Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Ky.

February 7, 1950

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D.1.7

Memorandum to: Dean D. V. Terrell
Director of Research

In a letter of September 22, 1949, Mr. Bray transmitted to you a request from a Committee of Department Engineers that the Research Laboratory undertake a study of unit weights of different aggregates that might be furnished for highway use in Kentucky. Heretofore the Department has considered the unit weight of gravel as 2800 pounds per cubic yard and that of limestone as 2400 pounds per cubic yard without regard to differences in sizes and other characteristics.

In accordance with this request, Mr. S. T. Collier, Senior Research Engineer, carried out unit weight measurements in the laboratory on a small scale, and supplemented these by measurements in the field on a large scale using a 1½-ton truck and having the bed of the truck loaded with equipment normally used at the aggregate sources. The attached report tells of Mr. Collier's findings and includes recommendations for unit weights that might be considered applicable by the Department in future operations.

In total there were 37 individual truck measurements and 80 separate laboratory determinations on aggregates representing 18 separate sources. Also, slag was included along with the gravel and limestone, and in addition there were several different categories of gravel taken into account. The greatest limitation in investigating the matter ".... of aggregates used in the State with reference to specific gravity and voids" as suggested by the Committee lay in the fact that there were only a few sizes being produced or stocked at any one of the sources and, therefore, it was impossible for Mr. Collier to cover the entire range as he would like to have done. In some cases he was able, by separating sizes of material available, to get some ideas of unit weights for these missing sizes through laboratory determination.

For the most part the interest probably lies with aggregates purchased on a tonnage basis rather than with those situations where specifications cover aggregate usage and payment is made on the unit price of the mix into which the aggregate is placed rather than on the unit price of the aggregate itself. That being the case, if it becomes necessary to condense the information that has been placed in Table IV, it is probable that unit weights representing sizes 36, 47, 610 and 10 would be the most useful. Beyond that it may be necessary to strike a representative value for all the three zones applicable to graded gravel and in that case I believe that the figures for Zone 1 would cover the sources that provided most of the materials.

However, members of the Committee would be in much better position than I to judge that. Certainly the crushed gravel and the bank or pit-run gravels should be kept separate from the uncrushed and graded materials. Slag probably could stand very well on a one-figure basis unless there was considerable interest in crusher run material which probably does have a lot of merit as a traffic-bound aggregate.

Although I prefer the breakdown which Mr. Collier has made, if any condensation is necessary my recommendations would be as follows:

| Aggregate | Unit Weight |
| --- | --- |
| Limestone | 2500 lb. per cu. yd. |
| Graded Gravel, uncrushed | 2900 lb. per cu. yd. |
| Graded Gravel, crushed | 2700 lb. per cu. yd.* |
| Bank run or creek gravel | 2800 lb. per cu. yd. (Western Kentucky) |
| | 3000 lb. per cu. yd. (terraces, streams, etc. clean deposits) |
| Slag | 2200 lb. per cu. yd. |

*Takes into account crushed gravel that might come from Zone 1 but not represented in the data.

Both Mr. Collier and I feel that we do not have a good basis for making any separation according to specific gravity and voids as such. However, this report shows some interesting possibilities along these lines, and he arrived at the tentative conclusion that possible variations within the limits of any given size could influence the unit weight so much that any table based on specific gravity values could be only approximate at best. Beyond that it would take many more measurements than we have been able to make to tie down to specific gravity influences conclusively.

I believe that this report represents a forthright approach to the problem presented by the Committee and that the information will serve as a reliable guide. However, if the Committee wants further study in order to fill in some of the gaps where estimates were made, we shall be glad to extend the work and ask certain producers to provide as many sizes as possible.

Respectfully submitted,

L. E. Gregg

L. E. Gregg
Associate Director of Research

Copies to Research Committee Members

Commonwealth of Kentucky
Department of Highways

# DETERMINATION OF UNIT WEIGHTS OF AGGREGATES IN THE LABORATORY AND AT THE SOURCE

by

S. T. Collier

Senior Research Engineer

February, 1950

## INTRODUCTION

As a result of meetings with producers, a committee of Highway Department engineers recommended that a study be made of various type of aggregates from statewide sources; the objective being to arrive at a standard of evaluating unit weight of aggregates of various but commonly recognized characteristics. It was further desired that a factor be determined which could be applied to a given aggregate for computing its unit weight with reasonable accuracy; taking cognizance of specific gravities and densities as influenced by particle shapes and gradation.

