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Economics and Procedures For Construction of Concrete Bridges

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Economics and Procedures For Construction of Concrete Bridges

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Economics and Procedures For Construction of Concrete Bridges

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Contents

Economical Construction Practices Inseparable from Structure Design

K. R. SCURR, Bridge Consultant, South Dakota Department of Highways, Pierre

This paper develops the thesis that modern technology has made available new and improved materials, equipment, and techniques that can contribute substantially to more economical construction of bridges. It discusses briefly the several categories in which outstanding advances have been made. It further develops the idea that the fullest advantage of economics inherent to these technological advances cannot be realized unless the designer is fully aware of them and creates structure design which permits their incorporation.

The paper avoids the use of examples, which reflect only the ideas of an individual designer, by emphasizing the fields and categories in which the advances have been made. It discusses the economies that can be achieved by a designer with a complete awareness of shop practices in fabricating plants, form building processes and devices, falsework types available, welding equipment and new materials.

It also emphasizes that any of the technological advances may be nullified by a designer who creates plans and writes specifications that inhibit their use.

• NEVER BEFORE has there been available to the structural designer and contractor such a vast reservoir of tools for more economical construction. These tools include new and better materials, new and improved techniques both in fabrication and construction, larger capacity handling equipment, and better form and falsework devices.

The full potential for economy resulting from these technological advances cannot be achieved, however, unless the designer is aware of, and uses, them. Construction and fabrication details indicated on plans must permit efficient use of the tools available to both fabricator and contractor. The use of specifications written for an earlier period when these means were not available often denies the contractor opportunity to exercise any initiative. Special provisions and plan notes are often so restrictive that real economy cannot be achieved. Only the designer can mobilize all the available tools in such fashion that they can combine to produce maximum economy.

This paper only attempts to discuss the several categories in which advances have been made. It merely generalizes the economic advantage that can be achieved by a designer who is acutely aware of the potential economy of designs that permit the maximum efficient use of new materials, construction methods, and equipment. Specific details, which reflect only an individual designer's preference, will be avoided.

STEELS

During the recent decade, the steel industry has made outstanding progress in the development of new steels. Some have generally improved mechanical properties and chemical compositions, and others are formulations having desirable characteristics for specific purposes. The designer must be aware of all these available new materials, their prices, and their advantages and disadvantages from a fabrication and construction standpoint.

Structural carbon ASTM A-7 steel has long been the most common grade used in bridge construction. It commands no premium in price and is still the most common grade used in main members and practically all secondary members where minumum section, size, and thickness specifications govern. The fact that the chemical requirements for A-7 steel do not provide a maximum carbon content limits its use in welded structures. However, a review of chemical analyses show that 95 percent or more of A-7 steel actually falls into the range of composition specified for weldability. The careful designer will make detailed design comparisons, both economic and functional, to justify the use of the premium steels.

Structural steel for welding, ASTM A-373, was developed to meet the demand for a weldable steel for bridge main members. It has given impetus to greater use of welded girders in place of large wide-flange shapes. It commands a modest price premium, but the saving in weight resulting from simpler welded details and fabrication economies more than offset this premium.

Structural steel ASTM A-36 steel is potentially the most useful of the recent steel developments. Its physical characteristics are improved by approximately 10 percent above A-7 steel and with a cost increase of only $1.00 per ton it produces real economy in bridge construction. However, this advantage has been denied to designers of Federal-aid bridge projects involving welded members by a controversy over the weldability of the A-36 grade. The majority of user organizations consider it to be fully weldable when proper procedures are used. A minority, which includes the Bureau of Public Roads, has rejected its use in welded bridges except as cover plates not exceeding 1 in. welded to rolled girder shapes.

The new high-strength structural steels ASTM A-440 and ASTM A-441 steels are most economical materials which have resulted in the extension of the economic range of welded plate girders well into the span lengths that were formerly considered appropriate only to trusses. Girders in the 200- to 350-ft range are now commonplace and permit the added advantage of unlimited vertical clearance for relatively long span structures. The higher price of these steels is more than offset by the reduction in weight resulting from their higher allowable design stresses. The costs are now so well-established by common usage that economic comparisons can be accurately made to establish the sections of trusses or girders that can profitably employ the higher strength, higher priced steels.

Still higher strength steels are available in special quenched and tempered grades. The best known of these, commonly called T-1 steel, is available for use, usually in high-stressed members of long-span trusses; its economy can be readily established by careful analysis and cost comparisons. Outstanding examples of the use of this material are the new Carquinez Strait bridge and the Benecia-Martinez bridge in California. A 100,000-psi yield strength steel is being used experimentally in pilot projects in Iowa involving the prestressing of steel girders. The economy of this plan would seem to hinge on the development of fabrication techniques. The principle is sound and designers should watch this development carefully.

Steel Fabrication and Erection

Fabricating plants are accustomed to working with structural sections rolled to tolerances adopted by the steel industry and to fabricating requirements, either welding or bolting and/or riveting, in conformity with AWS or AISC specifications. If a designer, by plan note or special provisions, requires more precise measurements, smaller tolerances or more restrictive methods, an additional charge is justified and some economy is sacrificed. Constant liaison with fabricators is desirable in order to know which details and operations are proving costly. Usually modifications of these details can affect economics at no sacrifice to the functional excellence of the design.

