Defiance of Statute and Engineering Law Wrecked Mammoth Dam

Original Plans and Specifications Approved by State Engineer Not Followed—Too High Water Level Under Makeshift Conditions of Construction and Operation

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THE failure of the Mammoth reservoir dam in Utah on June 24 and 25, resulting in the loss of the structure and a large volume of water stored for irrigation and in large property and other losses to the Denver & Rio Grande R.R., coal-mining companies and others, was due to violation of state legislation that resulted in makeshift construction. It was also due to careless operation.

The Mammoth reservoir is owned by the Price River Irrigation Co. It is located in the central part of Utah, in the Wasatch Mountains, six miles west of Scofield. Its altitude is 8500 ft. The watershed is about 20 square miles, reaching an altitude of 9750 ft. The reservoir held about 11,000 acre-feet of water at the time of failure. The stored water was used to supplement the low-water flow of Price River during the summer, for the irrigation of lands southwest of Price.

The average annual precipitation at Scofield, at an altitude of 7500 ft., is between 18 and 19 in. Snow frequently lies to a depth of 10 ft. on the level in this region at the end of the snowfall season in April.

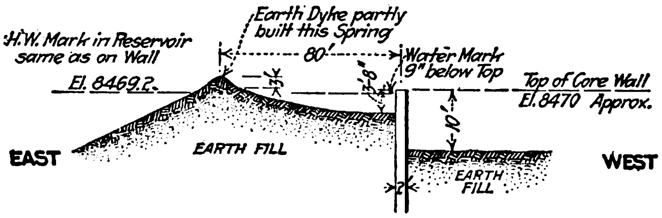
The dam was an earth-fill structure, with a concrete heart wall founded on bedrock, exposed in the stream bed and sides of the canyon. Bedrock is sandstone lying in strata sloping slightly downstream. Between the strata is either shale or clay.

The original plans and specifications, filed some years ago, and approved by the state engineer, had not been followed in any particular. After work had progressed along entirely different lines in violation of the state law requiring the approval of plans for dams still other plans were filed in the office of the state engineer, but the revised plans have never been approved.

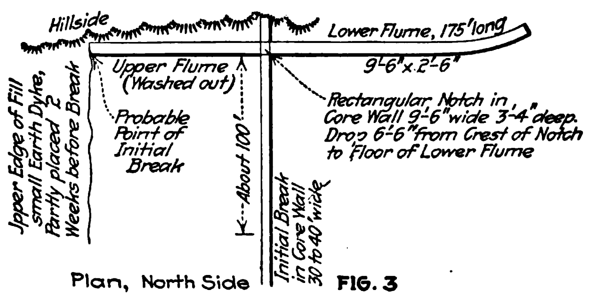
Dam Raised Piecemeal from Time to Time

At the time of failure, the dam had been built to an elevation of about 70 ft. above stream bed. It was 160 ft. wide on top, with a concrete heart wall along the axis. The top of the earth-fill on the downstream side of the wall was at an elevation 10 ft. below the top of the wall, and on the upstream side 3½ to 4 ft. below the top of the wall. The fill on the upstream side of the wall sloped upward from the wall to an elevation the same as the top of the wall at a point 80 ft. distant, where a narrow dike of earth had been thrown up with crest 3 ft. above the top of the wall. Part of this dike was built about two weeks before the failure. The dam had been raised from time to time to meet the demands as the project on which the stored water was used developed. The last raise, of 5 ft., was made in the fall of 1916, at which time the heart wall and the earth-fill on the upstream side of the wall were raised. The fill on the downstream side of the wall had not been raised. The lower portion of the fill had been sluiced in, the remainder having been placed by wagons and scrapers and compacted with a heavy corrugated-iron roller.

