for a single span the girder bridge and the slab bridge should have the same yardage, an advantage still rests with the slab type, as it has been found that contractors usually bid more favorable on this type. There is also another very important point in favor of the slab type. If for any reason there should be any defective material placed in the rail, or poor alignment in its construction. it may be torn down and replaced without disturbing the floor, even after the falsework has been taken down.

Cost Diagram.—Having found the expression that is the measure of the number of cubic yards in the abutments and superstructures of concrete slab and girder bridges, the next step is to combine the quantities with a unit price that we may determine the approximate cost of each type. For this purpose Fig. 3 has been prepared.

It has been found from the cost data of a large number of slab and girder type concrete bridges built under the supervision of the Illinois Highway Commission, that it is possible to get a very close figure on each individual item that goes to make up the cost of the bridge; first, the cost at the bridge site of sufficient cement to make 1 cu. yd. of 1:2½:4 concrete; second, the cost of the necessary lumber for forming 1 cu. yd.; third, the cost of reinforcing steel per cubic yard of concrete; fourth, the labor cost in mixing and placing 1 cu. yd. of concrete; fifth, the cost of sufficient aggregate to make 1 cu. yd. of concrete; sixth, the cost per cubic yard of concrete to make the necessary excavation to start the concrete of the footings. The two items that largely control the cost of a structure of this kind are the excavation and the necessary aggregate for the concrete. We find that the cost per cubic yard of concrete for cement, forms, reinforcing steel, and the mixing and placing, have narrow limits in their variation.

It therefore appears possible that some definite quantities may be fixed to the first four items and a curve plotted for the last two, combining them in such a way that the total cost may be readily determined after we have learned the number of cubic yards in the bridge.

The cost at the bridge site of sufficient cement to make 1 cu. yd. of concrete for a 1:2½:4 mixture may vary from $1.75 to $2.10. While the price of cement, the distance it has to be hauled, and the amount required for some aggregates, vary slightly, the extreme variation would not be over 20 cents per cubic yard from the average. From a general average of all cost data on this item, it would seem that we are probably safe in choosing for cement about $1.90 per cubic yard of concrete.

The cost of forms includes all the necessary falsework, bracing and form lumber for completing the bridge. While this item varies somewhat for different localities, and will vary again where the contractor can use some of his old lumber, it will fall between the limits of 75 cents and $2.50. Experience has shown that about $1.50 for the ordinary type of bridge is usually sufficient and might well be chosen for this cost curve.

The reinforcing steel varies from 50 lb. per cubic yard for substructures to 170 lb. per cubic yard for superstructures, or an average of about 110 lb. for the two combined. This steel delivered at the bridge site under ordinary conditions and bent ready for placing in the structure will cost about $2.10.

The item for mixing and placing concrete might vary from $1.50 per cubic yard for crushed rock concrete mixed by hand to possibly as low as 40 cents for gravel concrete mixed by machinery. This item should also provide for the necessary work in spading the concrete next to the form and securing the desired finish. In spite of the possible wide variation, we find the cost of this item varies but little from the fixed amount of $1.25. While all these quantities given above may seem somewhat in doubt as to their reliability, yet experience has determined that they are not far from the correct figures for normal conditions on the average bridge.

The item of excavation, which includes also cribbing, sheet piling, pumping, and all necessary work to start the concreting of the footings, has been found from the cost data on file to vary from 50 cents to $5 per cubic yard of total concrete in the bridge. The 50 cents per cubic yard is found only in some very favorable cases and on the smaller spans, where there is practically no cribbing, sheeting or pumping necessary. On the other hand, the cost of $5 per cubic yard of concrete is caused by a soft, seepy soil where cribbing, sheet piling and excessive pumping are necessary. Quite often the wide variation in the item for excavation is due to poor management on the part of the foreman in charge. This item, therefore, may vary considerably, but with experience with the excavation that is to be handled and with the type of bridge that is to be built, one is able to estimate this item sufficiently close for all practical purposes.

It will be seen that the cost of the aggregate delivered to the bridge site is the second item determining the price per cubic yard of concrete. Under the most favorable conditions with respect to location of a satisfactory aggregate supply, it would likely cost at least 50 cents per cubic yard to haul it to the mixing plant. On the other hand, the cost of aggregate at the bridge site might exceed $4 per cubic yard, as the structure may be isolated from a railroad station, and it may be necessary to ship in either gravel or crushed rock and sand, besides hauling it several miles into the country.

In the light of the wide range on these two items, Fig. 3 has been prepared to give the total cost of the bridge complete, including profit to the contractor under conditions where the cost of excavation, plus the cost of aggregate at the bridge site, might vary from $1 to $9.

For a specific case, we will assume that a concrete bridge has 120 cu. yd. of concrete. We will next investigate the condition of the foundation, and assume the cost for completing this part of the work, and express it as so much per cubic yard of concrete. We then approximate the cost of delivering at the bridge site the necessary aggregate to make 1 cu. yd. of concrete. For convenience let us say that these two quantities amount to $3 per cubic yard of concrete. Entering Fig. 3 with 120 cu. yd. at the left-hand side, and following this across to the $3 curve, or the $11 per cubic yard, which is the same thing, and then to the bottom of the figure, we find the cost of the bridge complete to be $1,300. The total cost per cubic yard of concrete is shown at the top for aid in determining the unit price.

From the figures heretofore given, we are able to determine approximately the number of cubic yards in either the slab or the through girder type of bridges, besides having a ready means of determining the probable cost. While the curves here developed apply only to the slab and through girder types of bridges, similar curves might readily be developed for the deck girder, the through girder floor beam type, or the arch, and would prove of equal service to the highway engineer, but their development is beyond the scope of this paper.

The foregoing is not intended to supply a substitute for engineering ability, but rather to furnish aid that will safely direct the engineer who will interpret with judgment and experience.