DAM CONSTRUCTION

AND

Failures During the last Thirty Years.....

BY

CHAS. P. BAILLAIRGÉ
M. CAN. SOC. C. E.

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DAM CONSTRUCTION AND FAILURES DURING THE LAST THIRTY YEARS.

(By C. BAILLARGE, M. Can. Soc. C.E.)

The last accident recorded in the New York "Engineering Record," for October, 1902, page 343, under the heading "A Reservoir Break at Camden, N. J.," bears the writer out in the conclusions of a paper of his, published in the "Canadian Engineer," reproduced by the "Record," and, again, by some of the European engineering publications, on "The Instructiveness of Failure."

The Camden reservoir embankment was, it is stated, made of sandy loam, measuring 70 feet at base, 10 feet across the top, with a height of 20 feet.

The inner face was lined with some 18 to 24 inches of stiff clay, covered with one layer of common brick, set on edge, and, apparently, at one time grouted, although when failure occurred nothing remained in the joints but mud. It had been built some thirty odd years ago.

Accidents thus lead us, while looking for the cause, to discover deterioration which might otherwise have remained unnoticed for years to come, or until, as occurred at the Bouzey dam in France, by the rotting away of its binding matter, the carrying away bodily of the dam or of a portion of it, by the mere force of the weight of water moving it forward on its bed; as also, at Austin, Cal., in 1900, though not, in that case, due to the same cause of deterioration of binder.

The Camden dam, under consideration, did not, however, fail through this cause, though as just said, it might have done so hereafter, by percolation, through the stiff clay underlying the brick lining and thence through the sandy and non-retentive material of the embankment proper.

The occurrence, on this occasion, was due to the negligence or omission to close the influent pipes to the reservoir, thus allowing the water to overtop the embankment, and gradually breaching it at the top, as with the Mississippi and its confining levees on either side, the outpour of water, soon to wear it away by erosion and make unto itself a channel as it did in this case, through which the whole reservoir was emptied.

The writer's attention being thus again called to dam failures in general, he would remind all those who are now so often called on, all over the country, to construct dams for water powers for the diverse purposes of pulp mills, water works and electric and other works, of the theory advocated by him in a paper read before the Society, on "Dams and Retaining Walls"; the conclusions of the writer being, that in designing nams in general, the thickness at any point of their height should be equal to the height of water above that point, including depth of overflow.

Had there been no overflow at Austin, the dam would have stood the pressure; but the overflow was twelve feet, which would have required an extension of or addition to the thickness, of as many feet, and have required the dam at top to be at least twelve feet in thickness or equal to the height of water overtopping it.

The overflow alluded to should not have occurred and would not, had enough been known about the possibilities of the watershed, to allow for it in one or more spill-ways capable of dealing with the surplus waters, or by a system of flood gates as provided at Assouan in the new dam across the Nile, and elsewhere.

The writer will now call the attention of the Society to, and endeavor to analyze a most instructive synopsis entitled "A list of failures of American dams," from the Presidential address of W. R. Hill, M. Am. S. C. E., before the American W.W. Assn., as published at pages 290, 293 of the New York "Engineering Record," for September, 1902.

This statement covers some forty-nine cases of failure during the last thirty years or thereabouts, almost every one of which was reported at the time of occurrence in the "Record," and by Mr. Hill credited to that paper.

The first case was an earthen dam, some twenty feet high, fifty feet broad at base and twenty feet at top, at Middlefield, which, in April, 1901, was destroyed by an overflow; though, on account of its having a double core or walls or partitions in it of sheet-piling, with rip rap faces on the up and down slopes, it could not be seen how such a thing could happen.

This would have been abundant to stand the pressure due to depth of water; nor did the dam fail either by percolation through it, much less by being moved bodily forward.

It was destroyed by overflow, and it could not be well seen how the overflow had brought about the result, on account of the two walls of sheet-piling within the dam and reaching to the top of it or nearly so. The writer of this memoir satisfactorily explained, as published in the "Record," at the time, that the over-rushing water had first worn and carried away the outer or lower section of earthwork with its rip-rap.

