NORTH CAROLINA
U.S. 401

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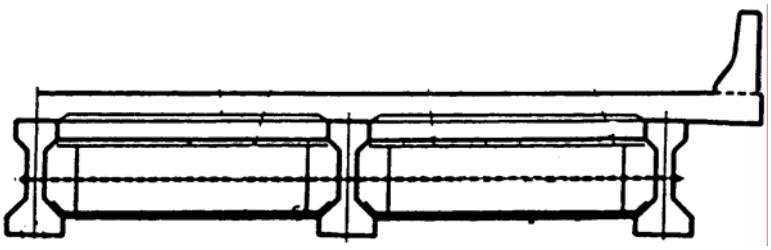
NORTH CAROLINA
U.S. 401

1. DESCRIPTION



Location:	U.S. 401 over Neuse River, Wake County
Open to Traffic:	Northbound – July 2000
	Southbound – September 2002
Environment:	Normal over river
HPC Elements:	Girders and deck
Total Length:	Two structures each 91 m long
Skew or Curve:	None
Girder Type:	AASHTO Types IV and III
Girder Span Lengths:	Two at 28.0 m and two at 17.5 m
Girder Spacing:	3.12 m
Girder Strand Grade:	270
Girder Strand Dia.:	0.6 in
Max. No. of Bottom Strands:	30 in Type IV, 16 in Type III
Deck Thickness:	215 mm
Deck Panels:	Stay-in-place metal forms

2. BENEFITS OF HPC AND COSTS

A. Benefits of HPC

There were several reasons why HPC was selected for use in this structure. The potential initial cost savings was the most significant factor. By utilizing HPC, it was possible to use five lines of girders instead of six that would have been required with a conventional strength concrete. In addition to the initial cost savings, it is expected that the effective life of the bridge deck will be improved resulting in lower maintenance and life-cycle costs. North Carolina is especially interested in using HPC as a way to reduce the chloride permeability of its bridge decks. To achieve this objective, the specifications require fly ash to be substituted for 20 percent of the portland cement in the concrete mix for the deck. The specifications for both the deck and the girders are performance based; the contractor is responsible for submitting a mix design that satisfies the performance parameters. It is anticipated that his approach will result in the lowest cost.

B. Costs

	Low Bid (1)	Average Bid (2)
HPC Deck:	$15.33/ft^2	$16.88/ft^2
Conventional Deck:	$15.33/ft^2	$15.61/ft^2
HPC Type III Girders:	$165/ft^2	$108/ft^2
HPC Type IV Girders:	$169/ft^2	$121/ft^2
Normal Strength Type IV Girders:	$142/ft^2	$123/ft^2

Total for two bridges was $1,900,900 or $59.61/ft^2 of deck area.
(1) As submitted by the low bid contractor.
(2) Six contractors submitted bids.

3. STRUCTURAL DESIGN

Design Specifications:	AASHTO Standard Specifications for Highway Bridges
Design Live Loads:	MS 18 or alternate loading
Seismic Requirements:	AASHTO Seismic Performance Category A
Flexural Design Method:	AASHTO Standard Specifications 9.17
Maximum Compressive Strain:	0.003
Shear Design Method:	AASHTO Standard Specifications 9.20
Fatigue Design Method:	None
Lateral Stability Considerations:	None
Allowable Tensile Stress	
—Top of Girder at Release:	0
—Bottom of Girder after Losses:	$6\sqrt{f_c^{'}}$ = 4.2 MPa
Prestress Loss:	35,585 psi
Method Used for Loss:	NCDOT Method
Calculated Camber:	46 to 53 mm at midspan of Type IV
Concrete Cover	
—Girder:	30 mm to stirrups at bottom of girder
	38 mm to stirrups at top of girder
—Top of Deck:	65 mm clear
—Bottom of Deck:	30 mm clear
—Other Locations:	—
Properties of Reinforcing Steel	
—Girder:	Grade 400
—Deck:	Top layer – epoxy coated. Bottom layer – uncoated
Properties of Strand	
—Grade and Type:	ASTM A 416, Grade 270, low relaxation
—Supplier:	—
—Surface Condition:	—
—Pattern:	6 strands draped in Type IV. Straight strands in Type III
—Transfer Length:	50 diameters = 30 in
—Development Length:	1.6 l_d from AASHTO Standard Specifications 9.28 = 3.642 m