## PROCEDURE

The project was strictly a laboratory procedure in the beginning. Samples of the materials were screened and reaportioned to meet the median gradation of as many standard sizes as possible for that source. Those sources were: three gravels from the Ohio River, two from the vicinity of Louisville and one from Henderson; one gravel from the Tennessee River; and one crushed limestone from Lexington. These aggregates were measured in the dry state by standard methods both loose and compacted.

After further consideration it was decided that in addition to laboratory measurements, field measurements would be more in keeping with the desired results. These measurements were made at aggregate plants or sources by loading a truck having a bed of known volume, using various methods of loading in common practice, striking the load off level by means of a straightedge, and weighing the truck and load at the producer's scales. A representative sample was taken for laboratory measurements in the majority of cases. Where there was moisture present in the aggregate, a rough moisture content determination (other than absorbed moisture) was made.

Laboratory unit weight measurements were made for both wet and dry conditions, with the gradation of sample being as nearly as possible representative of the field sample. The laboratory measurements were made in accordance to A.S.T.M. Standard C-29, employing a measure of one-half cubic foot volume (Fig. 5). A minimum of three measurements were made for any one sample to insure a check of within one per cent. In a few cases the coarser sizes were measured in a one cubic foot wooden box as a check against the one-half cubic foot container of different shape.

Field measurements of crushed limestone were made at quarries at Lexington, Somerset and Lawton; and from stocks at Paducah which originated at Princeton and Hopkinsville. For washed and graded gravels, the sources included Portsmouth and Cleves, Ohio, Carrollton, Louisville, Owensboro and Paducah. Slag was measured at plants in Ashland, Kentucky, and Portsmouth, Ohio. Two sources of bank gravel were also measured; one, a sand-gravel mixture located about three miles from Carrollton on Ky. 36, and the other (Power's Pit) in McCracken County.

The methods of loading the truck were by clamshell, bucket loader or from bins. The height of fall varied from two to four feet as a rule.

One exception was at the bins at Lexington, which were at a height of approximately twelve feet from the truck bed. The loading methods for the different field tests are given in Table I.

At the nine sources investigated in the Central and Eastern portion of the state, a $1\frac{1}{2}$ ton truck, with a bed of 70.74 cubic foot volume, was employed in making these field measurements. An identical truck was used at the Owensboro source. A third truck with a bed of exactly two cubic yard capacity was used for measurements of the four sources in District 1. Some of the equipment and methods involved in tests at the sources are illustrated in Figs. 1 to 4.

Conditions that prevailed at the various sources and some of the procedures applied to them were as follows:

Limestone

Lexington - The No. 2, No. 8 and No. 9 sizes were loaded from bins at a height of approximately twelve feet above the truck bed. The No. 6 was loaded from a stockpile by a bucket loader which allowed a drop of three feet to the truck bed. Some surface moisture was present in the No. 6, and its gradation was near the fine side of its limits.

Somerset - All sizes were loaded from stockpiles by means of a bucket loader allowing a drop of approximately three feet. Each material contained some surface moisture. Gradations for the No. 6, No. 610, and No. 9 was coarse, medium and fine respectively.

Princeton and Hopkinsville - Aggregates from both sources were measured at Paducah. The Hopkinsville No. 36 was loaded from a bin three feet above the truck bed. The No. 6's from both sources were loaded from a stockpile by a clamshell from two feet above the truck bed. All samples were dry.

TABLE I - LOADING METHODS

| Source | Aggregate | Clamshell Std. Size | Clamshell Drop Ft. | Bucket Loader Std. Size | Bucket Loader Drop Ft. | Bins Std. Size | Bins Drop Ft. |
|---|---|---|---|---|---|---|---|
| Lexington | Limestone | - | - | 6 | 3 | 2,8,9 | 12 |
| Somerset | | - | - | - | - | 6,9, 610 | 3 |
| Princeton | | 6 | 2 | - | - | - | - |
| Hopkinsville | | 6 | 2 | - | - | 36 | 3 |
| Lawton | | - | - | 6,610 2, 7 | 4 | 9 | 4 |
| Portsmouth | Gravel | 47,7,9 | 2 | - | - | - | - |
| Cleves | | 36,7 | 2 | - | - | - | - |
| Carrollton | | - | - | 6 | 3 | - | - |
| Louisville | | - | - | 6 | 4 | - | - |
| Owensboro | | - | - | 6, 8, 6 Cr. | 3 | - | - |
| Paducah | | 6,8,2 | 2 | | - | - | - |
| Carrollton | Bank Gravel | - | - | Pit Run | 4 | - | - |
| McCracken County | | Pit Run | 4 | - | - | - | - |
| Ashland | Slag | - | - | All | 4 | - | - |
| Portsmouth | | - | - | All | 4 | - | - |