When this was gone, the outer partition or wall of sheet-piling, only a few inches thick, being unsupported, leaned forward and broke or fell over. The outflow or scour then took hold of the fifteen feet of earthwork intervening between the fallen row of sheet-piling and that remaining; washed this away, causing the other, or inner wall, or wooden partition or bulk head, to follow the first, and finally, the upper third, or inner section of the embankment to go with the remainder.

This is quite an instructive case of failure, and, which could not have happened otherwise than by an overflow, the dam being impermeable, due to the sheet-piling or double core, it contained, and immovable on account of its weight.

In the next two cases cited by Mr. Hill, and which occurred, the first at Victor, Cal., in May, 1901, and the other at Lebanon, Ohio, in July, 1882, the dam in each case being of earthwork, without either core or protecting walls, and the heights respectively twenty-five and thirty feet, the destruction occurred by overflow or erosion; an inadequate spill-way obtaining in the first case, and no spill-way at all in the second.

Case No. 4 is one where the spill-way itself was washed out, the reservoir emptied, and the earth dam remained intact. This was at Lima, Montana, in May, 1894.

The 5th, 6th, 7th, 8th and 9th are again cases of earthen dams ; but in these five instances, the first was due to an insufficient spillway. The second had a central wall of sheet-piling. The third and fourth core walls of stone masonry. The latter had a stone core and wall of puddled clay, the better to secure its impermeability.

All these earthen embankments which would have probably withstood either percolation or displacement forward, are said to have been destroyed by flow of freshet water over crest of dam.

Case No. 10, the Hassyan dam, Pennsylvania, of February, 1890, is that of a rock filled dam of a height of one hundred and ten feet, one hundred and forty feet broad at base, and only ten feet at top, the outer slope of which was lined with heavy blocks of granite, the inner slope also lined with heavy ashlar laid dry, and this again with a wooden revetement.

Such loose structured embankments might, sooner or later, have failed by percolation, except possibly through the wooden lining, so long as undisturbed, and if driven to an impermeable foundation ; but, as it is, the above is said to have been destroyed by overflow, its twenty-six feet waste-weir being entirely inadequate.

In the foregoing cases, the damages done to adjoining or riparian property ranged from fifty thousand dollars to eight hundred thousand dollars, and the loss of human life from seven to one hundred and fifty.

The next case, or No. 11, is the ever memorable one of the Johnstown dam, across the south fork of the Conemaugh River, in May, 1889, where the persons drowned have been variously estimated at from four thousand to ten thousand, and the damages at nine million dollars.

This dam had been constructed in 1852 as a feeder for the Pennsylvania canal. It was of clayey earth, some seventy-five feet high, twenty feet wide at top, and with outer slope of one and a half to one, and inner ditto of two to one, with slight rip rap lining; its breadth of base being two hundred and seventy-two feet and a half. It contained five billion gallons of water, and hence the immense destruction and loss of life.

The grave mistake, says Mr. Hill, was made of having a depression in the crest of the dam towards the centre of its length, and again the spill-way, already too narrow in its construction, was further obstructed by a fish screen, grating or railing.

Freshet waters overtopped it, wearing it away, of course, to begin with, at the depression in the crest, until some four hundred feet of its length were washed away.

The foregoing eleven cases were, therefore, of the kind due to overflow or wearing away by erosion from the crest downward.

The next ten cases or Nos. 12 to 21, from May, 1876, to November, 1894, at the several places mentioned in detail in the "Record," and which it is not necessary here to enumerate, are all cases of earth dams, some with core walls of masonry or puddle, others with outer or inner protection walls of stone, clay, puddle, brick, stone or wood lining, in each of which cases, it is stated, leakage made its way around influent or effluent conduits of iron or steel, where it is extremely difficult to form an impermeable junction; and this can not but be a caution to engineers in general charged with like works, to see to it that all areas around pipes running through embankments be most carefully attended to, some process of roughening the surface of conduits for the purpose, either by striation or hacking with a cold chisel being necessary.

The next category of occurrences is where the foundation has proved unreliable, and has either settled under the superincumbent weight of the dam or proved pervious to water, as at the city reservoir of Ronoake, Va., in 1888, as well with the double reservoir at Knoxville, Tenn., and at Coushahochen, near Philadelphia, in 1873, where the bottom lining of clay, eighteen inches thick, broke away, was repaired, and failed again in 1876, 1879 and 1880.