The earth composing the fill is a clay loam. Some parts of the fill remaining show a very dense hard fill,



Cross-Section, East-West Near South End of Dam
FIG. 2



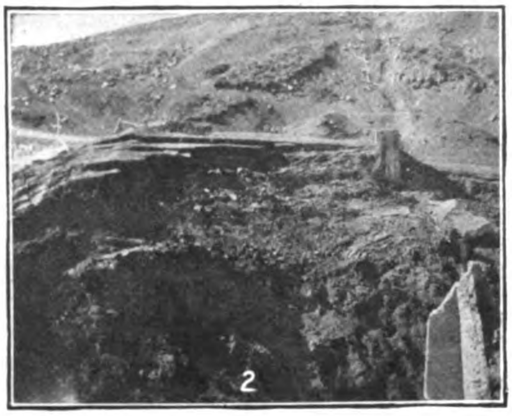
Plan, North Side FIG. 3

SKETCHES VISUALIZE THE CAUSES OF FAILURE

Relative levels of water in reservoir, heart wall, earth embankment above and below heart wall at time of break are shown in section and location of flume and initial break in plan

but the major portion shows the earth to lack cohesion, being very friable, having broken off and slipped during and after the washout as though only recently placed, fractured parts being very loose and crumbly.

The concrete heart wall was founded on bedrock, was joined to bedrock on both abutments and was about 450 t. long. It was 2 ft. thick, buttressed at intervals of 25 ft. on both faces. The buttresses were 2 ft. thick, 2 ft. long at the elevation to which the heart wall had been completed, sloping to 9 ft. long at the base. They were without reinforcement and were not tied by reinforcement to the wall or foundation. The plans call for vertical reinforcement of the heart wall near the upstream face with horizontal reinforcement also. Standing portions of the wall show ½- and ⅝-in. rods vertically at the center of the wall projecting above the top of the wall. One portion of the base also shows similar rods, and horizontal rods up to an elevation 12 ft. above the base, but none above. Some broken pieces show no reinforcement whatever. It appears, therefore, that



1. LOOKING AT RUINED DAM FROM BELOW

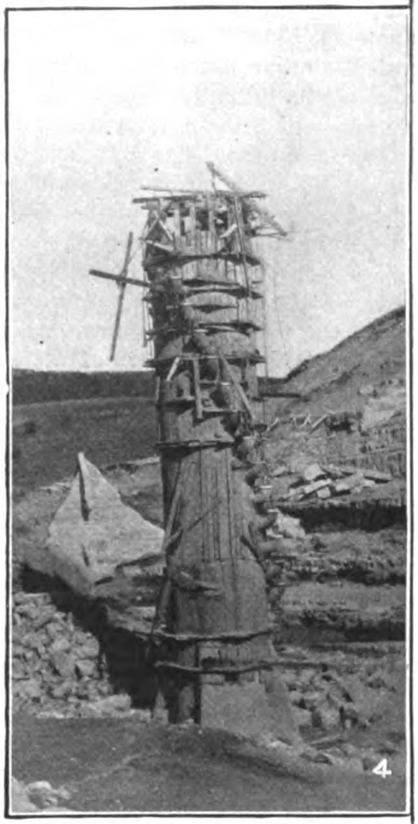
2. LOOKING SOUTH ALONG DAM AND HEART-WALL

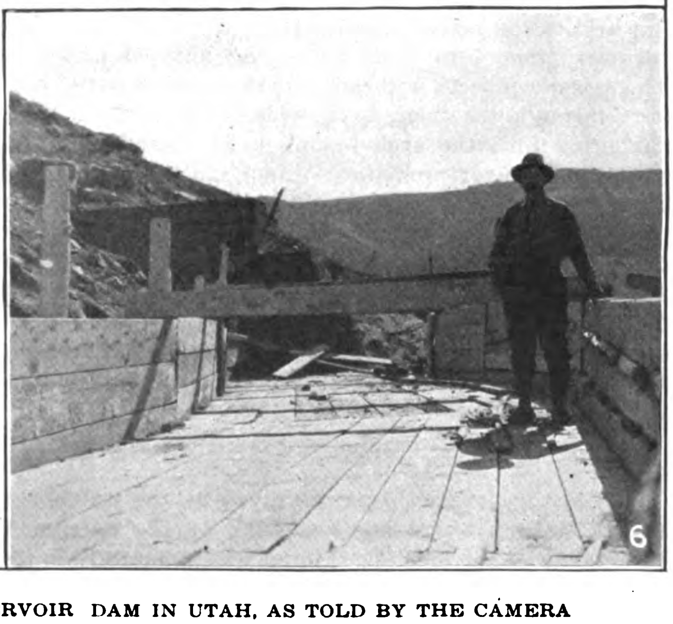
3. TIPS OF MAN'S FINGERS ARE AT WATER MARK ON HEART-WALL

4. UNFINISHED OUTLET TOWER STANDS UNHARMED

5. REINFORCEMENT SHOWN IN SECTION OF HEART-WALL ADDED IN 1916

6. LOOKING EAST THROUGH LOWER PORTION OF FLUME





STORY OF THE FAILURE OF THE MAMMOTH RESERVOIR DAM IN UTAH, AS TOLD BY THE CAMERA

the plans were not carefully followed. Intended for a seepage cutoff wall, its design, and more especially its construction, made it depend almost entirely upon the support of the earth-fill on either side for stability.