Heavier handling equipment and the ability to transport long loads, either on multiple railroad cars or by truck and trailer, enable the designer to provide for members of greater length to be fabricated in the shop with lower fabrication costs. Fewer field splices reduce the erection costs by reducing falsework requirements and the number of costly field connections, either riveted, bolted or welded. The erector may often furnish valuable suggestions as to modifications of the next design, which might result in more economical erection. For example, bracing frames can be designed to be fabricated in the shop and shipped as assemblies instead of individual members to be interconnected in the field.

A fertile field for economy is the duplication of members and details. Careful design, especially of handrail members, joists, panel lengths and cross-bracing frames may result in repetition of details that will affect reduced fabrication costs.

Techniques have been developed for continuous welding of plate girders which enable designers to use fabricated girders at a lower total cost than rolled sections of the same section modulus, by taking advantage of the more efficient distribution of metal. Carbon dioxide welding is showing great promise as an economical technique. Button welds connecting thin plates in secondary details may cut costs in the shop.

The merits of composite steel and concrete construction are so well-established as to need no mention. However, the type and method of fastening shear connectors influences economy of this construction also. The development of the automatically welded stud has reduced the "time in shop" sufficiently to show a net reduction in costs in most shops.

Hybrid steel girder design, using webs of lower strength steel and flanges of higher strength steel, offers promise of being an important step forward in economic design of girders. The design principle is valid, and testing already completed supports the design assumptions. However, the public agencies that must approve such designs are, as always, slow to accept anything new and final acceptance of the hybrid girder design probably hinges on wider acceptance of plastic or ultimate strength design for dynamically loaded structures and on further test data in fatigue strength of such girders.

Reinforcing Steel

The recent development of new, higher strength and large-diameter bars is a tool that will become more useful to the designer as wider acceptance is achieved.

The A-432 reinforcement bars are available at prices competitive with A-15. They will permit wider bar spacing and less steel or smaller concrete sections, all of which may result in economy. The wider spacing results in an economy by handling fewer bars and by easier pouring of concrete into forms and around the reinforcement. A-431 bars command a premium but may also prove economical as in the case of the A-432 bars. With either of these reinforcements economy dictates the use of 4,000-psi, or stronger, concrete. However, because such concrete is already in use in most States and concrete to 5,000 psi is easily and economically produced, this requirement poses no problem.

The king-size 14 S and 18 S bars have a distinct place in economical design. They can be utilized more easily and more satisfactorily than bundled bars which have been utilized with some success by a few designers. They are also quite useful in heavy frames, usually foundation elements.

CONCRETE

Cements, aggregates, additives, controls, and mixing and placing techniques have all been improved to such an extent that reliable 4,000-psi, and stronger, concretes can be custom-produced with negligible additional cost. When it suits his purpose, the designer need feel no hesitancy in specifying high-strength concretes, keeping in mind only the benefits obtained compared to the added costs incurred.

Lightweight aggregates now available commonly produce concrete in the 4,000 to 5,000-psi range with weights of 96 to 110 pcf. They usually cost substantially more per cubic yard in place, but the saving in materials in supporting members may justify its use in bridge floors.

Awkward, small-area pouring sequences formerly required for continuous span floors are costly operations. Larger mixing, pouring, and finishing capacities combined with judicious use of retarder additives often permit continuous pours with resulting economy.

Prestressed concrete construction is so well-established and so widely used that the designer need only know the comparative costs of prestressed structures and the alternative type of structure to make a proper economic selection. Because the industry has developed standard methods and shapes, much as in the case of the steel industry, it is incumbent on the designer to recognize these standards, especially when pre-tensioning is desired. More latitude is available when post-tensioning is desirable or permitted. Maximum economy usually results when only the tensioning forces are specified and the contractor is afforded the option of pre-tension or post-tension methods.

BEARINGS AND EXPANSION DEVICES

Bearings and expansion devices are the "jewelry" of the steel industry. There are more types and less uniformity in these details than in any other element of bridge construction and their cost in many cases is out of line with the value of the function performed. Fortunately, this situation is being bettered by use of comparatively recent developments.

Elastomeric-bearing pads give promise of more economy for bearings for relatively short-span bridges. They permit both movement and rotation of the span. Elastomer joint fillers are available which improve the sealing and riding qualities of joints between short spans.

The development of oil-impregnated bronze bearings has extended the length of the span that can be carried on sliding plates. However, the very long spans must continue to use combinations of rollers or pins and rockers that are very expensive to produce.

FORMS AND FALSEWORK

Form costs are a major item and the designer must keep in mind three questions and their answers in designing concrete details: (a) how will the form be built; (b) how will it be removed; and (c) can it be used more than once? A concrete design for which it is simple to make or procure forms that can be stripped without damage and re-used in the structure lends itself to maximum economy.

Metal and fiber forms are commercially available for column and floor unit sections. Although designs should not be made for use of any specific form, it is only good judgment to keep column sizes and floor spans and panels in dimensions that permit the contractor the option of building such forms himself or buying or renting them.

CONCLUSION

This paper has discussed a few, but by no means all, of the available means that the careful designer will consciously consider to attain his goal of economical construction. The attributes, over and above technical competence, that distinguish the master in his field from the merely adequate craftsman included the following:

1. Awareness and imaginative use of new materials, methods and machinery.
2. Familiarity with fabrication and construction procedures and a willingness to adapt designs to proven economical techniques.

Finally, it cannot be too strongly emphasized that the finest materials available, the improved techniques developed, and the contractors know-how on the job can be mobilized for the attainment of excellence and economy only by the design engineer with awareness, initiative, and imagination.

