NEW HAMPSHIRE
Route 104, Bristol

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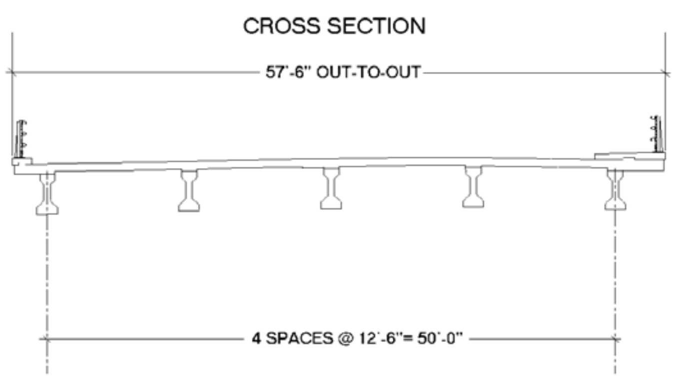
NEW HAMPSHIRE
Route 104, Bristol

1. DESCRIPTION



Location:	Route 104 over the Newfound River, Bristol
Open to Traffic:	1996
Environment:	Normal over water
HPC Elements:	Girders, deck, and approach slabs
Total Length:	65 ft
Skew or Curve:	8^o skew, 12^o curve
Girder Type:	AASHTO Type III
Girder Span Lengths:	One at 65 ft
Girder Spacing:	12 ft 6 in
Girder Strand Grade:	270
Girder Strand Dia.:	0.5 in
Max. No. of Bottom Strands:	40
Deck Thickness:	9 in
Deck Panels:	None

2. BENEFITS OF HPC AND COSTS

A. Benefits of HPC

Three important characteristics were determined to be critical for the success of HPC in New Hampshire. The first characteristic was to select a bridge site that provided a good representation of the majority of bridges built in New Hampshire—single-span structures less than 100-ft long. The second characteristic was to choose practical materials, which are readily available in the region and, with those materials, specify concrete which would have easily attainable strength and durability levels. The third characteristic was to test and evaluate the performance of the HPC materials and the in-situ performance of the bridge itself. With success, additional HPC bridges could be constructed with the potential of providing higher quality, more durable, and more economical structures.

B. Costs

The superstructure cost of $59/ft^2 of deck area compared to an average superstructure cost of $48/ft^2 for conventional bridges.

3. STRUCTURAL DESIGN

Design Specifications:	AASHTO Standard Specifications for Highway Bridges, 1992 with Interims
Design Live Loads:	HS 25-44 as modified for 125% military loading
Seismic Requirements:	AASHTO Seismic Performance Category A
Flexural Design Method:	AASHTO Standard Specifications 9.15
Maximum Compressive Strain:	0.003
Shear Design Method:	AASHTO Standard Specifications 9.20
Fatigue Design Method:	None
Lateral Stability Considerations:	Concrete diaphragms at midspan and ends except steel channel diaphragms in exterior utility bay
Allowable Tensile Stress	
—Top of Girder at Release:	$7.5\sqrt{f'_{ci}}$ = 605 psi
—Bottom of Girder after Losses:	$3\sqrt{f'_{c}}$ = 268 psi
Prestress Loss:	—
Method Used for Loss:	—
Calculated Camber:	1.44 in at release 2.58 in at erection 1.69 in after casting deck
Concrete Cover	
—Girder:	1 in
—Top of Deck:	3 in
—Bottom of Deck:	1-1/4 in
—Other Locations:	2-1/2 in
Properties of Reinforcing Steel	
—Girder:	Grade 60, epoxy coated
—Deck:	Grade 60, epoxy coated
—Approach Slab:	Grade 60, uncoated
Properties of Strand	
—Grade and Type:	Grade 270, low relaxation
—Supplier:	—
—Surface Condition:	—
—Pattern:	8 strands draped See 10. DRAWINGS for details
—Transfer Length:	—
—Development Length:	—

4. SPECIFIED ITEMS

A. Concrete Properties

	Girders	Deck and Approach Slabs
Minimum Cementitious Materials Content:	—	658 lb/yd^3
Max. Water/Cementitious Materials Ratio:	—	0.38
Min. Percentage of Fly Ash:	—	—
Max. Percentage of Fly Ash:	—	—
Min. Percentage of Silica Fume:	—	7.5%
Max. Percentage of Silica Fume:	—	—
Min. Percentage of GGBFS:	—	—
Max. Percentage of GGBFS:	—	—
Maximum Aggregate Size:	3/4 in	—
Slump:	5-7 in	2-3 in
Air Content:	5-8%	6-9%
Compressive Strength		
—Release of Strands:	6500 psi	
—Design:	8000 at 28 days	6000 psi at 28 days
Chloride Permeability: (AASHTO T 277)	≤ 1000 coulombs at 56 days	≤ 1000 coulombs at 56 days
ASR or DEF Prevention:	—	—
Freeze-Thaw Resistance:	—	—
Deicer Scaling:	—	—
Abrasion Resistance:	—	—
Other:	Corrosion inhibitor at 4 gal/yd^3 Type II or III cement	Corrosion inhibitor at 4 gal/yd^3 in deck only Type II cement

B. Specified QC Procedures

Girder Production	
Curing:	Steam
Internal Concrete Temperature:	$\leq$ 160 ^{o}F
Cylinder Curing:	Match curing
Cylinder Size:	6x12 in
Cylinder Capping Procedure:	—
Cylinder Testing Method:	AASHTO T 22
Frequency of Testing:	—
Other QA/QC Requirements:	—
Deck and Approach Slab Construction	
Curing:	Wet cure for 4 days with cotton mats and sprinklers
Cylinder Curing:	—
Cylinder Size:	6x12 in
Flexural Strength:	—
Other QA/QC Requirements:	5 yd^3 trial placement Each trial load of concrete was tested for slump, unit weight, concrete temperature, and air content

