the side of the plunge pool walls. They lowered a cable for me to grab a hold of so they could pull me up. I checked the chute, and found it to be all dry on one side. I decided I would walk up as far as I could. So I told them, "I'm on the way. I'll walk up." Believe me, I walked up all the way back to that ladder.

Q: Is that right?

A: The next afternoon, we had the board meeting to discuss spillway problems. I said, "Well, I want to tell you about an experience that I just had yesterday morning, and I recommend that all of you have that experience so you will know what that water is doing when it's coming down that chute at 50 miles an hour." Then I told them what happened to me.

None of them volunteered to try it. The chairman said, "Oh, all clap because you are here with us. You could have been dead." [Laughter]

Q: That was nice of him, wasn't it? One of the things that must have occurred to you going down there.

A: Yes. Well, I'm just rambling around here.

Reza Shah Kabir Dam, Iran

Q: You got to see a lot of airplanes, didn't you?

A: Yes. [Laughter] Oh, yes. One time, when coming back from Tarbela, a consulting firm in Chicago -- not Acres.

Q: Harza?

A: Harza. You're right. They had designed Reza Shah Kabir Dam [for Iran], a high, concrete arch dam, with a concrete flip bucket chute spillway. The first time the chute spillway went into operation with high flows, a lot of erosion occurred on the chute invert. Harza Engineering designed the dam, and followed through on the construction. Harza wanted independent consultants to evaluate the erosion problem.

The spillway chute eroded and failed. Harza also had a man at Tarbela, and they got in touch with us there and asked us to stop by in Iran on our way back to the U.S. and inspect the dam. We'd change airplanes at the capital of Iran, Teheran. That's where we boarded another one-hour flight up to the northern part of Iran. Then we had to take about a 30-minute car trip up the mountains to the dam site.

An Italian construction firm had just finished constructing the spillway for this dam when a large flood occurred which filled the reservoir and caused the spillway to go into operation with six- to seven-foot depths of high-velocity flow in the lower part of the spillway chute. This was about six months before Khomeini took over the Government of Iran.

They called Jim Ball and me, and we both accepted the assignment. After being briefed by the resident engineer and his assistants, we spent several hours inspecting the dam and damaged spillway. .. and saw that the construction was poor. We concluded that the construction people did a poor job of smoothing the floor of the high-velocity chute. It was rough, particularly at construction joints. The invert joints of the chute at the lower end were not smooth. There were places where the joints, either downstream or upstream, would be as much as three-quarters of an inch out of place. With water velocities of about a hundred miles an hour, negative pressures occurred at these joints. The negative pressures caused cavitation erosion of the concrete. There were five- or six-foot deep holes through the concrete invert and into the rock. The concrete slab was only 18 inches thick, and during the course of time, that slab failed, and then water got underneath at high velocity and just ripped the whole thing out.

We wrote our report on what caused the erosion and what should be done to repair the damage. Harza told the client that the construction was at fault, and he should repair the damage at his cost. The damaged chute was repaired. A few years later another large flood occurred, and the chute operated perfectly.

The Harza man had to leave early, but I stayed another day to talk some more with those people about what should be done to repair the spillway chute. I planned to leave the dam site and return to Teheran in time to catch the 2:00 PM flight to the U.S. I talked with the man in charge of transportation at the dam site and said I'd have to leave by car in time to catch the 12:00 o'clock, one-hour short flight back to Teheran to be sure I would catch my overseas flight. This man impressed upon the driver that he had to get me to the small airport in time to catch the flight to Teheran.

Coming down the mountain, the roadway was steep, and the curves were sharp. The driver was going too fast, and frequently had to put his foot on the brake as hard as he could. After about ten minutes, smoke came up from underneath the car.

I told him, "Stop. Stop. Smoke's coming out of here." So he pulled over to the side, and I went over to look, and the wheels were burning. He made the brakes so hot that it caused the grease around them to catch fire. About that time, a bus came up the road. This driver knew that he couldn't get me to the small airport in time to catch the flight to Teheran, so he stopped the bus and talked with the bus driver in their language there, and the bus driver motioned me to get on the bus.

So in about 15 minutes, I was back at the dam site again. I told the transportation man what happened, and he called another driver. I said, "Tell him, 'Go slow. Don't burn up the car. I've got enough time.'" The other driver was very careful, and I got down to the small airfield when the airplane was at the end of the runway, ready to take off.

I went to the main terminal and was told that the next flight to Teheran would be two hours later. I was advised to check with the private and rental airplanes office. Fortunately, I was able to get passage on a private plane about to leave for Teheran. When I got to Teheran, I found that my overseas flight was three hours late.

Q: All that, and you were still on time. [Laughter]

A: Yes, still on time. Holy Moses. What a day!.

That was an interesting job and trip to Teheran. Americans for a long time wouldn't dare go there. I went to Teheran just a few months before the Ayatollah took over. If it had been a year later, I would not have gone. Harza people still went there for several more years. The Iranian government owed Harza about a million-and-a-half dollars. After the Ayatollah took over, they didn't pay any of their debts for a number of years.

All the people who were owed money got together and got some kind of judgment against the Iranian Government. Whenever the Americans got some of Iran's assets, they'd keep them to pay off Iran's debts. Harza, finally, after about three or four years, got their million-and-a-half dollars.

Q: It took a little while to get any money out of those folks. Basically, it's not too easy to get money out of them, I guess.

A: That's right.

Q: It's a long, hard pull. Well, it must be different when you're out in places like Pakistan and Iran versus when you're in a place like Washington, and you have to go out to some district or some site out there. Your connections were a lot more tenuous.

Pardee Dam, East Bay Municipal Utility District (EBMUD)

Q: What were some of the other consulting jobs that you did?

A: All right. I've listed several consulting jobs I'd like to talk about. The first one is Pardee Dam, which was designed and constructed by the East Bay Municipal Utility District [EBMUD or East Bay MUD] in Oakland, California. There is a hydropower plant at the dam, which they wanted by adding several power units.

The dam was constructed before 1930, when there were no Federal safety regulations. Now, whenever a dam is designed, a report must be prepared on the safety of the dam for FEMA [Federal Emergency Management Agency]. If there are no safety questions, FEMA issues its construction approval. When a project change is desired, FEMA requires that the owner hire proper consultants to check the safety of the dam.

EBMUD requested FEMA's approval to add the two additional power units. FEMA said that a study had to be made to show that the dam is safe before approval could be granted. EBMUD established a consulting board to check the safety of the dam. I was a member of the board.

The first thing the board did was to check whether the dam was designed for a large enough flood. FEMA's requirement is that the dam be designed for the maximum probable flood. When the dam was designed in the 1920's, maximum probable flood were not considered. The board determined that the dam was designed for the maximum historical flood, which was only 70 percent as large as the maximum probable flood.

The board was told to determine what needed to be done to the dam so it would safely handle the maximum probable flood. Calculations showed that if a probable maximum flood should occur, the water would flow about 6 feet over the top of the 250-foot high concrete arch dam and about 11 feet over the top of an adjoining low earth embankment. The earth embankment would very likely wash out, and water going over the top of the concrete dam might severely erode its abutment, causing failure of the dam.

