LUNDGREN

Comparative Strength of Gravel and Broken-Stone Concretes

Civil Engineering
B. S.

1902

COMPARATIVE STRENGTH OF GRAVEL AND BROKEN-STONE CONCRETES

BY

CARL LEONARD LUNDGREN

THESIS FOR DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
PRESENTED JUNE 1902

UNIVERSITY OF ILLINOIS

May 30 1902

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Carl Leonard Lundgren

ENTITLED Comparative Strength of Gravel and Broken-Stone Concrete

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering

Ira O Baker

HEAD OF DEPARTMENT OF Civil Engineering

GRAVEL vs. BROKEN STONE CONCRETE.

The object of this thesis is to determine the relative merits of gravel and broken stone as an aggregate for concrete. The question has been before the engineering public for some time, and has been discussed vigorously by some of the most capable engineers; but a conclusion satisfactory to all has not yet been reached. The question arose with the adoption of concrete as a substitute for masonry, and interest in experiments made along this line has been increasing in proportion to the demand for concrete in engineering structures. Every engineer may be sure that he will be called upon at one time or another, to put in masonry of some sort; and if it should be concrete, as it is quite likely to be, he should know whether gravel or broken stone -- the two materials most commonly used for concrete -- makes the better aggregate for concrete. The chief bone of contention lies in the relative strength of the concrete when these two materials are used as the aggregate.

The writer, therefore, undertook a series of experiments to determine the relative crushing strength of concrete made with gravel and that made with broken stone. The experiments consisted in making a series of six-inch cubes using crushed limestone in one case, and gravel in the other, as the aggregate.

Time was not available for testing cubes made of more than one kind of cement; and, therefore, it was considered whether

natural or Portland cement should be employed, but it was decided to use the latter, since it is usually more uniform in quality and since the recent decrease in price has made it much more common than previously. However, the kind of cement would make no practical difference, as the conclusion reached would remain relatively the same whichever cement was used.

The cement employed was Hilton's English Portland, having a tensile strength of 450 pounds per square inch, and a fineness as shown in the table following. The top row of figures denote the number of meshes per square inch; the middle row the weight in grams which was caught upon the sieve, except the last quantity, which denotes the quantity that passed the No. 200 sieve; and the bottom row shows the preceding quantities in percents.

#50	#74	#100	#200	#200
5.5	120.2	56.4	165	638.5
0.5	12.0	5.6	16.5	65.3

The sand was taken from a bank north of Urbana, Illinois, and had been in a perfectly dry place for six months previous to the time of its use in this experiment. It was sharp and clean, a small quantity rubbed between the hands leaving them unsoiled. It was screened through a sieve having forty-two meshes to the square inch, before being used.

The gravel was also taken from a pit in Urbana, Illinois, and was stored in a perfectly dry place until it was used. Seventy-five percent, by weight, of the gravel passed through a sieve having holes one inch in diameter and was caught upon a sieve having holes

one-half inch in diameter, and the remaining twenty-five percent passed a sieve with holes 2 inches in diameter and was caught upon a sieve with holes 1-inch in diameter. It was washed free from all dirt and sand and was allowed to dry before being used.

The crushed stone was limestone from Kankakee, Illinois. It was screened the same as the gravel and the same quantity of each size was used. It was perfectly dry and free from all foreign material.

The proportions of the concrete were adjusted so that the voids of the sand were filled with cement and the voids of the aggregate with cement mortar.

The voids in the gravel and the broken stone were determined as follows:- After a quantity of gravel had been weighed, a large pail was partially filled with water and the gravel poured into it. Finally a known weight of water was added until it just covered the gravel. It is not sufficient to pour the water on the gravel, since the air contained in the latter can not escape freely, and hence will vitiate the result. The weight of the gravel and pail is known, so the weight of the water required to fill the voids is determined. The weight of one cubic centimeter of water equals one gram, so the number of grams of water used equals the number of cubic centimeters of sand required to fill the voids. Therefore, the volume of sand required to fill the voids is equal to the volume of the water so required, or the weight of sand is equal to the weight of water in grams multiplied by the weight in grams of a cubic centimeter.

The amount of sand by weight required to fill the voids in the broken stone was determined in the same manner as above, as also the amount of cement to fill the voids of the sand. The figures below show the quantity of sand to fill the voids in a certain number of grams of the aggregate, also the number of grams of cement to fill the voids in the sand used to fill the voids of the aggregate. The ratio of these weights gives the ratio of the ingredients of the concrete.

Determination of ratio of ingredients in broken stone concrete.

