Screenings
from the Soil Research Lab

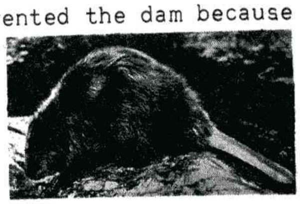
IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
AMES, IOWA

Fall, 1960
Vol.4, No. 4

DAMS

A few scattered remarks on earth dams

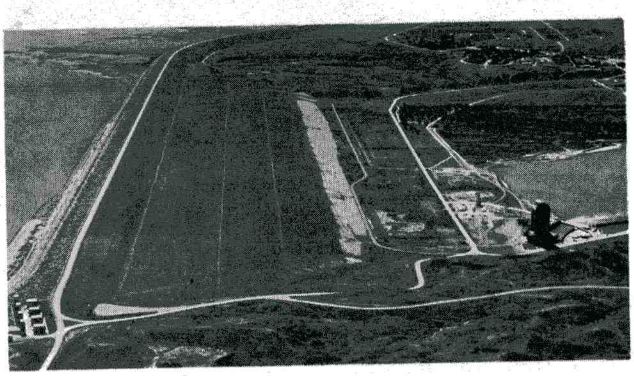
Nobody knows who invented the dam because most likely the inventor was not a man, but a beaver. Engineering is a very old profession if not the very oldest, traditions to the contrary.



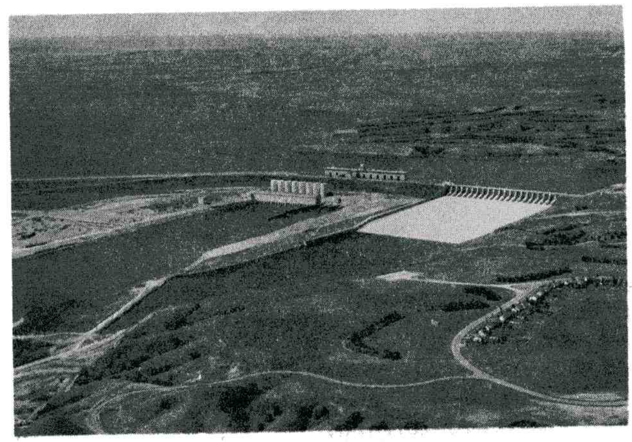
Pioneer dam builder.

History's eagerest beaver lived in a time when the earth was flat, and he decided to dam up the edges to make the world one vast beaver pond, like Communism. The project was moving along well when somebody said, "Noah, why don't you stop all this dam* foolishness before somebody gets drowned?" "None of your d. business," replied the beaver.

Rather than submit to life in a beaver pond, a group of reactionaries started a movement to stamp out the beavers, but the beaver proved too agile and sustained only a flattened tail. Eventually, of course, dam project was doomed because despite the propaganda, the earth was not very flat, and after the water was up for a few months it began to run off. Meanwhile the beaver had grown reflective and was rather frightened by it all, so he retired to a sedate life of nibbling alders.



Ft. Peck dam, the largest structure ever built by man. Soil for the dam was transported and deposited hydraulically. Tunnel control shafts are at lower left, powerhouse at lower right. A mile-long concrete-lined spillway is out of the picture in the foreground.



Ft. Randall powerhouse, intake and outlet works, and (at right) highway bridge over concrete spillway for extreme floods. The dam extends about two miles out of the picture to the left. Ft. Randall and Ft. Peck (below) are two of the series of six large earth dams on the Missouri River in the Dakotas and Montana.

As a matter of further record, the world's largest dam builder was the Giant Beaver, seven feet of fur coat plus tail and gnawing appetite. The Giant Beaver lived and died in the Pleistocene, along with many other gigantic experimental models such as the La Salle, Packard, big Buick and DeSoto.

The only other time the beaver caught up with fame was as an accessory for the beaver hat. Or rather, fame caught up with the beaver; the public fancied his exterior to be beautiful--which as any actress knows is how fame operates, often with devastating results for the famous. Only in recent years has the American beaver recovered. Others are not so fortunate.

