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VOIDS, SETTLEMENT AND WEIGHT OF CRUSHED STONE

BY

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ENGINEERING EXPERIMENT STATION

BULLETIN NO. 23 MAY 1908

VOIDS, SETTLEMENT AND WEIGHT OF CRUSHED STONE

BY IRA O. BAKER, PROFESSOR OF CIVIL ENGINEERING

INTRODUCTION

Crushed stone has become an important material of construction in modern engineering work. The chief causes for this are the great increase in the use of plain and reinforced concrete, and the increased activity in macadam road construction. The advances made in these lines have been so rapid that crushed stone has suddenly changed from a minor material to one of first importance in modern engineering construction. This has been done in such a short time that the present knowledge of the properties of crushed stone is entirely inadequate; and the determination of its weight, voids, and settlement, and the variations of these have never been attempted on any adequate scale, so far as the writer has been able to ascertain. Before commencing this article a diligent search was made of engineering literature for information upon this subject. No definite information was found concerning the weight of a cubic yard of stone of different sizes (except one item as noted in Appendix I) or the amount of settlement in transit. The only other reference on the subject was the request of a correspondent in one of the leading engineering journals for information regarding the weight of crushed stone. In answer a wide range of limits was given with the explanation that as no definite values were known, the general practice was to assume some value within these limits.

The need for reliable data on these subjects is very apparent to the engineer who makes designs and estimates. Accustomed to use all other materials, both of engineering and everyday life, and to deal with standard units of weights and measures, he finds here that there are no standards at all. For instance, practically all of the quarries sell stone by the yard, but the so-called yard in one place is not always the same as the yard at some other place. In most cases a certain weight is taken as a yard; but these weights are generally arbitrary amounts that are supposed to approximate the true value, and they differ for different localities and for the different kinds and sizes of stone. Consequently, the number of yards and therefore the cost of the stone for the same piece of work would differ according to the location of the stone supply. Furthermore, this ambiguity may cause difficulties to arise between the producer, the carrier, and the consumer. The producer measures the volume loose in the car after it is loaded from the crusher. The railway then weighs the cars and computes the number of cubic yards by assuming the weight of a yard. The consumer receives the invoice from the producer, and the freight bill from the railway, and tries to check them, but generally finds they do not agree. So it is evident that this lack of standards entails possibilities of constant controversy between the shipper, the railroad, and the consumer.

Again, it is well known that the volume of crushed stone shrinks in transit; and to make accurate estimates the engineer should know the probable amount of this shrinkage. If a certain number of yards of tamped or consolidated stone are required for a pier or for a certain length of macadam road, it is necessary to know how many yards to order at the quarry so as to have the required amount in the structure. As done at present, the engineer to be on the safe side usually orders considerably more than he thinks is enough, and even then he sometimes finds he has not made allowance enough.

In order to establish a definite standard for the different sizes and varieties of crushed stone, tests should be made until sufficient data have been accumulated to determine a definite value for the weight of a cubic yard of crushed stone under various conditions, or to establish a coefficient by which either the weight of a cubic foot or a cubic yard of the solid stone, or its specific gravity, can be multiplied to give the weight per cubic yard of crushed stone. It is obvious that to make the results of the greatest value will require a very large number of observations under a variety of conditions. It is the purpose of this article to give the results of a few tests along these lines.

Of the data hereinafter referred to, the observations on Chester stone and part of those on Joliet stone were made by Mr. Albert J. Schafmayer, a senior student in Civil Engineering, during the summer of 1906, while employed by the Illinois Highway Commission in connection with constructional work. A brief summary of Mr. Shafmayer's results was published in the report of A. N. Johnson, State Highway Engineer, in the first annual report of the Illinois Highway Commission. The observations on Kankakee stone and part of those on Joliet stone were made by Mr. Benjamin L. Bowling, an employee of the Engineering Experiment Station, during the fall of 1907. None of the investigations could have been made except for the generous cooperation of the officials of the State Penitentiaries at Chester and Joliet, and of the McLaughlin-Mateer Company of Kankakee.

Some observations were taken at Chicago and at Gary, Illinois, but unavoidable conditions at these plants prevented a completion of the work, and the results obtained are too incomplete to be of any considerable value, and hence are not further referred to.

The Stone

The observations referred to in this article relate wholly to limestone, although in the appendix some data are given concerning trap. The limestones experimented with were those quarried at Chester, Joliet, and Kankakee.

The Chester stone is a rather coarsely granulated gray limestone of the lower carboniferous group, and is quarried in the grounds of the State Penitentiary at Chester, on the Mississippi River, about half way between St. Louis and Cairo.

The Joliet stone is a compact, fine-grained magnesian limestone of the Niagara series, and is quarried in the grounds of the State Penitentiary at Joliet, about 40 miles southwest of Chicago. The output of the crusher consists of 28 per cent 3-in. stone, 53 per cent 2-in., and 17 per cent ½-in.

The Kankakee stone is a coarse-grained argillaceous limestone of the Niagara group, and is quarried at Kankakee, on the Kankakee River, about 55 miles south of Chicago.

Divisions of the Subject

The subject will be considered under the following heads: I. Specific gravity; II. Absorptive power; III. Percentage of voids; IV. Settlement in transit; V. Weight per cubic yard; VI. Coefficients for determining the weight of crushed stone.

I. Specific Gravity

A knowledge of the specific gravity of a stone is useful in determining the per cent of voids in broken stone; and the easiest way to determine the weight of a cubic unit of solid stone is to find its specific gravity.

$$\text{Specific gravity} = \frac{Wa}{Wa - Ww}$$

in which Wa is the weight of a fragment weighed in air, Ww the weight of the same fragment suspended in water. If the stone is porous to any considerable extent, the weight in water should be determined so quickly that the absorption during the weighing will be inappreciable.

Samples of stone were collected from the various parts of the Joliet, the Kankakee, and the Chester quarries which were being worked to produce the broken stone considered in the later parts of this paper. The values of the specific gravity are given in Table 1.

II. Absorptive Power

A knowledge of the amount of water absorbed by a stone is useful in determining the voids by the method of pouring in water, and is also useful in correcting the weight of wet stone.

The absorption was determined by thoroughly drying a specimen, weighing it, immersing it in water for 96 hours, drying with blotting paper, and weighing. The results are given in Table 2.