5. CONCRETE MATERIALS

A. Approved Concrete Mix Proportions

	Girders	Deck (1)	Approach Slabs
Cement Brand:	Lafarge	Ciment Quebec	Ciment Quebec
Cement Type:	III	II	II
Cement Composition:	—	—	—
Cement Fineness:	—	—	—
Cement Quantity:	777 lb/yd^3	660 lb/yd^3 (2)	660 lb/yd^3 (2)
GGBFS Brand:	—	—	—
GGBFS Quantity:	—	—	—
Fly Ash Brand:	—	—	—
Fly Ash Type:	—	—	—
Fly Ash Quantity:	—	—	—
Silica Fume Brand:	Sikacrete 950DP	Ciment Quebec	Ciment Quebec
Silica Fume Quantity:	50 lb/yd^3	8% (1)	8% (2)
Fine Aggregate Type:	Sand	—	—
Fine Aggregate FM:	—	2.8	—
Fine Aggregate SG:	—	2.66	—
Fine Aggregate Quantity:	1075 lb/yd^3	1190 lb/yd^3	1190 lb/yd^3
Coarse Aggregate, Max. Size:	3/4 in	3/4 in	3/4 in
Coarse Aggregate Type:	Traprock	No. 67 stone	No. 67 stone
Coarse Aggregate SG:	—	2.69	—
Coarse Aggregate Quantity:	1850 lb/yd^3	1815 lb/yd^3	1815 lb/yd^3
Water:	273 lb/yd^3	253 lb/yd^3	253 lb/yd^3
Water Reducer Brand:	—	WRDA w/HYCOL	WRDA w/HYCOL
Water Reducer Type:	—	A	A
Water Reducer Quantity:	—	20 fl oz/yd^3	20 fl oz/yd^3
High-Range Water-Reducer Brand:	Sikament 300	Daracem 100	Daracem 100
High-Range Water-Reducer Type:	A and F	F and G	F and G
High-Range Water-Reducer Quantity:	206 fl oz/yd^3	79 fl oz/yd^3	80 fl oz/yd^3
Retarder Brand:	Plastiment	—	—
Retarder Type:	B and D	—	—
Retarder Quantity:	14 fl oz/yd^3	—	—
Corrosion Inhibitor Brand:	DCI S	DCI S	—
Corrosion Inhibitor Type:	Calcium Nitrite	Calcium Nitrite	—
Corrosion Inhibitor Quantity:	4.0 gal/yd^3	4.0 gal/yd^3	—
Air Entrainment Brand:	Sika AEA-15	Daravair 1000	Daravair 1000
Air Entrainment Type:	Synthetic	Saponified Rosin	Saponified Rosin
Air Entrainment Quantity:	10 fl oz/yd^3	6 fl oz/yd^3	4.5 fl oz/yd^3
Water/Cementitious Materials Ratio:	0.33	0.38	0.38

(1) Mix designs were recommended by the University of New Hampshire. Minor changes were made for the approved mix.
(2) Cement and silica fume were preblended. Total cementitious materials were 660 lb/yd^3.

B. Measured Properties of Approved Mix

	Girders	Deck	Approach Slabs
Slump:	—	5-7 in	—
Air Content:	—	6-9%	—
Unit Weight:	—	—	—
Compressive Strength:	—	—	—
Chloride Permeability: (AASHTO T 277)	—	—	—

6. CONCRETE MATERIAL PROPERTIES

A. Measured Properties from QC Tests of Production Concrete for Girders

Cement Composition:	See Page 38
Actual Curing Procedure for Girders:	Steam
Curing Procedure for Cylinders:	—

Slump, Temperature, Air Content,
Unit Weight and Compressive Strength:

Girder No.	1	2	3	4	5	Average
Slump, in	5-3/4	6.5	6	6	7-1/4	6.3
Maximum Girder Temperature, ^{o}F	—	—	—	—	—	—
Air Content, %	7.4	6.8	6.2	5.9	6.8	6.6
Unit Weight, lb/yd^3	146.8	146.0	149.0	148.0	146.0	147.1
Compressive Strength, (3) psi						
NH DOT (6x12-in cylinders)	6862	7425	8780	8640	7070	7755
Fabricator (4x8-in cylinders)	8250	7780	8500	8375	7550	8091
Cores	8233	8209	—	—	7791	8078

(3) Cylinders tested at 28 days. Age not reported for cores.

Compressive Strength:	6700 psi at release (14-17 hours)
(Based on the average of	7400 psi at 3 days
several cylinders from	8000 psi at 7 days
Girders 1 through 4)	9000 psi at 56 days

B. Measured Properties from QC Tests of Production Concrete for Deck

Cement Composition:	See Page 38
Actual Curing Procedure for Deck:	Dry cotton mats placed within 15 minutes after the burlap drag. The mats were then wetted down and the deck wet cured for approximately 136 hours.
Slump:	3 – 5 in
Air Content:	4.0 – 5.8%
Unit Weight:	144 – 147 lb/ft^3
Compressive Strength:	5700 psi at 3 days
	6890 psi at 7 days
	7060 psi at 14 days
	7810 psi at 21 days
	9020 psi at 28 days
	9600 psi at 56 days
Cylinder Size:	6x12 in
Curing Procedure for Cylinders:	—

C. Measured Properties from QC Tests of Production Concrete for Approach Slabs

Cement Composition:	—
Actual Curing Procedure for Approach Slab:	—
Slump:	5-1/2, 7 in
Air Content:	9.2, 9.5%
Unit Weight:	139.8, 143.1 lb/ft^3
Compressive Strength:	6015, 6485 psi
Cylinder Size:	6x12 in
Curing Procedure for Cylinders:	—

D. Measured Properties from Research Tests of Production Concrete for Girders

Compressive Strength and
Modulus of Elasticity:

Source	Curing	Age, days	Compressive Strength, psi	Modulus of Elasticity, ksi
Girder 4				
UNH	Field/Moist	1.69	7830	4400
		2.62	8120	—
		6.87	7850	—
		14.04	8190	—
		27.8	9080	5050
		55.9	9160	5350
		365	10,430	5850
	Match/Moist	0.60	7160	—
		0.85	8360	—
		1.69	8070	—
		372	9330	4250
Fabricator	Not reported	0.60	6762	—
		0.85	7780	—
		7.00	8580	—
		28.0	8480	—
		56.0	9360	—
Girder 5				
UNH	Field/Moist	2.73	6390	4150
		6.85	7040	—
		13.88	6850	—
		27.9	7290	4550
		55.9	7720	4650
		365	8950	5150
	Match/Moist	2.71	7740	5600
		370	7840	3950
Fabricator	Not reported	2.62	6890	—
		7.00	7310	—
		28.0	7640	—
		56.0	7920	—

Field/Moist-cured specimens were 4x8-in (100x200-mm) cylinders placed on top of the girder under the curing blanket until time of release. Cylinders were stripped at 37-1/2 and 72 hours for Girders 4 and 5, respectively and then stored in a fog room. Most results are the average of three tests.
Match/Moist-cured specimens were 4x8-in cylinders initially match cured followed by storage in a fog room. Most results are the average of two or three tests.

Girder	Freeze-Thaw Resistance (4), %	Chloride Permeability (5) coulombs	
		Cylinders	Cores
4	108.0	1340	2860
5	106.0	1839	4000
Average	107.0	1590	3430

(4) ASTM C 666, Procedure A made at a concrete age of 307 and 305 days for Girders 4 and 5, respectively.
(5) ASTM C 1202 conducted at 56 days for cylinders and 522 days for cores after 10 months in service.

E. Measured Properties from Research Tests of Production Concrete for Deck

Compressive Strength
and Modulus of Elasticity:

Source	Age, days	Compressive Strength, psi	Modulus of Elasticity, ksi
UNH (6)	1.26	3360	—
	3.18	5700	—
	7.30	6430	3750
	14.25	7590	4200
	28.1	8580	4250
	56.1	9380	4150
	122.1	9750	4500
	365	9850	4450
Contractor (7)	7	6510	—
	14	7340	—
	28	8310	—

(6) UNH specimens were 4x8-in cylinders cured in accordance with ASTM C 31 Standard Cure.
(7) Contractor's specimens were 6x12-in cylinders.

Freeze-Thaw Resistance and
Chloride Permeability:

Sample	Freeze-Thaw Resistance (8), %	Chloride Permeability (9), coulombs
1	99	609
2	97	896
3	97	—
4	96	—
Average	97	753

(8) AASHTO T 161 Procedure A made at a concrete age of 140 days.
(9) ASTM C 1202 conducted at 56 days on cores from the deck.