The board next looked at the possibility of enlarging the spillway. If the spillway was enlarged sufficiently, the dam would not be overtopped nor would there be any question regarding its safety. The spillway is concrete-lined with eight ungated bays and a 15-foot high ogee crest at each bay. Downstream of the crest, the spillway was lined with a 12-inch concrete slab placed on a 1 on 4 slope.

One method of enlarging the spillway was to increase the crest length by adding more bays. It was decided that this was not feasible because of space limitations. The next method which was considered was to extend the spillway bay piers upstream of the spillway crest about 150 feet and connecting every other one at their upstream ends. The top of the pier extensions was placed at an elevation, so when the spillway operated, the pier extension served as the spillway crest. This elevation was several feet higher than the existing ogee crest. The existing crest would then be cut down about 10 feet to enable more water to flow through the spillway bays. The longer extended pier crest would result in larger spillway discharges for high reservoir levels. The board concluded that this method was feasible. It would not require raising the dam.

The third alternative would be to raise the dam about 12 feet, and make minor modifications of the existing spillway to pass the maximum probable flood without overtopping the raised dam. This method was the most costly of all, so it was abandoned. The board decided that the second method was the most economical way to handle the probable maximum flood without raising the dam. That's extending the spillway bay piers out some distance in front of the existing spillway, and having those piers act as a spillway crest. Then cutting out the existing spillway crest concrete between the existing bays, so that more water could be handled by the spillway.

The board was concerned with a problem regarding the 12-inch concrete slab downstream of the existing spillway crest. It was not anchored to the underlying rock. During spillway flows, high velocities could produce uplift pressures through defective joints that might cause complete failure of the concrete slab.

The board considered replacing the slab with a properly designed slab or adding three feet of concrete on top of the old slab with a large number of anchors into the underlying rock. The latter method would be very costly. The board concluded that the slab should be replaced with a properly designed slab. At our final meeting, the board discussed its studies and conclusions with EBMUD. They said, "We'll think about it and call you back later."

They never called us back. I found out later that they didn't call back because their cost estimate of the work required to make the dam safe was over $20 million. There were other places where the additional power could be obtained for much less cost, so they dropped the whole matter.

Q: On something like that, when you analyze those things, what kind of impression do you get of the people who designed and built that kind of structure?

A: Well, I never knew the people who designed and built that structure. They certainly lacked experience in those structures 50 years ago.

Q: You had a lot of those problems to deal with though, right?

A: Right. I had other similar problems on other projects. The basic problem regarding the design of Pardee Dam was that hydrology wasn't developed in those days to the point where anyone thought of a probable maximum flood.

Q: So one of the big things that changed for you was the definition of probable maximum flood?

A: Yes. The Corps of Engineers and FEMA used the probable maximum flood as the design flood.

Rafferty Darn, Canada

Q: Did you run into similar situations in other consulting jobs where they weren't built because of the costs required to come up to the Federal standards?

A: No, I didn't. In the United States, any dam that failed and caused excessive property damage and/or lose of life is now designed in accordance with Federal safety standards. I was on the board for Rafferty Dam in Canada, which was constructed even though it did not meet FEMA's safety standards. One Canadian member of the board, who was the top hydraulic engineer in Canada, said that designing Rafferty Dam for the maximum probable flood was excessive even though failure of that dam would cause large property damage and lose of life. He wanted to design the dam for the 1 ,OOO-year flood.

The 1,000-year flood was about 30 percent smaller than the probable maximum flood. I said, "Let's determine the difference in the cost of the spillways designed for those two floods."

In the initial design, most of the reservoir at Rafferty Dam was for irrigation and power. Consideration was given to increasing the dam height to provide some flood control storage in order to justify construction of the dam. The Corps of Engineers was interested in this flood control storage because it would reduce the channel design flood in the Souris River at Minot, North Dakota.

The levee heights at Minot, which were initially constructed for a 100-year flood, were frequently overtopped by larger floods. The Corps was in the process of designing the levees for a 500-year flood. Increasing the height of Rafferty Dam by about 20 feet would reduce the 500-year flood at Minot to a 100-year flood, and the levees would not need to be raised. The estimated cost of raising the dam was $47 million. The Corps estimated cost of raising the levees at Minot, if no flood control storage was provided at the dam, was about $112 million. The Corps agreed to pay the cost of raising the dam, thereby saving $65 million over raising the levees at Minot.

Q: So in something like this, would the Corps or the U.S. Government transfer funds to Saskatchewan Power?

A: That's right. They would transfer funds.

Q: To cover the difference between their original design and the one ...

A: Yes, for the difference in cost of the dam with and without flood control storage. The Corps has an agreement with Saskatchewan Power that it will start paying when dam construction begins. The Corps wanted to review the plans before construction started.

That brings me to the second point I want to discuss, and that is also on Rafferty Dam. It involves the hydraulic design of a fuse plug emergency spillway.

The initial design provided for construction of a concrete-lined spillway with a stilling basin. When design for the maximum probable flood was accepted, this spillway had to be greatly enlarged at a high increase in cost. I suggested that instead of enlarging the concrete-lined spillway, consideration be given to constructing a separate emergency fuseplug spillway to carry part of the spillway discharge at maximum flows.

Fortunately, conditions were favorable for constructing a fuseplug spillway about 1,000 feet from the left abutment of the dam. A 300-foot wide earth channel about 1,200 feet long, with its invert at about the same elevation as the concrete spillway crest, could be excavated. The fuseplug is located near the end of the earth channel. The fuseplug is a low gravel on rock embankment with its base on the bottom of the earth channel. The top of the fuseplug would be 5 to 10 feet below the top of the dam.

When a large flood occurs the concrete spillway is in operation. As the flood increases in size and exceeds the capacity of the concrete spillway, the fuseplug in the earth channel is overtopped and washes out. For the maximum probable flood, both the concrete-lined and fuseplug spillways will discharge at the design discharges.

The Canadians hadn't any experience with fuseplug spillways. I told them about Professor Kenny, who was at Washington State University. He was a consultant for a Pacific Northwest public utility district on the design of a dam in the State of Washington. He recommended that a fuseplug spillway be considered.

He tested the fuseplug spillway in a 1:50 scale model in the university laboratory. His main concern was how to construct the fuseplug, so when it's overtopped, it all won't wash out suddenly to greatly increase downstream discharges. The small scale model tests indicated good performance, but he wanted to test it full scale. He found a small stream where he tested a short length at full height, full base width and full cross-section. It was constructed of what he considered to be the correct mixture of materials. By releasing water upstream, he experimented with the mixture of materials. It was concluded that the correct mixture should withstand 2 to 3 feet of water of the top of the fuseplug before it started washing out, and it should continue to wash out at a slow rate until it is completely washed out.