4. SPECIFIED ITEMS

A. Concrete Properties

	Girders	Deck
Minimum Cementitious Materials Content:	—	—
Max. Water/Cementitious Materials Ratio:	0.40	0.43
Min. Percentage of Fly Ash:	—	20
Max. Percentage of Fly Ash:	—	20
Min. Percentage of Silica Fume:	—	—
Max. Percentage of Silica Fume:	—	—
Min. Percentage of GGBFS:	—	—
Max. Percentage of GGBFS:	—	—
Maximum Aggregate Size:	—	—
Slump:	⦸ 180 mm W/HRWR (3)	⦸ 5 in
Air Content:	4 ± 1%	4.5-7.5%
Compressive Strength		
—Release of Strands:	48 MPa	—
—Design:	69 MPa at 28 days	41.3 MPa at 28 days
Chloride Permeability: (AASHTO T 277)	800 to 2000 coulombs (4)	—
ASR or DEF Prevention:	Not specified	Not specified
Freeze-Thaw Resistance:	Not specified	Not specified
Deicer Scaling:	Not specified	Not specified
Abrasion Resistance:	Coarse aggregate ⦸ 40% per Los Angeles abrasion test	—
Other:	—	—

(3) Later changed to 200 mm.
(4) Target values.

B. Specified QC Procedures

Girder Production	
Curing:	Steam or heat
Internal Concrete Temperature:	⦸ 85 ^{o}C
Cylinder Curing:	With girders until release of strands followed by air curing
Cylinder Size:	100x200 mm
Cylinder Capping Procedure:	Neoprene caps allowed
Cylinder Testing Method:	AASHTO T 22
Frequency of Testing:	Nine cylinders from each end of the bed
Other QA/QC Requirements:	One test girder for each span
Deck Construction	
Curing:	Burlap and polyethylene sheets kept moist for 7 days
Cylinder Curing:	—
Cylinder Size:	—
Flexural Strength:	Not specified
Other QA/QC Requirements:	Test panel with each deck pour

5. CONCRETE MATERIALS

A. Approved Concrete Mix Proportions

	Girders	CIP Deck
Cement Brand:	Holnam	Holnam
Cement Type:	I/II	I/II
Cement Composition:	—	—
Cement Fineness:	—	—
Cement Quantity:	534 kg/m^3	348 kg/m^3
GGBFS Brand:	—	—
GGBFS Quantity:	—	—
Fly Ash Brand:	—	Roanoke
Fly Ash Type:	—	F
Fly Ash Quantity:	—	104 kg/m^3
Silica Fume Brand:	Rheomac	—
Silica Fume Quantity:	30 kg/m^3	—
Fine Aggregate Type:	—	—
Fine Aggregate FM:	2.54	2.36
Fine Aggregate SG:	2.62	2.65
Fine Aggregate Quantity:	537 kg/m^3	595 kg/m^3
Coarse Aggregate, Max. Size:	3/4 in	25 mm
Coarse Aggregate Type:	—	—
Coarse Aggregate SG:	2.94	2.63
Coarse Aggregate Quantity:	920 kg/m^3	1083 kg/m^3
Other Aggregate, Max Size:	—	—
Other Aggregate, Type:	78 M	—
Other Aggregate, SG:	2.94	—
Other Aggregate, Quantity:	267 kg/m^3	—
Water:	163.4 kg/m^3	148.3 l/m^3
Water Reducer Brand:	—	—
Water Reducer Type:	—	—
Water Reducer Quantity:	—	—
High-Range Water-Reducer Brand:	MasterBuilders PS 1232	Adva 100
High-Range Water-Reducer Type:	A and F	F
High-Range Water-Reducer Quantity:	3133 ml/m^3	As required
Retarder Brand:	Delvo	Daratard 17
Retarder Type:	B and D	B and D
Retarder Quantity:	1393 ml/m^3	As required
Corrosion Inhibitor Brand:	—	—
Corrosion Inhibitor Type:	—	—
Corrosion Inhibitor Quantity:	—	—
Air Entrainment Brand:	Micro-Air	Daravair 1000
Air Entrainment Type:	Surfactant	Saponified rosin
Air Entrainment Quantity:	232.1 ml/m^3	As required
Water/Cementitious Materials Ratio:	0.30	0.33