Deicer Scaling: 0 to 1

Specimens were cured in a manner to duplicate deck curing. Testing commenced at a concrete age of 30 days and continued to 100 cycles. No scaling was evident after 50 cycles.

7. OTHER RESEARCH DATA

Girder Curing Temperatures:

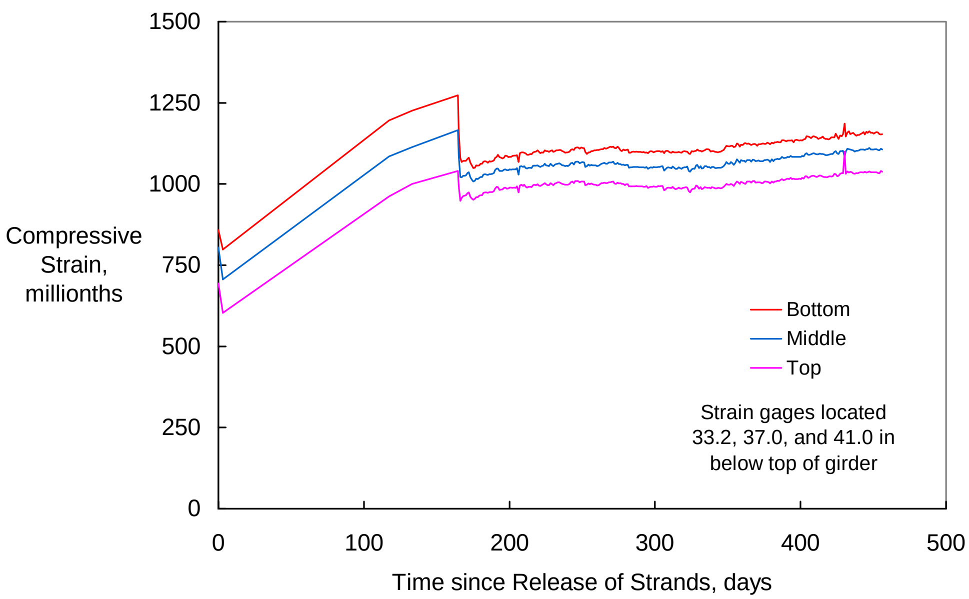
Girder 4			Girder 5		
Location (10), in	Max. Temp., °F	Time (11), hours	Location (10), in	Max. Temp., °F	Time (11), hours
0.44	160	14.0	0.31	152	12.7
4.75	173	13.2	4.69	166	12.7
22.3	170	14.3	22.5	161	13.8
33.2	173	13.8	32.8	168	13.8
37.0	173	14.2	36.8	168	13.8
41.0	169	14.0	40.7	163	13.8
44.5	160	15.7	44.5	151	15.0
Enclosure	147 151	— —	Enclosure	129 134	— —

(10) Measured from top of girder.
(11) Time from commencement of placing first concrete.

Deck Curing Temperature: Maximum temperature measured in the deck concrete was 109 °F and occurred 13-1/2 hours after completion of the deck placement

Concrete Strains: See Excel files for data

Concrete Strain vs Time for Girder 4

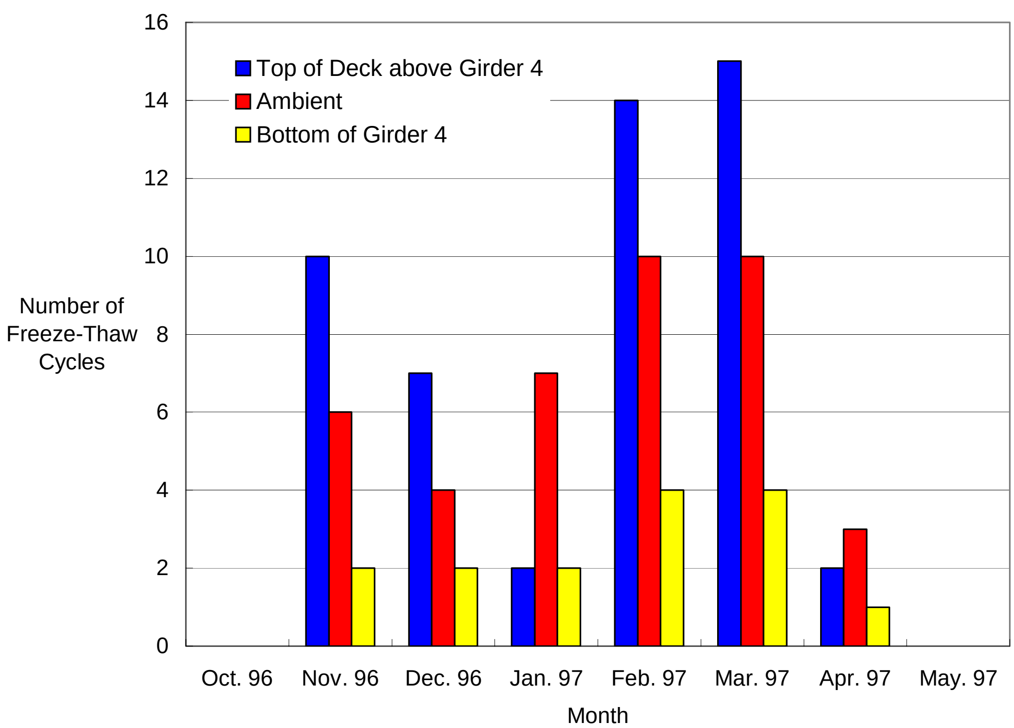


Camber:

Date	Girder 4		Girder 5	
	Age, days	Camber, in	Age, days	Camber, in
(12)	Release	1.24	Release	1.13
6/26/96 (13)	177	2.14	114	3.27
7/12/96 (14)	133	2.40	130	3.28
9/23/96 (15)	206	0.50	203	1.69
6/4/97	460	0.87	457	1.86
7/29/97	510	0.81	507	1.91

(12) March 1, 1996, for Girder 4 and March 4, 1996, for Girder 5.
(13) Before shipping.
(14) Girder set on bridge site.
(15) Deck was cast on 9/14/96.

Freeze-Thaw Cycles:



One freeze-thaw cycle corresponded to a drop in temperature below 28 ^{o}F followed by a rise in temperature above 32 ^{o}F.

Inspection:	No visible cracks in the deck were found during several post construction reviews conducted by research, construction, and design personnel. A "wet study" of the deck surface identified microscopic longitudinal flexural cracks in some areas over the girder lines. No shrinkage cracks or transverse cracks were evident.
Live Load Tests:	A load test was conducted just prior to opening the bridge to traffic. An 88,000-lb truck was positioned at several locations on the bridge and deflections measured.

8. OTHER RELATED RESEARCH

Prior to construction of the bridge, three potential concrete mixes for the deck were selected for field trials. For each mix, two slabs, 16-ft long, 4-wide, and 8-in thick were constructed. One slab of each pair contained epoxy-coated reinforcement. The other slab contained uncoated reinforcement. The slabs were exposed to truck traffic over the winter of 1995/1996 on the access road to a land fill facility. After a winter's exposure, the slabs were checked for cracking and condition of the reinforcement using core samples. One of the three concrete mixes attained superior durability performance as measured by scaling and abrasion resistance. The slab made with the same concrete also had the least amount of flexural cracking. The flexural capacities of the slabs were tested in the laboratory after exposure to truck traffic. All slabs had measured strengths in excess of design strengths and strengths based on actual concrete properties.

