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struction of highway bridges.

WACCAMAW RIVER BRIDGE IN GEORGETOWN

1. Supporting Long Piles Under Water:

The new bridge over the Waccamaw River at Georgetown has a number of piers consisting of a massive base at the water line and supported by piles in rather deep water. The earth material in the riverbed is of questionable quality so that the piles have long unsupported lengths below the pier base. It was felt that some lateral support was essential for these piers in the region of the riverbed.

The lateral support is provided by means of a 5 foot deep mass of concrete encasing all piles just above the riverbed. To provide an underwater form for the concrete mass, it was required that the contractor precast an open-end concrete box, 19 feet square, with sides 5 feet deep and 8 inches thick. This concrete box was lowered over the pile group to a prepared and level area on the river bottom. Tremie concrete was then placed inside this box to the top level, completely encasing all piles with a 5 foot deep horizontal layer of concrete.

It is felt that this method of pier construction in reasonably deep water is entirely satisfactory and results in considerable economy as compared with the conventional cofferdam type pier with the massive concrete base to the riverbed.

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WHY DO BRIDGE COSTS VARY BETWEEN STATES?

By F. C. TURNER, Chief Engineer, Bureau of Public Roads, Washington, D. C.

Why does a bridge superstructure in one State cost $9.55/SF, and another one, designed to carry the same loading and roadway, cost $5.95/SF, $6.34/SF, $11.30, $7.23, and only $5.00 in some other States?

The above wide-spread range of prices raises important questions which you and I must be able to answer with promptness and clarity. These costs which I have cited were calculated from a set of constant unit prices derived from average bid prices so as to reflect only the quantitative practices used, and thus to remove as a variable the local labor and other variable costs. No one of us can deny an urgent need for more cost consciousness by all of us in our design, development of plans, construction, and maintenance for the highway bridges under our control. This need has been recognized for many years by all of us, and I know that it is not a new subject of discussion for this committee.

For the last couple of years especially, I know that it has been one of your primary subjects of interest and that Bureau representatives at meetings and back home in your individual States have been putting a steadily increasing emphasis on it. I know this because I am the one who has been exerting the pressure. A number of memoranda have been circulated on the subject containing information, suggestions, or instructions. While we have been very much interested in the subject and have been doing extensive work on it for a long time, we have intensified this interest especially since the beginning of the enlarged Interstate program in 1956 and establishment of the so-called needs formula as a basis for apportioning funds to the individual States for this part of the program.

This needs formula necessarily imposes a burden on all those who share in the proceeds of monies distributed in this manner, that they base their needs estimates on the same set of measuring methods that their neighbors are using. We cannot permit one State to use a longer or shorter yardstick than their neighbors with which to make their own individual measurement of needs. This does not mean that every State has to build structures in exact duplicate of every other State, but it does certainly mean that the amount of money drawn from the common fund by any individual State to do a specific job must be determined by using the same units of measurement in all States.

The results of cost study reviews such as I have cited above raise questions as to whether this objective is being actually achieved. If it is found on strict and objective examination that the wide price variations are proper and supportable, then all is well and we can be satisfied that the ideal formula is being fully followed. But if in our examination, we find that the factors do indeed vary without an adequate explanation and justification therefor, then we are obligated as engineers and managers of the public trust, to make appropriate revisions in our procedures. For this is the law, and we have no personal choice in the matter. But we should not be doing it, just because it is the requirement of the law; but rather because it is the right thing to do in the public interest; for that is why it is the law.

I believe that we have now had sufficient experience and developed enough usable data on which to have preliminary judgment conclusions as to trends. I want to cite some of these for your information and also to use them as the foundation on which I shall lay a proposal for your consideration.

As reviewing agency for bridges from all States, we are constantly aware of the variations in bridge types and costs. Obviously, we are very much concerned about what bridges are costing in total (almost ⅓ of the Interstate cost, for example), and we must see that improvements and economies are made wherever possible.

We have recently tabulated quantities and other data from a considerable number of bridges representing a sample from nearly all of the States.

In this analysis the cost per square foot has been compared in the different States based on the out-to-out dimension of a 4-span structure over the Interstate or other expressway and a constant set of unit prices, using HS20 and H20 loadings. In discussion of this matter I shall not name the individual States, since to do so might imply that I am singling out some particular State for attention, but I do have available the actual data on which these statements are based together with the name of the State.