Weight of broken stone = 21,000 grams; Weight of water to fill voids in stone = 5,123 grams; and 1 cubic centimeter of sand weighs 1.493 grams. 5123 x 1.493 = 7647 grams which = the weight of the sand required to fill the voids in 21,000 grams of broken stone. Weight of water required to fill the voids in 7647 grams of sand = 2522 grams; 1 c.c. of cement weighs 1.19 grams; and 2522 x 1.19 = 3001 grams, the weight of the cement required to fill the voids in 7647 grams of sand. Ratio of ingredients = 3001, cement:7647, sand: 21,000, gravel: or 1, cement : 2 1/2 sand: 7, gravel.

Determination of ratio of ingredients in gravel concrete. Weight of gravel = 19,500 grams; Weight of water required to fill the voids in 19,500 grams of gravel = 5073 grams; and 5073 x 1.493 grams = 7574 grams, which = the total weight of sand required to fill the voids in 19,500 grams of gravel. Ratio of ingredients = 3000, cement: 7574, sand: 19500, gravel = 1, cement: 2 1/2, sand: 6 1/2 gravel.

The amount of water to be used in mixing the cement and sand was determined by making a few mixtures and deciding according to the writer's own judgment.

The cubes were made as follows:- After the gravel, stone, cement and sand had been measured out in their proper proportions, the sand and cement were carefully mixed upon a slate table until a uniform color was obtained. The water was then added and the whole mixed thoroughly. The aggregate -- gravel or broken stone -- was sprinkled with water, so it would absorb no water from the matrix, and was then mixed with the mortar. All lumps of mortar were crushed as the mixing proceeded. The concrete was then ready for the moulds.

The moulds were made of 1 1/2 inch material planed smooth, and consisted of two side boards and four cross pieces, which fit into grooves in the side pieces. The sides of the mould were drawn tightly against the intermediate pieces by means of four 1/2 inch bolts just outside of the ends. The moulds are easily removed from around the cubes with no danger of crushing the corners.

The concrete was placed in the moulds in 1 1/2 inch layers and tamped with a 10 pound tamper until water flushed to the surface. The three cubes in the mould were carried up together and their tops smoothed off with a straight-edge to obtain perfect surfaces. They were left in the moulds for twenty-four hours, and then were removed and placed in water until tested.

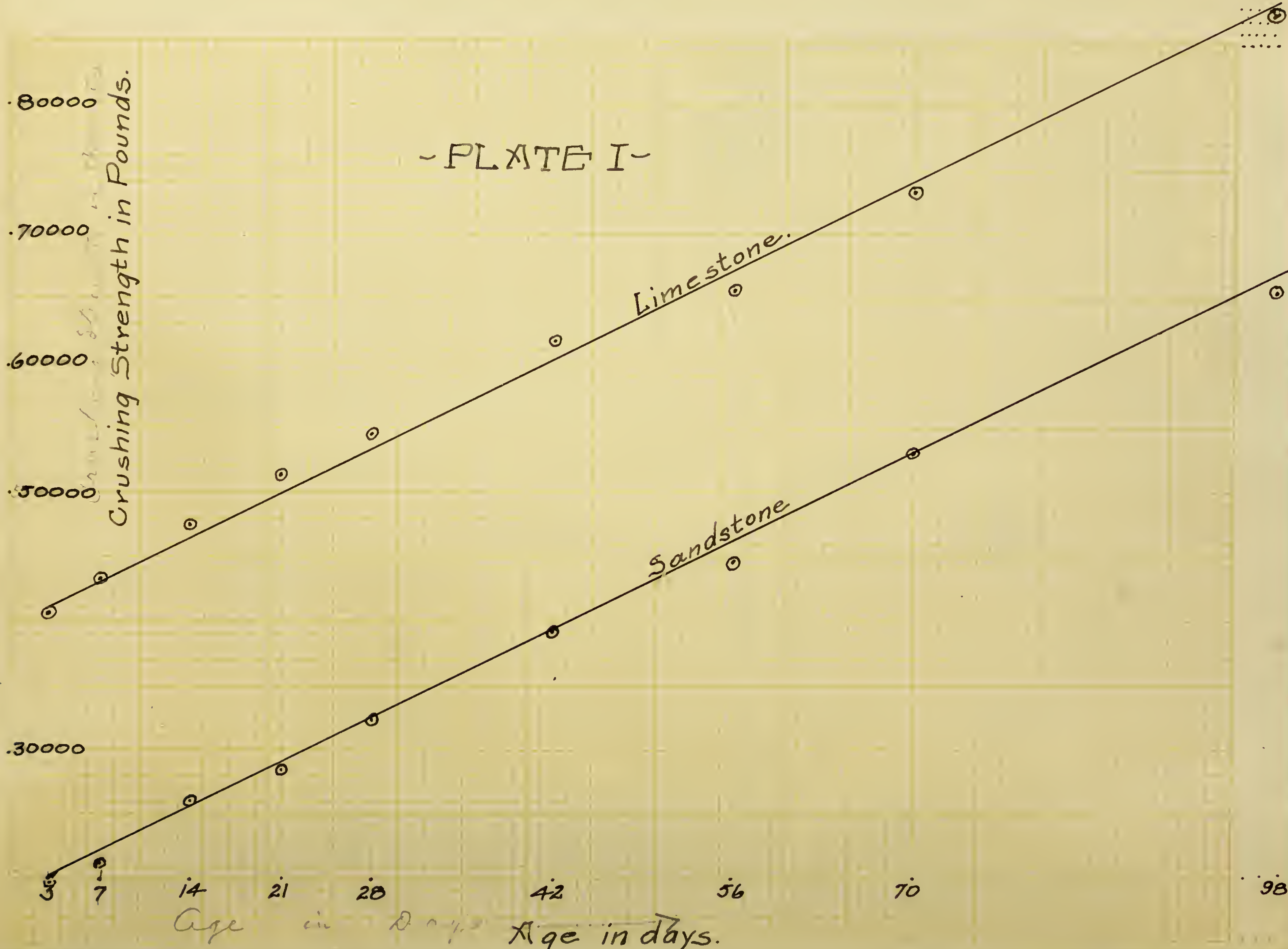
The testing was done on the machine in the University laboratory. Too much care can not be taken in preparing the cubes for the machine. Their surfaces should be perfectly flat and parallel to each other. Every cube was examined with a try-square and all surfaces smoothed with a file until they were as nearly perfect as could be obtained. Experiments show that cubes may be broken at any angle desired by leaving a corner or a small portion of the area higher than the remainder, since the pressure is applied upon only a portion of the area. This gives very undesirable as well as unfair results, because of the lack of similarity in the distribution of the pressure on different cubes. So it is very important that the surfaces should be as nearly flat as possible. The cubes were placed upon the table of the machine and a self-adjusting cap placed upon them. The pressure was applied as slowly as the machine would run until the ultimate crushing strength was reached, when the reading was recorded and notes were made of the manner of rupture and other conditions of interest.