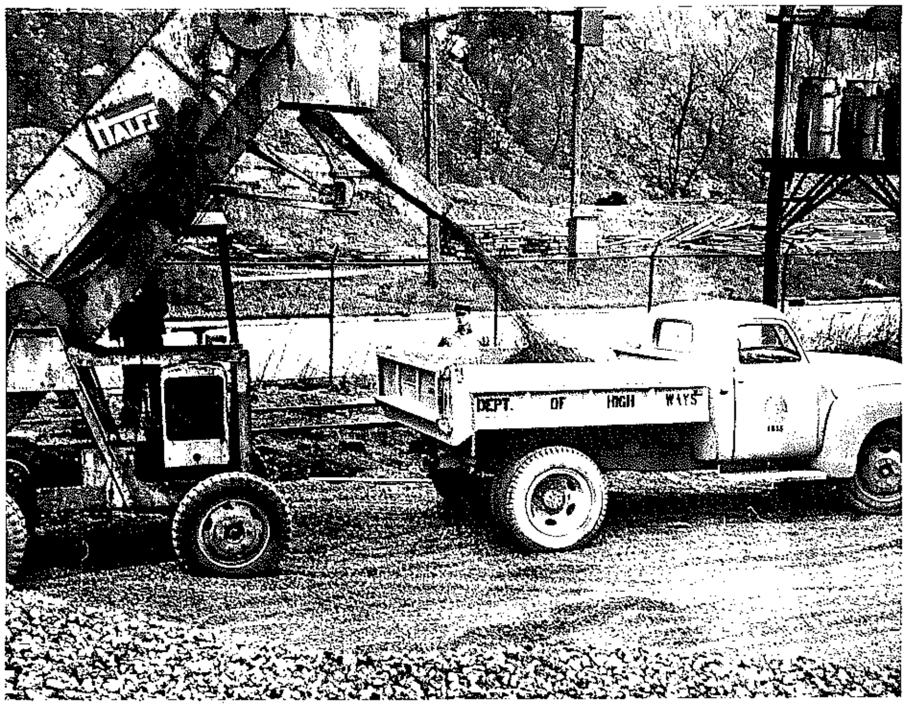


Fig. 1. Filling the truck bed from a stockpile/by means of a Bucket Loader. The chute is approximately four feet above the truck bed. This method of loading was used at eight of the sources.

