ON THE EROSIVE AND ABRADING POWER OF WATER UPON THE SIDES AND THE BOTTOM OF RIVERS AND CANALS

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CLEMENS HERSCHEL

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Power of Water

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SIDES AND THE BOTTOM OF RIVERS AND CANALS.

By CLEMENS HERSCHEL,

CIVIL AND HYDRAULIC ENGINEER, OF BOSTON.

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ON THE EROSIVE AND ABRADING POWER OF WATER UPON THE SIDES AND THE BOTTOM OF RIVERS AND CANALS.

By CLEMENS HERSCHEL, Civil and Hydraulic Eng., of Boston.

The title of this paper will recall to the minds of most engineers some well known, but, as will be shown, somewhat too highly valued observations of the "Ci-devant Colonel au Corps Royal du Genie," Le Comte L. G. Nançay Dubuat, who experimented 100 years ago—more exactly, between 1780 and 1784. To some it may also recall the fervent appeals of Mr. Thos. Login, M. Inst. C. E., 1867-69, in behalf of this same and but feebly illuminated branch of engineering and hydraulic science. Compelled to consider the matter, in the course of his professional practice, the writer has drawn freely upon all the German, French, English and American authorities within his reach; and, as showing the great utility and deciding influence which such a study may have in the consideration of water-courses, a concise history of the engineering problem referred to is here given; this is no less than that of the Cape Cod ship canal, in the state of Massachusetts.[1]

The Isthmus of Cape Cod, plainly to be seen on most any map, or globe, even, that represents the United States, is in effect nothing but a huge mole, or pier—a sort of fence run out into the sea, that separates the "Bay shore" of Massachusetts, and the sea-coast of Massachusetts, New Hampshire and Maine to the north of that, from the rest of the United States. But this is not all; navigation around this obstruction is of a very hazardous kind, because of the many and concealed shoals all along the route through the sound, and also on the outside of the islands of Martha's Vineyard and Nantucket; and from the fact that there is no harbor, not even for small coasters, between the southerly and the northerly ends of the Cape; further, because the sailing directions around this cape make less than a right angle with each other, because of the rigor of the climate in the winter, on account of the

[1] See also an article by J. P. Frizell, C. E., JOURNAL OF THE FRANKLIN INSTITUTE, 1871, on the same subject.

danger of collisions in the narrow channels between the shoals and in fogs, and from other such causes.

These difficulties may be measured by their effects, which comprise wrecks and losses of life and property to a remarkable extent. Thus, from 1843 to 1859, 17 years, there were 827 wrecks, of which a record could be found: 4 steamers, 40 ships, 71 barks, 191 brigs, 492 schooners, and 29 sloops; total losses, 500, partial losses, 327; average of the total losses (compiled from the records of 108 cases), $500,000 annually; average of the partial losses, $81,750 annually; loss of life, estimated at 30 annually.[1] For the ten years succeeding, 1859 to 1869, there were lost 13 steamers, 23 ships, 32 barks, 100 brigs, 446 schooners, and 3 sloops; total, 617 wrecks; total losses, 211, partial, 406. And all this on a length of steamer line of only about 160 miles. And, of course, these losses have their effect on the rates of insurance and the freight charges by vessels that pass the Cape.

It cannot be surprising, therefore, that the project of constructing a canal across the Cape should have frequently been spoken of, and, in fact, we find that ever since 1623, only three years after the settlement of the country by the prilgrims of Plymouth, the utility of going through or over the Cape, rather than going around it, seems to have been recognized, and that a canal has been contemplated for more than 200 years. It will not be necessary to give in this place a history of all the attempts that have been made to commence the construction of such a canal by public, as well as by private, means. Suffice it to say that 8 distinct efforts of this kind have been made, the last of these having been made in 1860. And now, lest any one will have found the explanation of this remarkable state of affairs in the topography of the country through which the canal is to pass, it will be proper to state at once that this topography is of the most favorable description. There is a valley running through the Cape at its narrowest part, precisely where it joins the mainland, at the head of "Buzzard's Bay," and where the distance from bay to bay, on line of this valley, is about seven miles and a half. The bottom, or intervale, of this valley, is some 600 ft. wide at its narrowest part, and is, in maximo, about 32 ft. above the controlling mean low water of the sea. The meaning of this phrase, "controlling" mean low water, being, that low tide in one bay is at a different eleva-

[1] From the report of the Legislative Committee of 1864. Some wrecks are included which should have been omitted; others were, no doubt, omitted, of which no record had been kept.

tion from what it is at the other, and the lowest low water is naturally the "controlling" low water. The average depth of cutting, for a canal 18 ft. deep at controlling mean low water, would be only about 35 ft. The material, as shown by borings to the proper depth, and from all the other information that can be reached, is, throughout, nothing but mud, sand, gravel, and a few boulders. Two tidal creeks occupy this valley, and their head-waters nearly overlap each other. Every report that has ever been made upon this project has spoken of it in highly favorable terms, and has estimated that the enterprise would be a profitable one, viewed from a national and political-economical standpoint. Why, then, has this canal never been built? Why has it not been built since 1860-64, date of the last investigation upon the subject by the state of Massachusetts?