III. Percentage of Voids

The per cent of voids in broken stone of different sizes has an important bearing upon the amount of cement and sand required

TABLE 1

SPECIFIC GRAVITY OF LIMESTONE

Ref. No.	Location of Quarry	Specific Gravity	Observer	Position in Quarry
1	Joliet	2.77	Schafmayer	Near Center, 4 to 6 ft. deep
2	"	2.78	"	" " " "
3	"	2.70	"	25 ft. W. of C., 4 ft. to 6 ft. deep
4	"	2.69	"	" " " "
5	"	2.72	"	" E. " "
6	"	2.74	"	" " " "
7	"	2.71	"	" N. " "
8	"	2.70	"	" " " "
9	"	2.63	"	" S. " "
	Mean	2.71		
10	Joliet	2.74	Bowling	25 ft. S. of C. of floor 30 ft. deep
11	"	2.68	"	" " " " "
12	"	2.74	"	At " " "
13	"	2.73	"	" " " "
14	"	2.69	"	25 ft. N. " " "
15	"	2.70	"	" " " " "
	Mean	2.71		
16	Chester	2.67	Schafmayer	N. end over 25 ft. deep
17	"	2.58	"	50 ft. S. of the preceding, over 25 ft. deep
18	"	2.59	"	100 " " " "
19	"	2.49	"	Center near top
20	"	2.66	"	N. end " "
21	"	2.50	"	S. " " "
22	"	2.48	"	Center " "
	Mean	2.57		
23	Kankakee	2.62	Bowling	S. end at top
24	"	2.64	"	" " " "
25	"	2.65	"	" " 20 ft. deep
26	"	2.65	"	" " " "
27	"	2.56	"	" " 40 ft. "
28	"	2.56	"	" " " "
29	"	2.60	"	N. " at floor
30	"	2.62	"	" " " "
	Mean	2.61		

in making concrete; and the per cent of voids in connection with the weight of a unit of solid stone is useful in determining the weight of a unit of volume of broken stone.

The percentage of voids may be determined in either of two ways: (1) by pouring in water; and (2) by computation from the specific gravity and the weight of a volume of broken stone.

1. *By Pouring in Water.* Determine the weight of water a given vessel will contain, then fill the vessel with broken stone, and determine the weight of water that can be poured into the

TABLE 2

ABSORPTIVE POWER OF LIMESTONE

Ref. No.	Kind of Stone	Weight in lb. per cu. ft.	Absorption		Position in Quarry
			lb. per cu. ft.	Per cent by Weight	
1	Joliet	170.66	1.23	0.72	25 ft. S. of C. of the floor, 30 ft. deep
2	"	166.98	.79	0.47	" " " "
3	"	170.85	.86	0.50	At Center " "
4	"	170.41	1.25	0.73	" " " "
5	"	167.61	1.13	0.68	25 ft. N. " "
6	"	168.60	1.28	0.76	" " " "
	Mean	169.18	1.09	0.64	
7	Kankakee	163.49	1.87	1.14	S. end at top
8	"	164.92	1.98	1.20	" " "
9	"	165.11	2.66	1.61	" " 20 ft. deep
10	"	165.30	2.81	1.70	" " " "
11	"	159.81	4.49	2.81	" " 40 ft "
12	"	159.68	4.67	2.92	" " " "
13	"	162.24	2.99	1.84	N. " at floor
14	"	163.73	2.85	1.74	" " " "
	Mean	163.04	3.04	1.84	
15	Chester	167.0	.69	.31	
16	"	165.8	1.22	.74	
17	"	164.5	1.89	1.15	
	"	165.1	1.34	.81	
18	"	161.5	2.54	1.57	
19	"	161.5	2.34	1.45	
20					
	Mean	164.2	1.67	1.01	

interstices of the broken stone. The ratio of the first amount of water to the second is the proportion of voids.

In this method three sources of error require consideration. (*a*). In pouring in the water, part of the contained air is not driven out; and therefore the resulting per cent of voids is too small. The error from this source may be reduced, if not entirely eliminated, by pouring the stone into the water; but this procedure introduces a new error, since the stone will not pack to the same degree as in the ordinary method of filling a vessel or bin with broken stone, and hence the result of pouring the stone into the water will also give too large a per cent of voids. (*b*). If the stone absorbs water during the test the apparent per cent of voids will be too great. (*c*). If the vessel has a wide mouth, as almost necessarily it should have, there will be a likelihood of considerable error in telling when the vessel is exactly full of stone and also of water. The resulting error may make the per cent of voids either too large or too small.

2. *By Computation.* Determine the weight of a known volume of broken stone. Compute the weight of an equal volume of the solid stone by multiplying the known volume by the weight of an equal volume of water and by the specific gravity of the stone. The difference between the weight of the volume of solid stone and that of the broken stone is the weight of stone equal to the volume of the voids. The ratio of this weight to the weight of the given volume of broken stone is the proportion of voids.

This method is subject to the error of determining when the vessel is exactly full of stone. In practice it is more complicated than the preceding method, but it is more exact.

Table 3 gives the per cent of voids for three sizes of Chester limestone determined by the two methods referred to above, by two independent observers for different methods of filling the vessels with broken stone; and Tables 4 and 5 the same for Joliet and Kankakee limestone, respectively. In each case the results are corrected for the absorption of the stone. Precautions were taken also to eliminate absorption by the walls of the vessel used. The distance of drop employed in filling the vessel corresponded to that employed at the time in loading cars of broken stone.

TABLE 3

PERCENTAGE OF VOIDS OF CHESTER LIMESTONE

No. of Test	Size of Stone	Method of Filling	Wt. of Stone lb.	Wt. of Stone and Water, lb.	Wt. of Water lb.	Vol. of Water cu. ft.	Per Cent of Voids	
							By Pouring in Water	From Specific Gravity
		By Use of Vessel Containing 27 cu. ft.						
1	¾-in. Scr.	15 ft. drop	2430	3150	720	11.52	42.7	43.9
2	"	"	2395	3095	700	11.20	41.5	42.4
3	"	"	2435	3140	705	11.28	41.8	43.8
						Mean	42.0	43.4
4	2 in.-¾-in.	15 ft. drop	2320	3110	790	12.64	46.8	46.4
5	"	"	2375	3165	790	12.64	46.8	45.8
						Mean	46.8	46.1
6	3 in.-2 in.	15 ft. drop	2370	3160	790	12.64	46.8	45.3
7	"	"	2390	3185	795	12.72	47.2	44.8
						Mean	47.0	45.0
		By Use of Vessel Containing 2.6 cu. ft.						
8	⅜-in. Scr.	Shoveled	226.5	293	66.5	1.06	41.0	45.8
9	"	"	227.0	293	66.0	1.06	40.6	45.7
10	"	"	216.5	283	66.5	1.06	41.0	48.9
						Mean	40.9	46.8
11	¾-in. Scr.	"	214.5	286	71.5	1.14	44.0	48.6
12	"	"	210.5	284	73.5	1.17	45.2	49.6
						Mean	44.6	49.1
13	"	20 ft. drop	229.0	293	64.0	1.025	39.4	45.2
14	2 in.-¾-in.	Shoveled	204.0	286	82.0	1.31	50.5	51.2
15	"	20 ft. drop	237.0	306	69.0	1.10	42.5	43.3
16	3 in.-2 in.	Shoveled	212.0	291	79.0	1.265	48.7	49.3
17	"	20 ft. drop	245.0	313	68.0	1.09	41.8	41.3