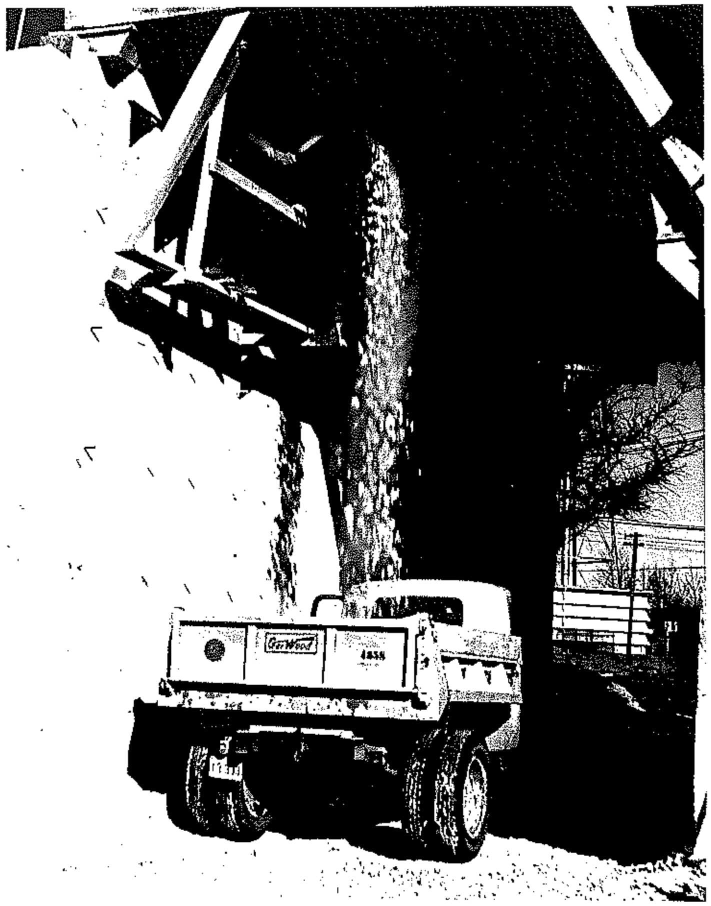

Fig. 2. Loading truck from bins at Central Rock Company plant, Lexington.

Fig. 3. At all aggregate sources the truck was weighed empty and full on the same scale in order to get the unit weight of the aggregates and also eliminate effects of differences among scales.

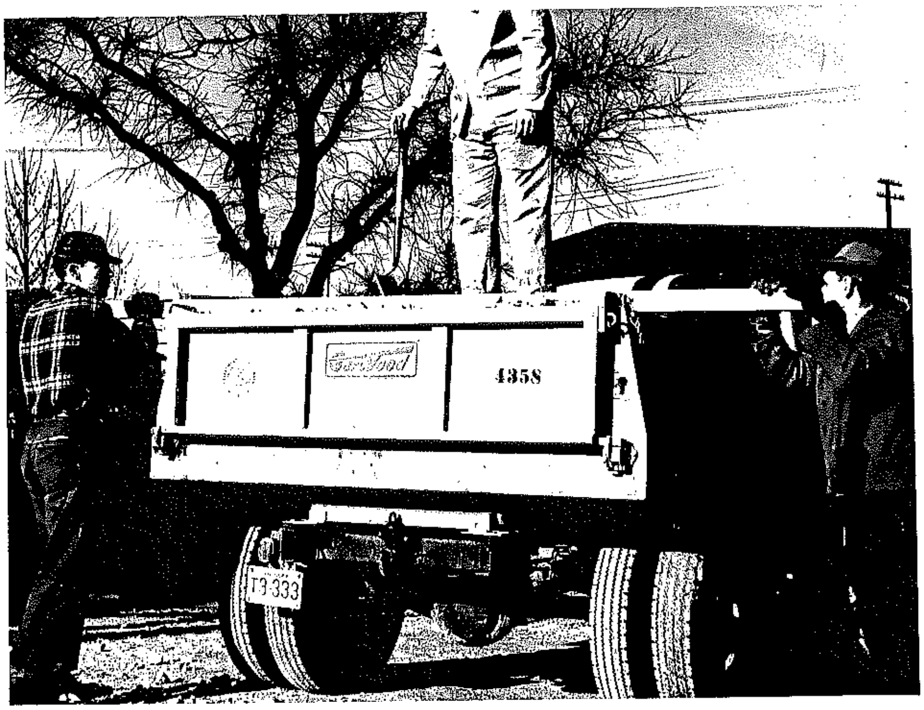


Fig. 4. Leveling off a load of limestone aggregate in a determination at the source. This truck, which had a dump bed and was of $1\frac{1}{2}$-ton capacity, was used for tests on materials from nine of the fourteen sources represented in the field tests. Trucks assigned to the First and Second Districts were used for tests at sources in the western part of the State