Small Makeshift Wood Flume for Spillway

No permanent spillway had been built. On the north side a wooden flume 9½ ft. wide and 2½ ft. deep was built along the junction of the fill and the hillside. This butted against the lower side of the heart wall, in which a rectangular notch of about the same dimensions was left. When the addition of 5 ft. to the heart wall was made in 1916, the flume on the downstream side of the wall was left in place, so that there was a drop from the crest of the notch to the floor of the flume of 6½ ft. On the upstream side of the heart wall a similar flume was built extending to the upper edge of the fill and terminating in the small earth dike. The floor of this flume at its upper, or east, end is said to have been from 4 to 5 ft. below the crest of the earth dike. No wing walls or cutoff walls had been built. The floor rested on mudsills, and the sides were supported by timbers that had been driven into the fill. Three 6-in. plank flashboards had been put in at the head of the flume, and water was being held 14 in. above the floor of the flume, or, according to the caretaker, 3 ft. below the top of the earth dike. No water was flowing through the flume, the inflow into the reservoir being handled through the outlet tower.

Incomplete Outlet Tower Proved Useless

The outlet tower is circular, 6 ft. inside diameter, of reinforced concrete. It is provided with four 12-in. inside diameter mud sluices at the bottom, with gates operated by screw lifts from the top of the tower. Eighteen one-fourth bend cast-iron inlets 12 in. inside diameter are located in a spiral around the tower. Their openings point upward, with round cast-iron covers, operated each independently by chains, cables or ropes from the top of the tower. No foot-bridge or adequate operating platform had been built, access being had by means of a lumber raft. The top of the tower had not been carried up as high as water was being held in the reservoir, the caretaker stating that water was from 4 to 5 ft. above the finished concrete. The tower connects with an arched concrete outlet culvert through the dam, 5 ft. wide, 4 ft. high to arch springing line, the arch having a 2½-ft. radius. The tower and culvert remained intact, about one-half of the culvert being exposed on its lower end. Two of the mud sluices and three of the inlets near the top of the dam were open. Lumber forms projected above the top of the concrete at the top of the tower, and on top of this was a mass of timbers to which the pulleys carrying the ropes and cables for operating the inlets to the tower were fastened. Some water was finding its way through the forms into the tower.

Watchman's and Caretaker's Accounts of Break

The history of the break, as given by the watchman and caretaker, is that at noon, June 24, the watchman being alone at the dam, everything was apparently in its usual condition, and water in the reservoir had not risen in the previous 24 hours. The watchman went to dinner about ¼ mile away, remaining 2 to 2½ hours. On his return, water was flowing through the earth dike at the upper end of the dam, at the north side, southwesterly across the earth-fill and out through a gap in the concrete heart wall, 30 to 40 ft. wide, which had broken out about 100 ft. south of the north end of the dam. This section appeared to have broken off to a depth of about 5 ft., probably along last year's junction plane.

It is the writer's opinion that this assumption is not correct. It is impossible that less than 4 ft. of water could have caused the breaking off of the wall at a depth of 5 ft. The break must have occurred near the level of the top of the earth-fill on the downstream side of the wall.

No Help at Hand

The watchman immediately summoned help by telephone, but the remoteness of the dam prevented any assistance arriving in time to be of use. It is certain that, under the conditions that prevailed, no human agency could have saved the dam. When the caretaker arrived by horseback about two hours after being notified, he made his way on the raft to the outlet tower and attempted to tear away the wooden forms projecting above the concrete, so as to allow a greater flow of water into the tower. He was only partly successful. The various ropes and cables for opening the inlets to the tower could not be operated, and there was nothing to be done but watch the dam crumble away. The rush of water through the break washed out the fill on the downstream side of the wall, and with it from time to time sections of the wall, until finally, more than 24 hours later, the main break occurred and the major portion of the water was released.