The board and Saskatchewan Power agreed that the emergency fuseplug spillway should be considered for Rafferty Dam. Since a small-scale model had already been constructed of the dam, concrete spillway and outlet works, the proposed spillway was added to that model. It operated well, and it was adopted as part of the project.

When the Corps reviewed the plans, they raised questions about the fuseplug spillway. "Where has it been used before? Has it been model or prototype tested? Will FEMA approve its use?"

By the way, the fuseplug Kenny developed and tested was constructed as part of the dam project for which he served as a consultant. As far as I know, it's never been overtopped. So the Corps wouldn't be able to go to FEMA and say, "It was done at this dam, it was overtopped, and it worked perfectly."

The Corps made a big issue about Rafferty Dam having an emergency fuseplug spillway. The board decided to consider reducing the size of the concrete spillway required to handle the probable maximum flood. Additional model testing was unsuccessful. It was concluded that it would cost significantly more to pass all the discharge through the enlarged concrete spillway. Saskatchewan Power decided to spend the additional money.

About that time, I was seriously considering retiring from consulting. I wrote Saskatchewan Power advising them that I was terminating my consulting practice and would no longer be able to serve on their consulting board. I immediately got a letter back from them saying, "You cannot retire from this board. You were the one who convinced us that the fuseplug spillway would work and that it would save us a lot of money. Since we're in this big hassle with the Corps, you've got to be on our board to convince the corps." I agreed to continue serving on the board. That was when the fuseplug spillway was still in the plans. In the course of the next six months or so, Saskatchewan Power gave up and decided to adopt the concrete spillway plan.

Q: This example at Rafferty and the Corps' reluctance to go ahead with what they didn't see as a proven design--did you find in your dealing with a lot of the districts and divisions that the Corps was ultra-conservative in their engineering approach?

A: Yes, they were. The Canadians, and many U.S. non-Federal organizations and engineers, frequently said that the probable maximum flood, as defined by the Corps, is ultra-conservative, and many of them don't use it. But when dealing with FEMA, it had to be used because they accepted it.

Q: So, the Corps, while naturally inclined to be conservative, was forced further in that direction by FEMA standards?

A: Yes. However, for some projects, it doesn't cost much more to use the maximum probable flood instead of the 1 ,OOO-year flood.

Susitna Dam, Alaska

Q: Before and after you retired, you consulted on Susitna Dam in Alaska?

A: Right …

Q: Were you involved in working on that before you retired? That project goes back a long way, doesn't it?

A: Well, let's see here. Susitna. I got it on a piece of paper. No, I don't think that … Here it is. I got involved after I retired, 1980 to 1983 I was on the board, and we had meetings in Alaska. I'm sure that the project had been thought of by Alaska Power Authority before that. They desired most of their power by burning oil which was plentiful and cheap in Alaska. However, in the early 1980's, the price of oil increased significantly, and it was being sold in large amounts to Japan. Then, when more power was needed, they decided to take another look at developing hydroelectric power at Susitna. Preliminary designs and cost estimates were prepared, with the board's assistance, for two dams and power plants.

Q: They were just studied then?

A: They were just studied, and they got plans ready to go now, if they decide to. I got word after the last board meeting that their decision was not to go forward with those dams yet.

Q: In hydraulics, what are the differences in considerations in designing a dam in an environment like Alaska or Saskatchewan, and one in, say, southern California?

A: One difference is in determination of the maximum probable flood. The largest flows occur during snow melt time in May and June. A heavy rainstorm on top of melting snow produces larger floods in Alaska. Other than that the greater temperature difference has little effect on the hydraulic design. No concrete construction is done during freezing weather. The construction period is limited to about six months each year.

Horse Mesa Dam

Q: I see you also worked for the Salt River Project.

A: Yes. I was a consultant on Horse Mesa Dam, which was constructed by the Bureau of Reclamation. The Salt River Project Water Authority purchases its hydroelectric power and is responsible for operation of the power plant, and some water releases for down river use.

The dam is a concrete arch dam, about 200 feet high, with two spillways, one on each abutment, and low ogee crests with no gates, but each one of them has three 40-foot gate bays. Each spillway has a concrete-lined channel chute with a flip bucket above the maximum water level downstream of the dam, which flips the water out into the downstream river channel.

The two spillways were not designed to handle the maximum flood. A large 30-foot diameter concrete-lined diversion tunnel was constructed on the right abutment. Large gates were constructed at the upstream end of the diversion tunnel, which, after the dam construction was completed, remained closed to store water in the reservoir, except during major floods when they were opened to assist the spillways in controlling the floods. When a large flood occurred, the gates were opened fully, which caused the tunnel to flow full. A flip bucket at the downstream end of the tunnel flipped the water into the river several hundred feet downstream of the dam.

The tunnel was on the right side of the dam, and it was directed at about a 30 degree angle to discharge in to the river. The river channel wasn't very wide, and both abutments were quite steep. There was a road on the left river bank that was used for access to the powerhouse. Large tunnel flows crossed the river and impacted on the left river bank, washing out the powerhouse road. Each time the road was washed out, it would be several weeks to three months before the road was repaired and the powerhouse was back in service. This resulted in considerable loss of power revenue.

The Salt River Authority decided to study what could be done to prevent the road from being washed out by every major flood. I was asked to serve as hydraulic consultant for the study. They didn't have a board. I met with the authority's engineers, discussed some preliminary plans that had been made and inspected the site. I suggested that a hydraulic model be constructed to test several possible remedial plans. The authority agreed with my suggestions.

The authority wanted to interview several laboratories and select the best qualified one to make the model studies. I suggested they interview the Bureau of Reclamation laboratory near Denver; the Engineering Consultants, Inc., outside of Seattle, Washington; and two other smaller laboratories in California.

These four laboratories were asked to submit prototype proposals for construction of the model and conducting the model tests. After the proposals were received, it was decided that the Bureau and Seattle laboratories were well qualified to do the work. Both of those were interviewed, and it was decided to have the work done in the Seattle laboratory because it was simpler than working with a Federal agency.

Chick Sweeney, who was head of the Seattle laboratory, found that the large tunnel flows in the model washed out the powerhouse road the same way as occurred in the prototype. One remedial measure, which was tested, was to construct a stilling basin at the downstream end of the tunnel. It turned out that the downstream end of the tunnel would need to be realigned and lengthened so the stilling basin could be located in the right river bank. This would be very costly.

The second remedial measure tested was to provide bank protection on the left river bank to prevent road damage. Various sizes of rock, rebars, and concrete blocks were tested. It was found that the best bank protection consisted of large concrete blocks at the toe of the bank with large rock placed on the bank slope up to the road level. A concrete slab was required in the area of major impact because sufficient large rock was not available. The authority adopted this remedial measure and made an estimate of its cost.

About a year later, one of the authority engineers called to inform me that the remedial works designed and cost estimate were completed but construction was not started because of a delay in obtaining construction funds. He said, "Meanwhile, we haven't had any major floods, and, if none occur in the next few years, construction may be delayed 10 years or more."

Q: Back to where you started from, huh?

A: That's right.