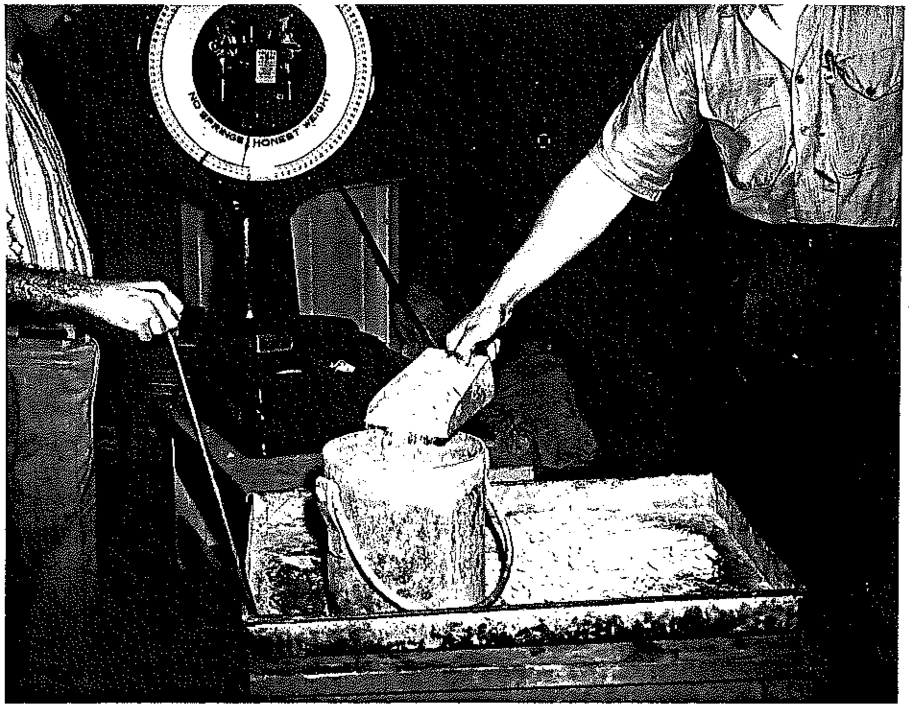


Fig. 5. Filling one-half cubic foot container in laboratory unit weight measurement. The rod held by the man on left was used for leveling off the surface rather than for rodding the material.

Lawton - At this source, sizes No. 6, No. 610, No. 2 and No. 7, (actually W. Va. No. 10 which was a little coarse for Ky. No. 7). were loaded by a bucket loader which allowed four feet of fall to the bed. The No. 9 was loaded from a bin at four feet. All samples were practically dry with the exception of the No. 610 which contained an appreciable amount of moisture. The method employed by this plant for stockpiling the No. 610 was to build the stockpile in alternate layers of No. 6 and No. 10 approximately one foot thick.

Washed and Graded Gravel

Portsmouth and Cleves - All samples measured at these sources were loaded from stock piles by clamshells from two feet of height. Each material contained about one per cent of surface moisture.

Carrollton - A bucket loader allowing four feet of fall was used at this source. This gravel was in stock piles and extremely wet.

Louisville - This material was also loaded from stockpiles by a bucket loader with a drop of four feet. The moisture condition was surface wet. Its gradation fell on the coarse side for size No. 6.

Owensboro - All samples at this source were loaded from stockpiles by a bucket loader from three feet of height. This gravel was extremely wet.

Paducah - A clamshell was used for loading this material, allowing it to fall two feet. Both samples contained some surface moisture and both were on the fine side of their respective gradation limits for No. 6 and No. 8.

Bank Gravel

Carrollton - This material was loaded directly from its natural deposit by a bucket loader which allowed four feet of fall. Its moisture condition was extremely wet. Fifty eight per cent of this material passed the No. 4 sieve.

McCracken County - This material was loaded from the pit (Power's Pit) by a power shovel in a manner identical to a clamshell from a height of four feet. It condition was that of its natural damp state.

Slag

Ashland and Portsmouth - Bucket loaders were used at both sources allowing four feet of fall in every case. All sizes were relatively dry with exception of Portsmouth Nos. 610 and 9. Sieve analyses indicated that the Ashland No. 610 and the Portsmouth No. 9 were on the fine side of their gradation limits.

## RESULTS

The results are compiled in Tables II and III and Figure 1. In table II are tabulated the averages of oven dry specific gravities and the percentages of absorbed moisture. Table III catalogs results according to sources, sizes, kind of aggregate, and methods of measuring. Among these data are several indications of the effect of different variables on the unit weights of aggregates.

### Size, Shape, and Specific Gravities

A graphic representation of the first five laboratory measurements was plotted in the form of Standard sizes versus unit weight in Figure 6. These sizes were separated into fractions and recombined to the median gradation for each size range for as many sizes as the samples could provide. This plot was made in curve form for easy comparison, there being no direct relationship between the plotted points for size and the corresponding unit weights. The points are connected merely for correlation of all sizes from a single source.

The weight differentials were fairly uniform for the different sizes, but with the particle shapes offering greater influence than did the specific gravities. The crushed limestone had a lower unit weight despite its higher specific gravity. The Tennessee River gravel had a much lower unit weight than its specific gravity indicates when compared with the Ohio River gravels. The reverse was true when compared with crushed aggregates. This is attributed to its particle shape-irregular though rounded.