Discussion

M. G. SPANGLER, Research Professor of Civil Engineering, Iowa State University, Ames—The author has presented a powerful and convincing argument in favor of closer and more intimate liaison between those phases of the production of a finished structure usually labeled "design" and "construction." The writer is in complete agreement with his thesis and wishes to offer a few experiences that lead to the same conclusion. If one may think of design and construction as the right and left hands of an engineering organization, here is a perfect example of the need for the right hand to know what the left hand is doing, and for the left hand to know and understand the reasons for what the right hand has done.

The writer's opportunities for observation of construction have been primarily in the field of underground conduits, such as sewers, culverts, and similar structures. On occasion, the lack of coordination between those who designed the structure and those responsible for its construction according to the plans and specifications has been appalling. In the fall of 1960 there was a great deal of talk about the "missile gap" during the presidential campaign, although it now appears that such a gap did not really exist or at least has closed very rapidly. The gap between engineering design and construction is, in many cases, much wider than the so-called missile gap, even at its widest point as proclaimed by the uninformed, and this gap is closing very slowly, if at all.

The lack of coordination between design and construction probably can best be described by citing some specific examples. These examples are real and not imaginary.

Several years ago in one of the provinces of Canada, a newly constructed storm sewer experienced extensive structural failure of pipelines 18 and 20 in. in diameter. Too often, and it was true in this case, when failures of this kind occur, the resident engineer comes out with a statement that the pipes were no good. This readiness on the part of engineers to attack the quality of the material used on his project is always somewhat puzzling because he is, in reality, condemning his own engineering service. It is the duty of the engineer in charge of construction to see to it that the materials furnished are of acceptable, specified quality. In the field of underground conduits there are plenty of tests the engineer can perform to insure good quality.

When such an accusation is made, the pipe manufacturer is put on the defensive. If he has faith in the quality of his product, he is on the horns of a dilemma; whether to counter such a claim and thereby possibly alienate the good will of a valued customer or tacitly to accept blame for the failure and possibly keep the customer's good will and sell him more pipe in the future.

In this case, the pipe manufacturer decided to resist the claim that the pipe was faulty. The writer was asked to investigate the cause of the failure. Examination of the plans and specifications and tests of the quality of the pipes indicated that they should not have failed if they had been installed according to these documents. In an interview, the resident engineer stated emphatically that the pipes had been installed on the specified Class B bedding and that the width of trench did not exceed that specified. The quality of bedding and the width of trench are vital elements in the structural performance of a sewer line.

Next, the contractor's foreman who had installed the pipe was interviewed out on the job. He described the method of bedding the pipes and his description fell far short of the high-quality procedure required to obtain a Class B bedding. He was then asked about the width of trench in which the pipes were laid. He stated that a back hoe was used for the excavation and pointed to a machine standing about one-half block away. When the width of the bucket was measured, it was found to be 4 in. wider than the maximum ditch width allowed by the specifications. The foreman expressed the opinion that in all probability the actual width of trench was somewhat greater than the width of the bucket. To verify this, a trench was dug at right angles to the pipeline down to the top of the failed pipe. The planes of contact between the backfill soil and the sides of the original trench were easily identified. A measurement indicated that the actual trench was at least 6 in. greater than that specified.

A quick calculation using the actual ditch width and the probable type of bedding obtained, as described by the foreman, indicated that failure of the pipeline was inevitable. It was simply overloaded by a wide margin. If it had been constructed in the manner specified, it would undoubtedly have carried the load without difficulty. This was a clear-cut case of poor coordination between design and construction and a lack of understanding of the importance of certain details of the design. The result was a very costly failure of what should have been a successful structure.

In another situation in a Midwestern State about ¼ mi of 20-in. sewer pipe failed during construction, and the contractor was required to reconstruct the line. An investigation revealed that the going was quite wet in this location. The contractor elected to use a shield in the bottom of the trench to protect workmen during pipe laying operations, and to reduce the amount of excavation. The shield was a steel structure with parallel vertical sides which were 5 ft apart, out-to-out. This dimension established the width of the ditch at the level of the top of the pipe and was much greater than the width permitted by the specifications. Calculations indicated that if the specified ditch width had been adhered to, the pipes would have carried the load safely, but with a shield as wide as the one used, the pipes were seriously overloaded and the failure could be accounted for readily.

The investigation revealed that the consulting engineer who had designed this project had a resident inspector on the job at all times during construction. The inspector did not at any time call the attention of the contractor to the fact that his ditch was too wide and that trouble might later develop because of this fact. He remained completely silent relative to this gross violation of the specifications. When questioned about this matter, he stated that he did not wish to tell the contractor how to do his job. The writer is not a lawyer, and does not pretend to know where legal responsibility resides in a case like this, although the contractor probably had to pay the bill for reconstruction of the line. However, the engineer had a moral obligation to guide the contractor and control the construction in accordance with the plans he had prepared. His failure to do so constituted a gross violation of his responsibility. Another clear-cut case of poor coordination between design and construction, in spite of the fact that the designing engineer and the engineer in charge of construction were one and the same person.

Several years ago the writer served on a task force that prepared Chapter IX on Structural Requirements of the American Society of Civil Engineers Manual of Practice No. 37 (Water Pollution Control Federation Manual No. 9) on Design and Construction of Sanitary and Storm Sewers. When the factor of safety for sewer design was under discussion, there were, as might be expected, wide differences of opinion as to a suitable factor of safety to recommend. One very competent engineer from the sewer design department of a major Midwestern city argued very strongly for a factor of safety that some members of the task force considered to be excessively high and uneconomical.

