Teton Dam Verdict: A Foul-up by the Engineers

An independent panel of experts has concluded that the collapse of the Teton Dam in Idaho last June was due primarily to poor engineering design work by the Bureau of Reclamation, the federal agency responsible for building the dam. The panel attacks Reclamation—the proud builder of more than 300 major dams, including such world-famous structures as Hoover and Grand Coulee dams—at what most observers considered the agency's strong point: engineering competence. Meanwhile, it assigns secondary importance to geological factors that earlier critics had cited as reasons why the dam was unsafe or should not have been built at that site.

Whereas Reclamation, in a statement issued just 6 days after the collapse, had claimed that, even with the benefit of hindsight, there was "nothing" the bureau could have done to prevent the disaster, the panel of experts has little doubt where to pin the blame. It concludes that, "under difficult conditions that called for the best judgment and experience of the engineering profession, an unfortunate choice of design measures together with *less than conventional precautions* (emphasis added) was taken to ensure the adequate functioning of the Teton Dam, and these circumstances ultimately led to its failure."

The dam collapsed on 5 June just as the water behind it was approaching full reservoir capacity for the first time. The inundation downstream killed 14 persons directly or indirectly and caused some $400 million in property damage, with some estimates running as high as $1 billion. In the wake of the tragedy, two groups were appointed to investigate the cause of the collapse. One was a government group, organized by the Department of the Interior, the parent agency for Reclamation; it is expected to issue a report within the next several weeks. The other was a panel of nongovernment experts appointed by the Secretary of the Interior and the governor of Idaho. It was this latter group—headed by Wallace L. Chadwick, a Los Angeles consultant and former president of the American Society of Civil Engineers—that issued the stinging indictment of Reclamation in a thick report made public on 6 January.* The prestige of the group, which includes prominent names from the worlds of engineering and dam construction, gives its indictment particular weight.†

The panel's conclusions are based on an extensive review of documents, photographs, and eyewitness accounts; numerous laboratory tests and analytical studies; and a detailed on-site examination of the dam, its auxiliary structures, and foundation. The right remnant of the dam was actually dissected in 5-foot vertical increments to allow taking of samples and inspection for evidence of water channeling.

The panel was unable to determine fully what caused the dam's failure, largely because the part of the dam that collapsed was carried away by the flood waters, thereby removing the crucial evidence. But the panel found persuasive evidence that water from the reservoir traveled through fissures in the canyon wall, penetrated protective barriers that were supposed to block those fissures, and then traveled to the core of the dam where it eroded tunnels that weakened the structure and caused it to fail.

The Teton disaster provided a "tragic lesson" in how not to design such projects in the future. As it turned out, the dam and its auxiliary barriers were built in such a way that they were highly susceptible to erosion and cracking. The dam was a multilayered earthfill structure built with various soils and rocks that were dug mainly from the bed of the reservoir. Such earthfill dams are common—Reclamation has built some 250 of them, with no previous failures. The core of the dam, accounting for more than half of its volume, consisted of a mound of fine, windblown silt that was compacted in an effort to make it impermeable to water. This core was covered by a blanket of sand, gravel, and cobbles, much as a thick layer of soil or rocks might cover the core of a mountain. And various other layers of earth materials and rocks formed additional shells, with somewhat differing configurations being used on the upstream and downstream sides. In all, there were five different zones of material in the dam. In outward appearance, the dam resembled a very steep dirt hill—some 305 feet high—blocking the canyon.

The designers confronted unusual problems imposed by conditions at the site. The rocks in the canyon walls and bed were highly fractured, providing numerous passages through which water might travel. In the early stages of drilling test holes, most of the cracks found were small. But during excavation of the dam foundation, some fissures were discovered in the canyon walls large enough for a man to explore for a distance of about 100 feet both upstream and downstream. An inspector easily walked down one of these fissures, which was about 4 feet wide, until he found his way blocked by a rock "the size of a pickup truck." The walls showed no indication of converging on the other side of the rock.