Probable Cause of the Dam Failure

Evidence and testimony point to the break having occurred in one way only, as follows: Water found its way around or under the upper end of the flume, which had not been properly bedded and protected in the earth dike at the upper end of the fill. This water filled the depression between the dike and the heart wall. Water marks on the upstream face of the heart wall show 9 in. below the top on the south end and 7 in. below the top at the north end. This mark corresponds to the high-water mark of the reservoir on the slopes above the dam. This water saturated the earth-fill sufficiently to overturn or push out by sliding a portion of the heart wall. Scour marks on the earth-fill under the lower flume just below the heart wall show that water pouring through the notch had deeply scoured the fill. This may have been a contributing cause to the failure of the heart wall.

Early reports laid the break to an unusual volume of water from melting snow entering the reservoir. This cannot have been the cause. The watchman's testimony is that the reservoir level had remained stationary for 24 hours previous to the break, and the high-water mark in the reservoir shows that the upper dike was not overtopped. Neither had there been any wind to scour out the fill.

It is also reported that there was a stream of about ½ sec.-ft. volume issuing from the hillside about mid-height of the dam, just below the lower end of the lower flume, which ceased after the destruction of the dam. This was reported a week after the break and after the writer's examination. This is given no weight as connected with the failure of the dam except that if water from the reservoir was finding its way around the north end of the dam, it may have partly saturated the fill on the upstream side of the heart wall and helped cause overturning of the wall.

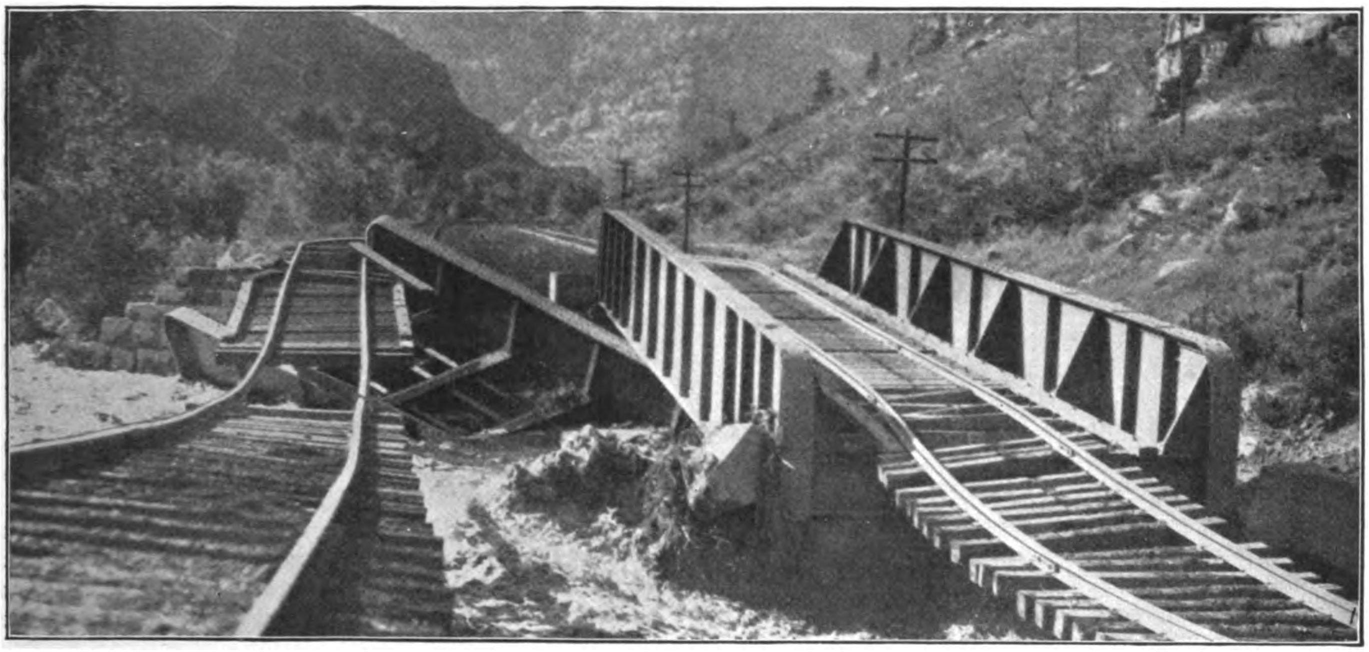
The disaster can be attributed only to utter carelessness in the lack of an adequate spillway and in the flimsy construction of what was intended for a spillway, together with the unsafe height to which water was held in the reservoir against the earth-fill forming the crest of the earth dam.