The reason advanced by this engineer in support of a high factor of safety was that in his city the sewer design department and the sewer construction department were entirely independent of each other. He stated that no matter how well-executed a design might be, when the plans were turned over to the construction department there was no assurance that the specified design details would be adhered to. Therefore, a relatively high factor of safety was necessary.

Such a lack of coordination between design and construction is indefensible. An administrative officer who permits such a lack of intercommunication is extremely unwise. The public is entitled to protection from the potentially costly results which may accrue from a situation such as this.

There are times when highway department construction forces are given too much leeway to change plans of structures without consultation with designers. Some years ago, a monolithic arch culvert design called for a break in the grade of the flow line to meet the conditions imposed by a cutting stream bed. The design provided for a steep grade in the upper two-thirds of length and then a flat grade to the outlet. The structure as designed had a break in grade which was concave downward in relation to a straight line from inlet to outlet. This design required a considerable, though not excessive, amount of excavation.

When it came to construction, the resident engineer decided to save some excavation and reversed the situation by flattening the grade in the upstream portion and steepening it at the downstream end, making the grade concave upward. This decision, made without consultation with the design department, resulted in two adverse features in the completed structure. First, the exit velocity of the effluent water was greatly increased, creating potentially dangerous scouring velocities below the culvert. Second, the site was located in a region where subsidence of the natural ground under the weight of an embankment was unusually great. This latter situation caused the culvert to settle a relatively large amount. Because of the concave upward conformation of the barrel, very high compressive stresses were generated at the junction of the upstream flat section and the downstream sloped section as this settlement developed. These compressive stresses were sufficient to crush the concrete in the crown of the arch at this junction.

Still another decision that was made in the field without consultation with designers was to permit end dumping of about the first 15 ft of the embankment material. This caused lateral forces to be exerted against the culvert and it was displaced laterally about 1 ft in the central region of the barrel. This lateral displacement caused the sides of grooves of the tongue and groove joints in the barrel to shear off, creating open joints for potential infiltration of soil.

This culvert is continuing to fulfill its function as a passageway for water under the highway embankment, but it is not as good a structure as the public paid for, and not as good as it might have been if there had been closer coordination between those who designed it and those who supervised its construction.

These examples have been few in number, but similar observations could be multiplied many-fold. There is a need for improvement in liaison between design and construction and a closing of the gap between these two important facets of engineering practice. Chief engineers and other administrative officers of engineering organizations; State highway departments; city and county public works dpeartments; and consulting engineers in private practice—all need to take a look at their respective organizations and be sure that the right hand of design knows what the left hand of construction is doing, and vice versa.

Continuous Integral Deck Construction

A Rational Approach to Placing Structural Deck on Three-Span Continuous Bridge Units

H. B. BRITTON, Senior Structural Specifications Writer, New York State Department of Public Works

Establishment of structural concrete slabs on three-span continuous structures has been accomplished, in general, by segmental placement. This has resulted in difficulty in obtaining properly constructed, smooth riding surfaces. When composite design and construction was adopted, the segmental practice introduced other undesirable side effects which were not realized until a later date.

A request to place the structural slab with integral wearing course on the three-span continuous units on the Bruckner Expressway in Bronx, N. Y., was received in June 1959. This is a divided structure having an over-all width of 94 ft, with each structure having a minimum travelway of 37½ ft. There is an 11-ft mall between the travelways. Each three-span continuous unit is approximately 210 ft long.

In recognition of the contractor's resourcefulness and ingenuity in providing equipment, together with experience gained by bridge office personnel since 1955 in the use of retarders, a field research program was set up so that data could be obtained relative to deflection of the stringers (theoretical vs actual), location of the reinforcing steel together with the required cover, and controlled addition of the retarding admixture, as well as a complete physical report of the concrete placed for this operation.

The results obtained have been significant in that this structure, which is 1 mi long, has exhibited minimal minute cracking in but a few of the many three-span continuous units. The riding quality of this structure is exceptional, as the average final field profile varies from the theoretical profile by only 0.020 ft.

• IN RECENT YEARS numerous articles dealing with the desirability and production of smooth-riding concrete bridge decks have been written. It is the consensus of the writers that the general public judges a structure almost entirely on the smoothness or roughness of the ride obtained.

The conventional technique of production, placement, and finishing of structural concrete decks on steel stringer construction has been adequately described by Harry A. Hartmann, Construction Engineer for the New Jersey Highway Authority, in his article on the Raritan River Bridge on the Garden State Parkway (1) and paper by the Portland Cement Association (2), as well as a paper by Nomer Gray of the firm of Ammann and Whitney (3).

These papers are classic and fundamental in their relation to time and the subject matter. However, a new era has been entered in which recognition must now be given to new materials and procedures, with the resulting new technique that will produce a better end product and assure the obtaining of a smooth riding bridge deck.

The paper by Gray should be required reading for every contractor and engineer in the field of bridge construction. It not only deals with the difficulties encountered in the attainment of the riding surface desired but indicates most clearly the responsibilities of the design engineer, the contractors, and supervising construction engineers, as well as their cooperative relationship one to the other. He has most certainly recognized the possibility of a solution to the problem of smooth riding bridge decks and indicated that there was need for a study and report on the results obtained. It is hoped that the findings contained in this paper will constitute a report on such a study and will justify its being used in conjunction with Gray's paper because he has so cogently outlined the many attendant problems.

MULTIPLE SPAN BRIDGES

Multiple span structures such as the numerous three- and four-span bridges carrying or crossing expressways and to a greater degree the much longer viaducts required in large metropolitan areas, should give cause to employ every means to eliminate the annoying thump at joint areas and the long waves in the wearing course, which, though meeting the ⅛-in. deviation in 10-ft criterion, yet cause a sensation of roughness at high driving speeds.