Q: Speaking of Arizona, did you have any involvement in either the Indian Bend Wash project or the Central Arizona project?

A: No, I wasn't involved in that at all.

Q: So you escaped those two?

A: Yes. Another thought about my retiring from consulting service. One of the Salt River Authority engineers called me to inform me that the Bureau of Reclamation was establishing a board of consultants for the design of a dam in Colorado. They were looking for a hydraulic consultant and wondered whether I would be available to serve on the board during the design and construction stages. I said that I would like very much to serve on a Bureau board, but the way Federal dams are designed and constructed it would be about 8 years before that job would be completed. I said, "You know that I am retiring and I can't serve on a board that long." I advised him to tell the Bureau that I was not available.

There were several retired Bureau hydraulic engineers available to serve on that board. I think the Bureau wanted someone outside of the Bureau to make it an independent board, not one with former Bureau employees.

Q: Yes--to give it objectivity?

A: That's right.

National Academy of Engineering

I wanted to mention something I was very, very proud of over the years. I got elected to the National Academy of Engineering in 1971. That's 20 years ago. There weren't very many Corps people in the National Academy then. Hathaway never made it. Slichter never made it. I don't know why.

I started to do my own private consulting in 1958, and the third job I had was in Caracas, Venezuela. That was a very interesting job. I can talk an hour about it, but I won't go off on that tangent now.

One of the jobs I had was for BC Hydro [British Columbia] on a large dam, the largest dam in Canada. The designers were a Canadian firm, and BC Hydro had a consulting board. There were two Canadians on it, and three Americans. Hunter Rouse and I were board members. He was a top professor at the University of Iowa for years. He's known throughout the world as the father of hydro-mechanics. He developed many theories. He's written a number of books on it, and he lectured all over the world on hydro-mechanics. He's retired now, and living in Arizona someplace.

Generally, in board discussions, Hunter covered theoretical aspects, and I covered practical aspects of hydraulic design. So when they suggested something, Hunter would expound on the theory involved. I would question the theory sometimes, and I'll admit sometimes I didn't know the theory, and I had to admit it to Hunter. But also, I would expound on the practical aspects of design based on my knowledge of what's been done before. And that way, we'd get a little tangled now and then, but it usually resolved pretty well.

I found out later, after I was elected, that he was the one who nominated me for the National Academy of Engineering. It was sort of a practice not to nominate people from your own firm or agency. He was a professor, and I was a government man, so that put him in the clear.

As I mentioned, there aren't too many Corps people who are members. Jack Morris is a member, and there are several others. Now, General Hatch [Lt. General Henry J. Hatch, Chief of Engineers, 1988-92] is nominated for election in this next election, which will be this fall. Oh, and another one that got elected was Clarke, one of the Chiefs of Engineers before Morris [Lt. General Frederick J. Clarke, Chief of Engineers, 1969-73].

Q: Frederick J. Clarke?

A: Fred got elected, too. Charles Noble was also elected.

Q: Well, that's a nice distinction to have.

A: I always thought it a great honor to be a member.

Environment and Engineering in the 1970's

Q: Let me remind you about the environmental movement of the 1960's, and ask you what kind of effect the environmental movement had on Hydraulics and Hydrology?

A: The major effect was that for every project the Corps of Engineers had to make an Environmental Impact Statement [EIS] and write a report on what effects the project would have on the environment. The district wrote the report, and it was reviewed by the division and the Chief's office.

In my Hydraulic Design Branch, we'd look at the report to see whether we had any comments on the hydraulic design. For dam projects, the hydraulic design usually would be the same as for dam projects with no environmental problems. But in some cases, the spillway size or height of dam may need to be altered so that too much water would not be released to cause downstream flooding, and environmentalists would say "That's not good for the environment."

I experienced that problem while serving on the consulting board for two Saskatchewan Power Corporation dams [Nipawin and Saskatchewan Forks Dams]. The dams were designed without any regard for possible downstream environmental problems. There were some environmentalists downstream, farmers particularly, who opposed construction of the dams. They said it would change the flow of the water in the river, which would damage the environment. During Provincial elections, some politicians thought they could gain many votes by backing the environmentalists. The problem was the environmentalists, erroneously, thought that construction of the dams with large spillways and outlet works would create larger downstream floods than would occur under natural conditions with no dams. I explained that the proposed dams would reduce the size of downstream floods.

Finally, it was decided to make an environmental impact survey. It was found that a rare species of fish existed in the river downstream of the dams. A large flood might make those fish become extinct. Also, there was a special kind of flower that could be completely destroyed. Those environmental effects were judged to be insignificant, and the dams were constructed.

Q: So it wasn't too much.

A: No, it wasn't too much. I got the impression that environmentalist use any argument to defend their priorities.

Q: Or to stop you from doing what the Corps wanted to do or whoever the developer was of the project then?

A: Yes. If the environmental problems were significant enough, they could have prevented the construction of the dams or required them to be redesigned.

Q: The two in Saskatchewan?

A: Saskatchewan, yes.

Q: Where you involved in any project in which environmental objection may have resulted in changed hydraulic designs?

A: I think there were some projects which had design changes, but they weren't major changes. I can't offhand recall any where the environmentalists controlled what the Corps was going to do on a major project.

Let's see now. There was a channel improvement project in Florida, which was designed and constructed by the Corps. The river channel wasn't large enough, so during major floods, swampy areas and adjacent properties were flooded. The flood damages justified improvement of the river channel to carry more water without flooding any of the land.

The environmentalists didn't like that; they wanted the land flooded because that made good swampland for fish, birds and whatnot. They were able to stop construction. The Corps had already constructed part of the project. The Corps hadn't made an Environmental Impact Statement or report, so they got an injunction against it which required the Corps to stop construction until they made an environmental impact study.

The study found that the channel improvement would reduce the wetlands areas, but there would still be enough swampland, so the environmental impact would be minimal. Then, the Corps got approval to complete construction of the channel improvement.

Q: Were you involved at all in the Florida barge canal situation?

A: The Florida barge ...

Q: Yes, that cross-Florida canal, in the northern part of that state.

A: Well, that's the one I'm talking about.

Q: Oh, that's it?

A: Yes.

Q: Okay. That was a major setback, that one.

A: That's right.

Q: It was just a regular canal with some locks in it, right?

A: Well, yes, I think there were a couple of small locks in there.

Q: But it certainly paled in significance to Tennessee-Tombigbee or something like that.

A: That's right.

Q: One of the major conflicts within the Corps itself that came out of the whole environmental movement was the emphasis on non-structural solutions for flood control. How did that affect your work because you were working so much in the hydraulics area?

A: Non-structural solutions. When the planners, who work with the environmentalists, decided to use a non-structural solution, I didn't get involved because I was only involved with the hydraulic design of structural solutions.

Q: There's a lot of comment in the Corps itself on the conflict in the organization between the advocates of structural and those of non-structural solutions.

A: Yes. Those conflicts occurred in the Planning Division. I never was involved nor had to make any decision one way or the other.

Q: So you only went to work when somebody decided it was going to be a structural solution.