The unfinished condition and design of the outlet tower formed a contributing cause. The very temporary makeshift provisions for controlling the inlets to the tower made it impossible to operate them. In opening, it is necessary to lift the full weight of the water standing over the covers to unseat them. This, with the arrangements at hand, made it impossible to open any but those near the top in any event. The caretaker also states that, when several of these outlets have been opened, the water falling into the tower creates such an excessive vibration that it is considered dangerous to open any more. This feature had been commented on previously in a report to the state engineer on the adequacy of the construction. Thus, the tower afforded no means in an emergency of letting out quickly a large volume. This is not the function of such an outlet, but a set of several large gates near the bottom of the tower with screw-lift stems and an operating platform adequate and easy of access would have afforded this extra emergency outlet.

Had the spillway been deep and wide enough, properly protected, with means for the quick removal of the flashboards, the calamity would most certainly not have happened. A spillway 20 ft. wide, 4 ft. deep, with floor 10 ft. below the crest of the fill, should have been provided.

Damage to Denver & Rio Grande Railroad

Water from the reservoir joins the Price River about 20 miles below the dam at Colton. Between this point and Hale, 11 miles above, the Scofield branch of the Denver & Rio Grande R.R. was entirely destroyed. From Colton to Helper many miles of the main line were destroyed, practically all bridges being wholly or partly washed out. At Castle Gate the depot was washed away. The bottom of Price Canyon is thickly lined with houses near the various towns, mostly homes of coal miners. There was ample warning of the impending disaster after the initial break, and they were able to move all their effects. Otherwise, a very heavy loss of life would have resulted. As it was, only one death occurred, that of a young woman sightseer whose automobile backed into the flood.



TWO OF THE DENVER & RIO GRANDE RAILROAD BRIDGES HIT BY THE FLOOD WATERS FROM MAMMOTH DAM FAILURE

These were 85-ft. bridges. The east pier of one was washed out and of the other cracked and twisted from foundations when flood cut a new river channel

Coal Mines Shut Down and Industries Threatened

The destruction of the railroad caused the practical shutdown of all the coal mines in the district, which is the leading coal-producing section of the West, the Denver & Rio Grande R.R. being the only outlet. Unless a very speedy opening of the road is effected, a coal shortage will shut down all the large industries of the state, since the amount in storage is estimated at less than two weeks' supply. This feature is particularly unfortunate. The shortage of cars for various reasons has rendered it impossible for the railroad to supply even the summer demand for coal in some sections; and in addition it had been hoped to store large quantities during the summer to guard against a repetition of last winter's experience, when unusually severe weather and other conditions made it impossible for small users and outlying communities to obtain coal at all.

The loss to crops to be served from the reservoir is problematical. The diversion dam for turning water from the Price River into the canals is intact. The natural flow of the river will be greater than usual this summer on account of the snow which still lies in considerable amounts on the mountain watersheds. This, with offers of water from other sources, makes the outlook favorable for no great crop loss.

Railroad officials hope to have the road open for nominal traffic by the middle of July, but it will take many months to get the railroad in good shape.

ELOQUENT WARNING AGAINST LAX OPERATING METHODS

The disaster is an eloquent warning against lax methods in the operation of structures that at best have elements of danger against which every possible precaution should be taken. State officials all over the United States should renew and increase their vigilance and insist that the laws governing the construction and operation of reservoir dams be rigidly enforced. The Price River Irrigation Co., at whose door the failure must be laid, is the least loser. The innocent parties, as usual, are the chief sufferers.

The examination on which this report is based was made in company with George F. McGonagle, state engineer of Utah, and J. L. Rhead, of the state engineer's office. The writer acknowledges assistance rendered by them, including photographs and drawings furnished.