A reduction in the number of joints in any given structure will enhance its riding qualities. This indicates that continuous structures of three or more spans with the elimination of any joints between the end finger joints would be advantageous.

As for the elimination of the long wave, this can be accomplished with proper design, evolvement of engineering technique in the field, and proper use of well-designed construction equipment.

CONVENTIONAL DECK-PLACING SEQUENCE

It has been the generally accepted practice to place the deck concrete for continuous structures in segments. A placing sequence is usually indicated on the contract plans. This procedure requires the contractor to place transverse bulkheads at designated locations. This creates within the finished structure a joint that causes an undesirable and objectionable thump. Further, because it is a more or less general rule to employ composite design for steel bridges with cast-in-place concrete decks, difficulties have been encountered in obtaining true composite action while attaining a smooth riding surface.

Conforming with composite design criteria, steel stringers are required to take all the dead load and they are cambered accordingly. The structural deck concrete should not be stressed and its bond to the shear connectors should not be strained under the applied dead load acting alone.

In considering a deck that is placed in segments, after the first segment has been placed, only part of the camber is removed from the supporting stringers, but the concrete has started to set and bend to the shear connectors in this intermediate deflected position. Not only does this span have incomplete camber release but upward deflection occurs in the stringers of the succeeding span. When the concrete for the next segment in the sequence is placed (which is usually before the previously placed concrete has reached full bond strength), the deflection picture changes radically. There is a very good chance that the bond between the deck concrete and the shear connectors in the previous segment is damaged, if not destroyed. Subsequent placements in the sequence change or attempt to change the deflected contour of the stringer again with the result that more bond to the shear connectors is lost or the theoretical grade of the finished surface is impossible to attain.

ADVANTAGES OF CONTINUOUS PLACEMENT

From the foregoing it would then appear that the most practical solution is to place the concrete progressively on continuous composite I-beam units. The ideal situation will be to get all the concrete dead load on the structure before initial set takes place. The stringers will then assume their final dead load deflected position. The concrete of the structural slab will be able to attain its set with zero stress under the resulting dead load acting alone. Because no live load is permitted on the structure until the concrete has attained its design strength, there is no application of a force that will develop movement to disturb the bonding of the structural slab to the shear connectors.

Prerequisites for Continuous Placement

Continuous placement can be a practical solution to the problem if the following factors are observed:

1. The intelligent use of admixtures having a proven performance record that are designed to delay, in a controlled manner to the desired degree, the initial and final set of the concrete beyond the normal setting time without producing any side effect such as unduly influencing air content, drying shrinkage, and curing characteristics.
2. The contractor's complete understanding of the factors involved, thereby providing responsible and adequately trained personnel as well as supplying the equipment required for the proper prosecution of the job.
3. The engineer's recognition of his responsibility for
   (a) Supplying the contractor with all necessary data for setting forms and placing reinforcement.
   (b) Collection of all required data for the control and production of concrete to meet construction conditions and methods.
   (c) Inspection technique to insure production of quality controlled concrete.

There are both structural and economic advantages to be gained by continuous placement of concrete for the structural decks of viaducts of this nature.

Structural Advantages

The structural advantages are due to the following:

1. Production of a monolithic, homogeneous structural slab having true composite action.
2. Elimination of construction joints.
3. Elimination of cold joints.
4. Reduction in plastic cracking and drying shrinkage cracking.
5. Assurance of sufficient cover over the top reinforcement which will provide required protection and prevent concrete popping and spalling at the top surface.

Economic Considerations

The economic advantages are due to the following:

1. Reduction in the number of moves on and off a given unit by the contractor's men and equipment affects completed construction.
2. Development of equipment and techniques will reduce the number of men required for proper placement and finishing of the concrete.
3. Labor and materials required for establishing transverse bulkheads can be saved.

Progressive concrete placement of structural decks on continuous units has been used in recent years but no data were collected that permit comparison of final field results with theoretical calculations. Further, some very serious problems have resulted from lack of knowledge. These negative results are important in that they have given direction to the test program.

CONSTRUCTION DATA

The purpose of the program undertaken was to test the validity of the assumption that by using a set-retarding admixture and improved techniques in placing and finishing, all concreting on three-span continuous structures could be progressed in a manner that would eliminate rough riding characteristics and at the same time provide complete composite action in the finished structure.

Test Project

The test program was conducted on June 18, 1959 on a portion of the elevated structure carrying the Bruckner Expressway in Bronx County, N. Y. This portion was constructed under Contract FIBE 57-3 covering a 1-mi section of the Expressway which when completed will be approximately 8-mi long and cost in excess of $68,000,000. This Expressway will ultimately connect the New England Thruway with the Major Deegan Expressway and the Triborough Bridge. It is a divided structure having an over-all width of 94 ft. Each structure has a minimum travelway of 37 ft 6 in.; safety walk, fascia parapet, and railing; and a 5 ft 6 in. mall area. This provides an 11-ft mall between the travelways. Each divided unit is made up of six I-beam stringers with an 8 ½-in. thick structural concrete slab with an integral wearing course. Composite action is provided through the use of stud shear connectors. The total length of each complete divided unit is 204 ft made up of three-spans each 68 ft long.