TABLE 4
PERCENTAGE OF VOIDS OF JOLIET LIMESTONE

No. of Test	Size of Stone	Method of Filling	Wt. of Stone lb.	Wt. of Stone and Water, lb.	Wt. of Water lb.	Vol. of Water cu. ft.	Per Cent of Voids: By Pouring in Water	Per Cent of Voids: From Specific Gravity
		By Use of Vessel Containing 2.34 cu. ft.						
1	½-in. Scr.	8 ft. drop	208.75	270.75	62.00	0.99	42.3	47.6
2	"	"	208.75	271.25	62.50	1.00	42.7	47.6
3	"	"	207.75	270.25	62.50	1.00	42.7	47.9
						Mean	42.6	47.7
4	2 in.-½-in.	8 ft. drop	218.75	285.75	67.00	1.07	45.8	45.1
5	"	"	221.75	288.50	66.75	1.07	45.6	44.3
6	"	"	218.50	285.75	67.25	1.08	45.9	45.1
7	"	"	220.00	286.75	66.75	1.07	45.6	44.8
						Mean	45.7	44.8
8	3 in.-2 in.	8 ft. drop	227.25	291.75	64.50	1.03	44.1	43.0
9	"	"	219.25	287.75	68.50	1.10	46.8	45.0
10	"	"	222.25	290.25	68.00	1.09	46.5	44.2
11	"	"	212.00	282.25	70.25	1.12	48.0	46.8
						Mean	46.3	44.7
12	½-in. Scr.	4 ft. drop	215.75	276.00	60.25	0.96	41.1	45.8
13	"	"	218.75	279.25	60.50	0.96	41.3	45.1
14	"	"	209.25	273.00	63.75	1.02	43.5	47.5
15	"	"	208.25	272.25	64.00	1.02	43.7	47.7
						Mean	42.4	46.5
16	2 in.-½-in.	4 ft. drop	203.00	277.25	74.25	1.19	50.7	49.0
17	"	"	209.75	283.25	73.50	1.15	50.2	47.4
18	"	"	209.75	282.75	73.00	1.17	49.9	47.4
19	"	"	212.25	283.75	71.50	1.14	48.8	46.7
20	"	"	213.25	284.00	70.75	1.13	48.3	46.5
						Mean	49.6	47.4
21	3 in.-2 in.	4 ft. drop	221.25	291.25	70.00	1.12	47.8	44.5
		By Use of Vessel Containing 2.43 cu. ft.						
22	3 in.-2 in.	4 ft. drop	211.25	287.75	76.50	1.22	50.4	49.0
23	"	"	216.25	289.25	73.00	1.17	48.1	47.7
24	"	"	212.75	285.75	73.00	1.17	48.1	48.6
						Mean	48.6	47.5

TABLE 5

PERCENTAGE OF VOIDS OF KANKAKEE STONE

No. of Test	Size of Stone	Method of Filling	Wt. of Stone lb.	Wt. of Stone and Water, lb.	Wt. of Water lb.	Vol. of Water cu. ft.	Per Cent of Voids	
							By Pouring in Water	From Specific Gravity
		By Use of Vessel Containing 2.11 cu. ft.						
1	⅜-in. Scr.	8 ft. drop	189.50	242.75	53.25	0.85	40.3	45.9
2	"	"	192.25	244.75	52.50	0.84	39.7	45.1
3	"	"	186.00	237.50	51.50	0.82	39.0	46.8
4	"	"	183.25	235.25	52.00	0.83	39.3	47.6
						Mean	39.5	46.4
5	1¼-in.-⅜-in.	8 ft. drop	193.50	253.50	60.00	0.96	45.4	44.7
6	"	"	197.50	258.00	60.50	0.97	45.8	43.6
						Mean	45.6	44.2
7	2¼-in.-1¼-in.	8 ft. drop	196.50	258.50	62.00	0.99	46.9	43.9
8	"	"	197.50	258.75	61.25	0.98	46.4	43.6
						Mean	46.6	43.8
9	2¼-in.-⅜-in.	8 ft. drop	202.25	260.50	58.25	0.93	44.1	42.2
10	"	"	201.50	260.50	59.00	0.94	44.6	42.4
						Mean	44.4	42.3
		By Use of Vessel Containing 1.15 cu. ft.						
11	⅜-in. Scr.	8 ft. drop	100.00	129.25	29.25	0.47	40.9	47.5
12	"	"	103.75	132.75	29.00	0.46	40.5	45.6
						Mean	40.7	46.6
13	1¼-in.-⅜-in.	8 ft. drop	104.25	137.50	33.25	0.53	46.5	45.4
14	"	"	104.50	136.75	32.25	0.52	45.1	45.2
						Mean	45.8	45.3
15	2¼-in.-⅜-in.	8 ft. drop	106.50	138.25	31.75	0.51	44.4	44.1
16	"	"	109.00	140.50	31.50	0.50	44.0	42.8
						Mean	44.2	43.5

TABLE 5 (Continued)

No. of Test	Size of Stone	Method of Filling	Wt. of Stone lb.	Wt. of Stone and Water, lb.	Wt. of Water lb.	Vol. of Water cu. ft.	Per cent of Voids	
							By Pouring in Water	From Specific Gravity
	By Use of Vessel Containing 0.694 cu. ft.							
17	$\frac{3}{8}$-in. Scr.	8 ft. drop	63.00	79.75	16.75	0.27	38.5	45.5
18	"	"	63.50	80.25	16.75	0.27	38.5	45.1
						Mean	38.5	45.3
19	$2\frac{1}{4}$-in.-$1\frac{1}{4}$-in.	8 ft. drop	65.25	85.25	20.00	0.32	45.9	43.6
20	"	"	66.50	86.25	19.75	0.31	45.4	42.5
						Mean	45.6	43.0

Precautions were taken to prevent absorption of water by the sides of the vessel; and it is believed that there is no possibility of error from this source in the data given in Tables 3, 4, and 5. In some of the experiments the vessel containing the stone was hauled from the chute to the scales on a wagon; and to eliminate a possibility of error in weighing, the team was unhitched while the weight was being taken.

Notice that the first part of Table 3 shows the percentage of voids for the different sizes of stone; while the second shows the variation due to the different methods used in filling the tub. An inspection of the table shows that with each vessel the voids increase with the size of the stone. It also shows that for both vessels the average percentages are fairly uniform, the greatest variation being in the case of the 3–in. (3–in. to 2–in.) stone. In comparing the tests in which the 15– and 20–ft. drops were used, the stone falling 20 feet invariably has a smaller percentage of voids than that falling only 15 feet. The lower part of the table shows that the voids were very materially less for the same size of stone when the tub was filled by the 20–ft. drop, than when the stone was shoveled in. These data show clearly that the density increases with the fall. However, the tests were not sufficient in number to justify an attempt to deduce a statement of the relation of the height of fall to the density of the mass.