B. Measured Properties of Approved Mix

	Girders	Deck
Slump:	125 to 200 mm	85 mm
Air Content:	3-6%	6 ± 1.5%
Unit Weight:	—	—
Compressive Strength:	7800 psi at 24 hours	—
	8800 psi at 48 hours	—
	9800 psi at 7 days	—
	12,480 psi at 28 days	—
Chloride Permeability: (AASHTO T 277)	—	—

6. CONCRETE MATERIAL PROPERTIES

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

Cement Composition:	—	
Actual Curing Procedure for Girders:	Hot water heat	
Average Slump:	4-7 in	
Maximum Girder Temperature:	—	
Air Content:	3-5%	
Unit Weight:	—	
Compressive Strength:	Range at release (27 hours)	7700 to 10,500 psi
	Average at release	9400 psi
	Range at 28 days	11,800 to 15,000 psi
	Average at 28 days	13,100 psi
Curing Procedure for Cylinders:	—	

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

Cement Composition:	—
Actual Curing Procedure for Deck:	Wet for 7 days
Slump:	4-5 in
Air Content:	5.7 to 6.8%
Compressive Strength:	Northbound 7150 psi at 28 days
	Southbound 5700 psi at 28 days
Curing Procedure for Cylinders:	—

C. Measured Properties from Research Tests of Production Concrete for Girders
Data were obtained for the southbound bridge

Compressive Strength and
Modulus of Elasticity:

Curing (5)	Girder No. (6)	Age				
		27 hours	14 days	28 days	56 days	100 days
Compressive Strength, (AASHTO T 22), psi						
Match	A4	5930 (7)	—	10,670 (7)	—	9690 (7)
	B4	8830	—	10,450	—	9750
	C4	9030	—	10,640	—	10,500
	D4	8950	—	10,580	—	10,980
Field (8)	A4	8080	9650	10,560	11,070	10,850
	B4	9130				
	C4	8400	10,140	10,170	10,740	10,700
	D4	7700				
Modulus of Elasticity, ksi						
Match	A4	—	—	4323 (7)	—	4521 (7)
	B4	—	—	4395	—	4288
	C4	—	—	4547	—	4541
	D4	—	—	4968	—	4960
Field	A4	—	4958	5240	5435	4484
	B4	—	4134	4911	4292	3935
	C4	—	4421	3816	4100	4270
	D4	—	4721	3860	4320	4369

(5) All specimen were 4x8-in cylinders. Match-cured specimens were stored in the laboratory at room temperature following match curing. The field-cured cylinders were initially cured on the side forms of the girders and then stored at room temperature until tested. All compressive strength and modulus of elasticity specimens were tested using steel caps with neoprene pads.
(6) Letter is span identification. 4 is first interior girder. Spans A and B use Type IV girders. Spans C and D use Type III girders.
(7) Indicates error in match curing due to failure in temperature control.
(8) Results for ages of 14 through 100 days are the average of three cylinders representing both beams.

Modulus of Rupture (9): 865 psi for Type III
765 psi for Type IV

(9) Average of three 6x6x20-in specimens tested at 28 days per AASHTO T 97.