Some fissures are present at virtually every damsite. They are deemed a hazard only if they allow a significant amount of water to reach the sides or downstream face of the dam, where it can erode the dam until it collapses. In an effort to prevent this from happening at the Teton site, Reclamation engineers built what they touted as an unusually tight barrier beside and beneath the dam. First, they cut trenches in the top of the canyon walls on either side of the dam to eliminate rock that was so fragmented there was no hope of plugging it up. The trenches were 70 feet deep and extended some 1000 feet into the canyon walls. Then, they drilled three parallel lines of holes in the bottom of the trenches and pumped in grout, a cementlike mixture, to plug the remaining fissures. The three parallel grout curtains extended far down into the rock of the canyon walls—300 feet or more in some cases, well below the base of the dam embankment. A single curtain of grout was also injected

*Report to U.S. Department of the Interior and to the State of Idaho on Failure of the Teton Dam, by Independent Panel to Review Cause of Teton Dam Failure, December 1976. To be available from the Government Printing Office. †Members of the panel, in addition to Chadwick, were Arthur Casagrande, professor emeritus at Harvard University and engineering consultant on dams and foundations; Howard A. Coombs, professor emeritus of geology at the University of Washington and consulting geologist on dams and power projects; Munson W. Dowd, chief engineer of the Metropolitan Water District of Southern California; E. Montford Fucik, board chairman of the Harza Engineering Company and designer of major dams; R. Keith Higginson, director of Idaho's Department of Water Resources; Thomas M. Leps, consulting engineer retained by California to investigate the failure of the Baldwin Hills Dam in 1963; Ralph B. Peck, professor emeritus of foundation engineering, University of Illinois, a 1975 recipient of the National Medal of Science; and H. Bolton Seed, professor of civil engineering, University of California at Berkeley, a member of the California Seismic Safety Commission. The panel's staff was headed by Robert B. Jansen, a civil engineer who was formerly chief of California's Division of Safety of Dams. Other key staffers included Clifford J. Cortright, staff engineer, and Laurence B. James, staff geologist, both formerly with California's Department of Water Resources.

into the canyon floor beneath the dam embankment. After the grouting was complete, the trenches at the top of the canyon walls were filled with the same silt used in the core of the dam. The end result was a supposedly impermeable barrier that extended in all directions around the dam. In theory, no significant amount of water could get through the barrier; it would have to take a long, circuitous route around or under the barrier, traveling such a distance that it would be unlikely to double back and attack the face of the dam, but would more probably reemerge further downstream where it would pose no threat to the dam.

The only trouble was, it didn't work.

The panel concluded that water got through the barriers implanted in the right wall of the canyon by two possible mechanisms. In each case the water cut a sizable hole through the supposedly impermeable silt that filled the trench at the top of the canyon wall. In one scenario, the water may have found an unplugged opening through the grout curtain (there were some) just below the trench. The flow of water may then have dug a channel through the silt just above. In the second scenario, the water may have breached the silt directly through cracks caused by differential strains or hydraulic fracturing. There is some evidence to support each hypothesis; perhaps both mechanisms operated together. In either case, after the water crossed the trench through one or more erosion tunnels, it took a sharp turn and flowed through joints in the rocks to the dam embankment, where it dug channels in the core material of the dam and ultimately caused that part of the structure to collapse.

None of this was inevitable. "The failure was caused not because some unforseeable fatal combination existed," the panel says, "but because the many combinations of unfavorable circumstances inherent in the situation were not visualized, and because adequate defenses against these circumstances were not included in the design."

The panel found Reclamation guilty of serious errors in judgment and performance. Some of the bureau's most significant failings included:

▶ Overreliance on a grout curtain that turned out to be imperfect. Reclamation engineers boasted that they had constructed three grout curtains instead of the usual one, thus making it almost certain they had plugged the highly fractured rock. But the panel found that the triple curtain was largely illusory. The two outer curtains simply served to shape and contain the center curtain; they were not watertight themselves. Thus, in the panel's opinion, there was actually only "a single-row curtain," and one that turned out to have leaks, at that. The panel says that, "too much was expected of the grout curtain." Multiple curtains would have been better. Moreover, "the design should have provided measures to render the inevitable leakage harmless."

