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Discussion on Jan. 17th.

Canadian Society of Civil Engineers.

INCORPORATED 1887.

ADVANCE PROOF—(*Subject to revision*).

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MASONRY DAMS AND RETAINING WALLS IN GENERAL, CONCRETE WORKS, ETC.

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(To be read Thursday, Jan. 3rd, 1901.)

It must be admitted that "retaining walls" in Canada have had but a poor or short-lived record; unless it be argued that their durability should, in the interests of the working classes, not be too persistent. But, as an engineer, the writer can not admit this. He has been associated with the reconstruction of many of these walls, and has witnessed the failure of so many others as to be entitled to say a word on the subject.

The City of Quebec is preeminently one of retaining walls; many of its streets on the inclined or hilly frontage of the town having had to be supported on the down side to level them up to necessary grade.

These walls have almost without exception been made unduly thin and altogether too much so to withstand the then pressures against them, or the stresses liable to obtain thereafter.

The Des Carrieres Street wall of some 600 feet in extent, in rear of Dufferin Terrace, erected about 60 years ago, under Government control, stood its own for only 30 years, and was rebuilt again under Government superintendence and at Government expense, it being then an enclosure wall of the so-called Governor's Garden of the period. This second edition of the structure again gave way to the earth pressure from in rear of it, and was rebuilt or erected a third time within the last few years under the writer's term of office as City Engineer, and at the cost of the city.

The retaining wall of the old parliament site at the head of Mountain Hill has during the same period of 60 years been rebuilt not less than twice.

The same fate has overtaken the Artillery Street wall, the Dambourges Street wall; and most of those along the north side of Cote d'Abraham, and other streets, have had to be rebuilt during the writer's time, and generally after a persistence of only 10 to 20 years or less.

The splendid cut stone retaining wall along Commercial Street, Montreal, though built hardly 50 years ago, is and has been for some years back giving way, in like manner, from earth pressure in the rear; and the walls of the new Louise Docks at Quebec have already become disgracefully out of plumb and alignment from the same cause.

The impression, of course, has been in all these cases, or was at the time of construction, that the several walls mentioned, having nothing to withstand or bear up against but the pressure of so much dry earth behind them, they needed not to be of a thickness or breadth of base greater than from one-fifth to one-third their heighth, sometimes even less than this, and as low as one-seventh thereof, or about 3 ft. for a 20 ft. wall.

The fact was overlooked that the dry earth backing might become waterlogged by infiltration, and especially so where no weepers had been provided for the removal of wet and moisture; or even with weepers, if the filling in their proximity was of too retentive or impermeable a nature, or where, in the case of weepers or no weepers, there had not been interposed between the back filling and the rear face of the wall a narrow space filled with loose material of a stony consistence to allow water, when reaching the wall, to run to the bottom thereof and thus find its way out or expend itself by absorption into the underlying soil.

Yes, the writer has noticed in very many cases of such retaining walls and of those separating tenements on sloping ground, or lying back to back (the one at a higher, the other at a lower level; the ground embanked on the one or upper side to raise it to level of street on that side; excavated on the lower side) that the percolation into the embankment had absolutely waterlogged the filling, and thus caused it to press with the pressure of a liquid or fluid on the intervening wall, causing it to bulge or swell, and thus fail by disintegration, or to give way bodily.

Not that this waterlogging of the filling was of a permanent nature, nor need it be; but only of momentary duration, as it might produce a thrust forward of the wall, of only the fraction of an inch, thus enlarging its (the water's) containing space, and making room for itself to subside in, and gradually pass through the wall to the lower level, or evaporate or be absorbed by the subsoil. This waterlogging would, of course, be intermittent, and might recur again at every succeeding return of heavy rains, and the wall again be thrust forward, and each time by an additional fraction of an inch, and up to final destruction or overthrow of the stony structure.

An unmistakeable proof of this intermittent and instantaneous action of water, and of the fact of its thus acting during only a second or fraction of a second, is still to be seen along the rear face of Dufferin Terrace, Quebec, where, in an illustrated paper read before this Society in the early nineties, and published in its Transactions, it was shown by the writer that an open fissure in the cliff in rear of the terrace had, under a persistent and heavy rain of several days' duration, in September, 1889, become filled with water, when, due to the thrust from the rear, an outward portion of the cliff fell forward with the destruction of much property and the loss of some 52 lives. The crevasse alluded to, thus filled with water to a depth of over one hundred feet, exercising a hydrostatic pressure which pushed the intervening rock forward by some six inches.