Coefficient of Thermal Expansion:

Measurement Type (10)	Concrete Age, days	Girder			
		A4	B4	C4	D4
VWSG	28	8.78	8.66	8.76	8.84
ERSG	28	8.64	8.82	9.58	8.93
AASHTO P 60	56	8.7		7.4	

(10) VWSG is a vibrating wire strain gage in a 6x12-in cylinder.
ERSG is an electrical resistance strain gage in a 6x12-in cylinder.
AASHTO P 60 tests were made using 4x8-in cylinders.

Creep:

Girder Spans	A and B (11)	C and D (12)
Girder Type	IV	III
Specific Creep, (13) millionths/psi	0.214	0.254
Creep Coefficient (13)	1.94	1.85

(11) For Spans A and B, tests were started at a concrete age of 3 days.
(12) For Spans C and D. tests were started at a concrete age of 5 days.
(13) Average values for two 4x8-in cylinders loaded for approximately 120 days. Specimens experienced some load loss between 3 and 30 days.

Shrinkage:

Girder Spans		A and B	C and D
Girder Type		IV	III
Shrinkage, millionths	3x3x11-1/4 in Prisms (14)	510	470
	Full-Size Girders (15)	45	85

(14) Average of three prisms for Spans A and B and two prisms for Spans C and D measured with a comparator.
(15) Average of three vibrating wire strain gages for a length of girder stored outdoors.

Chloride Permeability:

Age, days	Location (16)	Charge Passed (17), coulombs	
		Spans A and B	Spans C and D
56	Middle	4557	3704
90	Top	1261	3055
	Middle	1257	2530

(16) Location of slice cut from a 4x8-in cylinder.
(17) AASHTO T 277.

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

Compressive Strength: 5310 to 6700 psi at 28 days
5900 to 7020 psi at 56 days

7. OTHER RESEARCH DATA

Data were obtained for the southbound bridge

Concrete Curing Temperatures:

Concrete curing temperatures were measured at five cross sections in Girders A4, B4, C4, and D4. Ten thermocouples were placed at midspan, three at each quarter span, and three at a distance of span/50 from each end. Maximum measured concrete temperature was 162 ^{o}F.

Strand Forces:

Load cells were placed on 4 strands at the dead end of the bed to measure changes in strand forces from tensioning to detensioning.

Time	Temp, ^{o}F	Load Cell Force, kips					Comments
		Load Cell No.					
		1	2	3	4	Average	
Type IV Girders							
Initial	85	42.2	42.6	41.2	41.7	41.9	Just after tensioning
17 hrs	60	43.8	43.7	42.4	43.2	43.3	
40 hrs	60	43.7	43.7	42.4	43.2	43.3	
64 hrs	60	42.3	42.3	40.9	41.8	41.8	Before detensioning
Type III Girders							
Initial	62	42.8	42.7	42.5	42.9	42.7	Just after tensioning
24 hrs	60	41.0	41.3	40.9	42.1	41.3	
48 hrs	60	39.6	39.8	39.4	40.2	39.8	
55 hrs	70	42.6	43.2	42.5	43.3	42.9	Before detensioning

Camber:

Camber (18)	Girder			
	A4	B4	C4	D4
Measured, in	1-1/8	1-1/8	5/8	1/2
Predicted, in	1.3	1.3	0.52	0.52

(18) Midspan camber one hour and 24 hours after detensioning.

Transfer Length:

Girder	Transfer Length, in (19)
Type IV	26
Type III	28

(19) Transfer length of 0.6-in-diameter strands taken at 95% of the average maximum strain measured on two girders of each type.

8. OTHER RELATED RESEARCH

Not available.

9. SOURCES OF DATA

Southeast Regional High Performance Concrete Showcase Notebook, Auburn, AL, June 29-July 1, 1999.

Koch, T. "NCDOT's Experience with HPC," HPC Bridge Views, Issue No. 20, March/April 2002, p. 2.