Eager beaver business

Given the chance, small boys of America invariably follow in the wide path of the beaver, cutting trees and building experimental dams and watching water back up and spill over. Given the chance, large boys do likewise, which should help wives understand how much fun it is to be an engineer.

*Proofreaders remind us of an unscrupulous pun which from our purity of heart we almost failed to recognize. We promise to shackle it up and stand corrected.

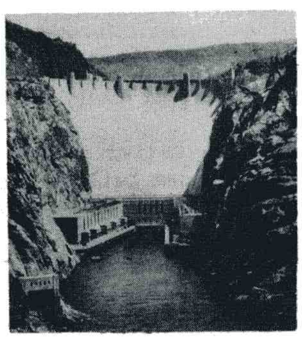
Return to Table of Contents

KINDS OF DAMS

Although beavers have the most experience and would probably dominate in unions where experience counts, man tempers his skill with originality and has stolen all the dam building laurels. Man dams are constructed from a variety of materials:

Leakiest dams are timber or timber cribs filled with rocks. Simplest dams, and those that usually catch the eyes of municipal authorities, are solid blocks of concrete cast in place in the river, called "gravity dams" because tipping and sliding are opposed by gravity and by friction caused by weight of the dam.

Rather more elegant are "hollow gravity" dams, which resemble a concrete wall with the top leaning downstream and propped up by vertical buttresses. Thus the dam is held against tipping by weight of the water. Hollow gravity dams save some concrete but require more elaborate forming.



Perhaps most spectacular are concrete arch dams such as Hoover Dam, where a concrete wall is arched upstream against the water and transmits the force as thrust against canyon walls. Arch dams are limited to deep, narrow, rocky canyons.

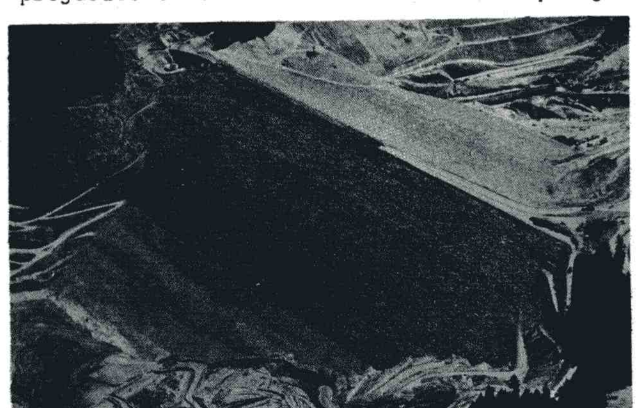
The earth dam situation

If concrete arch dams are the high and mighty glamour girls of the dam work, earth dams are more the shape of older girls where uplift fails, very broad at the bottom and tapering upward, perhaps with an occasional shelf, or berm, wide enough for a herd of elephants. The understanding male will recognize that earth dams constitute the largest man-made structures in the world, rather super colossal. Ft. Peck Dam in Montana, for example, has volume enough for 32 Great Pyramids plus a Sphinx or two, with enough mud Left over for 27 general elections.

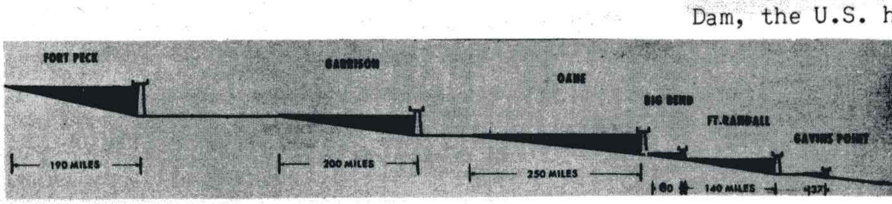
In smaller economy packages, earth dams outnumber all other types, particularly for construction of small reservoirs and farm ponds. In fact, conflicting sponsorship of government agencies has enhanced debate, to wit, which give better flood control, a few large dams on major rivers, or many small dams near river sources? The argument also demonstrates the fairness of statistics, which can be used effectively to support both sides. Actually the two arguments mesh rather well, like marriage.