A: That's right. Sometimes it took an act of Congress to decide which solution should be adopted by the Corps. When it's decided to adopt non-structural solutions, districts don't prepare design reports for review by the Hydraulic Design Branch, Structural Branch, and all other OCE Engineering Division branches.

Computer Modeling

Q: If we can move into a little different area--we talked about this before--it's the whole area of computer modeling. How effective and helpful was computer modeling for you? Would you have preferred to stay with actual building of the model?

A: I never got involved in computer modeling. I think that sufficient hydraulic modeling data became available for effective use in computer modeling. Formulas are developed, based on the hydraulic model data, which when used in the computer, reproduces the hydraulic model results.

Q: So, basically, the computer was only sort of programmed with the data that came out of the hydraulic model, and it was done in WES or somewhere else?

A: Yes, hydraulic model or field data. In some cases, computer modeling is used to solve fluid dynamics or other theoretical equations. Most computer modeling was done at WES.

Q: Now, I was looking at something last night, Margaret Petersen's book on river engineering, and she was mentioning that there is a distortion between the model and the reality. There's a reliability problem. Where does that come from, just the natural fact of trying to record these data elements on a small model versus the large actual thing?

A: Well, I think that's what she was talking about. A very small model has a distortion effect. For example, let's consider the determination of water levels for a certain discharge in a river channel. Water surface elevations measured in a small-scale model would not be the same as measured in a large-scale model because the model roughness factor cannot be simulated as well in the small-scale model as in the large-scale model. That is called the distortion factor.

Q: So really a lot of it has to do with the scale of the model you're using

A: That's right.

Impact of New Technology

Q: I know we touched on this, but what other technologies or new technologies and methodologies were introduced while you were at the Corps that significantly affected the way you did hydraulic engineering?

A: New technologies? Technology--instead of using textbooks and theoretical equations, you use model testing. That's a new technology. I suppose the next new technology is taking model test results and using computers. From there on, I don't know of any further advancement of technology.

Q: Well, how about some things in the construction side that would allow you in hydraulics to make different kinds of designs, I mean a superior type of concrete or something like that? Would that allow you to make a better design or a different type of design?

A: Yes, it would. There's been a lot of work in the last 15 or so years to improve the resistance of concrete to erosion. With ordinary concrete, if the physical shape of a high-velocity spillway or outlet works is not designed correctly, cavitation erosion of the concrete can occur quite readily. For example, cavitation erosion can occur on a concrete spillway floor when the velocity exceeds 50 feet a second and there is misalignment at a floor joint.

If the upper edge of a downstream monolith is higher than the downstream edge of an upstream monolith, then the high-velocity water striking the misalignment edge creates negative pressures just downstream of the misalignment. The negative pressure area is extended downstream a short distance by the high-velocity flow to positive pressures, which cause the negative pressures to collapse very rapidly. The rapid collapse of negative pressures produces high-tensile stresses. The high-tensile stresses are exerted on the concrete floor a few inches from where the cavitation pressures are developed. The concrete is porous enough so that the high-tensile pressures enter the concrete a short distance, and progressively, erodes the concrete floor.

There has been considerable work on developing superior concrete to withstand cavitation erosion. Epoxy solutions have been added to some concrete mixtures. It makes a stronger concrete that withstands cavitation pressures much better.

I think that has been developed fairly well on a small scale, and it's used where cavitation pressures are likely to occur. It seems to me there could be more effort made to make the concrete stronger. I don't know how, but right now the concrete is not very strong compared to steel.

Q: So that's an area that requires additional research?

A: I'm sure there's been considerable research done on it. It may well be that sufficient research has been done to decide that the cost of making concrete approach the strength of steel is beyond reason.

Cavitation Erosion

Q: Well, it sounds from the discussions of Tarbela and other projects that a lot of the problems that arise in these cavitation erosion areas arise from less than adequate construction techniques. That means the construction is not the way it's designed. How much did you get involved in that kind of thing with the Corps?

A: While a job was under construction, I very frequently went to see how things were coming along. I remember when I was on the consulting board for Magat Dam in the Philippines. The last time I was there to inspect, it was under construction. The spillway had a concrete ogee section, followed by a long concrete chute, about 1,500 feet long and 300 feet wide, on a 1 on 10 slope.

I walked over the spillway with the man who was in charge of construction inspection there. Construction of monolith joints was not done very well. I showed the inspector one joint that was a half inch higher on the upstream end of the monolith than it was on the downstream end of the monolith just upstream.

I explained the whole thing about cavitation erosion at monolith joints that I just explained to you. I said to the inspector, "Normally, this wouldn't be called good construction, but this dam isn't high enough and the velocity isn't high enough, to cause serious cavitation erosion. Also, the spillway will operate about once in 5 years, so there will be plenty of time to repair any cavitation erosion between floods."

Q: But it was an important requirement for you to get out and look at these construction projects?

A: That's right.

Q: Also, from what you say, it's only the areas where you had a lot of high-velocity discharge that you had the problems.

A: That's right. When the velocity was under about 50 feet-per-second, or there was not a lot of discharge with velocities over 50 feet-per-second, cavitation erosion was not a big problem. I told the districts that anytime large flows occur, they should check to see if there's any cavitation erosion.

Q: You've mentioned cavitation erosion repeatedly as being a major problem in high-velocity spillways, and with destructive consequences. What other kind of problems do you find in high-velocity spillways that are destructive as that?

A: Sometimes there is a destructive problem with high-velocity spillways that have a concrete stilling basin. For example, if a high dam having four spillway crest gates discharges with only two gates on one side of the spillway, most of the water enters the stilling basin in that side. The hydraulic jump would be very erratic with considerable return flow on the other side of the stilling basin where there is no flow from the spillway. The return flow on that side was caused by higher tailwater downstream of the stilling basin. When the river bed and banks downstream of the stilling basin consisted of loose gravel and rock, return flows would carry that gravel and rock into the stilling basin where it would erode the concrete floor of the stilling basin.

The Corps had this problem occur at quite a few stilling basins. The solution was, after the flood was gone, remove all the gravel and rock from the stilling basin, repair any concrete erosion, remove gravel and loose rock in the downstream river channel, and, in some cases, place some concrete or large stone protection downstream of the stilling basin.

Q: Despite all of the modeling, some of this correction only came from practical experience with the design.

A: That's right, after operation of the project.

Design Considerations: Spillway Gates

Q: We talked about this before, but was this a matter of experimenting with various configurations of the gates?

A: Yes.

Q: It sounds like an exotic science. Let me ask you about some key projects and see if you have any particular memories of some of these. The Arkansas-Red-White project. Were there any particular hydraulic design problems in that project that caused you any consternation?

A: The relatively low dams were constructed with concrete all the way across the river. There were no particular problems with the spillway, crest gates, or outlet works. There is a fairly good size navigation lock located at one end of the dam. One of the problems we had was that when large spillway discharge occurred with the spillway gates operating, high velocities in the downstream river channel made it difficult for vessels to approach the lock. Design changes had to be made, such as extending the spillway stilling basin wall on the lock side farther downstream or extending the lock approach channel and, in some cases, moving it farther into the river bank away from the main river channel. Usually, model tests were necessary to check the design.