We find for example in one State, which uses extensively a design with wide flange continuous I-beams, that its designs are considerably more costly than similar crossing structures designed by other States.

In an attempt to make a comparison between this State and other States having lower cost, two bridges were compared; one with a loading less than AASHO-H20 and the other one, a bridge designed by another State to carry a loading of HS20 based on 1961 specifications.

From the cross sections as compared, it was evident that for an appreciably lighter loading and a lower class roadway, the first State's structure was much more massive. The deck slab, curb and parapet were all quite heavy and as would be expected the structural steel cost more; $4.19 per square foot compared to $3.55 per square foot.

A comparison was then made of roadway slabs. This indicated that the first State uses a heavier slab than the second State for a smaller span and lighter loading.

Next, a comparison was made between the curb, parapet and rail details used by these States. For a minor road crossing, having 24-foot roadway width, the first State used a very massive curb and parapet, whereas the second State was using much lighter, but structurally adequate details, resulting in substantial economies for a much higher class road. The concrete and reinforcing quantities shown on these details alone accounted for a cost differential of 55 cents per square foot. From this item-by-item study of design details, there is a clear indication of possible savings in substantial amount from design revisions.

In another study, we compared the cost of prestressed concrete bridges. We found wide cost differences due to use of more beams and greater slab thickness in some cases than in others, for the same design conditions. The more costly bridges in this review indicated a unit cost of about $1.50/SF above the average of other States. Three prestressed bridges were studied, all having a 2-lane, 26-foot roadway with HS20 live loading. The interior spans on all three were approximately 75 feet. The cost per square foot varied between $6.04 and $8.06 for some of the following reasons:

> There is of course a direct relationship between number of beams, their size, and the resultant cost. For example, two States called for six beams, 48 and 50 inches deep, as compared to five beams, 45 inches deep in another State; with resultant costs of $4.81, $4.16 and $3.27, respectively. The low cost State used approximately the same beam spacing, but one less beam than did the other two States, resulting in a larger cantilever and a more balanced design. In the end spans, the highest cost States used six beams whereas the other State called for five. This alone accounted for the 65-cent/SF difference between the two. However, the lowest cost State used only four beams in the end span.
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> While a small difference in concrete cost for the deck was reflected by slab thickness differences, and some other relatively minor details, the main reason for the differential in deck cost was the use of straight

rather than trussed transverse slab reinforcing bars. From inspection, it was evident that the highest cost State was paying an extra 30 or 40 cents per square foot by not using the trussed transverse rebars.

Bearings and joints required by one of the higher cost States showed up as costing 23 cents per square foot of deck. This reflected the use of rather elaborate roller bearings and plate expansion joints for this type of bridge while the other States used neoprene bearing pads and filled joints at almost negligible cost.

In another analysis using continuous concrete box girder structures designed for the same live load, spans, roadway and girder spacing, the costs in two other States were compared.

It was revealed that in contrast to the high cost State, the lower cost State:

Used 2″ less deck slab thickness; 6″ less depth of structure. A flared web at pier determined by shear requirements rather than maintaining a constant width; Only one instead of two layers of steel in the bottom slab; Cut off the main steel at points conforming to required moment capacity rather than all at once; Used diagonal rather than vertical stirrups; and Minimum size fillets; among other details.

A study of T-beams indicated this type of bridge to be the most economical. Seven States that had T-beam bridges in the study all showed very good conformity and economy. Differences in cost resulted mainly from details such as curb and rail systems but not from differences in design practices. Some States are providing pedestrian walkways on all types of bridges. Other States use them only for bridges on higher classed roadways where the AASHO Specification requires them.

A composite curve of costs by bridge types was developed for loadings of HS20, H20 and Ohio CF400. This gave us a direct comparison between types and indicated very clearly that simple span I-beam bridges were consistently and notably more costly than the other types.

A State by State comparison of bridge costs was made by projecting all designs to an equivalent span of 70 feet, by which we could get a reasonably accurate gauge of cost. This showed clearly a wide range in design detail practices and costs per square foot for the same conditions of land, traffic, clearance, and other layout requirements.

Transferring these results to a map indicated graphically which sections of the country are above the rest in costs. It was readily seen that all of the northeastern section of the country falls into the category of higher than average cost based upon constant unit prices, possibly because of their extensive use of simple span steel beam bridges.