Could this pressure have been continuous, the thrust of the cliff forward would also have followed suit, or been continuous, the aperture widening more and more till the whole cliff fell forward; but it was not continuous, nor could it be, for the moment the fissure became enlarged the water level fell, and the pressure ceasing, the motion forward stopped short at the same time.

In addition to this action of a fluid or waterlogged substance against a retaining wall, there is also, in this climate, the yearly action of frost, which, in expanding the back filling, as water does in freezing, also pushes a wall forward or towards the open, and though but as little as the eighth or even the sixteenth part of an inch at a time, finishes in course of years by effecting its overthrow.

It is therefore seen that all retaining walls are liable to become like unto dam walls, which have to stand the pressure of water, and that as such the same rules as to strength and thickness should apply.

Also that where ice may or might form in rear of a wall, and where this ice in forming can not spend its effort on compressible material towards the rear, as where such substance is solid rock or equivalent thereto, the whole effort is then against the wall, and, if repeated from year to year, the wall must go, as nothing can withstand or nullify the effect of ice expansion; since, as is well known, if an iron shell, a bomb, be filled with water, hermetically plugged, and then exposed to frost, the shell, however thick it may be, will burst. The only remedy, then, in such a case, the only safeguard for the retaining wall, is to so roof in or impermeably cover the surface of the back filling with asphalt or other watertight substance, that no water can get at it, or penetrate the soil in rear of the wall in a way to run the risk of any ice forming as said above.

It may also be remarked here that a Mr. Bone, engineer of the Oregonia Bridge Co., has recently patented and built at Columbus a concrete-steel retaining wall, a section of which is to be seen at page 448 of the N. Y. "Engineering Record" for November 10, 1900. The thickness of this wall at base is less than one-sixth its height, and a simple glance at the figure will show, without resorting to any calculation of strains or resistances, that, unless the back-filling be self-supporting, such a wall can not continue for any length of time to stand the pressure of any ordinary back-filling against it without it tending to bend over or give way. The stiffening ribs of the iron or steel screen behind the wall are not nearly deep enough to act as efficient buttresses. They should for this purpose reach much further into the backing. The rod tying the base of screen to the foundation can have no effect in preventing it from tilting forward. For this purpose the tie rod should have been attached to screen at say two-thirds of its height, and reached out far back to some unyielding pile or concrete anchorage.

The subject of retaining walls would not be complete without an allusion to wooden walls instead of masonry for the same purposes. The author in his time has had occasion to build and rebuild at Quebec, thousands of feet lineal of street supporting structures *et al.*, of this kind, as well along the St. Lawrence and St. Charles water frontages as along the side hills of the city. The respective lives of these walls may be taken at from 15 to 20 years average for spruce, and 25 to 30 years for pine timber; while the portions under water, and even those extending to a few feet above low water, may endure indefinitely as far as material is concerned; but these walls, even though secured by cross ties running or tailing deep into the back filling, or to a depth, for the upper ones, fully equal to height of wall or wharf, give in course of time with the earth pressure and frost from behind, and thus gradually loose their batter (generally of 1 to 1½ in 12) by about a quarter or half an inch per annum, becoming vertical, and then begin to over-plumb, and about the time they are decayed to an extent to require repairing or rebuilding, the over-plumb reaches such a figure that they are ready to topple forward—that is, their fronts or timbered facings, which become torn away from the ties that head into them, as the outer ends of these ties or portions exposed to wind, water and weather also decay, thus allowing the front timbers to be thrust forward, whilst such portions of the ties as are buried in the back filling continue to endure and can outlive the outer timbers for years thereafter.

On the rebuilding of the facings, short ties may be thus used by spiking them to the remaining portions of the old ties, and when on a slope or side hill with tendency to slip forward, it is a good and even necessary precaution to bolt and, better still, to fox-bolt the ties to the adjoining or nearest rock, or attach them to piles or suitable pickets driven deeply into the subsoil; and this precaution is none the less pertinent in dealing with stone walls, which may thus be made to endure for a longer term of years.