9. SOURCES OF DATA

Waszczuk, C. M., "Crack Free HPC Bridge Deck—New Hampshire's Experience," HPC Bridge Views, Issue No. 4, July/August 1999, pp. 2-3.

Waszczuk, C. M. and Juliano, M. L., "Application of HPC in a New Hampshire Bridge," *Concrete International,* Vol. 21, No. 2, February 1999, pp. 61-62.

Wilson, C. R., "An Early Evaluation of the Use of High Performance Concrete in the Route 104 Bridge, Bristol, New Hampshire," A thesis submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering, May 1998, 212 pp.

SHRP High Performance Concrete Bridge Showcase Notebook, Waterville Valley, NH, September 22-23, 1997.

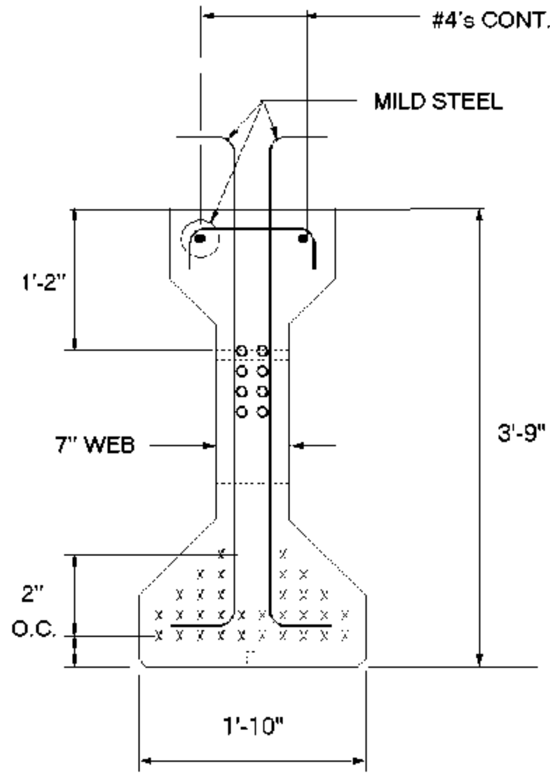
Juliano, M. L. and Waszczuk, C. M., "Application of HPC in Two Bridges in New Hampshire," *Symposium Proceedings, PCI/FHWA International Symposium on High Performance Concrete,* New Orleans, LA, Precast/Prestressed Concrete Institute, Chicago, IL, 1997, pp. 475-487.

Fratzel, T. M., "Evaluation of High Performance Concrete Slabs Including In-Situ Testing at a Bridge Deck Testing Facility," A thesis submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering, May 1996, 86 pp.

Mark D. Whittemore, New Hampshire Department of Transportation, Concord, NH.

Raymond A. Cook, University of New Hampshire, Durham, NH.

10. DRAWINGS



11. HPC SPECIFICATIONS

BRISTOL
BRF-X-T-024-1(11)
P-4365

August 29,1995

SPECIAL PROVISION

SECTION 528 -- PRESTRESSED CONCRETE MEMBERS

ITEM 528.11 PRESTRESSED CONCRETE MEMBERS – HPC

Description

1.1 This work shall consist of manufacturing, storing, transporting, and erecting precast pretensioned concrete members as shown on the plans. The relevant provisions of the AASHTO Standard Specifications for Highway Bridges shall be adhered to unless such provisions are in conflict with this specification.

Materials

2.1 **Concrete** shall be controlled, mixed, and handled as specified in the pertinent portions of 520 unless otherwise specified herein.

2.1.1 The Contractor shall design and submit for approval the proportions for a concrete mix which shall attain the following: a minimum average strength of 9400 psi at 28 days for 3 test cylinders when sampled in accordance with the requirements of AASHTO T141, molded and cured in accordance with the requirements of AASHTO T23, and tested in accordance with the requirements of AASHTO T22; a rapid chloride ion permeability of 1000 coulombs or less measured at 56 days using AASHTO T277.

2.1.2 To check the Contractor's design mix, test specimens of concrete shall be made from the proposed aggregates and cement. The Contractor shall inform the Engineer of the sources from which the material will be obtained in ample time to permit these tests and shall furnish, at no cost to the Department, whatever quantities of these materials may be required for the tests.

2.1.3 The slump of the concrete shall be between 5 and 7 inches with high range water-reducing admixture. Air entrainment shall be between 5 and 8 percent.

2.2 **Cement** shall be standard portland cement, AASHTO M85, Type II or III. Unless otherwise approved in writing, all cement used in the manufacture of the members in any one structure shall be from the same mill and of the same type.

2.3 Aggregate. The maximum size of coarse aggregate used shall be as specified for Concrete Class AA in 520.

2.4 Admixtures.

2.4.1 W.R. Grace DCI-S, or approved equal, corrosion inhibitor (calcium nitrite) admixture shall be used at a rate of 4 gallons per cubic yard.

2.4.2 All other admixtures shall meet the requirements of 520.

2.5 Prestressing Steel.

2.5.1 Prestressing steel shall be uncoated, seven-wire strand, as called for on the plans and as specified herein, conforming to the requirements of AASHTO M203 (ASTM A416) Grade 270 low-relaxation.

2.5.2 The Contractor shall furnish without charge certified copies of a representative load-elongation curve test report for each size and grade of strand, for lots of 10 tons or fraction thereof.

2.5.3 The Contractor shall furnish a certified mill test report for each heat and coil of wire used in the production of the strand, and certification that the wire and strand manufacturing processes occurred in the United States.

2.5.4 Each manufactured reel of prestressing steel strand to be shipped shall be assigned an individual lot number and clearly tagged for accurate identification. Such identification shall not be removed from the reel or strand until the reel is entirely used or until end-use fabrication has been completed.

2.6 Reinforcing Steel shall conform to the requirements of 544 and shall be uncoated except as otherwise noted.

2.7 All members shall be restricted to those which have been cast in the United States.

Construction Requirements

3.1 General. Design stresses are closely controlled, however the behavior in service depends upon the specified concrete being properly placed in forms of the correct dimensions around accurately positioned prestressed steel.

3.2 Qualification of Fabricator. The precast concrete manufacturing plant shall be certified by the Prestressed Concrete Institute Plant Certification Program. The Manufacturer shall submit proof of certification prior to the start of production. For straight strand members certification shall be, as a minimum, in category B3. For draped strand members certification shall be in category B4. The manufacture of the prestressed units shall be in accordance with PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products".

3.3 Method of Manufacture. Complete information as to the proposed method of manufacturing the members shall be submitted to the Engineer for approval.

3.4 Technician. The Contractor shall provide a technician having at least 5 years continuous experience in the manufacture of prestressed members, who shall supervise the work.

3.5 Inspection. The Engineer shall have free entry for the purpose of the required inspection at all times. At least four (4) weeks before the first casting, the Fabricator shall submit to N.H.D.O.T., Bureau of Materials and Research, a schedule showing the dates on which the members will be cast.