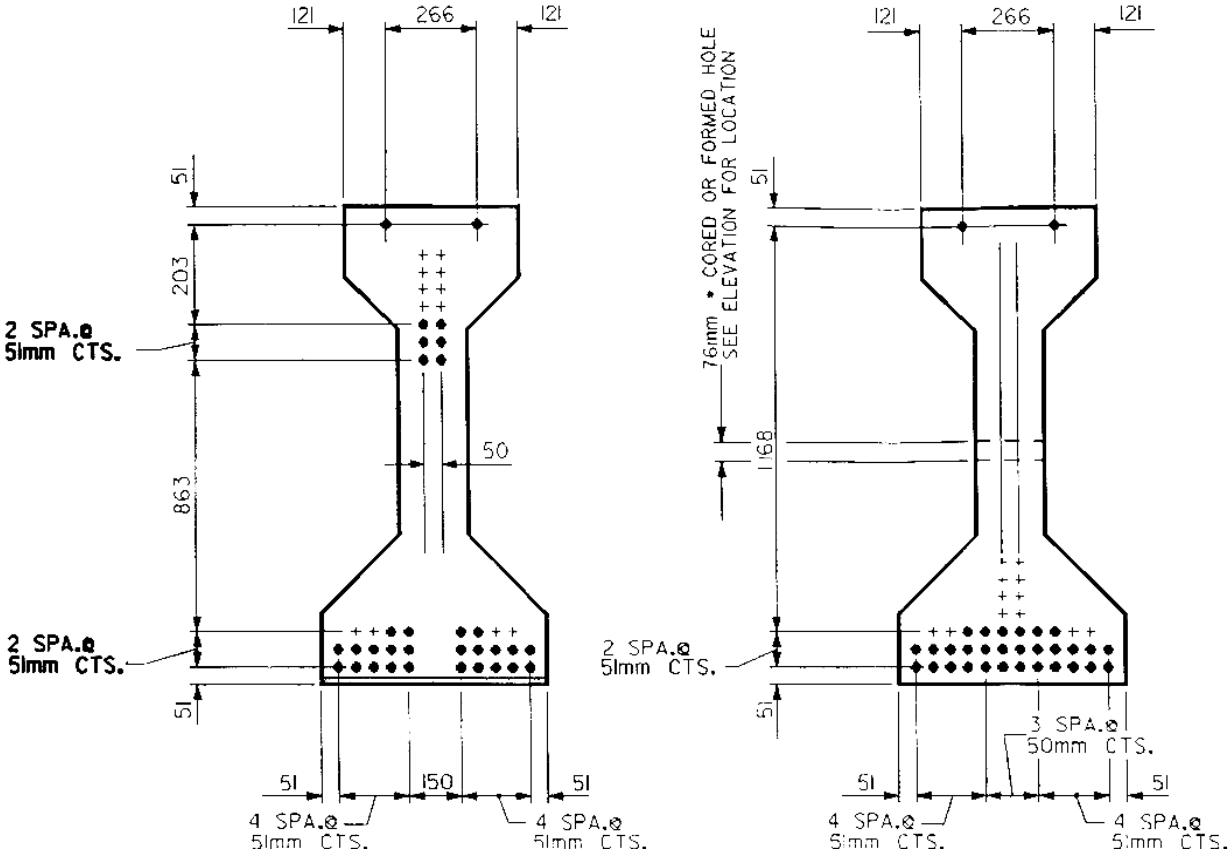
Kowalsky, M. J., Zia, P., Wagner, M. C., and Warren, B. A., "The Behavior of Prestressed High Performance Concrete Bridge Girders for US Highway 401 over the Neuse River in Raleigh, NC," North Carolina Department of Transportation, Report No. FHWA/NC/2002-003, 2002, 140 pp.

Azam Azimi, State of North Carolina Department of Transportation, Raleigh, NC.

Tom Koch, State of North Carolina Department of Transportation, Raleigh, NC.