For dam construction, soil is cheaper than concrete but more is required. Earth dams are preferred where soil is readily available and the required dam height is not excessive, earth volumes increasing geometrically with increased height. On the other hand earth dams are less sensitive to settlement than are masonry dams, and may be built on weaker foundations, and the long base length reduces under-dam seepage. Finally earth dams are the darlings of the park services because their appearance is less in conflict with natural surroundings.

In recent years the U.S. Bureau of Reclamation, among others, has been laughing at the prejudice that earth dams can't be very high.



Trinity Dam (above), recently completed in California, is 537 feet high, highest earth embankment in the world. Soil was transported to the job aboard a two-mile-long conveyor belt. The proposed Oroville Dam in California will be 730 feet high, or 4 feet higher than Hoover Dam, the U.S. highest.



A monumental series of earth dams on the upper Missouri, including several of the world's largest. Only Big Bend remains to be completed.

Return to Table of Contents

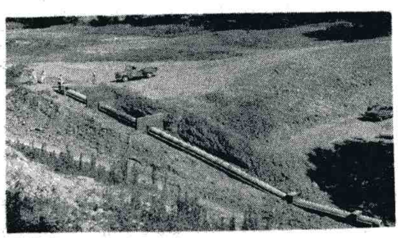
DESIGN OF EARTH DAMS

Strength considerations easily tingle the emotions of visitors to large dams, particularly visitors from the downstream side. Design of an earth dam embankment is relatively simple but requires a few minor precautions, such as extermination of muskrats.

Wave erosion of the upstream face is prevented on small dams by vegetation, on medium and large dams by a covering of boulder-size crushed rock called riprap. Protection against overtopping and sudden, disastrous erosion is obtained with a concrete outlet works and paved emergency spillway.

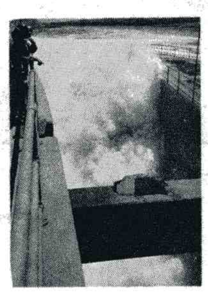
Limestone riprap for protection of the upstream face of Coralville Dam, Iowa River, Iowa.

On smaller dams the outlet may be simply a pipe or "drop inlet," and the emergency spillway may be a heavily sodded channel several feet lower than the crest of the dam.



Drop inlet spillway installed at the site of a future earth dam. Large concrete walls will prevent seepage along the outside of the pipe. USDA-SCS sponsored dam, Versailles, Illinois.

Water rushing through the outlets of high dams gains velocity such that it becomes wild and erosive, tending to slice a gorge downstream. The usual procedure is to dissipate excess energy and bedevilment in a stilling basin which includes a splashy "hydraulic jump," one of the few places where water freely runs uphill. That is, water rushing down through the outlet greeted at the bottom by a sudden change in channel slope tends to pile up deeper, with great turbulence and loss of energy. Also some of the violent kinetic energy of motion is converted into relatively stagnant potential energy of elevation.



Which way runs the water? That way, of course, for this is a hydraulic jump, one of the few places where water freely runs uphill. Other places are fire hoses and babies. Water enters the jump at some 60 mph; the sudden change in slope causes a terrific pile-up. Ft. Randall Dam, on the Missouri.

Typical small flood control dam, Snipe Creek Watershed, Kansas. Riser for the pipe outlet is housed by a protective screen at left center near the fence. In the foreground is the grassed emergency spillway.

Leaky lakes

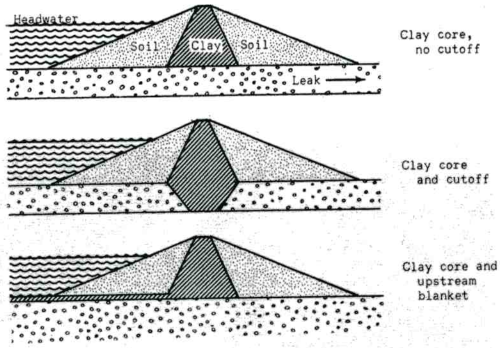
Nothing rankles like a leaky dam or reservoir, the folly is so conspicuous. Other engineering mistakes may fall down or explode and kill a few people, but are quickly repaired or removed and forgotten. A dry dam remains and pains; children laugh and grownups cry.