3.6 Jacking Equipment (Approval and Calibration). Prestressing shall be done with approved jacking equipment.

3.6.1 If hydraulic jacks are used they shall be equipped with accurately reading pressure gages. The combination of jack and gage shall be calibrated, and a certified graph or table showing the calibration shall be furnished. The calibration date shall be within a 12-month period immediately prior to the start of the work.

3.6.2 Should other types of jacks be used, calibrated proving rings or other devices shall be furnished so that jacking forces may be accurately known.

3.7 Jacking Forces (Computation and Record). Prior to stressing, the Contractor shall submit for approval the computations of the proposed gage pressure, the elongations of the prestressing strands, and the sequence of operations. A record shall be kept of the jacking force and the elongation produced thereby.

3.8 Placement and Stressing of Strands.

3.8.1 The prestressing strands shall be accurately placed to achieve the center of gravity of the steel as shown on the approved shop drawings. Prestressing strands shall be protected against corrosion and be free of nicks, kinks, dirt, rust, oil, grease, and other deleterious substances.

3.8.2 Layers of the strands shall be separated by steel supports in accordance with the Concrete Reinforcing Steel Institute Manual of Standard Practice and shall be of approved shape and dimension. Suitable horizontal and vertical spacers shall be provided, if required, to keep the strands in true position in the forms.

3.8.3 Each strand shall be stretched initially to a minimum gage pull of 1000 pounds before starting elongation measurements. All strands shall be in position before the stressing operation is begun.

3.8.4 Except for normal reinforcement in the bottom, the reinforcement shall be placed in position after the stressing is performed.

3.8.5 Stressing shall be performed by either simultaneous or individual application of tension to the strands to produce the elongation indicating a total force as required to achieve the specified final prestress after all the losses have taken place. The strands shall be prestressed in such a manner that the prestressing force will be distributed equally among the strands.

3.8.6 Several members may be cast in a continuous line and stressed at one time. Sufficient space shall be maintained between ends of members to permit access for cutting strands after the concrete has attained the required strength.

3.9 Safety Measures. Safety measures must be taken by the Contractor to prevent accidents due to possible breaking of the prestressed steel or the slipping of the grips during the prestressing process.

3.10 Forms. Forms shall be made and maintained true to the shapes and dimensions shown on the plans.

3.10.1 The forms shall be maintained in true alignment and of sufficient stiffness to prevent deflection under wet concrete.

3.10.2 The surface shall be smooth, and if necessary, joints shall be treated so that a minimum of joint marks are evident in the finished member.

3.10.3 Forms shall be constructed and end bearing plates placed so as to allow for any shortening of the member due to compressive stresses resulting from transfer of stress and from shrinkage.

3.10.4 Side forms shall be of steel or wood and shall be supported without resort to ties or spreaders within the body of the member. They shall be braced and stiffened so that no deflection or curvature takes place during placement of wet concrete.

3.11 Placement of Concrete.

3.11.1 Concrete shall not be deposited in the forms until the Engineer has inspected the placing of the reinforcement and prestressing steel, and has given approval thereof. Concrete shall be placed only in the presence of the Engineer and in accordance with 520.

3.11.1.1 Concrete shall not be placed in the forms of the instrumented girders (girder #4 and girder #5 as noted on the contract plans) until researchers have installed testing probes (thermocouples, strain gages, and wiring).

3.11.2 All reinforcement and strands shall be free of dirt, oil, grease, and other deleterious substances.

3.11.3. All items encased in the concrete shall be accurately placed in the position shown on the plans and firmly held during the placing and setting of the concrete. Clearance from the forms shall be maintained by supports, spacers, or hangers in accordance with 544.3.4 and shall be of approved shape and dimensions.

3.11.4 The details of all inserts, anchors, and any other item required to be cast into the members (whether detailed on the contract drawings or provided for the Contractor's convenience) shall be shown on the shop drawings. Members shall not be fired or drilled into for attachment purposes. All hardware shall be galvanized except as otherwise noted.

3.11.5 The temperature of the concrete shall not exceed 90^{o}F when placed in the forms.

3.12 Vibration of Concrete. Vibration of concrete shall conform to 520 or as ordered.

3.12.1 The vibrating shall be done with care and in such a manner as to avoid displacement of reinforcement, strands, shoes, or other inserts.

3.12.2 The size of the vibrator spud shall be proper for the size of the openings available.

3.12.3 External vibration will be permitted.

3.13 Roughness of Top Surface of Member

3.13.1 The top surface of all members shall be finished reasonably true by striking off at the top of the forms.

3.13.2 As soon as conditions permit before the concrete has fully hardened, all dirt, laitance, and loose aggregate shall be removed from the surface. The surface shall be finished as shown on the plans.

3.14 Curing.

3.14.1 Steam curing shall be used and shall conform to the following:

(a) The Contractor shall furnish sufficient canvas and framework or other type of housing to completely enclose the member so that the curing temperatures can be controlled.

(b) Steam shall be introduced into the enclosure through a series of steam jets which shall be evenly spaced within the enclosure.

(c) The initial set of the concrete shall take place before steam for curing is applied.

(d) The steam enclosure shall be maintained at 100% relative humidity to prevent loss of moisture and to provide excess moisture for proper hydration of the cement.

(e) During the application of the steam, the ambient air temperature shall increase at a rate not to exceed 40°F per hour until the maximum temperature of from 140°F to 160°F is reached. Curing at this temperature shall continue until concrete test cylinders, prepared from the fresh concrete at the time of placing, and cured under the same temperature and moisture conditions as the member, have attained 6500 psi compressive strength.

(f) Necessary equipment for testing the cylinders shall be available at the Fabricator's plant unless otherwise permitted.

(g) When discontinuing steam, the ambient air temperature shall not decrease at a rate to exceed 40°F per hour until the temperature has reached 20°F above the temperature of the air to which the concrete will be exposed.

3.14.2 The concrete shall not be exposed to temperatures below 32°F for 6 days after casting.

3.14.3 No forms shall be removed without approval. Proper care and precautions shall be exercised in removing forms so that no damage results to the finished surface.

3.15 Maintenance of Prestress. Stress shall not be transferred to the concrete from the strands until the concrete has attained a compressive strength of at least 6500 psi (or the release strength indicated on the plans) as shown by test cylinders cured by methods identical with curing of the member.

3.16 Release of Prestress.

3.16.1 The transfer of stress from the prestressing elements to the concrete shall be accomplished by a gradual release of jack pressure, or by cutting individual strands in an approved sequence.

3.16.2 The releasing of the prestress force shall be in such a manner that its lateral eccentricity is kept to a minimum.

3.17 Finish of Strands. Strands shall be cut and the member ends finished as shown on the plans. Strand ends shall be coated with an approved material to protect them from exposure to corrosive elements.

3.18 Patching of any surface irregularities, especially those resulting from honey-combing, shall be done only after inspection to determine whether or not the work is acceptable.

3.18.1 When patching is allowed, it shall be done within 24 hours after stripping, and the patching shall be damp cured for not less than a 3-day period and kept from freezing for the 3 following days.

3.18.2 Patching of damaged members in lieu of required replacement will not be permitted.

3.19 Dimensional Tolerances. All tolerances shall be in accordance with PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products."