Test Program

The test program as outlined contained the following requirements:

1. Theoretical deflection calculations to be submitted before placing any concrete.
2. Deflection measurements to be taken continually during the entire concrete placement operation.
3. Final deflection readings to be taken at the conclusion of the placement of all concrete.
4. A method be provided to insure the accurate location of the reinforcing steel together with the required 2-in. cover over the top reinforcement.
5. The proportion of the set-retarding admixture to be so controlled that the plasticity of the concrete in place be relatively the same at any given section and time.
6. A complete physical record to be kept for the concrete placed for this operation. This record to include gradation of the aggregates, together with temperature and moisture content. The record is also to include slump, air content, water reduction factor, temperature of concrete when placed, as well as ambient air temperature and humidity, weather and other conditions, timing of progressive placements, time when burlap drag was accomplished, time when curing was begun, method of curing, and results obtained.

Construction Methods

Thorough preliminary engineering work was considered vital to the success of a continuous deck placement. The aim was, of course, to have the finished roadway conform exactly to the computed values for line and grade.

Before placing concrete, the existing elevations of erected steel were checked and recorded. Each stringer was checked at each bearing point and at the quarter points of each span. Using the computed values of the final roadway elevations as a base and the actual elevations of the stringers considering grade, crown, vertical curve, and dead load deflections, a value was computed for the haunch fill at each point considered. Working from these definite values which were computed separately by contractor and engineer, the forms, reinforcing steel, and screed rails were set. It must be remembered that the screed rails which support the finishing equipment were mounted over the exterior stringers. This additional load was and must be considered when computing elevations above these two stringers.

Reinforcing steel for the structural slab was accurately positioned by welding plain steel bars to the shear connectors, and by using chairs of varying heights (Figs. 1, 2, and 3).

Equipment.—The normal equipment used in this construction procedure included trucks for the transportation of the dry batch ingredients for the concrete, a 34E paver, a 3-cu yd laydown bucket, one crane, movable finishing bridges, floats, and vibrators.

Special or unusual equipment employed on the structure included a Heltzel-Plane oscillating screed finishing machine capable of finishing a roadway surface 38 ft in width and an ingenious motorized track-mounted buggy for placing and distributing the concrete. This latter piece of equipment consisted of two parallel inverted trusses secured to end plates with wheels attached to allow it to use the screed rail in the same manner as the finishing machine and the follow-up bridges. The buggy carried a 1-cu yd side dump hopper and rode on tracks built on top of the parallel trusses. The dump

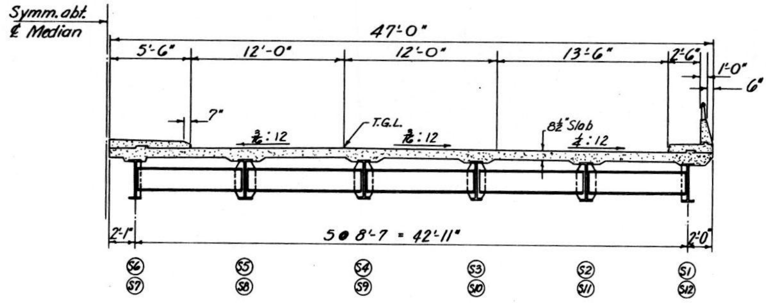

Figure 1. Transverse section.

hopper was activated by a hydraulic ram. On the outboard end of the assembly was mounted a 3-cu yd laydown bucket converted into a receiving hopper. Concrete was hoisted from the mixer site by means of a 3-cu yd laydown bucket and deposited into the receiving hopper. The concrete was then transferred from the receiving hopper to the side dump hopper by its operator and moved transversely into placement position. Concrete was then deposited in such a manner as to require a minimum of hand labor for its distribution to final positioning. At the present time this piece of equipment is not self-propelled but is kept ahead of the finishing machine by using planking as separators between the two pieces of equipment.

Before any concrete was placed, a template 1⅝ in. thick was attached to the screed of the finishing machine and then moved across the entire length of the area to check that the minimum clear cover over the top reinforcement would be maintained.

Placement of Concrete.—Meteorological data were obtained so that the set-retarding admixture could be properly proportioned to insure that uniform relative plasticity of the concrete could be maintained throughout the whole operation. Inspection was maintained for the control of the concrete, for slump, air content, and temperature.

The amount of concrete required for the entire three-span unit was 270 cu yds. Placement of the concrete was started at 9:50 AM and completed at 4:12 PM. The contractor had been instructed that once the operation began there would be no interruption in the placement, for coffee breaks, lunch, or the like. He would platoon his men so that the continuity of the operation be maintained.

It was determined that the set-retarding admixture (Plastiment powder) would be proportioned at 1¼ lb per bag of cement for concrete in the first span and one-quarter of the second span, then reduced to 1 lb per bag of cement for the concrete in the remainder of the second span, then reduced to ¾ lb per bag of cement for the concrete in the third span.

Construction Operation.—Concrete was mixed and placed for the entire 47-ft width of the section for a length of 15 ft. It was then properly consolidated by internal vibration before the oscillating transverse finishing machine was put into operation.

Figure 2. Deck under construction.

Figure 3. Bridge during construction.