Assuming the reservoir is tight, which should be checked before damming is even attempted, seepage has two possible routes--under the dam and through the dam. For example, sand or gravel make a very leaky dam. The remedy is to include a core of impervious material such as clay, even though such soil may have to be hauled for miles. If a clay core is altogether too expensive, steel or concrete may be used.

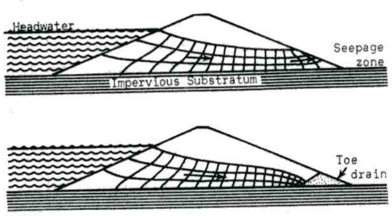
A more sneaky route for leaks is under the dam, a frequent problem because river sediments often contain permeable layers. A common preventative is to excavate a cutoff trench before the dam is built, and backfill with clayey material similar to that which will make up the core. Another approach is to drive an impenetrable steel curtain of sheet pile. Or if the permeable layer is too thick, the bottom of the reservoir may be coated with clay for a distance upstream, to increase distance the seepage water must travel and thus decrease the rate of flow.

Return to Table of Contents

TYPICAL EARTH DAM CROSS SECTIONS



A deeper route for under-dam leaks is through the underlying bedrock, limestone in particular being a likely place for caverns and tunnels. The remedy is some colossal dental work--drilling followed by pressure grouting, or pumping of a cement slurry down the drill holes. A little preliminary exploratory drilling is in order so the contractor will not be trying to fill a cavity the size of Carlsbad. Some areas such as limey parts of Kentucky would need a bigger dam underground.



Flow net

Once a dam cross-section is tentatively selected, seepage rate can be predicted by sketching a "flow net". The slightly tilting stream lines indicate probable paths of water molecules; the cross lines show the gradual loss of energy, or head. Rules for sketching a flow net are that all blocks are essentially squares.

Excavation of a cut-off trench which will be filled with impervious core material. Adjacent rows of well points are keeping the trench dry. Coralville Dam, Iowa. Purpose: flood control and duck hunting, but mainly flood control.

Flow rate is found from the equation:

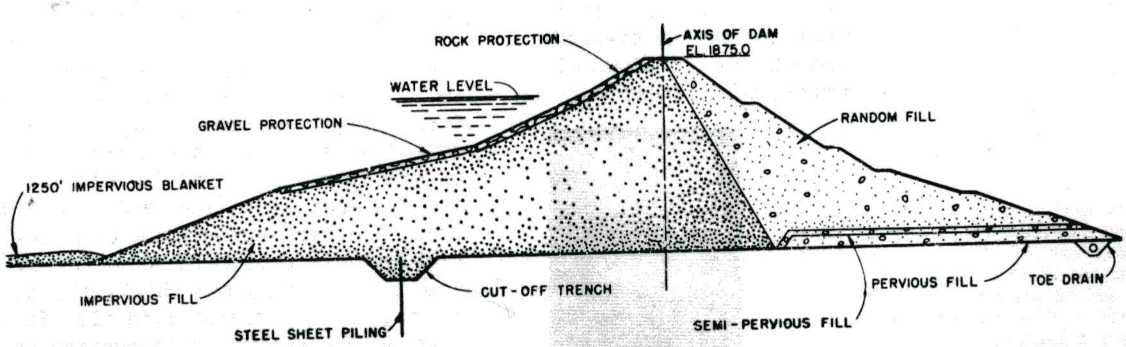
$$Q = k\,h\,l\,\frac{F}{N},$$

Where F is the number of flow paths, or spaces between pairs of stream lines, N is the number of spaces between the cross lines (equipotential lines), h is the total head loss, k is the coefficient of permeability, and l is the length of the dam. This is not particularly interesting, but we want to emphasize the quantitative aspect and keep with the trend. For example, what was formerly a shapely figure is now 38-24-36, or is it 34-34-36, or 34-36-49? Unquestionably there's a trend.