3.19.1 Camber shall be measured at consistent times within 24 hours after release of prestress.

3.20 Handling and Storing. Special care shall be taken in handling and storing the members to prevent any damage to the concrete.

3.20.1 Members shall be lifted at the designated points by approved lifting devices embedded in the concrete and shall be transported in an upright position.

3.20.2 The points of support and the direction of the reactions with respect to the member during handling and storage shall be approximately the same as when the member is in its final position.

3.20.3 Shock-absorbing cushioning material shall be used at all bearing points during transportation of the members.

3.20.4 The members shall not be subject to damaging torsional or impact stresses.

3.20.5 Members damaged by improper storing or handling shall be replaced by the Contractor at no cost to the Department.

3.21 Instrumentation. Researchers shall have free access for the purpose of installing instrumentation and monitoring two girders (girder #4 and girder #5 as noted on the contract plans) at all times. These instruments will be used to monitor internal temperature and strain in the beam prior to, during, and after construction.

3.21.1 Appendix A, attached to the end of the specification, gives detailed information for the instrumentation plan. The Fabricator and Contractor shall take the necessary steps to prevent damage to the instrumentation and cooperate with the research team during installation of the sensors and data collection. It is not anticipated that these activities will cause significant delays or work stoppages.

3.21.2 Instrumentation wires will protrude through the top of the girders contained within 1 ½" diameter flexible plastic tubing. Wires shall be stored in "bubble wrap" and adequately taped to the side of the girders to protect them from any damage during shipping, erection, and construction operations.

3.21.3 Researchers shall have access to survey the tops of the girders prior to and after the release of the prestressing strands.

3.21.3.1 A flattened area of sufficient size (4"± by 4"±) shall be provided at the centerline bearing and tenth points on the tops of the girders to facilitate taking elevations for measuring camber and deflections.

Method of Measurement

4.1 Prestressed concrete members will be measured as a unit. When more than one unit is specified in the contract, separate item numbers will appear for each separate and complete unit.

Basis of Payment

5.1 The accepted quantities of prestressed concrete members will be paid for at the contract lump sum price complete in place.

Pay items and units:

528.11	Prestressed Concrete Members – HPC	Unit

APPENDIX A

DETAILS FOR GIRDER INSTRUMENTATION PLAN

Two girders (girder #4 and #5 as noted on the contract plans) will be instrumented for internal temperature and strain data collection. Embedded sensors will be used to monitor behavior of the girders from the time of casting to several years after construction is completed. Instrumentation will consist of the following:

I. Thermocouples to measure (1) the level of heat of hydration during the curing process, (2) the temperature gradient in the girder after bridge construction, and (3) the temperature during data compilation.

   a. Thermocouples will be places at midspan along the vertical center line of the girder at the following depths (dimensions are measured from the bottom of the girder): 1/2", 4", 22 1/2", 40", 44 1/2".

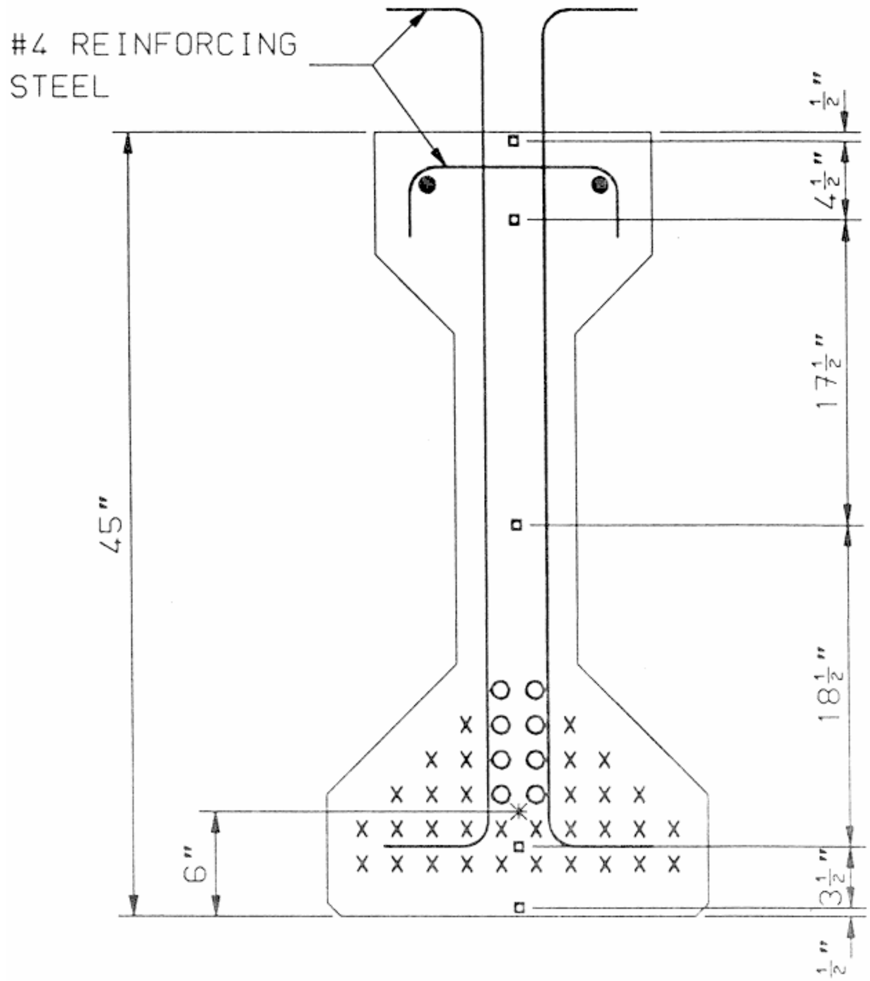
   b Data acquisition for heat of hydration will begin as soon as the concrete is placed and continue until the concrete temperatures reach ambient temperature. Data acquisition for temperature gradients will begin as soon as the beams are initially surveyed.

II. Strain gages to measure the long-term strains within the girder. The strains will be used to determine prestress losses from elastic shortening, creep, and shrinkage and will give an indication of the stresses within the girder due to dead load and live load.

   a. Three gages will be placed at midspan at a depth of 6" measured from the bottom of the girder.

   b. Data acquisition will begin as soon as the concrete is placed. Readings will be taken prior to and after every significant event that affects the stress in the girder (i.e. form stripping, transfer of prestressing force, erection of beams, etc.). After completion of the structure, readings will be taken to coincide with the deflection surveys.

Stainless steel inserts shall be cast into the bottom flange of all the girders as specified on the contract plans. Stainless Steel Hemispherical bolts or low profile acorn nuts with threaded lugs shall be installed in the inserts after erection of the girders is completed. These inserts and bolts will be used as part of a deflection survey to measure girder deflection due to creep, shrinkage, dead loads, and live loads. Elevations of the beam points will be performed initially once the girders are erected but prior to the installation of the deck falsework and subsequently after the bridge construction is completed but prior to opening the bridge to traffic. Deflection surveys will continue for several years after construction is completed.