Of course, the answer to these questions may be variously enunciated, but a tolerably fair one to the last of the two questions may be given, though it seems almost laughable to say so, by reference to only these two sentences in the report of 1864: "We have already spoken of the locks required, in consequence of the different levels of the sea at the two extremities of the canal. The mean of the daily maximum variations in the elevations of the two basins" (occurring 4 times in the 25 hours) "is 6·5 ft." (should have been 5·23 ft.); "and such a fall in the distance of eight miles, must, we need not say, be kept under control." Further than by these words, the *question*, whether or not locks were a necessary part of the plan, was nowhere discussed, but it was *assumed*, as by the last phrase in the second sentence above quoted, that canal locks were unavoidable. But the same report takes care to say that the current to be produced in the canal will not be detrimental to navigation; it "would not exceed from three to four miles per hour; it sometimes reaches nearly three miles per hour off West Chop, where the tide-waves cross each other in eleven fathoms of water." The report quoted from is a preliminary report, made by an "advisory council," and the inference is irresistible that the only reason that the advisory council assumed the necessity of, and recommended, locks, and all the evils that these entail, was on account of the supposed destructive effects which those currents were going to have upon the sides and bed of the canal. Subsequent engineers made the same assumption, and the fears so engendered have remained alive to the present day; so that it is yet impossible to speak of the Cape Cod ship canal to any merchant or other otherwise intelligent person in Massachusetts, without hearing it answered, that owing to the necessity of locks, breakwaters, etc., the cost of such a canal would be something quite tremendous and altogether impracticable.

This leads to the consideration of what have above been referred to as the evils entailed by the plan of having locks, or a lock at either end of the canal. First, as regards an increase of cost: 1. The cost of the locks themselves, which, to accommodate, as they would have to at the present day, some 40,000 vessels per annum, would have to be built in triplicate and quadruplicate form, and, from their size, would cost large sums of money to build and to operate. 2. Since the locks at the northern end would stand upon an open seashore, on a sandy beach, they would require highly expensive works for their protection, and for the protection of vessels about to use them. It will not be necessary to enlarge upon either of these points, as they will be sufficiently appreciated by all engineers of the present day. Suffice it to say that the estimates for the two kinds of canal—the one an open cut, with jetties at the northern end to lead to deep water, the other with locks and breakwaters and jetties—compare about as 1 to 4; that is, as 2 millions of dollars to 8 millions. Secondly, comparing the two plans as to their probable income: 1. The canal is most needed in the winter, that being the most dangerous season of the year for navigation, when many coasters absolutely decline to take freights from New York, and further south, for Boston, and further north. But it is precisely then when a canal with locks would be out of service, being frozen up. On the other hand, there are good reasons, which need not now be gone into, for believing that an open cut, a "cut-off," speaking after the manner of river engineering as applied to tidal waters, would remain open all the time, especially when used by steam navigation. 2. Less detention and danger to vessels in passing through an open channel, than in passing through locks; hence greater use of the canal in the one case than in the other. 3. Less cost of haulage, or of steaming through the canal in the first case than in the second. A vessel could drift through with the tide in about three hours, and could drift either way twice every 25 hours; and naturally this drift of the current would work to the advantage of the steamer quite as much as it would to that of the sailing vessel. So that taking it altogether, it is within the mark to say that the plan with locks is simply out of question as a remunerative enterprise. Where the first would be a highly profitable investment for private capital, the other may reasonably be shunned by even a paternal form of government; and has been shunned and has rested *in terrorem* in the minds of those interested for the past fifteen to seventeen years, ever since that unfortunate dictum—"such a fall must, we need not say, be kept under control"—and its resultant plans and estimates, and report of 1864.

To complete this sketch, and before examining the hydraulic question given in the title of this paper, it will be well to give, in concise form, the heights of tide that obtain at either end of the proposed canal, as carefully determined by observations of Henry Mitchell, the present Chief of Hydrography of the U. S. Coast Survey, in 1860-62. The table below will be all that is necessary; the heights read above (+) and below (—) the mean level of the sea, which is the same at both ends of the canal. This level is called grade 52·7 in the report.