Stability of slopes

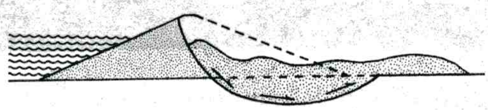
Perhaps the most important part of earth dam engineering is the question of stability, especially where much downstream populace and real estate can be imperiled. Embankment failures are landslides--that is, shear takes place on an internal surface, everything above the shear surface slipping and sliding downhill and engulfing as it goes. Sliding tendencies are related to shearing strength of the soil and to embankment geometry; slides are inhibited if the embankment has a broad bottom and low slope angle.

Cross-section of Garrison rolled-earth dam on the Missouri. Note the triple-barrelled attempt to reduce under-dam leakage: cut-off trench, steel sheet pile, and impervious upstream blanket.



Return to Table of Contents

For example, sands with a relatively high shear strength can safely stand in a rather steep heap, sloping as much as 34^{o} ($1\frac{1}{2}$ to 1), whereas clays require a low slope angle, 18^{o} (3 to 1) or less. Because low slope angle means more soil in the embankment, economy dictates some careful evaluations and studies of all available soils, particularly for large dams. Shear strength of soils can be increased by compaction, which gives an additional advantage of stamping out some of the permeability.



Earth dams also may suffer the nagging backache from too much seeping water. Seepage water emerging at the toe tends to push out the soil and create a marshful of mud. Preventatives are to incorporate tile or a sand or gravel drain. (See flow net sketches on the preceding page.)

Another circumstance to be avoided is sudden drawdown, or quick lowering of the water level in the reservoir, leaving seepage water perched high within the dam. Ordinarily, weight of the water in the saturated soil is borne by buoyancy, but with sudden drawdown buoyancy suddenly disappears. This is a critical time for slides--in fact, most river bank failures occur immediately after, not during, high water. The only preventatives for earth dams are to avoid sudden drawdown, which would flood the lower valley anyway, or to use a coarse, free-draining soil.

Rock fill dams

Related to earth dams but often discussed separately are rock fill dams, where rocks are used instead of soil. Safe slopes can be much steeper, and leaks are prevented by concrete, wood, steel or masonry facing, or use of an impervious earth core.

Sheepsfoot roller giving Oahe Dam (ō·ä'hē) its most vital ingredient, compactness. Compaction increases strength and decreases permeability. Check tests tell if soil densities meet specifications; if not, more rolling.

CONSTRUCTION

Earth dams are usually built in much the same manner as highway embankments: A layer of soil a foot or so thick is spread and compacted with rollers, then another layer is spread and compacted, etc.

A spectacular impetus to earth dam and all earth embankment construction came in the late '30's and '40's, when gasoline and diesel equipment took the place of mules and the W.P.A., and evolved into the gigantic earth hauling trucks, scrapers, and tractor-trailer units used today. Largest trucks now carry 50 tons, as much as a small freight car, and must be dismantled for transportation to other jobs. Hauling operations for the large dams are conducted at top speed, and haul roads are kept near perfection as endless successions of roaring, big-tired machines go around the route, in a fabulous display of power, speed, and timing.

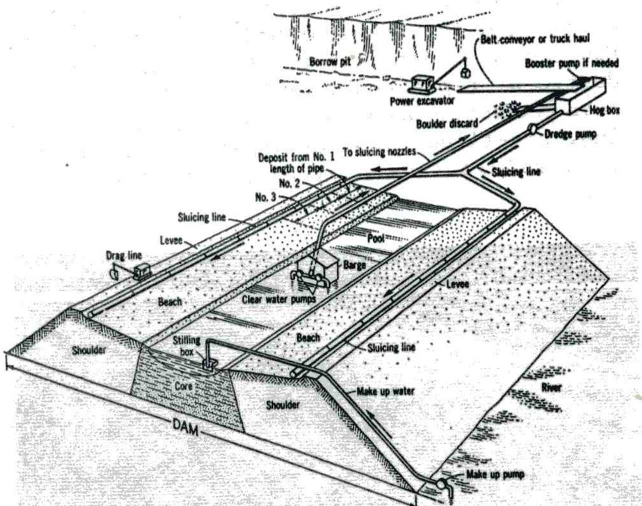
Hauling and sheepsfoot rolling for a section of Garrison Dam, North Dakota. Water sprinkler and disc harrows at right maintain proper moisture content for compaction.