Method of Loading and Determination

Due to certain factors entering into field operations the results were less consistent at the source than they were in the laboratory. With the exception of the Carrollton bank gravel, truck weights were greater than the laboratory weights, with the disparity increasing with the increase in size of the particles. The variation of the "fines" in a given size also effected the weight - the unit weight increasing with the increase of the finer sizes. An aggregate approaching a one-size material, such as No. 9, was consistently lower in weight than a more uniformly graded size from the same source.

The majority of samples taken during field measurements fell well within their repsective gradation limits. Some exceptions which were border line cases were:

| | | |
|---|---|---|
| Limestone - | Lexington No. 6 | - Fine |
| | Lexington No. 8 | - Coarse |
| | Somerset No. 6 | - Coarse |
| | Somerset No. 9 | - Fine |
| | Lawton No. 7 (W.Va. 10) | Coarse |
| Washed Gravel - | Portsmouth No. 5 | - Coarse (Failed) |
| | Louisville (A) No. 6 | - Coarse |
| | Paducah Nos. 6 and 8 | - Fine |
| Slag | Ashland No. 610 | - Fine |

Comparisons among laboratory samples from these sources indicates that the effect of gradation substantiates the statement made in a previous paragraph. Particularly outstanding are the samples of Tennessee River gravels in that they weighed approximately one hundred pounds heavier than the medium graded samples.

It is questionable that the laboratory sample of Ashland Slag No. 610 was representative of the material measured by truck.

Moisture

In the case where field measurements were made with wet aggregates, and the total moisture content could be determined with reasonable accuracy, the wet truck weights were corrected to dry weights (Table III). These corrections could not be applied reliably, however, to aggregates containing an appreciable amount of fines smaller than No.4 sieve size. This is borne out by laboratory measurements of Somerset limestone No. 610 and No. 9, Lawton limestone No. 610, and Cleves gravel No. 11, in which cases the laboratory unit weights dry were greater than when wet. Also the weight differentials were not as wide as the moisture contents indicated for: Somerset limestone No. 6; Portsmouth gravel No. 9; and Paducah (Tennessee River) gravels No. 6 and No. 8. Such results may be attributed to bulking properties of the finer particles and to an attraction among the particles that hindered their freedom of individual movement when falling into place.

Aggregate Type

It has long been established that for aggregates with identical size distribution, a greater density is obtained with that of a rounded particle shape than with that of an angular shape. Further observations indicate that the density increases as the rounded particle shape approaches the spherical. The same holds true for crushed aggregates as the particle shape approaches the cubical.

The results obtained in this investigation do not warrant classification of crushed limestone by the amount of void space effected by particle shape, inasmuch as the presence of flat and elongated pieces is discouraged by the specification requirements. Neither does it seem practical to give this characteristic very much consideration in classifying rounded aggregates, except for a few specific sources such as Tennessee River gravel. With specific gravities and gradations being equal the unit weights of the Ohio River gravels are approximately fifteen per cent heavier than those for crushed limestone - to compare wet gravel with dry stone.

The information available on bank gravel (pit run) permits at least two general classifications which are identified here as Western and Miscellaneous. The Western Kentucky bank gravels are deposits of a gravel-sand-clay mixture of varying combinations. The miscellaneous are sand-gravel mixtures relatively free of clay and silt. This material is found principally in terraces along the middle reaches of the Ohio River (Cleves, Ohio, Pits for example) and probably the many scattered deposits of creek gravel. The unit weight of pit run material from the one source investigated, 3200 pounds per cubic yard, may be heavier, due to its extremely wet condition, than would normally prevail for this type.

There are wide differentials in the unit weights of slags representing the many sources. However, the two sources investigated are at present the sole suppliers to this state. These materials compare closely enough that they may be given the same unit weight values.

