stratum of gravel or small stones, and when the water is rapidly drawn down in the reservoir the wet mass of clay is liable to slump and carry with it the concrete lining.

Engineers and superintendents frequently build reservoirs in earth and line the inner slopes and bottom with cement concrete before the banks have properly settled, and without first thoroughly soaking the interior walls. In a properly made bank there will be no subsidence to speak of, but to pave a reservoir without first allowing the water to remain up to high-water mark for days and even weeks, is to invite failures. The Cemetery Hill reservoir of Colorado, built in 1886 87 by the writer as engineer-in-charge, in accordance with plans and specifications prepared by chief engineer Allan, was not lined until 1890. In the spring of that year it was paved with Portland cement concrete, of which the greatest thickness did not exceed four inches. Five years later (1895) the writer examined the lining and found no failures, not even a crack. He attributes the success of this paving to the stable condition of the banks and to the water-soaked state of the interior. In the vicinity of Beaver Brook, Colorado, the farmers can get no water from wells, and they obtain their domestic supply from the irrigating canals in summer, which is run into cisterns lined with cement mortar or concrete. After many failures the writer suggested that they soak the bottom and sides of the newly excavated cisterns for weeks, then remove the water, ram gravel over the entire interior and line with cement concrete. It was found that a much thinner coating would suffice when the foundation was prepared in the manner just described.

The toughness, elasticity and imperviousness of asphalt concrete render it a suitable material for reservoir lining. It has, however, one serious defect which engineers have not yet been able successfully to overcome. A hot sun, or warm weather, will cause it to slide down the slope. In this kind of paving the thin coating of asphalt mortar which completely surrounds the paving brick renders the lining impervious and difficult to crack, while the rigidity of the brick prevents the wall from sliding upon its base. Stone rip-rap based on a thin coating of asphalt concrete can be substituted for the brick, and the entire wall well grouted with asphalt mortar.

In the New England States perhaps 85 per cent. of all the earthen dams now in existence have been built with core walls of puddled clay, masonry, or concrete. In California, the Rocky Mountain Region and as far east as Pennsylvania and New York, masonry core walls are seldom introduced.

About a year ago, the writer sent the following questions to a large number of hydraulic engineers and waterworks superintendents:

Ques. 1. If the reservoir dam is built with a centre core, state the materials used and mode of construction.

Ques. 2. Give the following dimensions of the centre core: bottom width at original surface, top width, depth of base below original surface, width of base at bottom, height over all.

Ques. 3. Does the water in your opinion percolate through the inner portion of the embankment to the centre core?

Ques. 4. Speaking generally, do you think the additional security gained by a concrete or masonry core justifies the extra expense?

The replies received to the above queries were so conflicting that it was impossible to harmonize the opinions expressed. If a classification were attempted it would be something like the following:

(1) Those who consider a masonry core wall essential.

(2) Those who consider any kind of a core wall an element of weakness and a useless expenditure of money.

(3) Those who would insert a masonry core wall as an additional safeguard in all important structures, the failure of which might endanger life or property.

(4) Those who would be guided entirely by the quality of the materials and the conditions connected with each case.

The chief advantages of a masonry core wall are:

(1) It prevents animals from burrowing holes through the embankment.

(2) It may prevent percolation.

The chief disadvantages are:

(1) The additional cost.

(2) The unequal settling of unlike materials of different density and weight.

(3) The liability of the earth in the upper part of the embankment becoming saturated and increasing the pressure on the wall much beyond the designed limit.

(4) The tendency of the wall to crack on account of the expansion and contraction due to changes of temperature, presence of water back of the wall, or on account of the unequal settling.

It has always seemed to the writer that the advantages to be gained from a masonry core wall are in no measure commensurate to the disadvantages arising from its use. A 12-inch brick wall laid in cement mortar will prevent the burrowing of animals as effectively as a concrete wall six feet in thickness. Besides, it is doubtful if there is an animal in existence which will burrow, for the sake of the pleasure to be derived from the exercise, through a well made gravel puddle. In the Western States cement concrete costs per cubic yard in place from $6 to $7, while earth suitable for earthen dams can be conveyed in wheel scrapers, puddled and rolled, for from 12 to 20 cents per cubic yard. A yard of concrete is thus equivalent to nearly 45 yards of puddled earth. The most pronounced advocate of concrete core walls will hardly dare maintain that the relative utility of equal volumes of a concrete wall and the adjacent earthen embankment is as 45 to 1.

In considering the safety of earth dams with masonry or concrete heart walls, the late James B. Francis assumed that the full hydrostatic head would be exerted against the wall, and that as the wall alone was wholly inadequate to sustain this pressure, the earth on the down stream side had to be made of sufficient weight to resist the total pressure.

Desmond Fitzgerald, in describing the high earth dams recently constructed under his supervision for the Boston Water Works, lays down a similar assumption. One embankment is 65 feet high, has an inner slope of 2 to 1, and an outer slope of 2 to 1 and 2½ to 1, a berm 6 feet wide on each side, and a concrete core wall 10 feet thick at the base and 2 feet at the top. "In considering," he says, "the stability of this kind of an embankment, we must assume that the full head of the reservoir is carried to the core wall."

The writer fails to see the benefits to be gained by this process of reasoning based on such an assumption. In the first place, hydraulic engineers are nearly unani-