Q: All that was normally done at WES?

A: That's right.

Q: Now that was all remedial work though, wasn't it?

A: Yes, most of it, but I was involved with the design of one or two later navigation dams and locks on the Arkansas-Red River project.

Q: So some of the later ones would have picked up those solutions.

A: Yes.

Q: When I was talking to Vern **Hagen**, he said that the Arkansas project presented a lot of problems for them because of the amount of sedimentation in that whole system.

A: Yes.

Q: When you designed things, how much did you account for sedimentation?

A: The old spillway crests weren't very high. The most critical condition with respect to sedimentation was assumed for hydraulic design. That occurred when the sediment level upstream of the dam was at the same level as the spillway crest. This would result in the smallest spillway discharge for any reservoir level. Vern was concerned about the maximum height of the reservoir water levels for the maximum possible flood, because of upstream flooding. He attempted to determine the actual sediment level in the reservoir, instead of assuming the most critical condition, as was done for hydraulic design. I think that's what he had in mind. Did he make any specific comment? He said he had a lot of problems.

Q: Yes, I think that's basically what he was doing and what he was talking about.

A: All right.

Q: I was just wondering when it passes over from hydrology to hydraulics. What kind of consequences did you have to consider?

A: If Vern had been successful in determining the reservoir sedimentation level for a spillway design flood, that level would have been used in the hydraulic design to determine the size of spillway and height of dam required to pass the maximum possible flood. Model tests indicated the difference to be relatively small, so the worst sedimentation condition was assumed for design.

Q: On the conservative side, then?

A: That's right.

Q: Was there anything else about the Arkansas-Red-White that you can remember?

A: No, not specifically. That was quite awhile ago.

Q: In the design of locks or dams--the other day we talked about tainter gates and vertical lift gates in various types of dams.

A: Yes.

Q: I've also noticed that the Corps has built roller gate dams and these double-lift gates, and this is what we were talking about the other day. McNary apparently has double-lift gates.

A: That's right.

Q: Could you discuss these various types of gates and why they're chosen, the pros and cons of the various types?

A: A tainter gate is a very simple gate. It should be used in the open and shouldn't have any water flowing over the top. When the gate is closed, no water flows underneath. When releasing water over a spillway or into a flood tunnel, the gate is raised and water flows underneath with very little gate vibration. Tainter gates should not be operated with large flows over the top of the gate because that causes excessive gate vibration.

I was on a consulting board for a large dam in Puerto Rico where that had three tainter gates on top of the crest. Unfortunately, a large storm made the water level rise quite suddenly and water started over the top of the gates which were closed. The operator started opening the gates, but they got jammed part open. The storm developed into a hurricane that caused large flows over the gates from many hours. The gate vibration caused all three gates to fail. The consulting board studied the problem and recommended what should be done to repair the damage.

Now a roller gate. A roller gate is something used on the crest of a dam. It's round like a drum, so that water can go over the top. Structurally, it's stronger because it's a solid body. Large flows can go over the top without producing excessive gate vibration. Primarily, though, the gate is lifted and large flows go underneath.

What other kind of gate did you want to talk about?

Q: Well, the vertical lift gate.

A: Those are used on spillway crests, also. When they're closed, they sit on the crest. When the reservoir water level rises above the spillway crest, the gates are raised so water flows underneath the gates and over the spillway. Water should never flow over the top of vertical lift gates.

Tainter gates are 10 to 20 feet high, but they may be 30 to 60 feet wide. The vertical lift gates are the other way around; they're not more than about 15 or 20 feet in width, but they can be 40 to 50 feet high. Tainter gates are more economical for wide spillway bays and vertical lift gates are more economical for narrow spillway bays.

Q: So the selection of the gate is based on the basic overall design of the project.

A: That's right.

Q: And the conditions. Are there physical conditions that prevent the use various types of gates?

A: No, economy is the main consideration. For example, vertical lift gates could be used for any dam, provided the width of spillway bays are limited to 20 feet, instead of 50 feet for tainter gates. But the cost of using vertical lift gates would be considerably larger because over twice as many costly gate piers would be required. On the other hand, if a spillway located in one abutment of a dam is, say 60 feet wide, it may be more economical to use three vertical lift gates with two gate piers than a 60-foot wide tainter gate.

Q: What about the double-leaf lift gates? Now what are they--they're vertical lift gates, right?

A: Yes. Double-leaf gate. I know that such gates were used by the Corps.

Q: McNary Dam apparently has them.

A: McNary Dam, that's right. Well, double-leaf means that the gate is constructed with independent upper and lower sections. As the reservoir water level rises gate operation begins by raising the top part of the gate. If the reservoir continues to rise so large flows go over the bottom gate leaf, then it is raised up out of the flow.

Q: So it's sort of like a sectional lift rather than a single piece?

A: Right.

Q: Okay. I was looking at this picture, and it had various things like that where more water comes out of one gate than the other.

A: Yes.

Q: Okay. Well, I learn something every time.

A: Well, I'm learning, too--that I've forgotten a lot of things.

Q: You know a heck of a lot more than I'll ever know.

A: It may come to mind though, if I think for a few minutes.

Miscellaneous Civil Works Projects

Old River Control Structure

Q: Let me ask you about a project you probably know quite well--the Old River Control Structure on the Mississippi River.

A: Yes. The Old River Control Structure was built to control the Mississippi River so the whole river wouldn't go down, what's the name of it.

Q: Atchafalaya?

A: Atchafalaya, right. I was involved with that project. The control structure consisting of a diversion channel, spillway, and large gates, was constructed in the right levee of the Mississippi River to control the amount of water that would discharge into the Atchafalaya. The district's design was model tested at WES.

One question that arose was whether a stilling basin was needed to prevent excess erosion downstream of the control structure. After looking at the model, it was decided that a stilling basin was needed because the Atchafalaya channel banks for some distance downstream were erodible. Significant erosion in the Atchafalaya could undermine the whole control structure.

Oh, one further thing. The control structure was located several hundred feet downstream from the old structure, which was the best location for other than hydraulic design reasons. This required flow to make almost a 90-degree turn from the Mississippi River into the approach channel. When the flow reached the control structure, the water level was much higher on the left side of the structure than on the right, if the gates were not operated uniformly, which probably would cause erosion of the left approach channel banks for some distance upstream of the control structure. Some concrete and rock bank protection was provided to prevent that erosion. The sharpness of the 90-degree turn at the upstream end of the approach channel was reduced based on model tests, to improve flow conditions in the approach channel.

Q: That had to be a very difficult engineering problem--trying to control the Mississippi River from going where it wants to go?

A: That's right. There's no theory about that. You've got to figure out what might happen based on experience. Then test a model and see if you're right. If you're not, improvements in the design should be made as indicated by the model tests.