Often the time of troubles in earth dam construction is during building, when soil has not regained full cohesive strength, and engineers don't know what to expect from the unexpected. In 1938 a very troublesome 10 minutes occurred at Ft. Peck, when about 5 million cubic yards of earth came tumbling down due to undetected bentonite clay seams. About 180 men were in the slide area; eight were killed.

In other instances earth dams have been built too fast, the gradually increasing weight consolidating foundation soils faster than pore water can escape. Excess pore water pressure separates soil grains, giving sudden lubrication and dangerous possibilities for shear. Pore water pressures are closely checked during construction.

Return to Table of Contents

A neat alternative quick trick for earth moving used in only a few of the largest dams, including Ft. Peck in Montana and Kingsley in Nebraska, is hydraulic fill: soil at the borrow pit is mixed or jetted into mud by use of giant nozzles, and the mud is sluiced to the job in pipe lines. There it is deposited from two parallel lines and retained by temporary alluvial deposits making up the shores and eventually the shell of the dam, while fine materials are carried into the lake and settle from suspension to form the less permeable core. As the dam increases in height, underlying materials consolidate and gain strength due to weight of the dam.



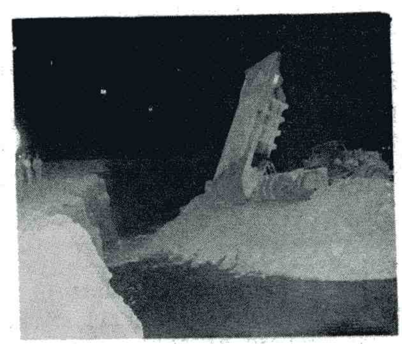
Hydraulic-Fill Construction

Closing drama

Large dams require years of methodical, round-the-clock construction involving many separate contracts and subcontracts, and played by a cast of thousands. At long last comes a unique drama, one of the few in engineering which so satisfactorily signifies triumph--the moments of final closure. The river has by this time become a violent torrent because of the sharply restricted channel, and hauling and dumping of earth must exceed rate of erosion if the river is to be tamed and plugged. Preparations are elaborate and excitement hangs, for these are telling moments.

The most recent closure of a large earth dam was in 1958 in Oahe Dam, near Pierre, South Dakota. The town was vibrant and booming with dignitaries and interested persons streaming in to socialize and watch a conquering of the mighty Missouri. Weather reports were noted with a nervous eye, the river flow was reduced from other dams, and all available earth moving equipment was made ready for the final push. By midafternoon the channel had been restricted until the water lashed with furious turbulence at the steadily growing and impinging banks. By evening the water was indeed riled as the channel was entering its final fight for life, and at 3:00 a.m. the end was near; the flow was greatly impeded and water was beginning to pile up. At 3:35 a.m. under the lights two bulldozers shoved the final plug, enabling one to walk across the Missouri on land.

Next to the last truckload for final closure, Oahe; the water is beginning to pile up. Truck holds approximately 50 cubic yards; note the comparative narrowness of the standard-width cab.



ACKNOWLEDGEMENTS

We are indebted to the Omaha District Office, U.S. Army Corps of Engineers, for photographs of the several earth dams on the Missouri, and to the Rock Island District Office for photos and plans of Coralville. We also owe our appreciation and a few free copies to the Soil Conservation Service, U.S. Department of Agriculture, for other good dam photos appearing in this issue.

RLH

Return to Table of Contents