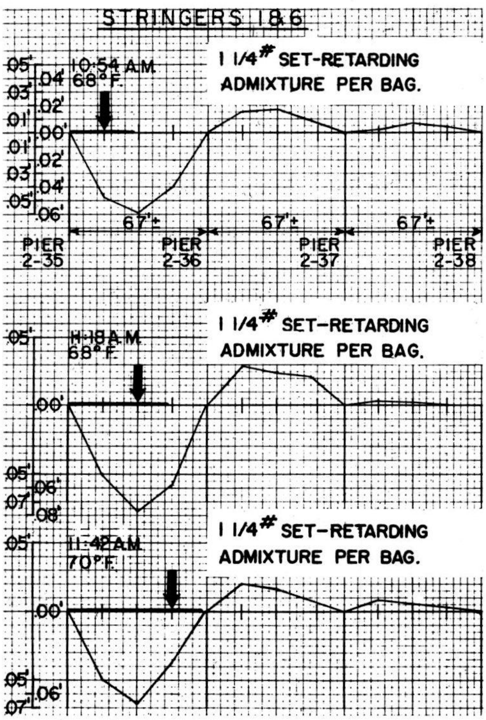

Figure 4. Progressive deflection chart, stringers 1 and 6.

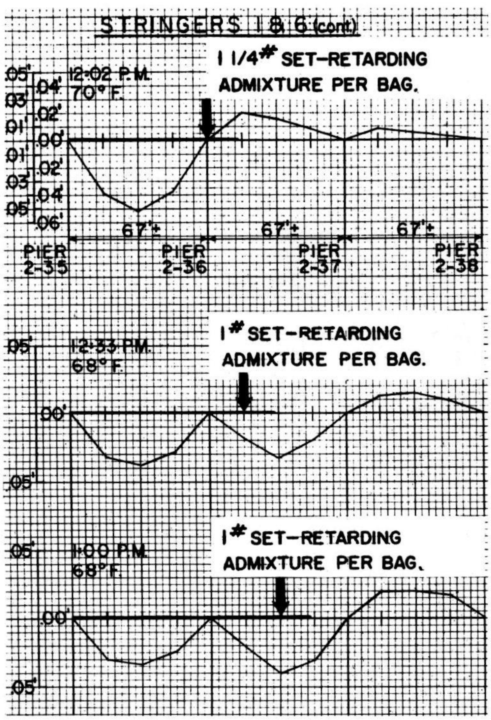

Figure 5. Progressive deflection chart, stringers 1 and 6.

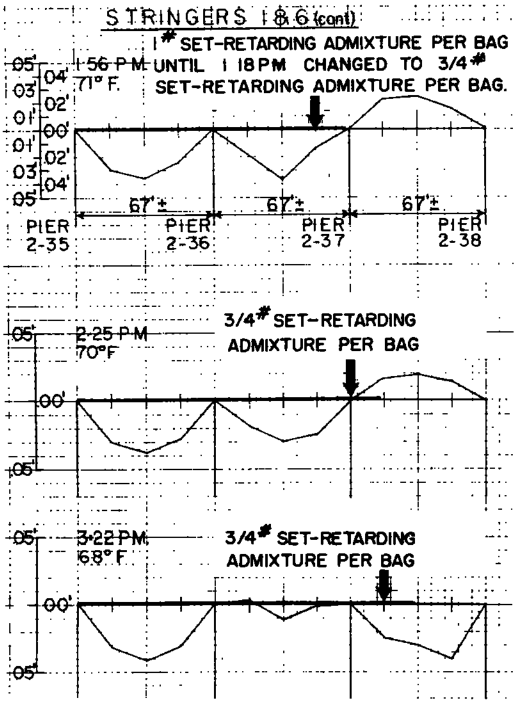

Figure 6. Progressive deflection chart, stringers 1 and 6.

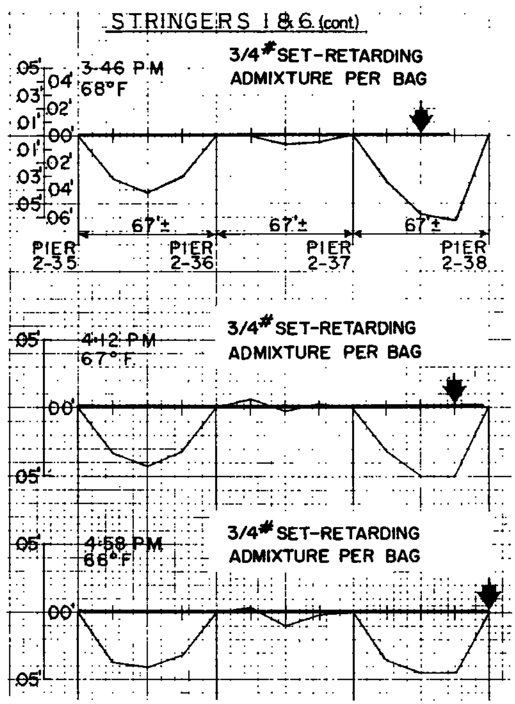

Figure 7. Progressive deflection chart, stringers 1 and 6.

Throughout the entire operation the concrete was placed and vibrated 15 ft in front of the oscillating transverse screed. In progressive deflection charts (Figs 4 through 7) this placement is represented by a heavy horizontal line at datum elevation 0.00.

During the placement, a metal gage plate 12 by 8 by 1/8 in. was thrust into the concrete just before the longitudinal float was used. This gage plate indicated accurately the actual distance from the top of the reinforcing steel to the surface of the finished concrete deck slab. This measurement of the concrete cover over the reinforcement was taken at all quarter points and recorded by the inspector. The largest measurement of concrete cover was 2 1/4 in. but in the majority of cases the measurement was 2 or 2 1/8 in.

The longitudinal finishing operation followed closely behind that of the oscillating transverse finishing machine. This operation was conducted from two movable bridges spanning the entire width of the structure.

After the straight-edging operation was completed, the finished surface was given a burlap drag.