Q: Were you involved at all in the solutions to some of those problems that occurred there in the '73 floods when they had that big erosion on the old structure?

A: Yes, I remember that. I went out after the flood to look at what had happened. Improvements of the old structure so it wouldn't fail were discussed, but it was decided that a new large control structure that could handle more water was the best solution.

Q: It takes a lot of work on the engineering design of something like that because you're playing with a pretty powerful force there?

A: That's right. Yes. There's no great structural and concrete design problem. With respect to hydrology, the size of large floods and how high the water levels will be in the river are known. But when flows from a large river are diverted and controlled so the whole river won't go down the Atchafalaya, that is a difficult hydraulic problem. But it's still there, I guess.

Q: It hasn't washed away yet.

A: No.

Q: On something like that, you really have to very seriously look at your foundation structures, don't you?

A: That's right. I recall that there was a foundation problem underneath the concrete control structure. Sheet steel pilings were driven down about 60 feet, and the top of the pilings were imbedded in the base of the concrete control structure. This greatly strengthened the foundations.

Sacramento-San Joaquin River System

Q: Did you get involved at all with the Sacramento-San Joaquin River system in California?

A: Sacramento-San Joaquin? Yes, I did. Friant Dam was constructed by the Bureau of Reclamation on the San Joaquin River. The Bureau also constructed Shasta Dam on the Sacramento River and Folsom Dam on a river that discharges into the Sacramento.

The main problem on the Sacramento concerned the hydraulic design of rock and riprap bank protection. The Section 32 Program legislation was passed by the Congress authorizing the Corps to make studies of streambank erosion control. A Steering Committee to carry out the studies was established. I was the chairman until I retired in '79. One or two meetings were held in Sacramento to inspect the Sacramento River bank protection works. It was suggested that several alternative bank protection works be tested. Several test sections were constructed and evaluated for several years.

Q: Was there any particular difference between those kinds of projects and some of the other ones you were involved with, say, on the Missouri River?

A: The Corps did not construct as much bank protection on the Missouri River as on the Sacramento because the velocities weren't as high and the bank erosion not as extensive. Also, there was a lot of readily available rock on the Sacramento, which made rock bank protection quite economical. On the Missouri, rock for bank protection usually had to be hauled 200-300 miles, which made the protection costly.

Q: So there was a price consideration there, I imagine?

A: Yes.

Tunnel and Reservoir Project (Chicago)

Q: Did you have anything to do with the Tunnel and Reservoir Project, the TARP project, in Chicago?

A: What project is it called?

Q: It's called TARP--the really deep tunnels that act as a reservoir?

A: Right. The deep tunnels were constructed underneath the city's streets and buildings to collect storm drainage and sewage water.

Q: Right.

A: No, I never got involved with that project. I don't remember whether that project was under the Corps or not; 1 don't think it was.

Q: But I was wondering if that kind of thing ever came across your desk.

A: That's right. The Corps had to get involved because of the impact studies. The Environmental Impact report was sent to the Chief's office for review. The project consisted of many small drainage and sewer outlets discharging into a large underground tunnel. The tunnels were large enough so they never ran full. The tunnels served as a deep reservoir, storing water during storms which sank into the underground afterwards.

Passamaquoddy Tidal Power Project

Q: I was just thinking of another problem--somewhat like Susitna Dam I imagine with water and concrete and cold weather--were you ever involved in the Passamaquoddy Tidal Power Project in Maine?

A: Not very much. When I first came to the Chief's Office, there were a lot of studies being made on that in New England Division. Reports that came into the Chief's Office were on planning and were sent to the Planning Division. No detailed design was being done. Consideration was given to providing a low submerged dam that would control the tidal levels and increase upstream water levels. The power plant would be downstream, and water would be released at a slower rate so that more of it could go through the power plant. I wasn't involved with any detailed design.

Bonne Carré Spillway

Q: Okay. Since we talked, I was thinking a little bit about the lower Mississippi River projects we talked about the other night. I was wondering if you ever got involved with the Bonne Carré spillway.

A: The Bonne Carré? That name is very familiar.

Q: That's that big spillway from the Mississippi River to Lake Pontchartrain.

A: Yes. I got involved in that. Model studies were not made because the spillway is long and the head is low. As I recall, a low lift lock was constructed.

Q: Okay.

A: But I do remember looking at the plans when they came in.

Jetties at the Mouth of the Columbia River

Q: Any other one of these projects that you wanted to talk about that you have been thinking about?

A: We haven't talked much about navigation channels. I listed here "navigation channel at the mouth of the Columbia River." Maybe we can talk about that a little bit. Are you familiar with the Columbia River? It's a wide river at the mouth and a long distance. ..

Q: It's got those long jetties going out, doesn't it?

A: Yes. It's got long jetties going out, a south jetty and a north jetty. One of the problems involved the jetties. When they were first constructed, large rock was used to extend the jetties seaward. The jetties were subjected to 10- to 15-foot high waves during storms, which damaged the jetties by undermining the rock or eroding it away, particularly at the ends.

For a long time, the jetties were repaired by placing more rock at the damaged areas. The rock was very costly, because it had to be hauled a couple of hundred miles on barges. So the Portland District was studying other more economical ways of maintaining the jetties. The Committee on Tidal Hydraulics was asked to meet in Portland to discuss the problem. The Committee suggested that consideration should be given to using artificial protection like concrete tetrapods. A tetrapod is similar to a jack, made out of concrete, with legs about 12 feet long, and they're very heavy. Their size and the weight depend on the forces that they have to withstand.

In constructing the jetty protection, a rock base is first placed at the toe of the slope and up the slope to the top of the rock jetty. Then one or two layers of tetrapods are placed on the rock up to the top of the jetty. Most of the tetrapod protection is required on the channel side of the jetties. When high waves attack the back side of a jetty, as frequently. occurs at the seaward end of jetties, then similar tetrapod protection should be provided there.

The use of tetrapod protection was accepted. Tests were made at Bonneville Hydraulic Laboratory on a sectional model of the jetty. Different rock and tetrapod sizes were tested for different wave heights. This provided design criteria for rock and tetrapod sizes for different wave heights.

Another problem involved maintenance of the navigation channel which was 40 feet deep. Vessels coming in from the ocean passed through the navigation channel for several miles to the seaward end of the jetties, then passed between the jetties for several miles and then continued up the navigation channel to Portland. The jetties are 800 to 1,000 feet apart at the seaward ends. During large storms, 15-foot waves would cause the vessel to pitch so much, that if its draft was more than about 25 feet, it would strike the bottom of the 40-foot channel. The navigation interests and the Corps in the Pacific Northwest came up with the idea of enlarging the depth of the channel to 48 feet, increasing the depth by 8 feet. The next question was how to do it.

One plan was to dredge it. The second plan was to construct spur dikes near the inside end of the jetties. The spur dikes would be attached to the jetties, and aimed toward the navigation channel. Those spur dikes would constrict the opening between the two jetties, which would reduce the amount of water flowing up the river, during rising tides and storms. Also, less sediment would go up the river, so the amount of dredging required would be less. It was concluded that the dredging probably would not be completely eliminated, but it might be reduced enough for the 48-foot channel to justify the construction of the spur dikes.