Of course, if the back filling is of stone, more or less stratified and piled in a way not to have a tendency to thrust forward, or if the filling is of such a clayey nature that percolations from the surface may, instead of sinking into it, run off towards the open and find their way through or between the face timbers, the wall may then endure during its natural life as regards decay without losing its plumb or perpendicularity.

These facts are coming to be appreciated, and it is satisfactory to state here that with our engineers in general (we notice it most in the works of the C. P. R., the Grand Trunk, and others of the kind where retaining walls to excavated features of these roads are visible) extra thickness now prevails, and has done for some years past, and precautionary measures are resorted to to render all such work more permanent and resisting than heretofore.

The recent giving way of a coffer dam at the Boston Navy yard is also a case in point, where the filling-in was like unto a fluid substance, and required a thickness of wall equal to that of one having water to bear up against.

These failures are the best, the most instructive lessons to an engineer when the cause of failure can be got at or made known. Nothing is to be learned from a structure of any kind which holds its own or persists, and does not give way, except that it is evidently strong enough; but it may also be too strong, ten times, a hundred times too strong, as of a column or pillar, or pier, or wall, which could bear ten times, a hundred times the weight it is called on to support. Now, the coffer dam alluded to was on sloping ground, with a consequently varying pressure of water against its sides, and the dam therefore made thicker, or the clay or puddle enclosing space between its walls wider at one point than at another, the dam being some 6 feet in breadth at its highest or shallowest portion, or inland, while increasing to not less than 36 feet at a salient angle where the depth of water rendered it pertinent to do so. The contractors were under the idea probably that the clay filling was or would be of such a nature as while watertight or impermeable, to stand its own, and be self-supporting, as would be the successive courses of masonry of a stone dam, each underlying course supporting the one above, and all those above it without crushing or giving way by spreading, like a plastic substance under a superincumbent weight. Under this idea of the non-giving nature of the clay, and of its self-supporting nature, the walls enclosing this dam were built of superimposed timbers of only 8 inches square at bottom, and thinned out to 4 inch timbers at top, and to prevent the inbursting action of the water from without these walls were braced with 8″ x 8″ timbers running horizontally across the dam from inner to outer wall thereof. The outer wall or towards the sea was moveover stayed or braced against giving outwardly, by sloped struts abutting against the bottom or ground of the foreshore, there being no danger of the structure giving on the in-shore side, where the ground was high and sufficiently resisting to prevent any tendency of bursting outwards on that side.

The horizontal ties above alluded to (some 36 feet in length) do not even seem to have been supported as they should have been against sagging at the centre, as the engineer in charge tells us that the weight of clay as dumped into the dam enclosure caused these ties to sag and break; when, under the plastic and spreading nature of the filling, the outer wall for some 50 feet of its length was thrust forward and the clay filling ran out of it towards the sea.

This example is here introduced as proof of how the most compact filling material when dumped through water and becoming intermixed therewith may reduce to a semi-fluid substance, and exert the same pressure against its retaining walls as would so much water.

This coffer dam is now being reinforced, as it should have been from the first, by a structure of solid wooden crib work built outside of it, and of proper breadth of base with stone filling to prevent the spreading of the dam walls, and thus, as the writer holds, this failure of such a dam and in such a depth of water as 30 feet must prove to be a most instructive lesson to every engineer or contractor in going over the same ground.

Let us again here repeat the maxim that there can be nothing so instructive to the architectural or engineering profession as a failure of any kind when its why or wherefore can be arrived at, and the writer takes this opportunity of suggesting to the members of the respective professions, engineers, contractors and overseers, the advisability whenever it can be done, in the case of any accident to a dam or other structure of whatever nature, of immediately or before the debris are cleared away, enquiring into the cause or causes of such accident, and of reporting them for the information of professionals in the respective lines.

STONE OR MASONRY DAMS.

The author has for years past contended, and sees no reason as yet to be of a different opinion, that stone dams should at every point of their height be at least as thick as the height or depth of water above that point, including overflow, which means, in other words, that the weight of masonry of the whole dam or above a horizontal plane at any portion of its height—stone masonry being assumed as of twice the weight of water—should be twice that of the pressure or weight of water above such level. This, of course, refers to a dam built in horizontal courses of masonry.