In 1894 the reservoir at Portland, Oregon, lined with five to six inches thick of concrete in which were imbedded at every two feet, both ways, three-eighths inch square twisted steel rods; the concrete cracked before water was let into it and a serious leak and other cracks appeared in bottom lining.

No. 26, of 1893, was the Wilburn storage reservoir of Brooklyn, N.Y., into which were pumped forty-three and one-half million gallons of water, the whole of which leaked out in ten days, when experts recommended that the entire base of forty-four acres be repuddled.

At Philadelphia, in 1894, after the Roxbury reservoir had been in use for nearly a year, fissures occurred in the bottom, through which the water leaked out, coming to the surface one thousand two hundred feet off, and to repair which it cost one hundred and forty thousand dollars.

Now, in explanation of these fissures, Pennsylvania, not being subject to volcanic action, or the seismic workings of earthquakes, the writer suggests that the fissures brought to light had, theretofore, existed and been filled in with earthy, sandy, or clayey material, which under the superincumbent pressure or action of the water, were, within the delay mentioned, washed out, thus allowing the water to percolate through them, and crop out as it did at a distance from the site of the reservoir, and the settling of the embankment ; and the washing out of the clay from in under the brick lining can be due to nothing else than percolation of this clay by the water through said fissures to the outcrop at a distance ; showing that any such fissures should be looked for in advance by denuding the surface, cleaning out the fissures of their clayey material and filling the interstices with concrete.

Case No. 28, in October, 1894, at the Queen Lane reservoir, Philadelphia, is thus stated : When filled to ten feet deep, many leaks occurred. The bottom was lined with four inch concrete on two feet thick of puddled clay put in in layers, rolled and watered. The underlying rock was gneiss and mica, of which the upper portion was more or less disintegrated. The cost of reconstructing interior lining and foundation was two hundred and seventy-five thousand dollars.

It is probable again in this case, the writer suggests, that had the surface been thoroughly examined and all soft and spongy places picked out, of material honey-comed by worms or other burrowers or dissolved out by surface water or swollen out by the action of frost, and the voids properly filled in with concrete and rammed down, or with solid clay, before the bottom or puddle of concrete was put in and settlement thus avoided, this expense of repairing would not have had to be incurred.

The next case is that of a wooden dam, holding seventeen feet depth of water, at Tacoma, Wash., and which failed from being undermined.

No. 30 was a stone dam, forty feet high, eight feet thick at top, and twenty-five feet at bottom. This, according to the writer's views, was too thin, the thickness being five-eighths only of the height, instead of equal or nearly equal thereto, which it should have been. In January, 1869, while under construction, a freshet carried away one hundred and sixty feet of it, and scoured out a cavity twenty feet deep in the river bed. The cavity was filled with loose rock, and a timber apron, filled with concrete placed upon it. Twenty-two years afterwards, or in 1891, two hundred and fifty feet of the dam were carried away by the undermining of the loose rock under the apron.

A clay dam with no core to it, at Dallas, Texas, twenty-nine feet high, failed, it is supposed by the running away of quicksand from beneath it, which caused it to settle, emphasizing again the necessity of investigating the nature of the foundation to a solid rock or unyielding bottom.

A masonry dam at Calaveras, Cal., thirty-five feet high, was carried away in 1895, supposed to be due to undermining, as an excavation was being made along its upper face to remove a cotton tree stump of which the roots extended under the wall ; but it is just as likely, the writer thinks, that it failed, due to want of proper weight to resist the water pressure, its thickness at bottom, being only two-thirds the height and reduced, thereafter or higher up to a thickness of thirteen feet, or less than half of the remaining height.

Case 33 is the Mill River reservoir dam at Wiliamsburgh, Mass. It was of earth, six hundred feet long and forty-three feet high. It is stated to have been undermined by its core wall not extending down as it should have done to a solid and impermeable bottom.

These are all extremely instructive and interesting cases.