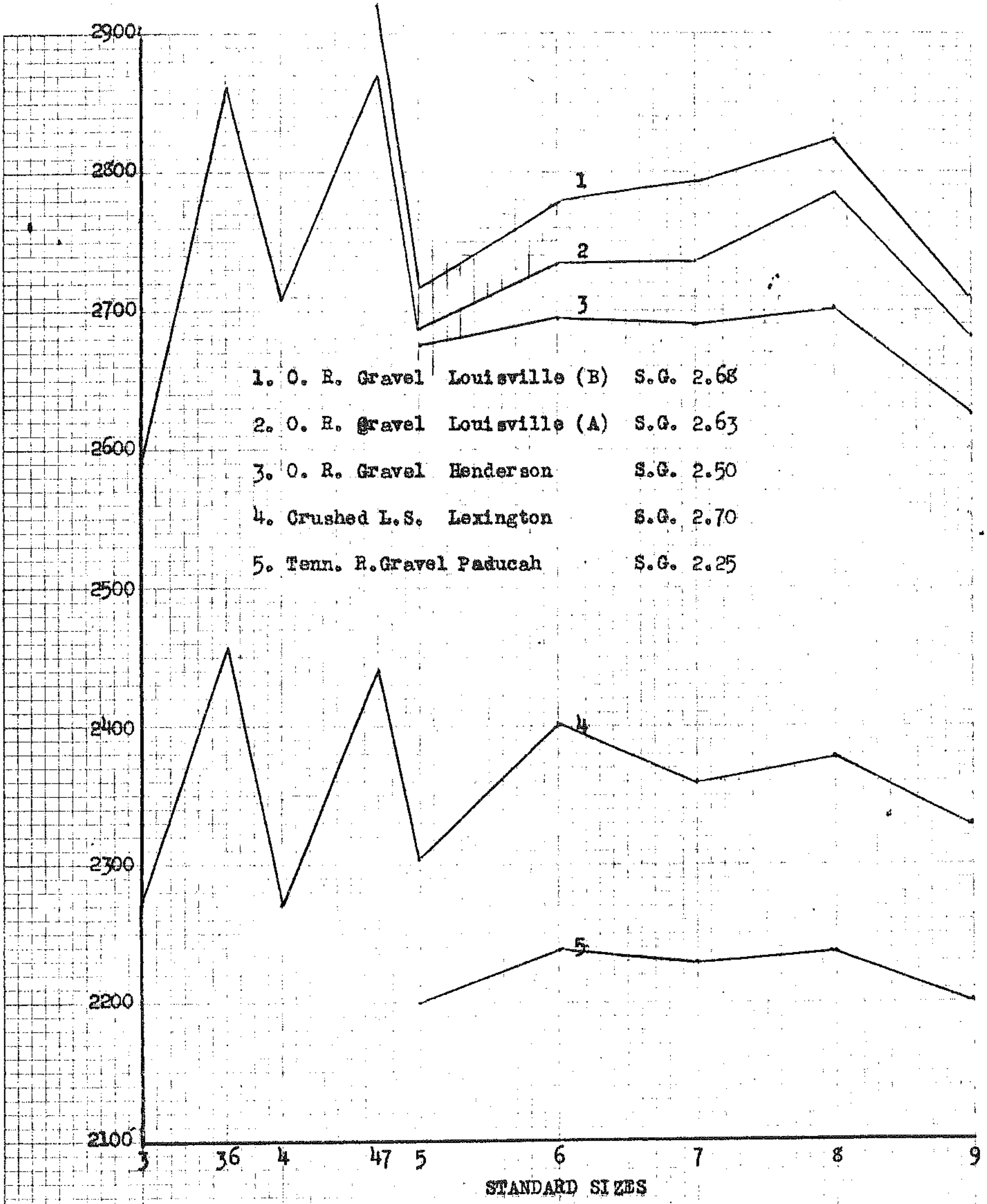


Fig. 6. Approximate relation between unit weights (loose) and standard sizes as determined by laboratory tests. For those determinations the aggregates were separated into fractions and recombined to obtain the median gradation foe each aggregate size.