A comparison of the results in the last two columns of Table 3 shows that for screenings the method by pouring in water gives a considerably smaller per cent of voids than by computation, while for the 2-in. (2-in. to 3/8-in.) and the 3-in. (3-in. to 2-in.) sizes there is practically no difference by the two methods. Substantially the same conclusions may be drawn from Tables 4 and 5.

Summary of Voids:—A summary of the results in Tables 3, 4 and 5 is given in Table 6.

TABLE 6

SUMMARY OF PER CENT OF VOIDS

Ref. No.	Location of Quarry	Size of Stone	Per Cent of Voids	
			By Pouring in Water	From Specific Gravity
1	Chester	3/8 in. Scr.	40.9	46.8
2	"	3/4 in. Scr.	43.0	45.6
3	"	2 in. to 3/4 in.	46.6	46.6
4	"	3 in. to 2 in.	46.1	45.1
5	Joliet	1/2 in. Scr.	42.2	47.1
6	"	2 in. to 1/2 in.	47.9	46.2
7	"	3 in. to 2 in.	47.5	46.1
8	Kankakee	3/8 in. Scr.	39.6	46.1
9	"	1¼ in. to 3/8 in.	45.7	44.7
10	"	2¼ in. to 3/8 in.	44.3	42.9
11	"	2¼ in. to 1¼ in.	46.2	43.4

IV. SETTLEMENT OF CRUSHED STONE IN TRANSIT

Sometimes crushed stone is bought by bulk, in which case it may make a difference whether the volume is measured at the beginning or at the end of the journey. Therefore experiments were made to determine the settlement of crushed stone during transit in wagons and also in railway cars.

Settlement in Wagons:—Observations were first made to determine the relation between the settlement in wagons and the distance hauled. An attempt was made to determine the amount of settlement for regular increments in the distance hauled. This was done by stopping the team and taking a measurement each successive 100 feet until the settlement for that distance was too small to measure. The measurements in all cases were taken by using two straight edges, one placed across the top of the box and the other resting on the top of the stone. Then as both straight edges were of the same width, each measurement was taken from the top of the upper one to the top of the lower one. Measurements were taken near each side and on the center line, near the front, middle, and back of the load, making a total of nine measurements for each load.

The data for Chester limestone are given in Table 7. The results vary surprisingly,—for example, compare tests No. 2 and 3, or 7 and 8, or 13 and 14. The haul was over about equal distances on macadam, cinders, and earth. The results were obtained within a day or two of each other, and it does not seem possible that the smoothness of the roads could have changed materially in the meantime. An attempt was made to drive equally carefully every time. About the only safe conclusions that can be drawn from these data are: (1) about half of the settlement occurs in the first 100 feet; and (2) the settlement at half a mile is practically the same as that at a mile.

TABLE 7

EFFECT OF DISTANCE HAULED UPON SETTLEMENT IN WAGON
Experiments on Chester Limestone by Mr. Schafmayer

Test No.*	Size of Stone	Method of Loading	Per Cent of Settlement for Hauls of— feet								
			100	200	300	400	500	600	700	2640	5280
3	¾ in. Scr.†	15 ft. drop	7.3	8.3	8.9	9.2	9.5	10.1	10.1	11.2	11.2
4	"	"	5.0	9.7	10.2	10.2	10.4	10.4	10.7	12.4	
6	2 in.–¾ in.	15 ft. drop	2.6	3.7	4.9	5.3	5.3	5.3	5.4	5.4	5.4
7	"	"	5.3	6.2	7.1	7.7	7.9	8.0	8.3	9.2	
9	"	Shoveled	3.5	4.1	4.8	5.3	5.3	5.7	6.5	7.3	
11	3 in.–2 in.	15 ft. drop	0.57	2.6	2.8	4.1	4.25	4.25	4.25	4.9	4.9
12	"	"	3.5	4.2	4.5	4.8	5.0	5.0	5.1	6.0	6.0
14	"	Shoveled	5.0	5.7	6.53	6.53	6.7	6.7	6.7	7.1	7.1

*These numbers refer to the series in Table 8.
†Dusty.

The per cent of settlement of stone from three different localities for a haul of practically one mile is given in Table 8; but the variation for any one size under identically the same conditions (for example, compare the first three lines of the table) is so great as not to warrant any attempt to draw conclusions. It was not possible to secure more accurate data except by an expenditure of time and money much greater than the value of the information seemed to justify.

Settlement in Cars:—The shortage of cars at the time these experiments were made and the desire of the shipper and also of the railway to hurry shipments forward seriously interfered with the scope and value of these

TABLE 8

SETTLEMENT OF CRUSHED STONE IN TRANSIT IN WAGONS

Test No.	Method of Loading	Orig. Vol. cu.yd.	Final Vol. cu.yd.	Per Cent of Settlement	Size of Stone	Dist. Hauled miles	Remarks
	Chester Limestone by Mr. Schafmayer						
1	15 ft. drop	1.41	1.23	12.7	⅜-in. Scr.	1	Same for ½ mile Mostly dust
2	15 ft. drop	1.41	1.25	11.4	¾-in. Scr.	1	Same for ½ mile
3	"	1.41	1.25	11.4	"	1	" " "
4	"	1.41	1.23	12.7	"	1	Stone dusty, wet
			Mean	11.8			
5	15 ft. drop	1.41	1.25	11.4	2-in.–¾ in.	1	Same for 2 miles
6	"	1.41	1.33	5.7	"	1	Same for ½ mile
7	"	1.41	1.28	9.2	"	1	
8	Shoveled	1.41	1.23	12.7	"	1	Same for ½ mile
9	"	1.41	1.31	7.1	"	1	Stone damp
			Mean	9.2			
10	15 ft. drop	1.41	1.27	10.1	3-in.–2 in.	1	A few tailings
11	"	1.41	1.34	4.9	"	1	Same for ½ mile
12	"	1.41	1.32	6.4	"	1	" " "
13	Shoveled	1.41	1.23	12.7	"	1	A few tailings
14	"	1.41	1.31	7.1	"	1	Same for ½ mile Stone dirty
			Mean	8.2			

TABLE 8 (Continued)

Test No.	Method of Loading	Orig. Vol. cu. yd.	Final Vol. cu. yd.	Per Cent of Settlement	Size of Stone	Dist. Hauled miles	Remarks
	Kankakee Limestone by Mr. Bowling						
15	*	1.80	1.61	10.6	⅜-in. Scr.	1	Chute at incline of 30°
16	*	1.61	1.46	9.3	"	1	" " "
			Mean	10.0			
17	*	1.80	1.67	7.2	1¼ in.–⅜-in.	1	" " "
18	*	1.61	1.45	9.9	"	1¾	" " "
			Mean	8.6			
	Joliet Limestone by Mr. Bowling						
19	4 ft. drop	1.81	1.66	8.3	½-in. Scr.	½	Chute at incline of 45°
20	"	1.86	1.69	9.1	"	½	" " "
21	"	1.81	1.63	9.9	"	½	" " "
			Mean	9.1			
22	4 ft. drop	1.81	1.69	6.6	2 in.–½-in.	½	" " "
23	"	1.79	1.67	6.7	2 in.–½-in.	½	" " "
			Mean	6.6			

* Lower end of chute even with top of wagon bed.

experiments. (See Table 9). It will be noticed that the settlement varies greatly for stone of the same size, loaded the same day, and shipped to the same destination on the same train,—for example, compare the second, third and fourth lines of the table. The settlement was measured by the same method as previously described for wagons, and was as carefully determined as possible by that method. Part of the error is doubtless due to a variation in the freedom with which the crushed stone ran out of the loading chute, and to a variation in the details of the method employed in leveling off the load.