▶ Use of "brittle" and "highly erodible" silts in the core of the dam and the trench fill. The brittleness, caused largely by Reclamation's decision to compact the silt "at less than optimum water content," increased the potential for cracking. And the erodible composition of the silt permitted water flowing through the cracks to dig large tunnels easily. What's more, placement of the silt against the heavily jointed rocks of the canyon wall and beds, where water could get at it, enhanced the potential for disaster. The panel concluded that the nature of the core material and the manner in which it was utilized "were major factors leading to the failure of the Teton Dam."

▶ Selection of a poor geometrical configuration for the trenches. The steep, rigid sides of the narrow trenches resulted in stress patterns that encouraged cracking, hydraulic fracturing, and erosion in the silt used to fill the trenches.

▶ Inadequate provisions for collection and safe discharge of seepage or leakage. In theory, the layer of gravel, cobbles, and sand immediately adjacent to the core of the dam was supposed to be permeable to water. Thus, when water seeped through, this layer was supposed to function much like the filter in a coffee pot—it was supposed to let the water drain through while holding back the silt in the core of the dam. But the panel found evidence that much of this layer was nearly as impervious as the core itself, thus raising questions as to "whether there was an effective downstream drainage zone anywhere."

▶ Insufficient instrumentation to enable construction engineers to be aware of changing conditions in the dam embankment and the canyon walls. The dam had probably been eroding for some time before visible signs of failure appeared on 5 June just hours before the structure collapsed. Had the engineers been aware of the leakage in the early stages, they might conceivably have been able to devise a remedy.

For the most part, the panel limits itself to pointing out the factors that led to the failure; it does not specify how Reclamation should have designed the structure. It does indicate that Reclamation might have adopted additional measures to prevent leaking and erosion, such as blanket grouting to protect the core of the dam from the highly fractured bedrock beneath it. And it asserts that the designers could have employed "a variety of defenses . . . to reduce the potential for cracking and to render harmless those that occur." Robert B. Jansen, the panel's staff director, told *Science* the panel felt that the designers, instead of relying on what amounted to a single line of defense (the trench and grout curtain), should have used multiple lines of defense and "more than one plane of protection."

The panel's findings conflict with many of the criticisms leveled at Reclamation in the aftermath of the disaster. Some critics said Reclamation should never have pushed ahead with the project after receiving warnings from the U.S. Geological Survey that the damsite was in a region of high seismic risk and that there might be a fault near the right abutment of the dam. But the panel found no evidence that such a fault exists and no evidence of any significant earthquakes on the day of failure. Other critics said Reclamation should have pulled back after test holes in the reservoir floor indicated that there might be serious leakage. But the panel considered such leakage "as primarily of economic importance and not related directly to the safety of the dam." There were also complaints that the reservoir had been filled too rapidly, posing an unwarranted risk. The panel hedges on that issue. At one point it states that "a slower rate of filling would have delayed the failure, but, in the judgment of the panel, a similar failure would have occurred at some later date." But at another point it acknowledges a "possibility" that the disaster could have been averted if the rate of filling was slower and the instrumentation was adequate to warn engineers of problems in time to lower the reservoir.

The message of most critics was the same: the site was so poor that Reclamation should not have built there. This theme was particularly strong in a report issued on 23 September by the House Committee on Government Operations. The committee complained that the "momentum" of construction led Reclamation to continue the project, once commenced, despite numerous warning flags about possible hazards. Its report accused Reclamation of "an attitude bordering on arrogance" in believing it could "engineer" a solution to any and all problems that arose at the site. But the expert panel concluded that site se-

lection studies were "appropriate and extensive" and that the selected site was "as favorable for the construction of a dam as any of the other sites studied." It added that preliminary investigations gave the designers "adequate knowledge of the site conditions," including the jointed character of the rock. What troubled the panel is that Reclamation, after getting this information, followed design practices it has used for many years without giving sufficient consideration to the difficult conditions at the Teton damsite.