The next case is that of a dividing wall of a reservoir, at Little Rock, Arkansas. This wall of masonry, thirty-six feet high was but twelve and a half feet thick at base and seven feet at top, with seven million gallons of water at each side of it. Now, when the water was drawn off from one side of it for repairs or cleaning purposes, it is evident it had the same pressure to bear as a dam wall proper, and as its thickness at base was but one-third the height, it must have been evident in advance that it would give way the moment one side of the reservoir were emptied.

Following on, we have an earth dam of fifteen feet high and twenty-eight feet base, with a dry bowlder lining on down side, of which the failure is ascribed to faulty construction.

No. 36 is a dam at Vernon Heights, Oakland, Cal. It was but eight feet high, but though built of asphalt concrete, it being but two feet thick at bottom and one foot at top, it evidently could not stand the pressure at such a poor ratio of thickness to height or depth of water to be supported.

A reservoir at Scranton, Penn., failed in 1895. It was of rubble masonry with dressed granite faces and only ten feet thick, with a height of twenty. It was, however, flanked with buttresses, but these were twenty-four feet apart when they should have been but half that distance to be of any service. The wall failed for want of thickness, the base being but half the height instead of equal thereto, as it should have been according to the writer's theory in the premises.

Case 38 is one of the failure of an earthen dam built of and on porous soil. It had to go.

No. 39 is an interesting case in its bearing on the question of curved dams. This one, at North Field, Vermont, was of wood, one hundred feet long or length of arc with radius, forty feet. It was entirely built (evidently not by an engineer) of hemlock timbers, all ten feet long and twelve inches square. The logs were laid only one thick or deep, the one overlying the other to a height of not less than twenty-five feet. All the logs were butted the one against the other without any halving or dovetailing, each series of twenty-five logs in height forming a chord or face of a polygon, or, rather, of a portion of a polygon of forty feet radius.

This circular or polygonal wall of one hundred feet on the curve was lined on the inside with three inch deals, laid upright, and even these were not laid "broken-jointed," but butted the one upon the other. All the logs were treenailed the one to the other.

Had such a dam been straight, it is evident it would have immediately failed, broken down, fallen over, or burst before it was even filled to its height of twenty-five feet, while, on the contrary, due to its curvature, it is only after it was twice filled within eight days that it failed.

This may be taken to warrant the assumption that a stone dam curved in plan to proper radius, and with joints so tight as to be incapable of one stone becoming dislocated or pushed through between those adjoining it, would offer more resistance to the water pressure behind it; though, as Mr. Mansergh, the ex-president of the Institution of Civil Engineers of England, said, in his presidential address, the advantage of a curved dam could only be advocated for one of short span, with absolutely unyielding abutments ; and this, the writer made plain, he thinks, in his paper read last year before the Society, where he showed that the lock gates of a canal, if straight across the lock, would be burst open by the pressure, while they derived their strength from being thrown into a curve and thus rendered equivalent to a trussed structure.

The two next dams mentioned, are one at Kinsman Street reservoir, Cleveland, Ohio, of 1886—the other, of concrete, at Des Moines, Iowa, of 1893, both of which failed in some not satisfactorily explained way, due to ice pressure and faulty construction.

No. 42, a case of 1896, is a Montreal dam, built of stone masonry, backed with puddle and then with an earth and stone embankment, which is said to have leaked to the extent of three hundred and fifty thousand gallons per diem, due to ice pressure, near the high water line.

No. 43 is the upper stone dam, fifteen feet base and eighteen feet high, at St. Anthony's Falls, Minneapolis, Minn.; the failure of which is also ascribed to ice pressure.

The next case is that of the Wanahoy City, Pa., Water Company, said to have been built of puddled clay, and which if so built, and as it was only twenty-five feet high, with a twenty-five feet width or thickness at top and a hundred and thirty feet at base, could hardly have failed otherwise than by percolation from beneath it, though the cause of failure is given as unknown, its inner slope being paved and the outer one protected by a covering of large stones.

The following three cases are of dams of which no particulars are given as to size or how or of what material constructed, and where the probable cause of failure assigned is that of being overtopped by freshet water as with the Johnstown dam and the ten others preceeding it in this recital.

No. 46 :—Two dams of reservoir, near Ansonia, Conn., said to have been carried away in 1884, when one railway and two highway bridges were destroyed and damages done to the extent of two hundred and fifty thousand dollars. These failures were, presumably, due to insufficient weight of masonry to resist the pressure.