TABLE 9

Settlement of Crushed Stone in Transit in Railway Cars

Test No.	Method of Loading	Original Depth of Load feet	Final Depth of Load feet	Per Cent of Settle- ment	Size of Stone	Destination	Length of Haul, miles
	Joliet Limestone by Mr. Schafmayer						
1	8 ft. drop	2.4	2.4	0.0	¾-in. Scr.	Springfield	149
2	8 ft. drop	2.4	2.2	8.3	" "	McLean	105
3	" "	2.0	1.75	12.5	" "	"	"
4	" "	2.6	2.3	8.3	" "	"	"
			Mean	9.7			
5	8 ft. drop	2.1	2.08	1.4	2 in.-¾-in.	Springfield	149
6	" "	2.2	1.9	13.9	" "	"	"
			Mean	7.6			
7	8 ft. drop	2.3	2.1	8.7	" "	McLean	105
8	" "	2.2	1.9	13.9	" "	"	"
9	" "	2.7	2.5	7.4	" "	"	"
10	" "	2.6	2.33	9.7	" "	"	"
11	" "	2.6	2.4	7.7	" "	"	"
			Mean	9.5			
12	8 ft. drop	2.6	2.5	3.8	3 in.-2 in.	Springfield	149
13	" "	2.6	2.3	10.5	" "	"	"
			Mean	7.2			
14	8 ft. drop	2.2	1.95	11.4	" "	McLean	105
15	" "	3.2	3.1	3.4	" "	"	"
16	" "	2.1	2.0	5.0	" "	"	"
17	" "	2.7	2.35	12.9	" "	"	"
18	" "	2.7	2.6	3.7	" "	"	"
19	" "	2.2	2.2	0.0	" "	"	"
20	" "	3.33	3.0	9.0	" "	"	"
21	" "	2.3	2.05	10.8	" "	"	"
22	" "	2.7	2.5	7.4	" "	"	"
23	" "	2.7	2.45	9.2	" "	"	"
24	" "	2.7	2.4	11.1	" "	"	"
25	" "	2.6	2.35	9.6	" "	"	"
26	" "	2.2	2.0	9.1	" "	"	"
			Mean	10.2			

TABLE 9 (Continued)

Test No.	Method of Loading	Original Depth of Load feet	Final Depth of Load feet	Per Cent of Settlement	Size of Stone	Destination	Length of Haul, miles
	Joliet Limestone by Mr. Bowling						
1	8 ft. drop	2.37	2.17	8.4	½-in. Scr.	Bloom'ton	91
2	" "	2.52	2.31	8.3	2 in.-½-in.	"	"
3	" "	2.80	2.62	6.4	" "	"	"
			Mean	7.4			
4	" "	2.57	2.37	7.8	3 in.-2 in.	"	"
	Chester Limestone by Mr. Schafmayer						
1	15 ft. drop	3.00	2.7	9.5	¾-in. Scr.	Springfield	180
2	" "	2.75	2.4	12.5	" "	"	"
3	" "	2.50	2.25	9.8	" "	"	"
			Mean	10.6			
4	Barrows	2.67	2.58	3.4	3 in.-2 in.	"	"
5	15 ft. drop	3.00	2.7	9.5	" "	"	"
6	Barrows	2.58	2.33	8.2	" "	"	"
			Mean	7.0			
	Kankakee Limestone by Mr. Bowling						
1	8 ft. drop	2.27	2.15	5.4	2¼ in.-⅝ in.	Bloom'ton	86

It is probable that part of the difference is due to the difference in the care employed in switching the car from the loading chute. At Joliet the cars were switched about a mile from the crusher to the yards in the city, to be weighed; and at the time they were weighed a casual examination was made of the settlement, and the conclusion was drawn that from ⅛ to ½ of the total settlement took place while the cars were being switched. The cars were continually being moved while they were in the yard, and hence more accurate observations could not be made as to the effect of switching upon the settlement. The distance from Joliet to McLean is 105 miles, and apparently a further haul of 44 miles to Springfield did not materially increase the settlement. The great variations in results obtained under seemingly like conditions make it unwise to attempt to draw any conclusions. Apparently more tests must be made before any reliable conclusion can be stated concerning the total amount of the settlement or the law of its variation.

The depth of load in Table 9 is the mean of nine separate measurements, and was computed to the nearest hundredth of a foot although it is recorded only to the nearest tenth. The more accurate values were employed in computing the per cent of settlement. However, to eliminate any possibility of error in the arithmetical work, the per cent of settlement was computed to a greater number of places than is justified by the data. A similar statement applies to several of the tables in the subsequent parts of this paper.

Summary of Data on Settlement:—A summary of the data in Tables 8 and 9 is given in Table 10.

TABLE 10
SUMMARY OF DATA ON SETTLEMENT

Ref. No.	Location of Quarry	Size of Stone	Settlement after a Haul of	
			½ mile or more in wagons	75 miles or more in cars
1	Chester	⅜-in. Scr.	12.7	....
2	"	¾- " "	11.8	10.6
3	"	2 in.–¾ in. Scr.	9.2	....
4	"	3 in.–2 in. "	8.2	7.0
5	Joliet	½ in. Scr.	9.1	8.4
6	"	¾ " "	....	9.7
7	"	2 in.–½ in. Scr.	6.6	7.4
8	"	2 in.–¾ " "	....	9.5
9	"	3 in.–2 in.	....	7.8
10	Kankakee	⅜ in. Scr.	10.0	....
11	"	1¼ in.–⅜ in. Scr.	8.6	....
12	"	2¼ in.–⅜ " "	....	5.4

V. Weight Per Cubic Yard of Crushed Limestone

Broken stone is usually sold by weight even though the unit is nominally the cubic yard, since it is the custom to determine the number of cubic yards in a shipment by weighing the shipment and dividing the total weight by the supposed weight of a cubic yard. It does not appear that any adequate observations have been made to determine the weight of a unit of volume of the different sizes and kinds of crushed stone.