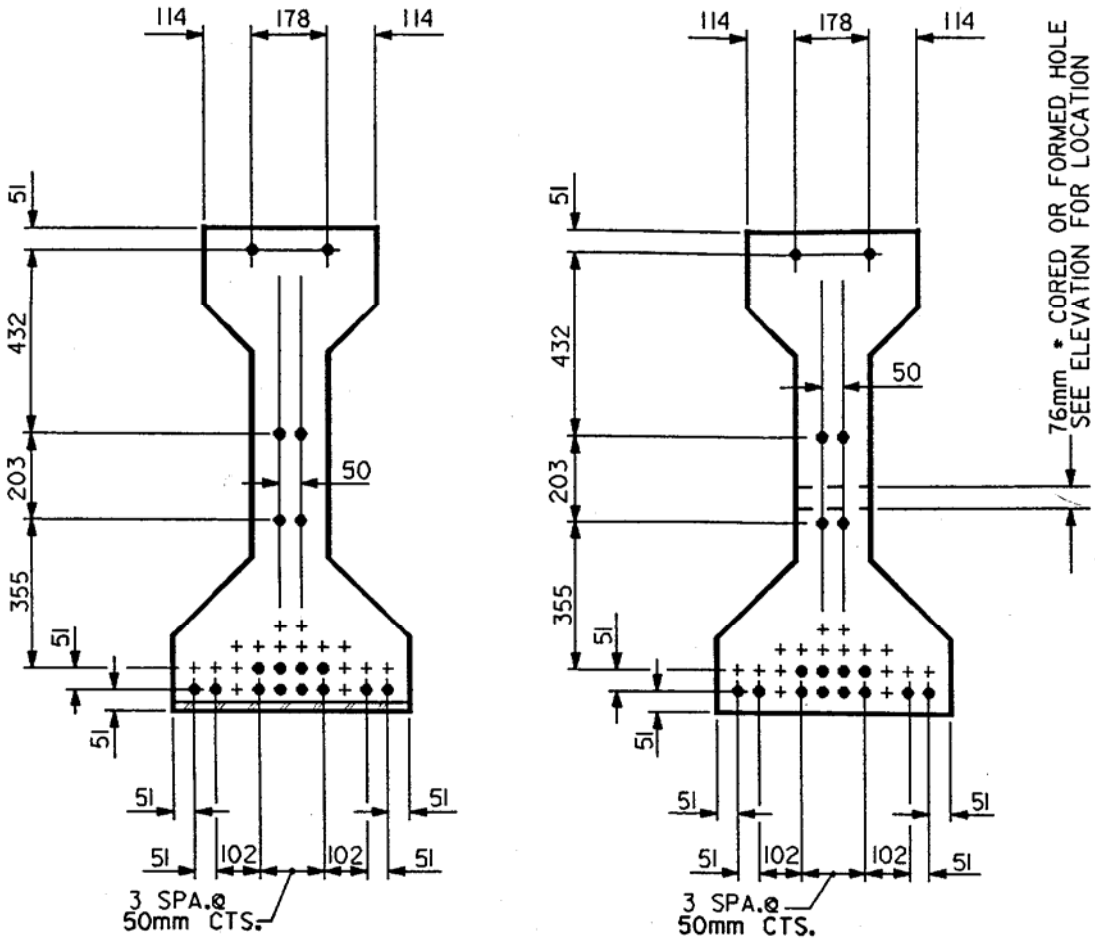
Paul Zia, North Carolina State University, Raleigh, NC.

10. DRAWINGS



End Midspan

Type IV Girder



End Midspan

Type III Girder

11. HPC SPECIFICATIONS

HIGH STRENGTH PRESTRESSED CONCRETE MEMBERS (SPECIAL)

High strength prestressed concrete members shall meet the requirements of Section 1078 of the Standard Specifications, with the following exceptions:

1.0 Materials

The coarse aggregate shall have a Los Angeles abrasion loss of not more than 40 percent and a sodium sulfate soundness loss at five cycles of not more than 8 percent.

Portland cement shall be pretested and come from a single source. Strength uniformity of the cement shall be certified by the manufacturer in accordance with ASTM C917. The certification shall be submitted to the Engineer with the contractor's proposed mix design.