No 47 :—A reservoir dam across Becos River, six miles above Eddy, New Mexico, in 1893. This dam is stated to have been rock filled. Lower slope, one to one, upper slope, one and a half to one, paved with stone, and slope thence carried out in earth and extended to two to one, height forty feet. Cause of failure not assigned, but must likely have been by leakage through the thin layer of earth, paving in rear of it, and then through the rock filling behind that.

A dam not otherwise described, near head of Broad Brook, in Ellington, Conn., was carried away in 1890, the flood sweeping down the valley, destroying five dams, two railway trestles and six bridges ; damages, fifty thousand dollars.

The next case and the last cited (No. 49), is the Austin dam, across the Colorado River, near Austin, Texas. It was sixty-eight feet high, built of masonry, with cut stone facings, costing one million four hundred dollars ; some five hundred feet in length of it, out of a total length of twelve hundred and seventy-five feet, having been bodily carried down stream, due to insufficient weight or thickness to stand the pressure, when the flood overtopped it by twelve feet, as already stated.

Of course, it can not be argued in this case that there was inadequate spill-way ; for since the dam was nearly a quarter of a mile in length, and the flood rose to twelve feet above it, no adequate spill-way could have been provided to deal with such an overflow.

The only reliable provision in such a case would have consisted in foreseeing the probability of such a rise in the water, or the remotest possibility thereof, by even going back forty to sixty or one hundred years for flood statistics of the river. Such a costly structure would endure a century or more, as it would, if of a thickness or weight calculated to resist the water pressure capable of being brought against it by such an overflow. It should have been of such solid construction as that of the Eddystone lighthouse in the British Channel, where the stones are dovetailed and bolted together, to prevent it being disintegrated piece meal by overflow, toppling over on its toe, or sliding bodily forward, due to the pressure behind it.

The writer has advocated that unless dams be built either in courses normal to the apron of the structure, so that to give way, the water pressure behind the dam would have to force it up and over an inclined plane, or unless its component stones be dovetailed together, both horizontally and vertically, and bolted together and to a solid rock bottom, as just mentioned in relation to the Austin dam and Eddystone lighthouse, failure will likely occur. Where, in the course of time, the binding material or cement as at Bouzey, in France, already alluded to, may become disintegrated and reduced to its primary elements of sand and lime dust, the dam should, at any point of its height, be of a thickness equal to the depth of water above that point, and of such additional weight or thickness as may correspond to any probable or even possible overflow during freshets. He is glad to see that engineers, of their own independent bent of mind, and due to calculations founded on their own experience and that of others, and taught the philosophy thereof by so many dam failures, are now reaching this advocated standard of ratio of base of dam to height of water to be supported.

The Lachine dam is fully up to this standard of thickness.

The Chambly dam would also have reached the same standard had its weight not been so much decreased by a series of sluice gates in such close proximity to each other.

The Chaudière dam is also more than fully up to the standard required, though in this case it may be prudent, as suggested by the writer, to build within it an inclined apron of crib work to allow ice shoves in the spring to pass clear over it ; as, otherwise, the additional pressure due to a large field or body of floating ice driving along and up against the dam, might overcome not only its weight, but also its adherence by frictional resistance and jagging into the bed of the river, even though toothed or keyed into the bed rock.

Our Lorette dam, Quebec Water Works, is, in respect of solidity and durability, a model of its kind. Built by the late prudential George Baldwin, of Boston, it is as thick as it is high, even at its overflow, and this overflow has been eroding it or tending to do so since 1852, or for the last fifty years, without any other effect than the washing away of the cement mortar from between the granite components of the dam ; and the height of water overtopping the dam has often ranged up to as much as twenty inches and more, and sometimes even to a depth of thirty inches, and during all this interval of half a century, nothing more serious has happened than the disintegration and washing away of the binding mortar from between the upper or apron stones of the dam and of some of the outer face stones thereof ; and with the slightest repairs in the way of pointing, this dam may continue to do duty not only for another half a century, but almost indefinitely for all time to come.