Curing was accomplished by the use of quilted covers which were kept wet and left in place for five days.

Concrete Control

Six cylinders for test purposes were cast (or molded) for each 100 cu yd of concrete or portion thereof. This was done so that two cylinders of each set could be broken at 7, 14, and 28 days.

The report of the data compiled for this program indicated the placement of 270 cu yd of concrete in 6 hr 22 min. A reduction in the water requirements of 22 percent was noted while maintaining a slump of 2 1/4 in. with an average air entrainment of 6 percent, compared to similar non-admixture and non-air-entrained concrete.

The following test results are the average on 6 cylinders at the designated age:

7 days, 2,810 psi; 14 days, 3,920 psi; and 28 days, 4,105 psi.

Deflection Measurements

The measurements of the deflection of the stringers for the continuous placement of concrete for the three-span continuous units were taken so that the effect of this type of operation might be better visualized as well as to confirm or disprove the validity of the thesis relative to the possibility of intermediate deflections in the stringers.

Telltales were installed at the quarter points of each stringer and reference elevations established. Level rod tapes measuring to 0.01 ft were installed before the commencement of the program. This resulted in 18 telltales being installed for each span. Deflection readings were recorded during the progress of the work. Three level crews were deployed (one crew for each span), and on a given signal indicating that the finishing equipment had reached a quarter point, readings were taken on all 18 telltales in each of the three spans. The results of these readings are shown on the progressive deflection graphs for stringers 1 and 6 (Figs. 4 through 7). These stringers are the exterior ones which support the rails on which the concrete placing and finishing equipment travels. The progressive deflection pattern for stringers 2 and 5, and 3 and 4 similar to those obtained for stringers 1 and 6 differs only in magnitude.

Final deflection measurements were taken on completion of the placing and finishing of the concrete on the three-span continuous unit. These measurements were taken in order to compare them with the second set of final deflection readings taken two days later so as to have representative results that could be compared with the theoretical deflection data.

Final measurements indicating the deflection on stringer 1, for purposes of indicating the relation between the theoretical and the first and second actual, and the theoretical and actual crown elevation of the finished structure, are given in Table 1. The results contained in this table indicate that the original assumptions have been confirmed.

CONCLUSIONS

The program, although large in scope, was well worth the efforts expended. The purpose for which this program was set up has been accomplished. It has resulted in a structure without any type of construction joints in the 204 ft between finger plates and without any evidence of plastic shrinking or drying shrinkage cracks or checking in the entire surface.

The results obtained prove that continuous multiple-span placing of concrete has wide application together with structural and economic advantages. This paper shows the way to attain highly successful results through the proper use of materials, methods, and control.

In the 2 ½ years since construction, this deck has exhibited only a few discontinuous transverse cracks which can hardly be observed except during the drying period after a rain.

To date approximately 3 mi of Bruckner Expressway have been constructed using the methods described herein. Results obtained are of the same order of excellence as those achieved at the test area.

Because the program undertaken here has proven that smooth riding structures have been advanced from the theoretical

TABLE 1

FINAL MEASUREMENTS FOR DEFLECTION STRINGER 1 AND CROWN ELEVATION

Location	Stringer (ft)			Elevation (ft)	
	1st[a] Actual	Theor	2nd[b] Actual	Actual	Theor
Pier 2-35				65 498	65 495
1/4	0 034	0 040	0 032	65 394	65 398
1/2	0 042	0 051	0 040	65 327	65 314
3/4	0 031	0 028	0 030	65 247	65 230
Pier 2-36				65 184	65 147
1/4	0 000	0 000	0 001	65 094	65 063
1/2	0 010	0 004	0 012	65 017	64 979
3/4	0 000	0 000	0 002	64 936	64 895
Pier 2-37				64 843	64 812
1/4	0 030	0 028	0 025	64 762	64 728
1/2	0 048	0 051	0 040	64 643	64 644
3/4	0 040	0 040	0 033	64 567	64 560
Pier 2-38				64 486	64 479

[a]Taken directly after completion of finishing of concrete
[b]Taken in morning, 2 days after placing

to the actual, the author feels that certain guides should be established so that the results desired may be achieved.

When construction of this type is anticipated or desired, recognition of the results desired and the methods required, must begin at the design stage. Proper recognition must be given to the contractor's methods of operation as well as his equipment and personnel. Advantage should be taken of the advance made in equipment design that will aid in obtaining a better end product, while at the same time providing gains of an economic nature.

As an illustration of this, when this test program was made, the largest oscillating transverse finishing machine could produce a finished surface 38 ft in width. On the present contract of the Bruckner Expressway, the contractor is using an oscillating transverse finishing machine that will finish a section 52 ft in width. The use of this piece of equipment allows the contractor to produce the accelerating and decelerating lanes at the ramp areas at the same time the travelway portion of the concrete is being progressed.

The preliminary engineering work described under "Construction Methods" is essential for the successful placement of a continuous concrete deck with regards to forming, location of reinforcement, and the attainment of the finished roadway indicated on the contract plans.

The quality of the concrete should be controlled throughout the entire operation. The proportioning of the set-retarding admixture must be so controlled that the plasticity of the concrete in place be relatively the same at any given section and time. Factors to be considered for this proportioning of the retarding admixture will be the number of cubic yards to be placed, the rate of placement, the ambient air temperatures anticipated, as well as the temperature of the concrete at the time of placement.

Care should be taken during the finishing operation not to overwork the concrete surface. The curing of the concrete should be started as soon as is practicable after the texture finish has been accomplished.

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