An equivalent map was then made based on the individual States' average unit prices, showing most of the same States still to be high.

Next, cost comparison was made between 2- and 4-span bridges over a divided highway consisting of two 24-foot roadways and a 30-foot median. The results showed that the 2-span bridge could be built for the same cost as the 4-span bridge when using welded girders 18 inches deeper than used in the 4-span rolled beam bridge. On

November 29, 1963, the Bureau issued a Circular Memorandum to Regional and Division Engineers in which was incorporated much of this particular study data. As stated therein, economy, maximum safety and pleasing appearance are not incompatible with each other in the design of grade separation structures. Often these objectives can be achieved in designs without shoulder columns, and at no additional cost. Fewer and longer spans give drivers a sense of openness which contributes to relaxed driving and increased safety. The absence of shoulder columns permits possible future widening of the lower roadway pavements and produces a reduction in the cost of maintenance.

Based on these several years of continuing and rather extensive study of the practices being followed in individual States, there is in our judgment sufficient evidence now available to the engineering profession to clearly show that design practices in many cases are resulting in structure costs higher than can be justified on the basis of accepted criteria relating to the necessary level of traffic service and economic use of construction and maintenance funds. It is now time for us to critically and objectively analyze our work and to select from the multitudinous assortment of individual practices, those which for each given set of circumstances will give us the needed service at the lowest overall cost.

One easy way for the Bureau to handle such a question from our own standpoint would be to simply set an arbitrary dollar amount as the limit of Federal fund participation. From our standpoint alone, this simple method has much to offer in case of administration and a minimum of manpower needed for the study of individual designs. It is therefore a tempting way for us to handle the matter, and in some quarters would meet with loud approvals.

But, we are more interested within the Bureau in solving the problem on a basis of what is the best answer in each individual set of circumstances, which circumstances we recognize can be variable over a considerable spectrum of climate, materials availability, labor costs, contractor capability, traffic demands, and a host of other factors which a prudent manager of the public's business must weigh, and at the same time, assign thereto an appropriate value. This requires the experience, training, and ingenuity of competent specialists in the bridge design and construction field. The best results in individual cases cannot always be achieved by an arbitrary arithmetic approach devoid of common sense and judgment. Nor do we in the Bureau desire to impose a decision or policy determination made unilaterally without benefit of consultation and joint conclusion with the States as working partners in a common endeavor aimed toward the same objective.

I bring this urgent matter to this committee's attention once again for the purpose of making a proposal to you. Under the organizational concept of the AASHO, in which the Bureau holds a single dues-paying membership, just as do each of you, the means to resolve this question is in your committee's hands. I am proposing to you the establishment of a work program that will find the answers with which to provide guidelines for each State to follow uniformly wherever similar situations prevail. If the comparatively heavier designs used in some States as I have just described to you are really needed, then in similar circumstances elsewhere they are also needed for proper engineering design, and anything short thereof is inadequately designed. The converse is equally true.

Therefore, I propose to you the establishment of special task forces of bridge design engineers to study this problem of bridge designs and costs. The instruction to these groups would be that they develop positive recommendations covering a range of different situations which all States can then follow in like circumstances. Their study should be based on the sound principles of engineering economies and should result in a series of typical bridge plans based on optimum design for each one of a range of circumstances. These could supplement the Bureau of Public Roads' present standard plans for highway bridges, and be accepted and used as a guide by all the States, just as are the Standard Specifications for Bridges developed by this committee in years past.

These task forces should include the best non-executive bridge design engineers available, supplemented as needed by able detailers and draftsmen. In my opinion there should be included to the maximum extent a goodly number of probable future executive personnel.

I suggest that these groups be organized on a full time basis with instructions that the work be completed within one year.

The Bureau is prepared to assist each working group in whatever ways we can do so, with money, facilities, and personnel.

Such a plan would not handicap the opportunity to develop new and experimental designs and concepts, because such can be handled as experimental projects, either under the Research programs available in several forms, or the regular experimental project provisions of current Bureau procedures. Meantime we can bring to bear the proven advantages of mass production on a repetitive basis, using designs which have been chosen from experience to produce the needed result at minimum costs to the public.

As a profession, as individual members thereof, and as those public officials carrying the responsibility for solution to this question, we cannot fail to work actively in the public's behalf. I hope that we ourselves will provide the answers to the questions I raise; for no other group anywhere is so qualified as we to know the right answers.

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