Tests to determine the weight of a unit of volume of crushed limestone were made on stone from Joliet, Kankakee, and Chester, both in wagons and in cars, at the same time the record was taken of the settlement, as previously described.

Before beginning to load a car, measurements were taken from a straight edge laid on top of the car body to the floor of the car. These measurements were taken on each side of the car and at the center transversely, and at each end and the middle longitudinally. The stone was loaded into the cars by means of a chute in the bottom of the bin. After the car was loaded the upper surface was leveled off, and the depth of the stone below the top of the car body was determined by measuring down from a straight edge across the top of the car to a similar straight edge lying on the crushed stone. From the above measurement the volume of the stone was computed.

The cars were then switched to the scale track where they were weighed by a representative of the National Weighing Association, each weight being verified by either Mr. Schafmayer or Mr. Bowling. From these data the weight per cubic yard of the loose stone was computed. Measurements similar to those made at the crusher were taken when the car reached its destination; and the weights per unit of volume of the stone when compacted were computed as before.

The data and results of the observations on Joliet, Chester, and Kankakee stone are given in Tables 11, 12 and 13 respectively. For car loads, the "original weight" is after the car was switched about a mile, and the "final weight" is after being shipped 75 miles (a greater distance makes practically no difference); and for wagon loads the weights are at the loading bin and after being hauled a half mile or more.

TABLE 11

WEIGHT PER CUBIC YARD OF JOLIET LIMESTONE

Test No.	Size of Stone	Wt. of Stone, lb.	Original No. of cu. yd.	Final No. of cu. yd.	Original Wt., lb. per cu. yd.	Final Wt. lb. per cu. yd.
	Car Loads by Mr. Schafmayer					
1	¾-in. Scr.	94500	36.0	36.0	2625	2625
2	"	75500	28.9		2612	
3	"	94400	34.6	31.7	2730	2980
4	"	54700	20.9	18.2	2610	3000
5	"	96900	36.2	33.2	2680	2920
				Mean	2652	2881
6	2 in.–¾-in.	78700	30.6	30.2	2570	2600
7	"	69700	31.5	27.1	2210	2570
8	"	58500	24.8	22.7	2360	2580
9	"	54300	23.6	20.3	2300	2680
10	"	67500	31.0	29.1	2180	2320
11	"	82600	37.5	34.0	2200	2430
12	"	84400	37.5	34.8	2250	2430
				Mean	2296	2516
13	3 in.–2 in.	92400	36.6	35.2	2520	2620
14	"	52700	23.0		2290	
15	"	102300	42.0	40.6	2440	2620
16	"	78600	31.8		2470	
17	"	63050	25.2	23.6	2500	2670
18	"	66600	27.7	24.3	2380	2740
19	"	88600	38.6	37.4	2300	2370
20	"	75800	31.6	31.6	2400	2400
21	"	94800	41.4	37.7	2290	2520
22	"	69000	30.0	26.4	2300	2610
23	"	87900	38.8	36.0	2270	2440
24	"	88300	38.8	35.4	2275	2490
25	"	86900	38.8	34.8	2240	2500
26	"	72800	32.2	28.8	2260	2530
27	"	88200	36.5		2420	
28	"	91000	37.2		2426	
29	"	91300	37.5	33.9	2430	2690
30	"	76800	31.3	28.5	2450	2700
				Mean	2370	2564

TABLE 11 (Continued)

WEIGHT PER CUBIC YARD OF JOLIET LIMESTONE

Test No.	Size of Stone	Wt. of Stone, lb.	Original No. of cu. yd.	Final No. of cu. yd.	Original Wt. lb. per cu. yd.	Final Wt. lb. per cu. yd.
	Car Loads by Mr. Bowling					
31	½-in. Scr.	83800	31.52	28.85	2659	2905
32	2 in.-½-in.	82800	34.40	31.82	2407	2602
33	"	79600	33.64	30.82	2366	2583
				Mean	2386	2592
34	3 in.-2 in.	58300	26.47	24.37	2202	2392
	Wagons Loaded by Mr. Bowling					
35	½-in. Scr.	4195	1.81	1.66	2318	2527
36	"	4260	1.86	1.69	2290	2521
37	"	4165	1.81	1.63	2301	2555
				Mean	2303	2533
38	2 in.-½-in.	4185	1.81	1.69	2312	2476
39	"	4150	1.79	1.67	2318	2485
				Mean	2315	2480

It will be noticed that there is considerable variation in both the original and the final weight per cubic yard. Notwithstanding the variation it is believed that the number of observations is so great as to make the means reasonably reliable; but the table shows that the maximum error of any one observation may be as much as 10 per cent, and hence great accuracy can not be expected from a single observation. Similar results are shown for Chester stone,—see Table 12. There are three errors that affect these results: (1). Errors in determining the value of the stone at the quarry and at the destination. (2). Errors in the weight of the car as stenciled upon it. The original weight may have been de-

TABLE 12

WEIGHT PER CUBIC YARD OF CHESTER LIMESTONE

Test No.	Size of Stone	Wt. of Stone lb.	Original No. of cu. yd.	Final No. of cu. yd.	Original Wt. lb. per cu. yd.	Final Wt. lb. per cu. yd.	Remarks
	Car Load by Mr. Schafmayer						
1	¾-in. Scr.	109100	41.97	38.0	2600	2870	Damp
2	"	70600	28.14	24.6	2509	2870	
3	"	92900	36.72	33.1	2530	2810	
				Mean	2546	2850	
4	3 in.–2 in.	96500	41.60	38.2	2320	2530	Hand made
5	"	81500	32.91	31.8	2476	2560	Damp
				Mean	2398	2545	
6	3 in.–2 in.	106100	41.97	38.0	2528	2790	Wet
	Wagon Loads by Mr. Schafmayer						
7	¾-in. Scr.	3550	1.41	1.23	2518	2886	15 ft. drop
8	"	3550	1.41	1.25	2518	2840	15 ft. drop
9	"	3460	1.41	1.25	2450	2770	15 ft. drop
10	"	3420	1.41	1.23	2425	2780	15 ft. drop
11	"	2430	1.00		2430		No haul, 15 ft. drop
12	"	2395	1.00		2395		No haul, 15 ft. drop
13	"	2435	1.00		2435		No haul, 15 ft. drop
				Mean	2453	2819	
14	2 in.–¾-in.	3360	1.41	1.28	2380	2625	15 ft. drop
15	"	3250	1.41	1.23	2305	2642	Shoveled
16	"	3460	1.41	1.33	2450	2600	15 ft. drop
17	"	3200	1.41	1.31	2270	2445	Shoveled
18	"	2375	1.00		2375		No haul, 15 ft. drop
19	"	2320	1.00		2320		No haul, 15 ft. drop
20	"	3250	1.41	1.25	2305	2600	No haul, 15 ft. drop
				Mean	2444	2582	
21	3 in.–2 in.	3200	1.41	1.23	2270	2601	Shoveled
22	"	3330	1.41	1.33	2360	2505	15 ft. drop
23	"	2390	1.00		2390		No haul, 15 ft. drop
24	"	3480	1.41	1.34	2470	2595	15 ft. drop
25	"	3290	1.41	1.31	2335	2510	Part dirt, shoveled
26	"	2370	1.00		2370		No haul, 15 ft. drop
27	"	3350	1.41	1.27	2376	2638	15 ft. drop
				Mean	2367	2570	

termined when the car was wet; while in the observations under consideration the cars were dry. (3). In weighing a string of cars, either empty or loaded, there is some error due to the action of the coupler.