City Planning Commission Proposed

A City Planning Commission for Cincinnati, Ohio, has been provided by the Charter Commission in one of its sections for a proposed new city charter. The Planning Commission is to consist of seven members, and the charter provides an annual appropriation of $30,000 for the years 1918, 1919 and 1920, and thereafter appropriation of funds is to be made by the council. The powers and duties of the commission will be to make plans and maps of the whole or any part of the city, or any land outside of the city which bears a relation to the general planning scheme of the city. The maps and plans are to show the recommendations of the commission for new streets, alleys, viaducts, bridges, subways, parkways, playgrounds and any other public grounds or public improvements, also the removal, relocation, widening or extension of existing public works. Power is also given the commission to control, preserve and care for historical landmarks and decide upon the location of works of art and statuary belonging to the city.

Mineral Water and Barometric Levels Synchronize at Saratoga Springs

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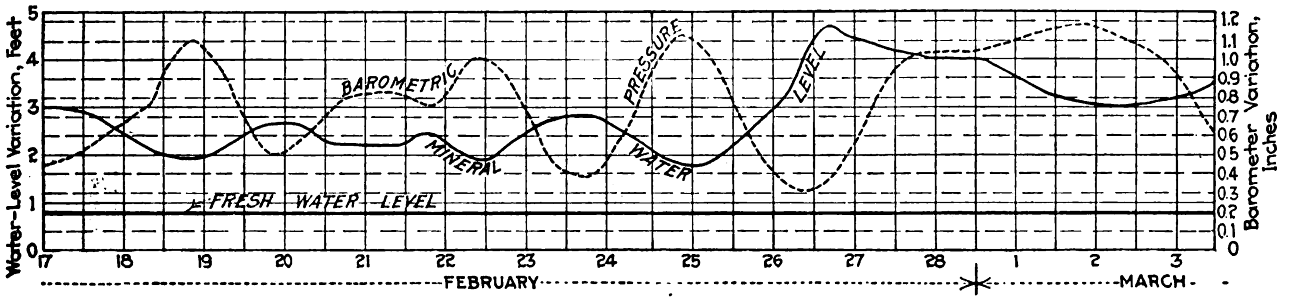
OF PARTICULAR interest to hydraulic engineers is the dual water system underlying the City of Saratoga Springs, one a reservoir of pure soft water, the other a reservoir of strongly carbonated mineral water.

The state geologist has shown the following section of the strata at Saratoga Springs, from above downward: 75 ft. drift sand and gravel; 25 ft. clay; 100 ft. gravel; 300 ft. shales and slate; 500 ft. limestone; 400 ft. sandstone; ancient gneiss and metamorphic rock.

Above the clay the pure soft water is found, while below the clay the mineral water is found—weak mineral water in the shales, strong mineral water in the limestones and sandstones.

There are 122 mineral springs and wells on the state reservation, ranging in depths from 125 to 1006 ft.



LEVEL OF SARATOGA SPRINGS MINERAL WELLS FLUCTUATES WITH BAROMETER

These wells all extend below the clay and all yield mineral water of varying mineralization.

Above the clay 75 wells were opened ranging in depth from 20 to 40 ft., all yielding pure sweet water. As the reservation contains 540 acres, we have one well on every 2½ acres of land or an ideal system of bore holes from which to study the two water systems.

The mineral water comes to the surface with a temperature of between 50 and 54° F. (10 to 12° deg. C). It is interesting to note that the temperatures are appreciably higher in the summer than in the winter, the waters being 2° F. warmer in August than in April. The specific gravity of the water will vary with the amount of dissolved solids, ranging from a minimum of 1.0034 to a maximum of 1.0123.

The waters are alkaline saline, or saline, and nearly all contain enough iron to be classed as chalybeate. The mineral waters are all naturally carbonated, the average rate of CO_2 gas to water being about 4½ to 1. There is a constant stream of mineralized water flowing from the southwest to the northeast. It is a current of living water, gathering strength as it flows slowly through the rocks, until with its vitalizing charge of carbon dioxide gas it issues clear and sparkling to the surface. This reservoir of mineral water follows none of the laws of percolating waters. Its movement is entirely independent of the fresh percolatory water above. It is not uncommon to see the mineral-water horizon rise while the fresh-water horizon lowers. Sometimes the two horizons move in synchronism, but always the movement of the mineral-water horizon is many times greater than that of the fresh-water horizon.