If the virtue or binding qualities of the cementing material could persist for all time, or for so many years as the dam were expected or called on to endure, this thickness of dam would not be advocated; but that it does not persist beyond an indefinite number of years is or was shown some few years ago by the failure of the Bouzey Dam in France, when some 232 lives were lost by the rush of water through the gap in the dam; and that it may not even persist for a single year, by the failure of the Austin Dam, so-called, or, in fact, that, as in that case, the cementing material between the courses was possessed of no adhesive quality whatever in the way of making a monolith of the whole structure.

Then, if the cement can not be relied on to bind the structure into an indestructible whole, nothing remains to stand the pressure of the water tending to push the dam forward, but the weight of the structure and its co-efficient of friction of stone on stone or masonry on masonry. This co-efficient is known to be but .5, though given as .7 to start a stone from a state of repose, which it is evidently not prudent to rely on, as shown by the accidents alluded to at Bouzey, Austin and elsewhere. Portions of each of these dams were moved bodily forwards or down stream, without being either overthrown or disintegrated. An endeavour has been made to show that the toe of the Austin Dam was undermined, but this only corroborates the writer's views, as proved by the fact that when there was no more resistance at the toe to stand the thrust, the only remaining opposition to the dam moving forward was its adhesion to its foundation, and its weight. And yet, in spite of such presumable adhesion, and in spite of its frictional resistance, it was thrust completely forward, and to a considerable distance down stream.

What other conclusions, then, can be arrived at than that it was deficient in weight and therefore in thickness to such an extent as not even to develop an amount of friction capable of causing it to hold its own, or to resist the tendency of the water to push it forward, which it much have done had its weight under a co-efficient of 0.5 been at least twice that of the impounded water, or pressure due to weight or depth of water.

The conclusion to be arrived at is, therefore, inevitable, the author takes it, that for horizontally coursed masonry, where the cementing material has ceased to be binding, and where nothing is left to resist its being thrust forward but its co-efficient of friction 0.5, its weight should be twice that of the total pressure tending to move it forward, or, in other words, it should be (taking its weight as already set forth at twice the weight of the water, or say 125 pounds to the cubic foot) of a breadth of base at bottom level of reservoir or of impounded water equal to the height or depth not only of the water so impounded, but of the upper surface of the water when over-topping the dam—by whatever number of feet so over-topping it (11 to 12 feet in the case of the failure at Austin) or with an overflow of that number of feet above the crest of dam.

The theoretical section of dam would thus be that of a triangle, or in the case of no overflow the crest of dam would be a mere edge or arris, or of a width at top equal to the height of overflow, but in practice this upper edge is thickened out for practical considerations to at least 3 or 4 feet, to allow of heavy and resisting coping stones, and as a pathway for foot passengers across the dam, while it may and generally is extended out to such a number of feet (8 to 10 feet) as will allow of a wheeled vehicle passing over it with room on one side to meet a foot passenger on the way, and this extra thickness at top is brought about by gradually curving out and up the down face of the dam in a way to give the required width at top.

A dam when intended to answer as a pathway or road from one bank of a river to the other, should, of course, be provided with a spill-way or freshet water, though, in the case of the 12 ft. depth of overflow at the Austin, no reasonable size of spill way could have been devised, no system of pipes and gates from the bottom which could have even commenced to deal with such an excess of water, and as such an eventuality may happen in years, which may not have happened for a quarter or even half a century, as at Galveston, it is better to be on the safe side and in proportioning the dam allow for a possible overflow of such a number of feet as circumstances may render possible even if not probable; since the difference in cost can thereby be only slightly enhanced, which is absolutely as nothing beside the terrible disaster of loss of life and of having to expend hundreds of thousands of dollars to rebuild a dam, and during an interval of months or even years leaving a whole town or village or a city in total darkness and without power to drive its electric cars, or to work any of its public or private machinery or industries.

The foundation of a dam should of course be dug down to a solid and impermeable substratum, and this, stepped up and down to allow of the masonry or concrete interlocking in a way that there may never arise the eventuality of such a structure sliding forwards on its base or bottom.

What precedes, as already stated, relates only to horizontally coursed masonry dams, and where material is at hand to give the dam its required weight and thickness; but when material is scarce or expensive, the want or deficiency can be made up for or compensated in either of two ways, to wit: by throwing the courses up from a horizontal position on the up dam side to an inclined one on the down side, say by tilting up the beds or courses in a way to have them normal or perpendicular, or more or less so, to the outer slope or apron of the dam. By this system a much lesser thickness of dam wall can be made to answer; the tendency of the dam to go forward being in such case resisted not only by the force or weight necessary to overcome the friction of stone on stone, or of masonry on masonry, but, in addition to that, the force required in pushing the structure forward to raise it along an inclined plane and under favorable circumstances; a dam thus constructed might possibly be made of only half or two-thirds the thickness advocated for horizontally coursed masonry.

