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ON THE HYDRAULICS OF THE HEMLOCK LAKE CONDUIT OF THE ROCHESTER, N. Y., WATER-WORKS.

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WITH DISCUSSION.

The Rochester Water-works were made a dual system, involving a domestic supply by gravity from Hemlock Lake and a supply by direct pressure from the Genesee River, for the suppression of fires. Upon the completion of the line from Hemlock Lake to Rush Reservoir its designing engineers published its capacity under normal conditions, as 9 292 800 gallons in twenty-four hours. In the annual report of the Executive Board of the City of Rochester for the year 1876 may be found a discussion of the hydraulic questions involved, together with a theoretical demonstration, that the daily discharge of 9 292 800 gallons was in accordance with the more recent determinations as to the discharge of large conduits.

The source of the domestic water supply of the City of Rochester, Hemlock Lake, is 385.6 feet above the city datum, and distant, along the pipe line, about 29.3 miles. Mount Hope, the distributing reservoir, is about 1.4 miles from the center of the city, and the normal water surface is 124.4 feet above the city datum. When filled to its normal depth of 15 feet, Mount Hope Reservoir stores 22 500 000 gallons of water. Rush Reservoir, intended chiefly for additional storage, is distant from Mount Hope 46 064 feet (8.72 miles) along the pipe line.* The normal water surface at Rush Reservoir is 117.4 feet above the normal water surface at Mount Hope, the depth in the Rush Reservoir being, at normal elevation, 18 feet. At this depth it stores 70 000 000 gallons. From Rush Reservoir to Hemlock Lake the distance is 101 261 feet (19.2 miles) along the pipe line,† and the mean low water surface of the lake is 143.8 feet above normal water surface at Rush Reservoir, or 385.6 feet above city datum as stated in the foregoing. Leading from Hemlock Lake toward Rush Reservoir (see profile) the first 50 776 feet of the conduit is 36-inch wrought-iron pipe, this portion of the line having been laid with a total fall of 21 feet or on a grade of 0.411 per 1 000 feet. The diameter for the balance of the distance from the end of the 36-inch wrought-iron pipe to Rush Reservoir is 24 inches, the material being partly wrought-iron pipe and partly cast-iron as defined in the following: (1) From the end of the 36-inch wrought-iron pipe 1 914 linear feet of 24-inch wrought-iron pipe; (2) 30 550 lineal feet of cast-iron; (3) 13 809 linear feet of wrought-iron pipe; (4) finally, 4 212 feet of cast-iron pipe to the face of the gate-house at Rush Reservoir. Adding the length for the continuation of the pipe line to the point of discharge in the bottom of the reservoir, gives a total of 5 222 feet. From the end of the 36-inch wrought-iron pipe to Rush Reservoir the grade is continuous, and taken to the end of the pipe in the discharge well it is to normal water surface at the rate of 2.26 feet per 1 000. Between Rush and Mount Hope Reservoirs the conduit is of 24-inch cast-iron pipe, with a grade, when reckoned from normal water surface of both reservoirs, of 2.51 per 1 000 feet.

In designing this pipe line the engineers considered it desirable to make two grades, forming thereby a compound conduit. The location actually adopted, however, involved a number of cuts, in order to keep the upper section (the 36-inch) down to the assumed grade of the line located, and at the several points where these cuts occur the actual position of the conduit is shown on the profile by a heavy line. At

* This is the distance as measured from face to face of gate-houses.
† Also measured from face to face of gate-houses.