The peculiar ebb and flow of the mineral-water system, while noticed for years, has never been satisfactorily explained until recently. Many observers attribute the ebb and flow to the attraction of the moon. It was noticed by men operating the natural carbonic acid gas plants that invariably greater quantities of gas were received in the gasometer whenever there was a south wind blowing.

The curves on page 56, showing mineral-water level, fresh-water level and barometric pressures, prove conclusively that the fluctuation or rise and fall in the mineral-water level is due to barometric pressure alone. The solubility of carbonic acid gas varies directly as the pressure up to about six atmospheres pressure, when the law ceases to hold. A high barometric pressure holds a given quantity of gas in solution. A low barometric pressure releases a given quantity of gas and permits it to appear as a bubble where it occupies space and immediately displays an equal volume of water and causes the mineral-water level to rise. An increased barometric pressure drives this gas back into solution where it occupies no volume, the bubble disappears and the mineral-water levels falls.

It is seen from the curve that the fresh-water level shows no variation over a period of two weeks, while the mineral water shows a fluctuation of 2.8 feet.

A Letter Answered:

Does the Army Need Engineers as Officers?

This is the case of a candidate for a commission in the Engineer Officers' Reserve Corps who has become discouraged at the outlook, as viewed from the barracks of a training camp. His statement that "there is no apparent use for the experienced engineer in the Army Corps of Engineers" is one which should not be allowed to pass without comment. *Engineering News-Record* quotes below the main portions of the letter from its correspondent and presents, in rebuttal, a discussion based upon information secured from an authoritative source. Brief editorial comment appears on another page.

A LETTER from an engineer in training for a commission in the Engineer Reserve Corps of the Army, received by *Engineering News-Record,* is a complaint, good natured enough in places, but nevertheless a complaint that the prospects of his being of service to his country in the capacity for which he was urged to volunteer are very small. This journal has been able to maintain close contact with the development of the military situation as it affects engineers and takes this opportunity to describe the present situation as it sees it, and to dispel misapprehension into which the correspondent, typical of many others, has been led.

Impressions of Camp

The important extracts from the letter follow:

"Sir—I am a volunteer in training for an officer's commission, Engineer Corps, United States Army, in a Far Western camp. I am a middle-aged man, with wife and children dependent upon me; an engineer in a specialized line, with extended experience and able to handle men—qualifications pointed out by the recruiting circulars as most important for those applying for commissions. My income in civil life supported my family in comfort, but not in excessive luxury. In other words, my entering the service entailed considerable financial sacrifice. On points aside from money, I have had to leave my family, in a manner, to the tender mercies of friends and the less tender advice of relatives.

"In joining, I intended to apply for a captaincy. I found, however, that the Government, when making the examinations, had candidates agree to an appointment of next lower rank than that aimed at, if the desired rank could not be obtained. To put it frankly, it was impossible for me to support my family on the salary of a first lieutenant. I was willing to give all of my time and experience to the Government at a captain's pay, but I could not see my way clear to do it for less. Therefore, I applied for a majority, hoping to get a captaincy.

"I came into the service as a duty, and because I thought, from the circulars urging engineers to join the officers' training corps, that my experience might help. I find in the camp a number of other engineers, well known in the profession, of moderate incomes but uncommon ability, who, like myself, have sacrificed much in order to 'do their bit.'

"A few days ago, we were pleasantly surprised by having a regular-army instructor tell us that all commissions already given, and the rank applied for, meant nothing. On completion of our course of training, the Government would consider everything, and even those with reserve commissions might expect to be reduced in rank.

"Now there were some in the engineering division who were seriously affected by this news. One able engineer stated frankly that in offering his services he had applied for a commission where his income would support his family, that anything less than this was impossible; and that, if he had to take a chance of a subordinate position, it would be best for him to withdraw at once. This he has done.

No Use for the Experienced Engineer

"But to return to the main point, which is that there is no apparent use for the experienced engineer in the Army Corps of Engineers. There you have it. 'Engineer' in civil life means one thing. 'Engineer' in military life has only one similarity to it. It is spelled the same. They do not need experienced engineers in the Engineering Corps.