SECTION AT MIDSPAN

SCALE: 1" = 1'-0"

● DENOTES MILD STEEL (#4)
X DENOTES STRAIGHT STRAND
O DENOTES DRAPED STRAND
✳ DENOTES STRAIN GAGE
▫ DENOTES THERMOCOUPLES

PROJECT Bristol

FED.No. BRF-X-T-24-1(11)

STATE No. P-4365

DATE September 1, 1995

S P E C I A L P R 0 V I S I 0 N

AMENDMENT TO SECTION 520 -- PORTLAND CEMENT CONCRETE

Item 520.7003 Concrete Bridge Deck – HPC

Item 520.33 - HPC, Approach Slabs

Add to 1.1:

1.1.1 The work consists of furnishing, placing, and curing structural portland cement concrete for use in a high performance concrete (HPC) bridge deck and approach slabs.

Add to 1.2:

CLASS	PSI	LBS	BAGS	GALLONS	MAXIMUM W/C	PERCENT
AA(7)	7200	658	7.0	4.27	0.38	6 to 9

(7) 7 1/2% of total cement shall be silica fume.

Add to 2.6

2.6.4 Cotton mats shall consist of a filling material of cotton "bat" or "bats" (minimum 400 grams/square meter); covered with unsized cloth (minimum 200 grams/square meter); tufted or stitched to maintain stability; shall be free from tears; and shall be in good general condition.

Amend 2.11.2 to read:

2.11.2 Thirty (30) days prior to the start of work a HPC mix design appropriate for the raw materials, admixtures, and blends of approved aggregates shall be submitted to the Bureau of Materials and Research for approval. No work shall be started on the project until the concrete mix design is approved. The HPC mix design shall contain the following:

Compressive Strength
Amount of Cement (lbs/cy)(bags/cy)(including pozzolan additives)
Fine and Coarse Aggregate Gradation
Air Content
Water/Cement Ratio
Chemical Admixture dosages
Laboratory test results (Strengths, Air Content, W/C ratios, Slump)

The Contractor shall submit three 4" dia. x 8" high cylinders to the Bureau of Materials & Research at least twenty (20) days prior to use for permeability testing. Cylinders shall be submitted between the ages of 5 to 11 days to be tested at 14 days. Subsequent use of an approved design will not require this screening test.

Delete 2.11.3.

Amend 3.1.3.2 by deleting the following:

The (*) after (c) Curing box for concrete cylinders, and all the paragraphs following the referenced (*).

Add to 3.1.6

3.1.6.3 At least two weeks prior to the deck slab or approach slab placement, a preplacement meeting shall be held to review the specification, outline the deck instrumentation and monitoring plan, and facilitate coordination between all the parties involved. Individuals attending this meeting should include the Project Engineer, Contractor, Concrete Supplier, representatives from the Departments' Bureaus of Bridge Design and Materials & Research, and representatives from the University of New Hampshire.

3.1.6.4 A minimum 5 cubic yard trial mixture containing silica fume shall be placed in a form simulating actual pouring conditions at the project site utilizing the proposed concrete mix and methods of placing, finishing, and curing. This shall occur at least one week before the actual deck or approach slab placement.

Add to 3.5.1:

3.5.1.2.1 Concrete shall not be placed in the deck forms until researchers have installed the stainless steel inserts and testing probes (thermocouples and wiring) in the deck.

Delete the second sentence of 3.5.3.1.

Add to 3.5.3

3.5.3.7 No concrete shall be placed if the evaporation rate is greater than 0.1 lb./SF/HR as determined by Chart #1 or if the ambient air temperature is above 85^{o}F.

3.5.3.8 No concrete shall be placed if the ambient air temperature is below 50^{o}F. Project weather temperatures of the cure period shall be 50^{o}F or higher. Should the temperature drop below 45^{o}F during curing, measures shall be taken to insure that the temperature of the concrete is maintained at or above 45^{o}F for the cure period.

Add to 3.9.2:

3.9.2.1.1 The self-propelled finishing machine shall be capable of forward and reverse motion and a type approved by the District Construction Engineer. The finishing machine shall be equipped with a vibrating pan to consolidate the concrete, a power driven strike-off auger, a power driven finishing roller, and a pan float. The vibrating pan shall vibrate at a frequency between 2500 and 7000 vpm.

3.9.2.5.1 For concrete deck and approach slab surfaces specified to be sawn after the concrete achieves the required strength, the Contractor shall provide the concrete with a gritty textured final surface finish. This finish shall be achieved by dragging a multiple-ply damp fabric transversely across the deck or approach slab surface immediately behind the screed machine.

3.9.2.5.2 The addition of water to the surface of the concrete to assist in the finishing operations will not be permitted.

3.9.2.5.3 Bullfloating will not be allowed except as needed to correct irregularities or close an unacceptably open surface.

Amend 3.9.2.6 to read:

3.9.2.6 The finished surface, before texturing, shall be uniformly smooth, dense, and even. Variations in concrete surface in excess of 1/8 inch, above or below the proper finished elevation, or surface irregularities of more than 1/8 inch in 10 feet, will not be accepted.

3.9.2.6.1 The concrete surface shall be checked out at random by the Engineer with an approved straight-edge not less than 10 feet long. The straight-edge shall be furnished by the Contractor. It shall be maintained in good, usable condition by him at all times.

Amend 3.10.1 to read:

3.10.1 Concrete bridge deck and approach slab exposed surfaces shall be cured by the wet mat curing method. This curing method shall consist of keeping the concrete continuously wet by maintaining wet cotton mats in direct contact with the concrete for a period of 96 hours. Damp burlap blankets may be placed on the damp concrete surface for temporary protection prior to the application of the cotton mats. The cotton mats then may be placed dry and wetted down immediately.

3.10.1.1 The burlap or the cotton mats shall be placed immediately after the concrete surface is dragged. Failure to apply the wet burlap or cotton mats within 10 minutes after the concrete is placed will be cause for rejection of the work as determined by the Engineer.

3.10.1.2 Care shall be exercised to ensure that the cotton mats are weighted down adequately to provide continuous contact with the concrete surfaces. The cotton mats shall be kept continuously wet for a period of 96 hours by means of soaker hoses or other continuous wetting systems.

Add to 3.12:

3.12.2 All shrinkage cracks shall be treated as directed by the Engineer.

Add to Construction Requirements

3.13 Instrumentation: Researchers shall have free access for the purposes of installing instrumentation and monitoring deck concrete at all times. These instruments will be used to monitor the internal temperature, and the concrete deck deflection due to creep, shrinkage, and live loads.

3.13.1 Stainless steel inserts as specified on the contract plans shall be supplied by the Contractor. Researchers will install the inserts at the prescribed locations specified on the plans.

3.13.2 Appendix B, attached to the end of the specification, gives detailed information for the deck instrumentation plan. The Contractor shall take the necessary steps to prevent damage to the instrumentation and cooperate with the research team during installation of the sensors and data collection. It is not anticipated that these activities will cause significant delays or work stoppages.