points where the natural surface of the ground is below the assumed limiting pipe grade, the upper side of the pipe is merely below the surface of the ground far enough to insure safety from freezing; but inasmuch as the profile is on an exaggerated scale, it is obviously difficult to show the actual location of the pipe in relation to the ground surface at every point. In studying the profile it is sufficient to remember that at all points other than in the cuts where the actual position of the pipe is shown, as already described, the pipe line is, generally speaking, nearly parallel to the surface of the ground and from 3 to 5 feet below it, slight variations having been made in order to ease off curves at places where the natural surface changes abruptly. The dotted line connecting the heavy portions indicating the pipe line in the cuts, may be taken as showing where the top of the pipe would be for the whole distance, provided it were laid *in train* to a continuous grade, said dotted line being of course parallel to the theoretical grade line along the center of the pipe and 1.5 feet above it for the 36-inch section. From air valve 53 to Rush Reservoir the conduit is, as indicated on the profile, 24 inches in diameter, and the approximate position of the hydraulic grade, when the conditions of delivery are such as to give the lowest possible position of the hydraulic grade, is shown by a dotted line.

Obviously the conditions which determine this position of the hydraulic grade are, that the elevation of the lake surface be such as to just run the 36-inch section full at the upper end, in which case the hydraulic conditions for the portions of the 36-inch conduit which are laid to a pipe grade in the cuts would be expressed by saying a full pipe in train; the hydraulic grade of the 36-inch, under these conditions, corresponding to the pipe grade, provided the resistance is the same throughout the whole extent of the 36-inch pipe. The approximate position of the hydraulic grade at the time of making the following described tests is shown on the profile by broken line, thus: ——— - - ——— - - ——— - - (Plate XII).

The foregoing gives rather briefly the main points in the hydraulics of this pipe line, and we may now proceed to a brief discussion of some of the recent determinations of the actual delivery of this pipe as made by the present writer during the last season. Before doing this, however, it is proper to state that when the Rochester water-works were considered finished in 1876, the population of the city was about 82 000. In 1880 it was 89 000, and in 1890 the census returns show 133 896. This considerable increase in population has naturally led to a large use of water, and for the past three seasons the storage has been so drawn upon as to render the situation at times somewhat alarming. On the 1st of May, 1890, the storage at Rush Reservoir was about 44 000 000 gallons. As warm weather came on in June this was drawn upon at the rate of from 1 000 000 to 2 000 000 gallons per day, and at this rate of decrease it could be only a very small number of days before the city would be without any storage at all.

Mr. Brush, in the discussion of a paper on the "Fresh Water Algæ," etc., which the author had the honor to read before the Society about two years ago, has vividly described the excitement prevailing in Hoboken at a time when the water supply of that city became seriously affected with bad tastes and odors. His description is quite tame in comparison with the hubbub prevailing in Rochester in 1890 at the prospect of a serious water famine in the middle of the summer. The city papers were filled with editorials and communications from citizens, and at the height of the excitement the Executive Board of the city, as being charged by law with the care and maintenance of the water-works, directed the present writer to take such measures as would, if possible, avert a water famine at that time. The language of the resolution of the Executive Board directing such measures was exceedingly strong, and under its provisions full authority was given to adopt any precautions and make any expenditures necessary to produce the desired result.

During all this time of popular discussion, everything said and written had been on the supposition that the Hemlock Lake conduit was delivering at the rate indicated by the measurement made soon after its completion in 1876, or, at the rate, under normal conditions, of about 9 292 800 gallons in twenty-four hours. It appeared to the author, however, that the proper basis of any restrictive measures would be a clear idea of the present delivery, and accordingly, his first step was in the direction of determining definitely what quantity was being delivered at that time. For this purpose four measurements were made, and as the mean of the four it was ascertained that the actual delivery, including allowance for evaporation at Rush Reservoir and other allowances, was at the rate of 6 742 000 gallons per day, taken in the discussion for even figures at 6 700 000 gallons, a quantity representing approximately the net delivery. Relative to these measurements it may be stated that the determination of the quantity of flow was obtained by observing the height to which the water rose in Rush Reservoir in a given period of time. The dimensions of the reservoir being known, the daily inflow is obtained by a simple computation. Three of the four observations, of which the mean is given as 6 742 000 gallons in twenty-four hours, were for a period of twelve hours and one for a period of twenty-four hours.