The channel or preliminary cutting for which the velocities given in the table have been computed, for several times of the tide, has its bed about 20 ft. below the mean level of the sea at the southern end, and about 22·5 ft. below it at the northern end. It is 66 ft. wide at the bottom, and has temporary side slopes of 1·25 on 1, making the water-line from 111 to 134 ft. wide. The velocities given have been computed by Hagen's formula for *large rivers and canals*, this formula having been selected on account of its great convenience in use, and simplicity, while it remains, at the same time, a very reliable formula for large rivers and canals; but those who may prefer any other formula will readily see that the present is not one of those cases where a difference of ten and of even more per cent. in the resultant answer will be of consequence. The average skipper cares very little whether he has to tow against 3·3, or 3·6 or 3·7 knots per hour for a distance of 7·5 miles. The bottom velocities are calculated from the simple rule given by Schlichting, derived from Hagen's formulæ, and exactitude in their case, within about 10, or even 25, per cent., may also be shown to be of no serious import. These formulæ are:

$$\text{Mean Velocity} = 6 \, . \sqrt{\frac{\text{Area}}{\text{Wetted perim.}}} \sqrt[6]{\frac{\text{Fall}}{\text{Length}}}, \quad \frac{\text{Mean Velocity}}{\text{Surface Velocity}} = 1 - 0{\cdot}0326 \sqrt{\text{Depth}}; \text{ and Bottom } V. = 3 \text{ Mean } V. - 2 \text{ Surface } V.$$

If this sketch has served to give a rude description of the locality and canal, during the study of which the materials for the balance of

SIMULTANEOUS TIDAL OBSERVATIONS AT TERMINI OF PROPOSED CAPE COD CANAL, AUG. 14, 15, 1860, AND COMPUTED CURRENTS THROUGH CANAL.

Hour.	Height of tide in ft. at the northerly terminus.	Height of tide in ft. at the southerly terminus.	Fall in ft. on a length of about 40,000 ft.	Direction of current.	REMARKS.	CURRENTS.			
						Mean Velocity, Feet per second.	Surface Vel.		At bot. and sides. Feet per sec.
							Feet per second.	Miles per hour.	
0	−1·2	−1·6	0·4	S.	Nearly highest spring tides.				
1	−3·2	−1·0	2·2	N.	Fall = 0 at 0 h. 10 m.				
2	−4·7	−0·6	4·1	N.	L. W. northern end, at 2 h. 25 m., when fall = 4·5.				
3	−4·5	−0·0	4·5	N.					
4	−3·7	+1·1	4·8	N.		3·7	4·3	2·9	2·5
5	−2·2	+1·55	3·75	N.	H. W. southern end.				
6	−0·45	+1·35	1·8	N.	Fall = 0 at 6 h. 50 m.				
7.	+1·2	+0·8	0·4	S.					
8	+3·0	−0·2	3·2	S.	See Note.	[4·3]	[5·0]	[3·3]	[2·7]
9	+3·7	−1·2	4·9	S.	H. W. northern end.				
10	+2·9	−2·1	5·1	S.					
11	+1·4	−2·8	3·7	S.	L. W. southern end.				
12	0·0	−1·6	1·6	S.					
13	−1·95	−1·05	0·9	N.	Fall = 0 at 12 h. 35 m.	2·5	3·0	2·0	1·7
14	−3·75	−0·4	3·35	N.		3·3	3·8	2·6	2·2
15	−4·3	+0·4	4·7	N.	L. W. northern end.				
16	−3·3	+1·6	4·9	N.		3·7	4·3	2·9	2·5
17	−1·4	+2·4	3·8	N.	H. W. southern end at 17 h. 40 m.				
18	+0·7	+2·6	1·9	N.					
19	+2·8	+1·9	0·9	S.	Fall = 0 at 18 h. 45 m.	2·8	3·3	2·2	1·8
20	+4·5	+0·5	4·0	S.		3·7	4·4	2·9	2·4
21	+5·5	−0·8	6·3	S.	H. W. northern end.	4·1	4·8	3·2	2·6
22	+4·9	−1·7	6·6	S.	Max. fall = 6·7 at 21 h. 40 m.				
23	+3·1	−2·1	5·2	S.	L. W. southern end at 23 h. 20 m.				
0	+1·3	−2·0	3·3	S					
1	−1·1	−1·8	0·7	S.	Fall = 0 at 1 h. 10 m.				

Mean fall in 25 hours = 3·43 ft. [irrespective of direction].

NOTE.—Calculated for a fall of 8 ft. and full canal—an extreme case.