The table on the following page shows the results of the tests made on the cubes. The same data is shown graphically in PLATE 1 on page - 8 -.

-TABLE I-

Crushing Strength of Concrete Cubes

Age when tested	Gravel Concrete					Broken Stone Concrete.					Ratio = Broken Stone / Gravel
	Total per Cube, pounds				Pounds per sq. in	Total per Cube, pounds				Pounds per sq. in.	
Days	No. 1.	No. 2	No. 3	Mean		No. 1	No. 2.	No. 3	Mean.		
3	19800	20400	19200	19800	550	42400	40300	39700	40800	1133	2.06
7	20700	19900	22700	21100	586	40700	45200	43400	43100	1200	2.04 ~~48.5~~
14	21400	24800	25900	24000	666	48700	46100	48100	47600	1322	1.99
21	27690	28360	29930	28860	802	54960	48860	50800	51500	1431	1.78
28	34600	32000	31500	32700	908	57940	50430	58000	54700	1519	1.67
42	38840	40470	38400	39250	1080	59700	63100	62600	61800	1717	1.59
56	45300	45100	44300	44900	1250	65700	68200	63800	65900	1831	1.46
70	52600	51900	54800	53100	1475	75400	71900	72900	73400	2040	1.38
98	65600	64300	66300	65400	1816	86600	85800	89700	87200	2422	1.33


-PLATE I-
Crushing Strength in Pounds.
.80000
.70000
.60000
.50000
.30000
Limestone.
Sandstone
3
7
14
21
28
42
56
70
98
Age in days.

These experiments show conclusively that broken stone concrete is stronger than that made with gravel -- see the last column of TABLE 1, on page - 7 -. It will be noticed that the broken stone is at the early ages twice as strong as gravel concrete and that this ratio decreases as the concrete grows older until at ninety-eight days it is one and one-third times as strong.

The greater strength of the broken stone concrete is due to the fact that the cement adheres more closely to the rough surfaces of the fragments of broken stone than to the smooth surface of the gravel. Also, part of the resistence to crushing is due to the friction of one piece upon another; and consequently broken stone has an advantage in this particular. It is owing to this element that the ratio of the strength of the broken stone concrete to the gravel concrete is greater at the earlier ages of the concrete.

The above conclusions are in harmony with the well known fact that broken stone macadam is better than a gravel surface for a road, as was to be expected, since concrete is simply macadam with a better binder.

On making the cubes there developed an objection to gravel concrete which seems not heretofore mentioned. The gravel concrete seemed to be somewhat plastic, so that when it was tamped down in one place it sprang up in another, particularly when completing the cubes. This is what might have been expected since there is but little internal friction between the rounded surfaces of the gravel.

In view of the above facts it must be concluded that unless there is a marked difference in the cost of gravel and broken stone that the latter should be preferred in making concrete.

E N D.