At the time of making these measurements the surface of Hemlock Lake was considerably above normal surface, while the water surface at Rush Reservoir, into which the measured delivery took place, was several feet below normal elevation, the difference due to such departure from the normal being sufficient, if the conduit were in proper hydraulic condition, to produce a delivery of about 9 700 000 gallons in twenty-four hours instead of the 6 700 000 gallons which was actually found to exist; that is to say, the delivery was about 3 000 000 short of its capacity as stated in 1876.

In October a further measurement of the discharge was made by E. Kuichling, M. Am. Soc. C. E., for a period of seven hours and the foregoing results verified; the flow at that time being, with liberal allowance for evaporation, percolation, etc., at the rate of a trifle over 7 000 000 gallons per day. The author's own measurements are believed to be accurate within limits of 2 or 3 per cent. The difference thus found to exist between the actual delivery at the present time and the delivery as stated in 1876 is so exceedingly marked that the author has concluded a brief discussion of the hydraulic questions involved, together with a short statement of some further investigation, undertaken with a view of determining why the falling off should be so great, would be of interest to the Society, and this paper is an attempt to briefly present the same for consideration and discussion. The restrictive measures designed and successfully applied will be described in another paper.

The question of actual delivery being settled, the Executive Board further directed the author to make an investigation with a view of determining the reason for the considerable loss in delivering capacity of the conduit, and for such work the numerous air valves along the line offered convenient points of attachment for the application of piezometers. Moreover, for the 36-inch section the vertical distance from the surface of the ground to the hydraulic grade line was not so great but that actual piezometer heights could be measured by setting up tubes of wrought-iron pipe and taking the elevation of the top of the piezometric column by direct instrumental observation. For the 36-inch section and that portion of the 24-inch above air-valve 48, the determinations were all made by direct observation of the height of the piezometric column as indicated, while for the balance of the line the determinations were made by the use of pressure gauges. As preliminary to the work of determining the height of the piezometric column at the various air valves along the conduit line the levels were rerun from Hemlock Lake to Rush Reservoir and new bench marks established at or near each air valve. For this work two levelers were employed, each working independent of the other. The conditions expressed in the instructions to them were that their work must agree at any given bench mark within 0.02 of a foot, or failing to agree within that limit, the work was to be rerun until this limit of accuracy was reached. The greatest variation on any bench mark is 0.015 feet, and this was secured, generally speaking, without rerunning the work. What this represents in the way of care on the part of the levelers may be inferred from the character of the ground as indicated by the profile.

In taking the heights of the columns at the air valves, the stand pipe was extended vertically upward with wrought-iron pipe of the same size, this being 2 inches in the case of one pattern of air valve and three and a half in another. After so extending the stand pipe temporarily, the valve was opened and the column of water allowed to rise to its proper piezometric height; and after waiting a few minutes the height of water surface was determined by measurement to a point previously determined instrumentally on the air valve box below. In a few cases where the piezometric height left the top of the water column below the surface of the ground, the measurement was taken from instrumentally determined points down to the water surface rather than up. The location of points where this condition occurred is shown on the profile (Plate XII). The observations as to height of piezometric column were all made by two independent observers, recorded by each in his own note-book, and compared only after the necessary numerical computations for the elevation of water surface in the tube had been made. On that portion of the line where the distance from the surface of the ground to the hydraulic grade line is too great to admit of the application of tubes, and consequently the direct measurement of the actual height of column, pressure gauges were substituted as already noted. For this purpose two gauges were attached to each air valve at the same time, and allowed to remain for half an hour. The elevations of the centers of the gauges were instrumentally determined in a manner similar to that previously described for the height of piezometric column, and likewise every measurement and reading of gauge was checked by two observers working independently.

From data so derived the following table has been constructed :

TABLE No. 1.

SHOWING LOCATION OF AIR VALVES ON THE PRESENT CONDUIT OF THE ROCHESTER WATER-WORKS, AND THE HYDRAULIC GRADES BETWEEN SAID VALVES AS ACTUALLY EXISTING IN JULY AND AUGUST, 1890.