2.0 Portland Cement Concrete Composition and Design

All concrete shall develop the minimum compressive strength shown on the plans at the age of 28 days. Concrete shall be air entrained to provide an air content of 4 percent, plus or minus 1 percent. Concrete shall have a maximum slump of 85 mm before the addition of high range water reducer and 180 mm with high range water reducer. The maximum water-cementitious material ratio shall not exceed 0.40. Fly ash, microsilica, and ground granulated blast furnace slag or their combinations may be used as part of the cementitious material at a rate consistent with industry practice and with the approval of the Engineer. High range water reducer shall be used at a rate not to exceed the manufacturer's recommended dosage.

Mix designs, stated in terms of saturated surface dry weights, shall be submitted on M&T Form 312 at least 90 days prior to using the proposed mix. Laboratory test results of at least six 100 mm x 200 mm cylinders at 28 days shall accompany Form 312. The test cylinder concrete shall be sampled from a design mix of a batch size of at least 3.0 cubic meters. The average strength based on test results of the six cylinders shall not be less than 10 MPa above the minimum strength required by the plans.

Any change in mix design or in the source of mix components or admixtures shall require the Engineer's approval. Request for any change shall be submitted to the Engineer at least 90 days prior to the date of scheduled intended use.

3.0 Testing

For the purpose of testing for the required 28 day compressive strength and also for the required compressive strength for the transfer of prestressing load, the Contractor shall furnish, at no cost to the Department, a minimum of nine concrete cylinders made from a sample of concrete placed near the live end of the bed and a minimum of nine concrete cylinders placed near the dead end of the bed. Two cylinders from each end shall be tested to determine release strength. Three cylinders from each end shall be tested to determine acceptance strength. Cylinders shall be made in 100 mm x 200 mm steel molds in accordance with AASHTO T23, except that the cylinders shall be cured in the same manner as the members represented until the strands have

been released. Cylinders shall be placed in clusters at random points along the casting bed. After the strands have been released, cylinders shall be air cured in an approved common area near the testing apparatus for the remainder of the 28 day curing period. Cylinders shall be tested in accordance with AASHTO T22 except that the neoprene caps may be used. Approved apparatus.for testing the transfer strength of the cylinders shall be provided by the Contractor. This apparatus shall be maintained to within 1.0 percent accuracy and shall be calibrated at intervals not to exceed 12 months by an approved testing company at no cost to the Department. The Engineer reserves the right to require verification immediately after a testing machine is relocated and whenever there is a reason to doubt the accuracy of the indicated load, regardless of the time interval since the last verification. If the coefficient of variation of the 28 day cylinders exceeds 15 percent, the Engineer may require additional tests.

Additional concrete shall be dedicated to the production of forty 100 mm x 200 mm cylinders, six 76 mm x 76 mm x 286 mm prisms, and three 150 mm x 150 mm x 508 mm prisms for each of the eight instrumented girders. The Department will provide all molds and labor required for the production of these specimens. A portion of these cylinders will be match-cured, and the Department will provide for the instrumentation, equipment, operation, and data collection for the match-cured specimens.

4.0 Temperature

The Contractor shall construct a mock-up of the member with thermocouples to monitor temperatures. If the temperature of the mock-up concrete exceeds 85 degrees C, the Engineer may require cores to evaluate the strength of the concrete. Use of the 1.5 meter test girders for monitoring temperatures will not be permitted.

5.0 Mixing

If truck mixing is used, trucks shall be loaded to within at least 0.765 m3 of rated capacity, and concrete shall be mixed at a speed of 16-18 revolutions per minute.

6.0 Payment

No separate payment will be made for high strength concrete. The cost of furnishing and incorporating the high strength concrete, including the cost of additional concrete for the cylinders and prisms, is considered a part of the work of fabricating and furnishing the prestressed concrete units.