Table 11 shows that the weight per cubic yard of screenings is more than that of coarser stone, but also shows that 3-in. stone weighs more per cubic yard than 2-in. Similar results obtained for wagon loads, and also for Chester and Kankakee stone, both for car loads and for wagon loads—see Tables 12 and 13.

TABLE 13

WEIGHT PER CUBIC YARD OF KANKAKEE LIMESTONE

Test No.	Size of Stone	Weight of Stone, lb.	Original No. of cu. yd.	Final No. of cu. yd.	Original Wt. lb. per cu. yd.	Final Wt. lb. per cu. yd.	Remarks
		Car Load by Mr. Bowling					
1	$2\frac{1}{4}$ in.-$\frac{3}{8}$-in.	62900	27.83	26.32	2260	2390	
		Wagon Loads by Mr. Bowling					
2	$\frac{3}{8}$-in. Scr.	4085	1.80	1.61	2270	2537	
3	"	4170	1.61	1.46	2590	2856	
				Mean	2430	2697	
4	$1\frac{1}{4}$ in.–$\frac{3}{8}$ in.	3840	1.80	1.67	2133	2299	
5	"	4050	1.61	1.45	2516	2793	
				Mean	2325	2546	

Summary of Weights:—Taking an average of the preceding results for each size of stone from each quarry the summary shown in Table 14 is obtained.

TABLE 14

SUMMARY OF WEIGHTS OF CRUSHED LIMESTONE

Results in Pounds per Cubic Yard

Ref. No.	Location of Quarry	Size of Stone	Wagon Loads		Car Loads	
			Wt. at Crusher	After a Haul of ½ mile or more	Wt. at Crusher	After a Haul of 75 miles or more
1	Joliet	½-in. Scr.	2303	2533	2659	2905
2	"	¾-in. Scr.			2652	2882
3	"	2 in.–½-in.	2315	2480	2386	2592
4	"	2 in.–¾-in.			2296	2516
5	"	3 in.–2 in.			2361	2553
6	Chester	¾-in. Scr.	2442	2797	2546	2850
7	"	2 in.–¾-in.	2344	2582		
8	"	3 in.–2 in.	2367	2569	2348	2545
9	Kankakee	⅜-in. Scr.	2430	2697		
10	"	1¼ in.–⅜-in.	2325	2546		
11	"	2¼ in.–⅜-in.			2260	2390

Relations between Actual and Nominal Weight of Crushed Stone.—As is well known, it is the universal custom to load a car more than its rated capacity; and similarly it seems to be the custom of laborers when loading a car with crushed stone, to put in more than directed. This fact causes an erroneous idea of the weight of a yard of the material among the railway officers, as they weigh the car and divide the weight of the stone by the nominal number of yards to obtain the weight per cubic yard. Since the actual volume is not measured, the number of yards is taken from the bill of lading submitted by the shipper, which is approximate and is usually too small; and consequently the weight per cubic yard derived by this method is usually somewhat too great. For example, the Superintendent of the Wabash, Chester and Western Railway weighed a large number of cars of stone at Chester, and obtained by this method weights of 2600 pounds and over per cubic yard. In all his observations the number of yards was taken as given on the bills.

To determine the relation between the actual weight of crushed stone and the weight found as above, accurate measurements of ten cars being loaded at Chester were made by Mr. Schafmayer to ascertain if the high weights per cubic yard obtained by the railroad were due to overloading. The results of these tests are shown in Table 15. In every case the actual contents of the car are greater than the number of yards in the bill. The average excess is 1.71 yards for an average nominal load of 26 yards, an average excess of 6.6 per cent. This gives an apparent average weight of 2558 pounds for a yard actually weighing only 2400 pounds. It can be readily seen that under such conditions, it is not surprising that railway officials have an exaggerated idea as to the weight of a cubic yard of crushed stone.

TABLE 15

EXCESS OF ACTUAL LOADING IN CARS OVER BILLING

Ref. No.	No. of Yds. Named in Bill of Lading	Actual Number of Cu. Yd.	No. of Yds. in Excess of the Billing	Per Cent of Excess	Actual Wt., lb. per cu. yd.	Apparent Wt., lb. per cu. yd.
1	25	25.7	0.7	2.8	2420	2488
2	25	25.7	0.7	2.8	2420	2488
3	25	27.7	2.7	10.8	2420	2684
4	25	27.7	2.7	10.8	2420	2684
5	25	27.7	2.7	10.8	2420	2684
6	25	25.8	0.8	3.2	2420	2510
7	30	32.0	2.0	6.7	2420	2583
8	25	25.7	0.7	2.8	2420	2488
9	30	31.4	1.4	4.7	2420	2534
10	25	27.7	2.7	10.8	2420	2684
Av.	26	27.71	1.71	6.6	2420	2581

VI. COEFFICIENTS FOR DETERMINING WEIGHT OF CRUSHED STONE

In the introduction it was suggested that possibly coefficients could be determined by which to deduce the weight per unit of volume of crushed stone when the weight of a unit of solid stone or the specific gravity was known. Table 16 shows such coefficients for the various sizes for three kinds of stone, at the crusher and also at the destination, both in cars and in wagons. The