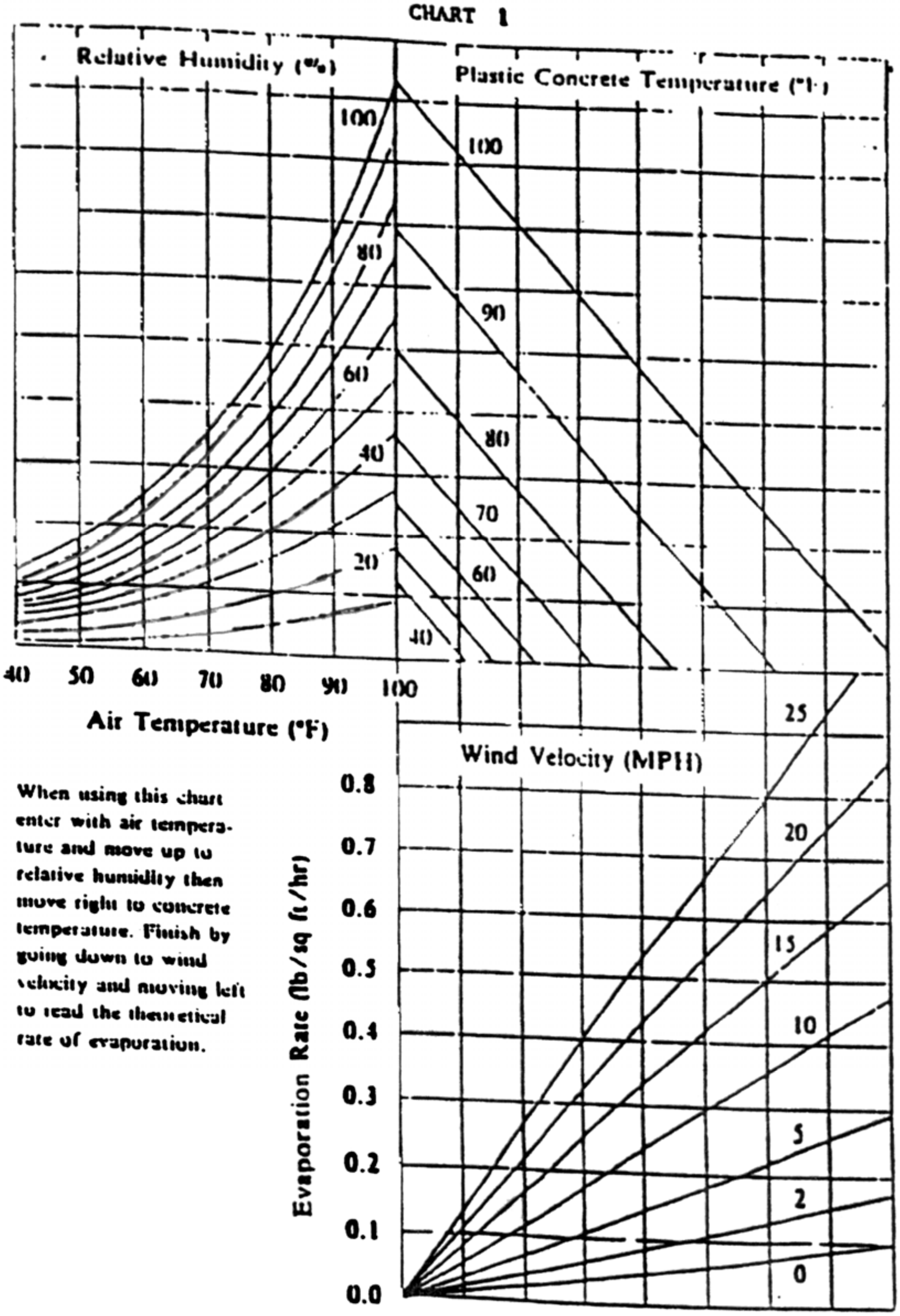
Amend 5.2 to read:

5.2 Concrete above footings (Class A) and concrete bridge deck - HPC will be paid for at the contract lump sum complete in place. Concrete for HPC, approach slabs will be paid for at the concrete unit price per cubic yard in place.

Add to pay items and units:

520.7003	Concrete Bridge Deck - HPC	Unit
520.33	HPC, Approach Slabs	CY

CHART 1


Relative Humidity (%)
Plastic Concrete Temperature (°F)
100
80
60
40
20
100
90
80
70
60
40
40
50
60
70
80
90
100
Air Temperature (°F)
Wind Velocity (MPH)
25
20
15
10
5
2
0
Evaporation Rate (lb/sq ft/hr)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
When using this chart enter with air temperature and move up to relative humidity then move right to concrete temperature. Finish by going down to wind velocity and moving left to read the theoretical rate of evaporation.

APPENDIX B

DETAILS FOR DECK INSTRUMENTATION PLAN

The deck will be instrumented for internal temperature data collection. Embedded sensors will monitor the temperature from the time of concrete placement to several years after construction is completed. Instrumentation will consist of the following:

I. Thermocouples to measure (1) the level of heat of hydration during the curing process, (2) the temperature gradient in the deck slab after bridge construction, and (3) the temperature during data compilation.

   a. Thermocouples will be placed in the same vertical location as those specified in girders #4 and #5. The thermocouples will be installed at the following depths (dimensions are measured from the top of the deck slab): 3/4", 4", 8".

   b. Three thermocouples will also be placed at midspan of the deck span in between the locations of thermocouples specified above. These thermocouples will be installed at the same depths as specified above.

   C. Data acquisition for heat of hydration will begin as soon as the concrete is placed and continue until the concrete temperatures reach ambient temperature. Data acquisition for temperature gradients will begin as soon as the beams are initially surveyed.

II. Stainless steel inserts supplied by the Contractor and installed by the Researchers shall be cast into the underside of the deck slab at the specified locations noted on the plans. Stainless steel hemispherical bolts or low profile acorn nuts with threaded lugs shall be installed in the inserts after the falsework has been stripped. These points will be used as part of a deflection survey to measure the slab deflection due to creep, shrinkage, and live load. Elevations of the deck points will be taken in conjunction with the beam points (See Appendix A attached to end of Special Provision for Section 528).

ROUTE 104, BRISTOL
Cement Compositions

Component	Percent		
	Girder	Deck	
		w/o Silica Fume	w/Silica Fume
Silicon dioxide (SiO_2)	20.1	21.5	27.18
Aluminum oxide (Al_2O_3)	5.5	4.9	4.40
Ferric oxide (Fe_2O_3)	2.3	3.1	2.67
Calcium oxide (CaO), Total	63.2	63.7	59.18
Calcium oxide (CaO), Free	1.2	0.7	—
Sulfur trioxide (SO_3)	3.5	2.9	2.96
Magnesium oxide (MgO)	2.6	2.4	2.18
Alkali equivalent (Na_2O)	0.76	0.8	—
Potassium monoxide (K_2O)	—	—	0.98
Strontium oxide (SrO)	—	—	0.18
Manganese sesquioxide (Mn_2O_2)	—	—	0.04
Zinc oxide (ZnO)	—	—	0.05
Chromium sesquioxide (Cr_2O_3)	—	—	0.02
Loss on ignition	1.2	0.7	0.84
Insoluble residue	0.3	0.3	3.44
Tricalcium aluminate (C_3A)	11	7.6	7.15
Tetracalcium aluminoferrite (C_4AF)	7	9.6	—
Tricalcium silicate (C_3S)	54	50.9	—
Dicalcium silicate (C_2S)	17	23.1	—