Number of air valve.	Station.	Distance in feet.	Elevation of hydraulic grade.	Hydraulic gradient, rate per 1 000 feet.	Number of air valve.	Station.	Distance in feet.	Elevation of hydraulic grade.	Hydraulic gradient, rate per 1 000 feet.
Well-house.	0	0	387.55		56.......	486x15	1 545	365.53	0.48
91.......	91x98	9 198	383.49	0.44	55.......	489x09	294	365.33	0.67
90.......	98x21	623			54.......	497x03	794	365.08	0.31
89.......	106x12	791			53.......	508x19	1 116	364.65	0.38
88.......	114x30	818	382.75	0.33	52.......	527x20	1 901	357.37	3.83
87.......	120x06	576	382.42	0.57	51.......	536x58	938	355.18	2.33
86.......	128x20	814			50.......	545x02	844	353.35	2.17
85.......	132x98	478			49.......	562x09	1 707	349.57	2.21
84.......	139x83	685			48.......	569x46	737	347.94	2.21
83.......	150x08	1 025			47.......	591x41	2 195	343.55	1.99
82.......	161x45	1 137			46.......	610x36	1 895	338.40	2.71
81.......	165x33	388			45.......	615x14	478	337.78	1.29
80.......	171x20	587			44.......	660x38	4 524	327.35	2.30
79.......	184x15	1 295	379.48	0.46	43.......	662x35	197		
78.......	191x32	717	379.20	0.39	42.......	677x10	1 475	323.72	2.17
77.......	200x92	960	378.81	0.40	41.......	693x23	1 613	320.03	2.28
76.......	220x37	1 945	377.97	0.43	40.......	699x78	655	319.05	1.50
75.......	230x87	1 050	377.51	0.44	39.......	716x35	1 657	316.05	1.81
74.......	258x75	2 788	375.94	0.56	38.......	726x16	981	311.81	3.03
73.......	266x06	731	375.74	0.27	37.......	741x80	1 564	309.19	1.67
72.......	278x17	1 211	375.24	0.41	36.......	787x63	4 583	{300.51	1.89
71.......	281x19	302	375.13	0.38				{305 20	
70.......	292x51	1 132	374.64	0.43	35.......	828x57	4 094	298.47	1.64
69.......	313x17	2 066	373.71	0.46	34.......	849x13	2 056	292.38	2.96
68.......	323x45	1 028	373.18	0.51	33.......	856x23	710	288.18	5.91
67.......	332x52	907	372.65	0.58	32.......	867x33	1 110	284.45	3.36
66.......	343x68	1 116	372.29	0.32	31.......	870x97	364	283.10	3.71
65.......	359x78	1 610			30.......	882x40	1 143	279.58	3.08
64.......	380x38	2 060	370.88	0.38	29.......	897x91	1 551	272.91	4.30
63.......	391x08	1 070	370.39	0.47	28.......	922x37	2 446	265.69	2.95
62.......	406x26	1 518	369.65	0.48	27.......	928x42	605	263.65	3.37
61.......	422x10	1 584	369.00	0.41	26.......	948x55	2 013	256.07	3.76
60.......	428x62	652	368.36	0.98	25.......	954x54	599	254.62	2.42
59.......	441x34	1 272	367.62	0.57	24.......	984x04	2 950	245.31	3.15
58.......	463x70	2 236	366.61	0.45	23.......	1 002x67	1 863	241.79	1.89
57.......	470x70	700	366.28	0.47	Reservoir.	......	.....	236.77	

The foregoing Table No. 1, gives the elevation of the hydraulic gradient at nearly all the air valves, and the variation in the rate between the different valves. By way of classifying these variations as to the kind of material of which the pipe line is composed, Table No. 2 was constructed, showing the rate of hydraulic gradient in the wrought-iron and cast-iron sections separately. The air valves, however, are not located at the ends of the different sections, and per consequence sections of wrought-iron lap short distances into cast and *vice versa*, the amount of such lapping being determined by reference to the profile in connection with the column of remarks in Table No. 2.