TABLE II. - AVERAGE BULK (Oven Dry) SPECIFIC GRAVITIES AND PER CENT OF ABSORBED MOISTURE

| SOURCE | Bulk (oven dry) Specific Gravity | Per Cent Absorption |
|---|---|---|
| | Limestone | |
| Lexington | 2.70 | 0.6 |
| Somerset | 2.62 | 2.0 |
| Princeton | 2.69 | 0.6 |
| Hopkinsville | - - | - - |
| Lawton | 2.62 | 1.8 |
| | Washed and Graded Gravel | |
| Portsmouth, Ohio | 2.50 | 2.2 |
| Cleves | 2.62 | 2.2 |
| Carrollton, Ky. | - - | - - |
| Louisville A | 2.63 | 1.0 |
| Louisville B | 2.68 | 2.0 |
| West Point | 2.50 | 2.0 |
| Henderson | 2.45 | 3.0 |
| Owensboro | 2.51 | 2.4 |
| Paducah | 2.27 | 6.0 |
| | Slag* | |
| Ashland | 2.39 | 1.9 |
| Portsmouth | 2.31 | 1.5 |

*Data Furnished by National Slag Association

| | Size | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | | 8 | | 9 | | [illegible] | | Bank or Crusher Run | |
| A | ruck | Lab. | Truck | Lab. | Truck | Lab. | Truck | Lab. | Truck | Lab. |
| | | 2360 | 2451 | 2397 | 2290 | 2273 | | | | |
| | | | | | 2305<br>2260* | 2240<br>2284 | | | | |
| | | | | | | | | | | |
| L | | | | | | | | | | |
| | 62(2) | 2311(2) | | | 2347 | 2330 | | | | |
| | 740<br>560* | 2723<br>2643 | | | 2626<br>2550* | 2600<br>2565 | | | | |
| | | | | | | | | 2681<br>2730 | | |
| | | | | | | | | | | |
| | | 2792 | | 2827 | | 2708 | | | | |
| G | | 2735 | | 2784 | | 2681 | | | | |
| G | | | | | | | | | | |
| | | 2692 | | 2708 | | 2627 | | | | |
| | | | 2794 | | | | | | | |
| | | | | | | | | | | |
| | | 2255 | 2570(4) | 2414<br>2322 | | 2203 | | | | |
| 1 | | | | | | | | | 3229 | 3256 |
| ( | | | | | | | | | 2830 | |
| | | | 2107 | 2048 | 2084 | 1985 | | | 2473(5) | 2217 |
| | | | | | 2046 | 2034<br>1992 | | | | |

## CONCLUSION

Unfortunately the several plants visited were not producing more than four or five sizes at most and a number of the sizes listed in Table III were not at all available for field measurements. Hence a great many of the unit weights listed in Table IV are only theoretical, nevertheless these are suggested as reasonable and probable relationships among the average weights of materials in the various groups if they were produced.

These values were arrived at only on the basis of the general trends indicated by field and laboratory measurements of the various types and sizes available. Some of the sizes listed are very likely non-existent in many sources; for example, No. 36 and No. 2 from the Tennessee River, and No. 2 in appreciable amounts in any of the river gravels.

In Table IV the uncrushed graded gravels are divided into three zones. Zones 1 and 2 are distinguished only by difference in specific gravities. Zone 1 includes Louisville up river to above Cincinnati. Two sections are included in Zone 2; the Portsmouth section beginning probably as far down river as Maysville or below and extending east; the Owensboro section beginning in the vicinity of West Point and extending to down river beyond Henderson. Zone 3, the Tennessee River, might well include the Cumberland River.

TABLE IV - CLASSIFICATION OF UNIT WEIGHTS BY AGGREGATE TYPES AND STANDARD SIZES

| STANDARD SIZES | POUNDS PER CUBIC YARD | | |
|---|---|---|---|
| Limestone | | | |
| 36,47,610 & 10 | 2500 | | |
| 2 to 8 | 2400 | | |
| 9 & 11 | 2300 | | |
| Crusher Run | 2500 | | |
| GRADED GRAVEL | Zone 1* | Zone 2* | Zone 3* |
| Uncrushed | Louisville Cincinnati | Portsmouth Owensboro | Tennessee River |
| 36, 47, 610, 10 | 2900 | 2800 | 2600 |
| 2 to 8 | 2800 | 2700 | 2500 |
| 9 & 11 | 2700 | 2600 | 2400 |
| Crushed | | | |
| 36, 47, 610, 10 | | 2600 | |
| 2 to 8 | | 2500 | |
| 9 & 11 | | 2400 | |
| Bank Run Gravel Western | | 2800 | |
| Miscellaneous | | 3200 | |
| Slag | | | |
| 36, 47, 610 & 11 | | 2200 | |
| 2 to 8 | | 2100 | |
| 9 & 11 | | 2000 | |
| Crusher Run | | 2400 | |

*Description of these zones are given in the last paragraph preceding this table.