Continuous Integral Deck Construction

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

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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

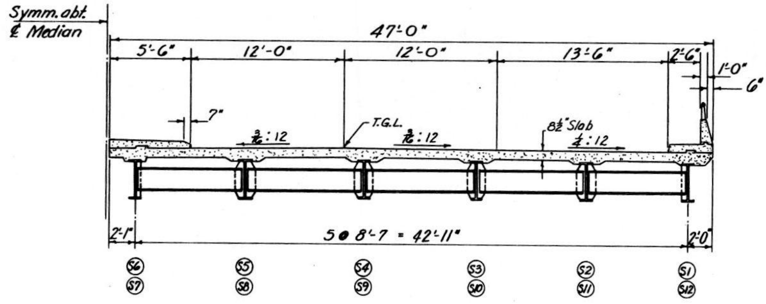

Figure 1. Transverse section.

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.

Figure 2. Deck under construction.

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 3. Bridge during construction.

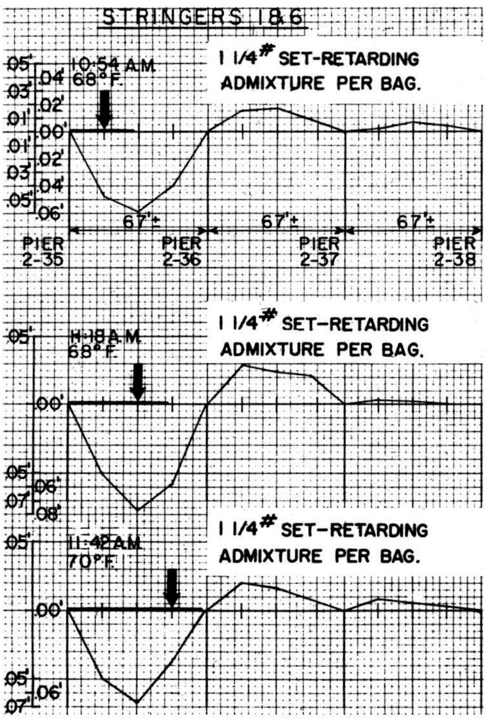

Figure 4. Progressive deflection chart, stringers 1 and 6.

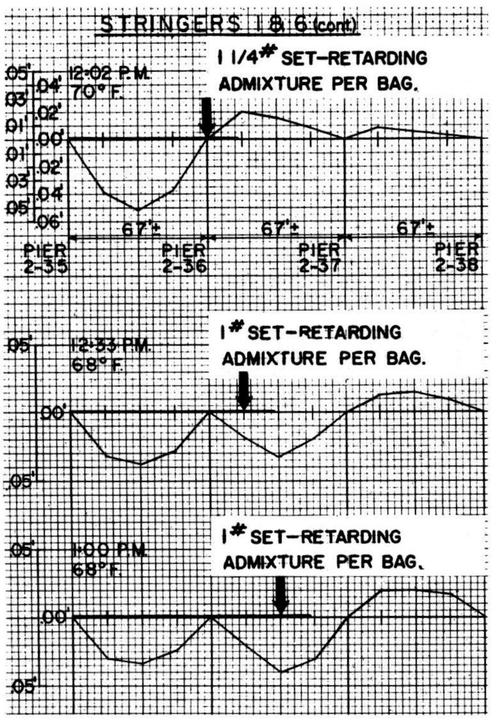

Figure 5. Progressive deflection chart, stringers 1 and 6.

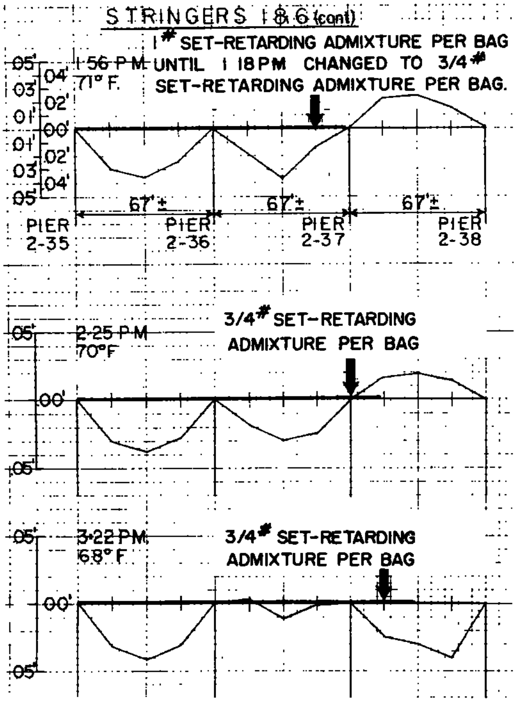

Figure 6. Progressive deflection chart, stringers 1 and 6.

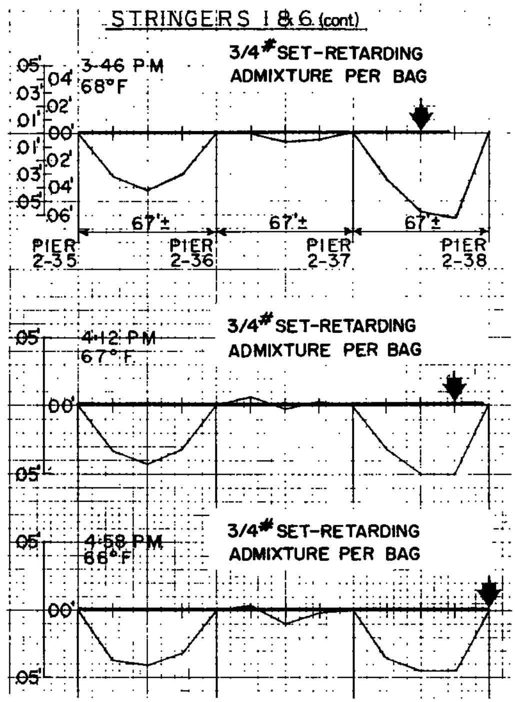

Figure 7. Progressive deflection chart, stringers 1 and 6.

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 ⅛ 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 ¼ in. but in the majority of cases the measurement was 2 or 2 ⅛ 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 ¼ 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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