On the day the panel's report was released, the Interior Department and Bureau of Reclamation announced steps to improve dam construction procedures. Interior has entered into discussions with the National Academy of Engineering to conduct a safety review of those dams identified as having "possible deficiencies that could affect their safety." At this point, that includes at least 13 dams. Interior will also hire a consulting firm to review the technology and methods used by Reclamation in its dams program. For its part, Reclamation will expand instrumentation of future dams and be more conservative in the initial filling of reservoirs. It will also obtain "independent technical reviews of the designs of all major future dams." That might help avert another tragedy in which engineers make an error in judgment and there is no one around to second-guess them.—PHILIP M. BOFFEY

The Rockefeller University: No Time for Philosophers

When The Rockefeller University makes the news it is customarily a report of another triumph in the laboratory or a further honor for a faculty member. Last summer, however, the word from Rockefeller was less auspicious; the university had fired its philosophers.

The Rockefeller, a graduate university concentrating heavily in the life sciences, is the evolved form of the Rockefeller Institute for Medical Research, founded in 1901 by John D. Rockefeller. It has been a leading model for medical research in the United States, and its laboratories have been the base for dynasties of distinguished researchers. Sixteen Nobel laureates have been associated with the institution, and seven are still active in research there. Because of Rockefeller's prestige and affluence, the furor over the philosophers attracted attention far beyond the boundaries of the university's 15-acre enclave on the East River in New York City. The incident was regarded as trouble on Olympus, and to the embarrassment of almost everyone involved, even landed on page one of the *New York Times* one Sunday last August.

At the time, the university's action was portrayed as a violation of the tenure principle. In fact, it never came to that. The philosophers were not dismissed, but, as they saw it, the administration invoked economic necessity and depicted the philosophers' future at the university in such bleak terms that they finally accepted a settlement and departed.

The philosophy group was a small one—only four tenured faculty members were involved—and very highly regarded in academia. One qualified observer called it "the most distinguished philosophy department per capita at any American university." Even under the conditions prevailing in the academic job market, all four philosophers received good job offers from good places.* Arrangements between the university and the four philosophers, Donald Davidson, Joel Feinberg, Harry G. Frankfurt, and Saul A. Kripke, varied in details, but in each case the university provided a settlement of 3 years pay to smooth the way.

This is not to say that the parting was easy or particularly amicable. The philosophers all feel that a threat to tenure was used by the administration to exert pressure on them to settle. While the matter did not come to a head until a year ago, serious discussion of whether there was a place for the philosophers at Rockefeller goes back 2 or 3 years.

The philosophers date the buildup of pressure from 1974 when the university vice-president Albert Gold had conversations with each of them. They recall that Gold said he was speaking informally and unofficially but with the knowledge of Rockefeller president Frederick Seitz. Gold observed that a significant number of members of the faculty and of the board of trustees felt that the "experiment" with philosophy at Rockefeller had failed. He said that Seitz was committed to the principle of tenure and would support the philosophers as long as he held his office. Gold noted that Seitz was approaching retirement age and that in view of the prevailing attitudes toward their discipline and future uncertainties, they might wish to think about moving.

During this period, junior faculty in philosophy were not promoted or replaced when their appointments lapsed and for 2 years no graduate students in the subject were accepted. At first the philosophers thought this was due to the austerity measures being taken, but they concluded finally that the administration was making its message to them unmistakable.

The philosophers say that on more than one occasion they were told that their claim on university resources would not be as strong as that of their colleagues in other disciplines, and they say they were left in some doubt about whether they would qualify for cost-of-living increases.

There was discussion by the philosophers of taking legal action, but they decided against it. And there was also some talk of asking the American Association of University Professors to consider censure action on the tenure issue, but apparently no formal overture was ever made. Rather, the philosophers, feeling increasingly isolated and having the option of settling elsewhere in hospitable circumstances, accepted the administration's offer. Kripke was the last to come to terms. In early July, in fact, he had received a letter from Seitz which said that the philosophy program was being terminated and that after another academic year and with the salary payment accepted by his colleagues, Kripke's "appointment will be deemed to expire." Seitz withdrew the letter in the face of faculty reaction, but Kripke

*Donald Davidson has taken up a professorship at the University of Chicago and Harry G. Frankfurt is similarly established at Yale. Joel Feinberg is finishing out this academic year at Rockefeller and will move to a professorship at the University of Arizona at Tucson in September, and Saul A. Kripke is serving out this year as an adjunct professor at Rockefeller and is a visiting professor at Princeton.