TABLE 16

COEFFICIENTS BY WHICH TO DETERMINE THE WEIGHT IN POUNDS PER CUBIC YARD OF CRUSHED LIMESTONE

Kind of Stone	Size of Stone	Having the Weight of a Cu. Ft. of Solid Stone			Having the Weight of a Cu. Yd. of Solid Stone			Having the Specific Gravity		
		Wt. of Solid Stone, lb. per cu. ft.	Coefficient		Wt. of solid stone, lb. per cu. yd.	Coefficient		Sp. Gr. of Stone	Coefficient	
			Car	Wagon		Car	Wagon		Car	Wagon
		Weight at Crusher								
Chester	3/4-in. Scr.	160.4	15.9	15.3	4331	0.588	0.566	2.57	990.7	954.5
Joliet	1/2-in. Scr.	169.1	15.7	13.6	4566	0.582	0.504	2.71	981.2	849.8
"	3/4-in. Scr.	169.1	15.4		4566	0.572		2.71	963.8	
Kankakee	3/8-in. Scr.	162.8		14.9	4397		0.553	2.61		931.0
Mean	1/2-in. Scr.	165.4	15.7	14.6	4465	0.581	0.541	2.65	978.6	911.8
Kankakee	1 1/4 in.-3/8 in.	162.8		14.3	4397		0.529	2.61		890.8
Chester	2 in.-3/4-in.	160.4		14.6	4331		0.541	2.57		912.1
Joliet	2 in.-1/2-in.	169.1	14.1	13.7	4566	0.523	0.507	2.71	880.4	854.2
"	2 in.-3/4-in.	169.1	13.6		4566	0.503		2.71	847.2	
Kankakee	2 1/4 in.-3/8-in.	162.8	13.9		4397	0.514		2.61	865.9	
Mean	2 in.-1/2 in.	165.4	13.9	14.2	4465	0.513	0.524	2.65	864.5	883.2
Chester	3 in.-2 in.	160.4	14.9	14.8	4331	0.554	0.546	2.57	933.1	921.0
Joliet	3 in.-2 in.	169.1	14.0		4566	0.517		2.71	871.2	
Mean	3 in.-2 in.	164.8	14.4	14.8	4448	0.536	0.546	2.64	902.2	921.0
		Weight at Destination								
Chester	3/4-in. Scr.	160.4	17.8	17.6	4331	0.658	0.651	2.57	1108.9	1096.9
Joliet	1/2-in. Scr.	169.1	17.2	15.0	4566	0.636	0.555	2.71	1072.0	934.7
"	3/4-in. Scr.	169.1	16.9		4566	0.625		2.71	1053.5	
Kankakee	3/8-in. Scr.	162.8		16.6	4397		0.613	2.61		1033.3
Mean	1/2-in. Scr.	165.4	17.3	16.6	4465	0.640	0.606	2.65	1078.1	1021.6
Kankakee	1 1/4 in.-3/8-in.	162.8		15.6	4397		0.579	2.61		975.5
Chester	2 in.-3/4-in.	160.4		16.1	4331		0.596	2.57		1004.7
Joliet	2 in.-1/2-in.	169.1	15.3	14.7	4566	0.568	0.543	2.71	956.5	915.1
"	2 in.-3/4-in.	169.1	14.9		4566	0.551		2.71	928.4	
Kankakee	2 1/4 in.-3/8-in.	162.8	14.7		4397	0.544		2.61	915.7	
Mean	2 in.-1/2-in.	165.4	15.0	15.4	4465	0.554	0.570	2.65	933.5	959.9
Chester	3 in.-2 in.	160.4	15.9	16.0	4331	0.588	0.593	2.57	990.2	1000.0
Joliet	3 in.-2 in.	169.1	15.1		4566	0.559		2.71	942.0	
Mean	3 in.-2 in.	164.8	15.5	16.0	4448	0.574	0.593	2.64	966.1	1000.0

means are stated in Table 16 in such a manner as to show the average result for each size.

Disregarding whether the stone is measured in a car or a wagon, and also disregarding whether it is measured at the crusher or at its destination, the following summary of Table 16 is obtained.

Size of Stone	Mean Coefficient by Which to Multiply the Weight of a Cubic Foot of Solid Limestone to Obtain the Weight of a Cubic Yard of the Crushed Stone
½-in. screenings	15.5
2 in. to ½ inch	14.6
3 in. to 2 inch	15.2
Average	15.1

Notice that the coefficient is largest for the finest stone, and smallest for the intermediate size. The same is true for trap (see Table 17) even though the sizes slightly differ. This seems to prove that the weight of screenings is greater than that of coarser stone, while the weight of the intermediate size is less than that of either extreme size.

Appendix I

Weight of Voids of Crushed Trap

A careful search has been made of engineering literature, and below is the only definite information discovered.

In the Journal of the Association of Engineering Societies, Volume 11 (1892), page 424, W. E. McClintock, at present Chairman of the Massachusetts Highway Commission, gives an account of six experiments made by him to determine the weight of a unit of volume of crushed trap. In the first experiment he weighed the contents of a bin holding 29⅛ cubic yards,* and found the weight of stone that had passed a ½–inch screen to be 2605 pounds per cubic yard, and in another test under the same conditions, to be 2690 pounds; and when the broken stone was wet the weight was 2480 pounds per cubic yard. In another experiment he weighed the stone in a bin holding 89.8 cubic yards, and found the weight of stone that had passed a 1½–inch screen and had been caught on a ½–inch screen to be 2423 pounds per cubic yard. In a third experiment he weighed the stone in a bin containing 89.7 cubic yards, and found the weight of the stone that had passed a 3–inch screen and had been caught on a 1½–inch screen to be 2522 pounds per cubic yard. He also measured six cars and weighed the contents, and found the weight of the last mentioned size to be 2531 pounds per cubic yard. The following statement shows the relative proportions of the several sizes of crushed trap.

Size of Stone	Per Cent
½–inch screenings	13.24
1½ inch to ½–inch	23.89
3 inch to 1½ inch	62.87
Total output of crusher	100.00

From the weight per cubic foot of solid stone given by Mr. McClintock and the above weights of the broken stone, the per cent of voids was computed. A summary of Mr. McClintock's experiments is given in Table 17, and the coefficients for trap are given in Table 18.

*Mr. McClintock privately informed the writer that the average drop of the stone into the bins was about 8 feet.

TABLE 17

WEIGHT AND VOIDS OF CRUSHED TRAP

Ref. No.	Size of Stone	Weight in lb. per cu. yd.	Per Cent of Voids, computed
1	½-in. Screenings, in bin, dry	2605	
2	" " "	2690	
	Mean	2648	46.5
3	in bin, wet	2480	
4	1½ in. to ½ in. in bin	2432	50.2
5	3 in. to 1½ in. in bin	2522	
6	in cars	2531	
	Mean	2526	48.1

TABLE 18

COEFFICIENTS BY WHICH TO DETERMINE THE WEIGHT IN POUNDS PER CUBIC YARD OF CRUSHED TRAP

Ref. No.	Size of Stone	Having the Weight of a Cubic Foot of Solid Stone		Having the Weight of a Cubic Yard of Solid Stone		Having the Specific Gravity	
		Wt. of Sol. Stone lb. per cu. yd.	Coefficient	Wt. of Sol. Stone lb. per cu. yd.	Coefficient	Specific Gravity	Coefficient
1	½-in. screenings	180.7	14.6	4879	0.541	2.90	914.4
2	1½ in.–½ in.	180.7	13.5	4879	0.500	2.90	839.7
3	3 in.–1½ in.	180.7	13.9	4879	0.515	2.90	872.2
	Mean	....	13.7	....	0.519	....	875.4

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