Another question that was raised was whether the constriction at the end of the jetties caused by the spur dikes would produce erratic wave patterns and sandbar erosion with the navigation channel. It was concluded that the only way to answer this question was to make a model study of the whole thing. The last time I had anything to do with this project, the decision had been made to adopt the first plan of dredging the 48-foot channel to determine how much more dredging would be required than for the 40-foot channel. If the increase is not excessive, then the channel would continue to be maintained by dredging. If the dredging is greatly increased, then a cost estimate would be made of the construction of the spur dikes.

Hydraulic model tests would need to be made to determine whether one or two spur dikes are required. It'd be more uniform. With only one, the amount of dredging I think would be considerably more than if you had two. But if you had two, then it'd cost twice as much to build one. Then you run into costs of building those against the reduction in the amount of dredging that you would expect. The model could give some idea how much reduction in dredging. As far as I know, the model has been constructed and the navigation channel is being maintained by dredging.

Q: Are there any other coastal projects like that that you have been involved with--navigation channels or harbors of refuge that have had similar problems?

A: Yes, there are several small ones. Grays Harbor on the Pacific Coast is a much smaller harbor with similar problems. A model was constructed and tests indicated that jetties and some bank protection within the harbor were required.

Head of Passes, Mississippi River

There was a navigation problem on the Mississippi River at the Head of Passes. That's where part of the flow leaves the Mississippi River navigation channel and goes down another pass--I've forgotten its name. The problem concerned what type of control structure was required to prevent excessive flows from leaving the main Mississippi River to cause greatly increased maintenance dredging of the navigation channel. Tests made on the large Mississippi River model at WES indicated that a flow control structure was necessary at the Head of Passes, similar to the one constructed farther upstream.

Q: The Atchafalaya?

A: Atchafalaya, right. There were problems on other navigation channels, but not as large or important, cost wise, as on the Columbia River.

Humboldt Bay Jetties

Q: Did you get involved with the Humboldt Bay jetties?

A: Humboldt Bay jetties?

Q: Yes, in California.

A: Yes. They were built before I got there.

Q: Yes, they were pretty old; they go back to the 19th Century.

A: That's right. The only thing I remember is that they were constructed of rock and considerable erosion occurred during major storms. They are maintained by continually repairing eroded areas with more rock.

Most Difficult Hydraulic Engineering Problem: Mica Dam

Q: What was the most difficult hydraulic engineering problem you ever faced? We talked about your Tujunga Wash flood channel problem.

A: That wasn't hard at all. I think one of the most difficult hydraulic engineering problems was on Mica Creek Dam, which is on the Columbia River in British Columbia, Canada. I served on the consulting board for that project.

Mica Dam was designed by BC Hydro. It's a large earth dam about 450 feet high. It required a large concrete chute spillway on a good rock abutment on the left side of the dam. A large tunnel, which led to a powerhouse, was located on the right side of the dam. A large 36-foot diameter diversion tunnel was located at streambed level near the center of the dam. Lastly, outlets were required to release flood flows with high reservoir levels.

One solution which was considered was installation of gates in the diversion tunnel. By constructing two gate piers at the tunnel, three large gates could be installed to control outlet releases, except for one problem. Whatever type of gate that would be installed could not operate under the 400 or more feet of maximum head. The next consideration was to install two levels of smaller slide gates; one level at the tunnel entrance and the other halfway up the dam. The upper level of gates would be a second entrance and a separate small outlet conduit discharging into the large diversion tunnel. This plan had several hydraulic problems and would be costly.

Finally, the plan that was adopted consisted of constructing two concrete plugs in the large diversion tunnel; one at the entrance and the other about 400 feet downstream of the entrance. Two 7 x lo-foot slide gates were installed in each tunnel plug. The part of the diversion tunnel between the two tunnel plugs served as an expansion chamber.

The two sets of gates can be operated under equal heads for any reservoir level. For example, for the maximum reservoir head of 450 feet with both sets of gates fully open, the upstream set of gates discharges into the expansion chamber which produces 225 feet of back pressure, and the downstream set of gates discharges into the open diversion tunnel. This way, the maximum head that either set of gates need to discharge under is 225 feet, which is about the upper limit for slide gates.

To our knowledge, that had never been done before. Hunter Rouse and I were on that board, and Hunter, who was a theoretical expert, said, "It will work." I said, "Hunter, I think we've got something here. Let's model test it."

A large 1: 10 scale model was constructed in a Canadian laboratory in Vancouver. The model was constructed with clear plastic so flow conditions in the expansion chamber and downstream open diversion could be observed. Pressures were obtained at critical locations. The model tests verified that this plan would be satisfactory.

A City of Vancouver water supply pipe was near the laboratory. It had considerably higher pressure than was used for the 1: 10 scale model tests. I said, "Let's hook that up to the model and see what happens." The City of Vancouver was reluctant to give its approval because of possible damage to their water supply. But the laboratory finally got approval and the hook-up was made. The model operated very well under the higher head.

That plan was constructed at Mica Dam. I don't know of any other place in the world where a large outlet tunnel with an expansion chamber in it has ever been constructed. It has operated satisfactorily under high heads several times since construction was completed 15 or so years ago.

Q: In reaching a solution like that, is that purely you sitting there and saying, "This might work; here's the problem and let's look at this"?

A: Exactly. The thing I had to go on was that I knew that these slide gates would operate under 250 feet maximum head. Slide gates like these are installed at Pine Flat Dam, where the Corps has operated them under 250 feet of head.

Initially, there was one question that brought forth a lot of discussion concerning flow in the expansion chamber. The question was whether excessive surging back pressures in the expansion chamber just downstream of the upstream set of slide gates would cause excessive vibration and difficult operation of the slide gates. Fortunately, the model tests showed that those pressures did not surge excessively, and that good flow occurred in the expansion chamber.

Q: Would your model have shown you that it was going to behave well?

A: Yes. The model showed that good flow occurred in the expansion chamber, and that there were no great surgings of any kind. Model piezometers indicated no serious pulsations of pressures in the expansion chamber. Without the model results, I don't think we would have dared construct that plan.

Q: Nor would BC Hydro have paid the money.

A: Yes. But they were glad to see that it worked because the other plan that was considered would have cost a lot more money.

Q: Well, I guess that's why they hire consultants like you, right?

A: I don't know. I think they went with Hunter Rouse first because he was known all over the world in hydraulics and hydro-dynamics. I think Hunter said, "You better get Jake Douma here to help me."

Q: It's nice to have a guy like that you could give a couple dollars back to for helping you.

A: Yes.

Q: I don't have any more questions here; we've gone over a lot of things.

A: That's for sure!

Q: Would you like to discuss anything else? I think we've pretty much gone over everything I had to ask. I want to thank you for having me in your house, for talking, and for spending the time to do this interview.

A: Well, that's fine. I enjoyed it.