The Quaker dam, New York, now under construction, which will be the highest and longest in the world, comes up to the required standard. If the ratio of its breadth to its height at every point is not equal to depth of water to be impounded above that point, the structure makes up for deficiency in weight by its splendid and thoroughly bound construction.

The dam by Sir Benjamin Baker, across the Nile, at Assouan, some six hundred miles above Cairo, in Egypt, also thoroughly sanctions the idea that to be on the safe side, in view of the possible destruction or disintegration hereafter of the binding material, leaving nothing but the weight of structure to resist that of impounded water, the dam should be twice the weight equivalent to any pressure of water, so that the friction of stone upon stone or the force to be exerted in overcoming such friction, being 0.5 of its weight, water being only a little less than one-half the weight of masonry, one may be on the safe side in making the dam at least twice the weight of the water impounded.

At the Quaker dam a spill-way is provided, and where a dam has only the watershed behind it of a mere island as Manhattan, there never can be such a danger of overflow as at Austin (or elsewhere), where a large portion of a continent may bring in its contingent now and then, and where the overthrow of the dam might possibly have been guarded against by such a system of flood gates as Baker has provided at Assouan, not only for irrigation purposes during drought, but to prevent the eventuality of such an overflow as that which, at Austin, carried away the very dam itself.

Enough has now been said to put engineers on their guard in relation to dam failures, forty-eight cases of which are here given as having happened in the United States alone and only during the last twenty-nine years.

Mr. Hill adds that some forty-eight other failures of dams and reservoirs are known to him, and that it is very unfortunate that the records relating to them do not contain any description of the structures, the purpose of their construction or their cause of failure.

We have, fortunately, few cases to register for Canada, that of Chambly being one in point, and one at Chicoutimi, which the writer reported on at the time (now some two years ago), was due to a leakage at base of dam and around the western extremity thereof, where the dam abutted directly against an earth embankment, while at the eastern end, it rested against solid rock.

In this case, water having, under the head pressure from within the dam, forced its way by percolation through the soft material of the cliff against which the western end of the dam reposed, the aperture was, of course, speedily worn away by erosion, to the size of a sewer, and then of a culvert, then to that of a tunnel, when the roof thereof gave way and the whole cliff, about sixty feet in height, slid gradually into the gap and was washed away to an extent of some sixty yards in breadth by nearly three hundred in length, altogether more than three hundred thousand cubic yards, which was carried into the Saguenay River, rendering its waters muddy and unfit to drink for a whole week or more after the occurrence.

This dam has now been rebuilt substantially on the lines reported at the time by the writer, that it should be, with an extension wall from its west end, reaching across the gap formed by the landslide. This wall will act as a core wall to the additional length of the dam, it being embanked on each side to form a water tight barrier with another, or guard or protection wall, at foot of the up stream slope or embankment to prevent any future washout in that direction.

As a final remark, for the benefit of those who have not read Sir Benjamin Baker's recital of how he mastered the difficulty at Assouan, of building a dam through a rapid where there were fifteen feet depth of water rushing past at a velocity of fifteen miles an hour, over the roughest rock and bouldered bottom: upon consultation with the contractors, he caused to be dumped into the river, below the site of dam, an immense quantity of the heaviest stones obtainable, many of which weighed from twenty to thirty tons or more. As some of these were moved by the rush of water, he caused to be dumped into the rapids, railway waggons with heavy irons and stones, tied and bolted to them, so as to obtain masses of fifty tons weight, which could resist the force of the stream, and then covered the whole with thousands upon thousands of sacks of sand. Having thus created over one-half of the river, at a time, a comparatively impervious barrier and raised the waters on the inside of it to the quiescent state of a lake, he could thus employ divers and lay out his foundations in a more leisurely manner, though even so, as quickly as possible, and under almost constant anxiety that some flood would occur in the interval and wash everything away.

To bring this paper down to date in its conclusions, the writer would remark that the enterprising editors of the "Canadian Engineer" have published, in their February, 1903, issue, photographs of a second failure of the Chambly Dam, but this time of a portion of it where there were no sluice gates to weaken or lighten the structure, as in the portion previously washed away.

The conclusion is therefore inevitable that the dam was not of sufficient weight, nor was its base so grooved into the underlying bedrock, to prevent it from beng pushed bodily forward.