The other mode of constructing, to avoid thickness, is or would be that of the Eddistone Lighthouse in the British Channel between France and England, that is, by dovetailing and interlocking all the component stones of the structure, and that, of course, not only horizontally, but also vertically, and the lower foundation courses thus also vertically into recesses cut purposely in the solid rock, or again, may be, by fox-bolting every course, the one to the other, and the whole to the rock foundation.

This salient feature in the erection of masonry dams is, the author is glad to notice, coming to be recognized, and his advocacy of breadth of base equal to height is taking hold of the engineering mind, as at Massachusetts, Jersey City, Denver, etc. Why! the very dam of our Quebec Impounding Reservoir at Lorette or St. Ambroise, and stretching for 200 feet in length across the river St. Charles, was built by Mr. G. Baldwin of Boston, a very safe and cautious engineer, and moreover 50 years ago, of a thickness not only equal to the height or depth of water impounded, but, and as if by intuition, to such a further thickness or breadth of base as to allow for an overflow of some 3 feet, and on more than one occasion since 1851, when the dam was put in, the overflow has quite or nearly reached this figure; though ordinary spring freshets cause the water to overtop the crest of dam by only two feet, or less, and even this does not happen every year, the normal overflow varying from an inch or two to eight or ten.

CONCRETE DAMS.

The profession has now taken to the building of dams of concrete instead of masonry. We now have in the Province of Quebec at least some five dams so constructed; one at Chambly, one at Lachine, one across the Jacques Cartier River, one across the Montmorency, and one just completed across the Chaudiere, a few miles west of Quebec, by Mr. Stearns, a nephew of the gentleman of like name whom the Society had the pleasure of listening to on the occasion of our trip to Boston at the end of January and beginning of February of the present year, the last of the nineteenth century, on his grand scheme, now under way for the Metropolitan W. W., whence some twenty-eight Massachusetts towns or boroughs within a radius of fifty miles around Boston are to be supplied. Mr. Stearns, of the Chaudiere works, is a specialist at concrete structures, having built entirely of concrete an arched bridge of some 30 feet span, and other structures. This gentleman is of opinion that concrete dams, on account of their thus monolithic nature, are, and will prove to be stronger or more resisting than dams of stone masonry, and what is of great importance, that they can be built for half the cost of dams of masonry, which would seem to be the case when it is considered that the dam across the Chaudiere river, which is 850 feet in length, 23 feet broad at base, 20 feet 3 inches high above bed of river, and thus as thick as it is high, costs but $200,000.00, with all the adjuncts of a spill-way, an enclosure of double the height for the three penstocks to draw from, each of them over 8 feet in diameter, running out and down the face of cliff as at Niagara, in a way to give a head of 110 feet at the turbines, the cost of which, and of the power house and rock excavated tail race are all included in the above sum of less than a quarter of a million of dollars, while intended, as they are, to supply Levis, St. Romuald and adjoining parishes with electric light and power plant to drive electric cars.

It has just been said that the Chaudiere dam carries out the author's theory of breadth of base equal to height or depth of water impounded, and allowing for overflow, while at Lachine and Chambly, at Jacques Cartier and Montmorency, the breadth of base is fully equal to and even in excess of depth water held back.

Referring again to the Massachusetts dam over the Nashut at Clinton, 35 miles from Boston, which is to impound 63,000 million gallons of water (the greatest reservoir in the world after that of Perigar in India, and only less in height than the great Crotan dam now under construction for the New York Water System), its length being about 1,400 feet, and height at centre 200 feet; this dam, which at first sight appears of less thickness than that advocated by the writer, is in reality found to be of such equality, when allowing for its great thickness at top, and its height, 25 feet above level of water in dam; that is, it gives the requisite weight duly to resist any tendency to thrust it forward, and, moreover, two of its features are those already alluded to, it being specified by Mr. Stearns that courses of masonry shall rise toward the downward face of the dam by one in four (1 in 4), while the contract also requires that the making of horizontal beds of masonry shall be avoided, but that on the contrary the beds shall be stepped, and that in each underlying bed there shall be stones projecting in a way to become incorporated in the next course above.