ACCESS FOR INSTRUMENTATION (SPECIAL)

1.0 General

The Contractor shall provide Department Personnel with access to the north bound structure for the purpose of installing instrumentation and monitoring equipment in the bridge deck, bent diaphragm, test panels, prestressed concrete girders, and 1.5 meter test girders.

2.0 Bridge Deck, Test Panels, and Bent Diaphragm

The Contractor shall notify the Engineer at least thirty days prior to initiation of each bridge deck pour of the northbound structure or simultaneous test panel pour to accommodate instrumentation. Prior to pouring concrete, and following the completion of the tying of the bridge deck reinforcing steel, a maximum of two days shall be made available to Department Personnel for instrumentation purposes.

3.0 Girders

A total of eight prestressed concrete girders will be instrumented, including one interior girder and one 1.5 meter test girder from each span of the north bound structure. Measurements will be made during the production of these eight girders. All instrumentation and data collection will be made by the Department. For the purpose of installation of equipment, a maximum of one day per instrumented girder will be required. least thirty days prior to the scheduled casting of each instrumented girder, the Contractor shall notify the Engineer. For instrumentation and data collection purposes, the Contractor shall provide Department personnel with access to each instrumented girder as required before, during, and following casting.

REINFORCED CONCRETE DECK SLAB @ STA. 80+30.50 -L-: **(SPECIAL)**

1.0 General

This special provision shall govern materials, forming and all other related work in the construction of a reinforced concrete deck slab and test panels in accordance with applicable parts of the Standard Specifications, the details shown on the plans, and as outlined in these special provisions.

2.0 Materials

All cast-in-place concrete shall be Class "AA" conforming to the requirements of Section 1000 of the Standard Specifications, except that all concrete for the reinforced bridge deck and test panels shall develop a minimum compressive strength of 41.3 MPa at the age of 28 days and Class F fly ash shall be substituted for 20% of the portland cement in accordance with Article 1024-1 of the Standard Specifications.

3.0 Construction Methods

The slab overhang from the exterior girder to the outside edge of superstructure shall be constructed using removable forms.

No profile grade-line adjustment will be allowed unless permitted by the Engineer.

Curing methods for the concrete, including test panels, will conform to the Standard Specifications except as follows:

The Membrane Curing Compound Method will not be allowed. A curing medium consisting of burlap under polyethylene sheets or another material consisted on the deck and test panels and approved by the Engineer shall be place kept moist for a minimum of seven (7) curing days. The burlap or other approved curing medium shall be wet when placed on the deck. Water shall be applied to the curing medium through soaker hoses or another method approved by the Engineer. Water shall be applied in amounts to keep the medium moist but will not be allowed to flow or pond on the deck.

4.0 Measurement

Reinforced concrete deck slab(s) constructed under this item will be measured by the square meter of horizontal surface area using the nominal dimensions and configuration shown in the Layout Sketch for computing surface area as shown on the plans, transverse measurement being made out to out of slab including raised median and/or sidewalk sections. Concrete Barrier Rail will be measured in accordance with the item under which it is furnished and will not be a part of this item.

The quantities of concrete and reinforcing steel shown on the plans include test panels, concrete diaphragms, end posts, sidewalks, and other required attachments based on the profile grade and plan camber of girders. The quantities also include the 25 mm additional concrete due to the corrugation of the metal forms and based on the profile grade and plan camber of the girders.

No measurement will be made for concrete or reinforcing steel due to a variation in camber of the girders from the plan camber.

5.0 Payment

The quantity for which payment is made will be that quantity shown in squares meters on the plans. Where the plans have been revised, the quantity to be paid for will be the quantity shown on the revised plans.

The unit bid per square meter will be full compensation for all work covered by this special provision and applicable parts of the Standard Specifications but not limited to furnishing and placing concrete, reinforcing steel, deck drains, and any other material, erecting and removing all falsework and forms, protecting concrete in wind, rain, low humidity, high temperatures or other unfavorable weather, constructing joints, constructing drains, finishing concrete and curing concrete.

Payment will be made under:

Reinforced Concrete Deck Slab @ Sta._____……..... Square meter