In reference to these grades for short distances, it may be remarked, that by repeating the tests on different days it was observed that slight variations from the previous results were in some instances found. If, however, we consider long stretches of pipe, as has been done in Table No. 2, the error incident to the shorter distances is thereby eliminated, and we reach results which may be accepted as representing the real state of the case within a small limit of possible error.

TABLE No. 2.

Air Valve.	Station.	Distance in Feet.	Elevation of Hydraulic Grade.	Rate of Hydraulic Gradient per 1 000 Feet.	Remarks.
Well-house at Lake..	0	0	387.55	....	36-inch wrought-iron pipe.
53	508 + 19	50 819	364.65	0.45	
52	527 + 20	1 901	357.37	3.83	24-inch wrought-iron pipe.
35	828 + 57	30 137	298.47	1.95	14 lineal feet 24-inch wrought-iron pipe. 30 123 lineal feet 24-inch cast-iron pipe. 30 137 = total between valves.
24	984 + 04	15 547	245.31	3.43	427 lineal feet 24-inch cast-iron pipe. 13 809 lineal feet 24-inch wrought-iron pipe. 1 311 lineal feet 24-inch cast-iron pipe. 15 547 = total between valves.
34	849 + 13	....	292.38	....	24-inch wrought-iron pipe.
25	954 + 54	10 541	254.62	3.58	

In order to compare the results of these tests, we will assume that, for the observed discharge, the rate of hydraulic gradient in the 36-inch pipe ought not to exceed 0.3 feet per 1 000 feet, while in the 24-inch it should be 1.75 feet per 1 000, these quantities representing fairly the results of observation on clean pipes as determined by different experimenters. Making the comparison, a number of important facts are shown to exist, as for instance:

First.—That the average rate of hydraulic grade in the 36-inch pipe is 50 per cent. greater than it should be for clean pipe with the observed discharge.

Second.—That in the section of 24-inch wrought-iron pipe, between air valves 53 and 52, the rate of hydraulic gradient is 120 per cent. in excess of the normal with the observed discharge.

Third.—That in the section of 24-inch pipe, between air valves 52 and 35 (30 137 feet in length, of which 30 123 feet is cast-iron), the rate of grade is only slightly in excess of the normal.

Fourth.—That in the section from air valve 34 to 25, all 24-inch wrought-iron, the rate of grade is over 100 per cent. in excess of the normal for the observed discharge.

Fifth.—From all of the foregoing it is further concluded that the excessive resistance prevailing in this pipe-line at the present time is mostly confined to the wrought-iron section; the excess in the cast-iron being, generally speaking, only such as may be reasonably expected in pipe a long time in use.

In the absence of a thorough examination of the interior of the pipe, positive statements as to the exact cause of the trouble cannot be made, though it is not difficult with the information now at hand to form a clear idea of the location of the difficulty. An inspection of Table No. 1 shows the amount of variation in the rate of grade at different points. Occasionally the grade is substantially what it should be, as between air valves 67 and 66, where for a distance of 1 116 feet it is 0.32. At a number of places, however, the rate is much higher than the normal, and it has been positively stated that at these places work of an unsatisfactory character was done in the original construction. An inspection of the reservoir record indicates that the present flow has probably not been exceeded for several years, but the lack of completeness of the record renders it impossible to say what the changes have been. The present flow is, however, so much less than the reputed capacity of the conduit, that, in the opinion of the author, the Rochester conduit cannot be taken as proving the correctness of the modern views as to the value of C to be used in the formula $V = C\sqrt{RS}$ when pipes of large diameter and long lengths are under consideration.

NOTE.—The discussion on this paper and the next follows the latter.

PLATE XII.
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