The greatest precautions have been taken in this case to guard against failure on account of the numerous and populous communities below the dam, and the important manufacturing interests centreing there—for instance, some 875 borings have been made to an average depth of 20 feet, aggregating 16,905 feet lin.—the rock has been drilled to reveal its nature or geological features, as well as its position, in 38 places, giving together a depth of 2,489 feet, one hole being as much as 286 feet deep.

The contractors, a very prudential feature, are to stop short with the blasting before they reach the actual depth at which the masonry is to be started, and the remainder of the rock thence removed by barring and wedging, so as not to disturb the underlying beds or strata in a way which, by causing them to become loose, might possibly be creative of leaks beneath the dam. The prospecting has been more thorough here than ever before in works of like nature. This drilling led to some heretofore unexpected features in the strata, such as finding beds or pockets of gravel beneath the solid rock or granite.

The same thing, however, was met with in the case of the dry dock at Levis, opposite Quebec City. Under a stratum of hard pan was found a bed of sand of considerable thickness, and such that the entrance to the dam had to be carried in, and the dam thus shortened by some 65 ft., requiring an expenditure of $118,000 for a coffer dam—all this and the curtailment due to not drilling down or boring some distance into the apparent rock bottom, which would have revealed the fact, and saved the large expenditure. This graving dock is now being lengthened from the rear end, and, in fact, now-a-days harbors are being dug, as at New York at present, to a depth of 40 feet, in view of the ocean liners of the future drawing 37½ ft. of water (the difference, of course, to allow for "swell" of ocean), while docks are being made 1,000 feet in length, preparatory to that length of vessel being obtained early during the forthcoming century, to commence on the first of January next (1901).

Another extensive dam now under construction, as mentioned in the New York "Engineering Record" of October 13th, page 349, is that for the Denver W. W. It is being built across the so-called "Goose Creek Gorge"; its height of impounded water is to be some 200 feet. This dam, it is true, is but 168 feet base, but the upper base or summit has a breadth of not less than 28 feet, increasing the base of the theoretical triangular section to 196 feet, which is close upon the depth of water to be impounded, while the additional height of dam, or up to 210 feet, more than makes up the difference in weight required to stand the thrust.

A 3,400 feet dam is also being built some 70 feet high at Boonton for the Jersey City Water Works. In writing to a New York engineering paper on this subject of dams, the author says, and the same thing may be repeated here:—"Is it not "strange that, while we are so particular in recommending "a factor of safety of from 3 to 5 in bridges and other structural "iron work, etc., and of as much as from 5 to 10 in structures "where disintegration is possible under heavy loads and the effects "of weather, wear and tear, we have been in the habit of constantly "neglecting any factor of safety at all, so to say, in the erection "of such structures as dams, where failure must and almost always "does lead to dire loss of life and property."

Nor need it be said here that Mr. Stearns has no doubt adopted the far more prudent system of not only giving the dam its proper cross section of weight equal to more than double that of the water impounded, as here advocated, but that in requiring in addition to that, that the beds be tilted, and the courses made purposely non-continuous, but stepped into altars, while introducing stones vertically binding the courses the one to the other as an additional precaution against any portion of the dam having a tendency to slip forward over the courses below, he is doing nothing more than introducing for the first time, may be, a proper factor of surety, a prudential and really essential one.

The power works above alluded to have all developed within the last five years, and so of the "St. Lawrence Power Works" at Massena, where the dam has an extent of over 700 feet. These works are remarkable as outstripping those at Niagara, where, under a head of 150 feet and turbines mounted on vertical shafts, the power developed to date, and though comparatively colossal, is but 50,000 H.P., while at Massena, instead of ten 5,000 H. P. turbines, or sets of turbines and Westinghouse generators, the number thereof is to be 15, giving 75,000 H.P. with a capacity in the canal or head race of double that figure, or 150,000 H.P. Massena, it may be said, is on the American side, and at the head of the "Long Sault" rapids, the canal or head race being some 16,200 feet in length, with 6,000,000 cubic yards of excavation, now all but completed. The fall is 50 feet, and available head 40 feet, but the supply of water much greater than that which, from the same source, has been made available at Niagara, since the whole flow of the St. Lawrence or drainage from the upper lakes runs through the Niagara river to Lake Ontario, the delivery over the falls being 18,000,000 cubic feet per minute. To utilize the available head the turbines at Massena are mounted on horizontal shafts, and deliver into a small river, the Grasse, which thus answers as a tail race for the outflow—though it still remains to be seen whether, as with the so-called drainage works at Chicago, there may not arise international difficulties incident on one nation robbing the other of so much water, which, instead of being returned to the St.

Lawrence direct, goes off on a side issue; in one case from Chicago to the Gulf of Mexico; in the other, from Massena, as already stated, to the Grasse river at a distance of 3 miles or more from the St. Lawrence, while such action may also be fruitful of local complications by flooding the Illinois on the one hand and the Grasse river on the other.

But with this question we have not here to deal, and it is only introduced as a reminder to engineers that such river diversions, and be they only partial, may give rise to suits at law, when the engineer might be taken to task for not having foreseen the thing and advised his patrons thereof.

CURVED OR BOWED DAMS.

There is another class of dams where thickness is or may be partly compensated for by bending the dam up stream into a bow on the principle of a lock-gate of a canal. Such a dam occurs at Parsons, Kansas, where a masonry dam of 100 feet reach has been made convex up stream and to a radius of 200 feet. This dam is but 10 feet high, with a base of 6 feet; but as it is 2 feet thick at top, if a line be drawn through its vertical section from its outer edge at base to its inner edge at top, and the triangle thus cut off turned up-side down, and applied, thus increasing the base by 2 feet, the base will then be within 20 per cent. of being equal to the height, and the arched feature may be taken to make up in resisting strength for the want of sufficient base to conform to the writer's theory of "base of dam equal to height or depth of water, including overflow, if any."

As to this practice of arching a dam horizontally or in plan, Mr. Mansergh, President of the Institution of Civil Engineers, England, in his presidential address of November the 6th, says:—"In 1878 I built a small dam on the River Wyre . . . about 57 feet high above the river, across a narrow gorge, where I could give the wall a curve in plan of only 100 feet radius. In such a situation the structure could obviously be made much lighter than say the Rankin type section for a long straight wall," which corroborates what I have just said of thus adding strength and resistance to a dam wall by throwing it into a bend up stream, and thus saving thickness and weight of masonry.

Mr. Mansergh also strengthens the writer's position on the unadvisability of horizontally coursed masonry in a dam, and the necessity of binding the masonry vertically, when in the same address he says, alluding to the new Crotan Dam, which is not erected as at first intended, at Quaker's Bridge, but two miles further up the valley: "I have just received some photographs of this work, which " represent the wall as being built in horizontal courses of roughly "squared stones, a method which I do not approve. What we "want in such a wall is ample weight, and good vertical binding, "and this can be secured by building in stones of from two tons to "six tons in weight, practically as they come from the quarry, "and surrounding them with smaller stones and good concrete well "rammed in so as not to leave any interstices."

He then goes on to say, alluding to dams which he is now building across the Elan River: "We are getting, in the Elan walls, "say nearly 50 per cent of solid blocks, and the whole structure "will weigh when complete 157 to 160 lbs. per cubic foot, and will "practically be monolithic."

And finally, if it be argued that the writer, in assuming stone masonry to be only of double the weight of water, while it is in reality about 20 per cent. heavier, and that he is thus going beyond his own theory of weight of dam equal to twice that of water impounded, he can only urge his theory as rendering assurance doubly sure by thus further increasing the factor of safety.

This subject of dam building is becoming one of vast importance, as all the water powers of the country are being taken hold of for power purposes, or for water works, which are also power problems whereby water may be forced up to a given level without the cost of pumping, and as no one but an engineer can cope with such problems as the harnessing of the rivers of the world to give power to mankind—the truth of the writer's motto, "The Engineer the master spirit of the age," heading an article of his which appeared in the "Canadian Engineer" of July and October last, and reproduced at page 293 of the London "Engineering Times" for September last, is indisputable—for as he truly says in his last paragraph under the above heading:

"There is, however, another and more summary way of judging "of the merits and qualifications of an engineer in comparison to "those of persons exercising other callings. It is this: Of an "engineer or almost any other man of common sense, you can "make an alderman, a mayor, a premier, a president, a king, "or a Kruger; and this at, so to say, a moment's notice; but of "none of these can you make an engineer without years of study, "practice and the keenest of observation."