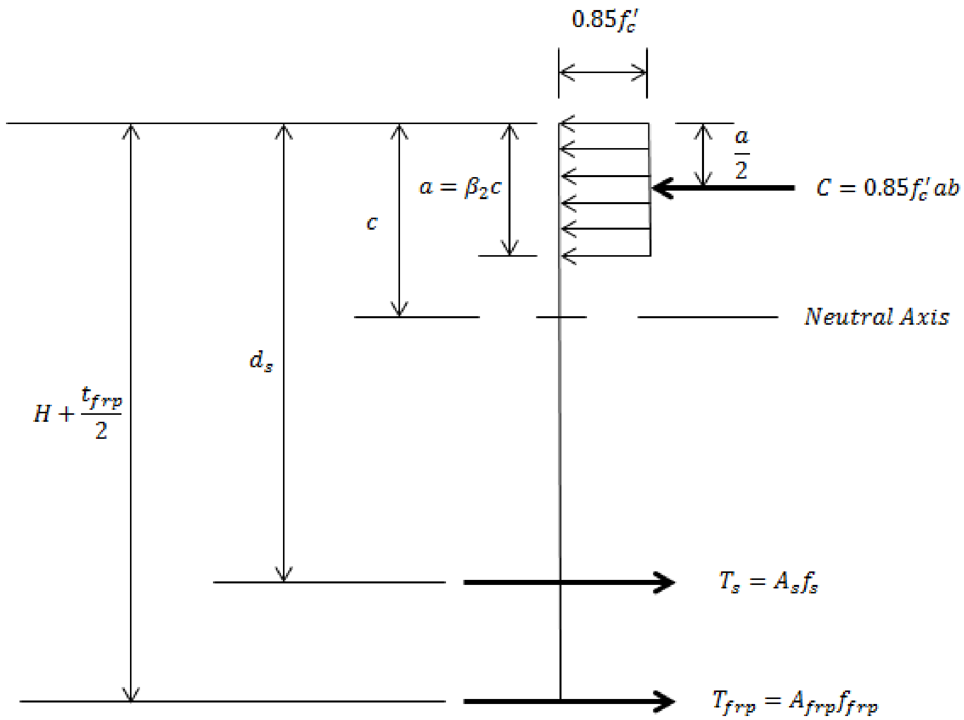

Fig. 4—Section Forces using Whitney's Rectangular Stress Block for Concrete

List of Symbols:

α	Bearing-Slip Model Factor
$a_{no\ frp}$	Depth to Neutral Axis assuming no FRP
A_s	Area of Steel Reinforcement
b	Width of Beam Section
β	Concrete Strength Factor
β_s	Bearing-Slip Model Factor
d_s	Depth to Steel Reinforcement
ε_t	Strain to Confirm Elastic Section
f_y	Yield Strength of Steel
f_c'	Concrete Strength
L	Distance from Midspan to End Bolt Location
n_i	bolt number
N_b	Bearing Yield Strength of FRP
N_f	Bearing Ultimate Strength of FRP
N_i	Shear Force at Connection i
s_b	Slip Experienced at FRP Yield Strength, N_b
s_f	Slip Experienced at FRP Ultimate Strength, N_f
s_i	Slip at Connection i
s_{max}	Maximum Slip
x_i	Distance from First Connection to Connection i

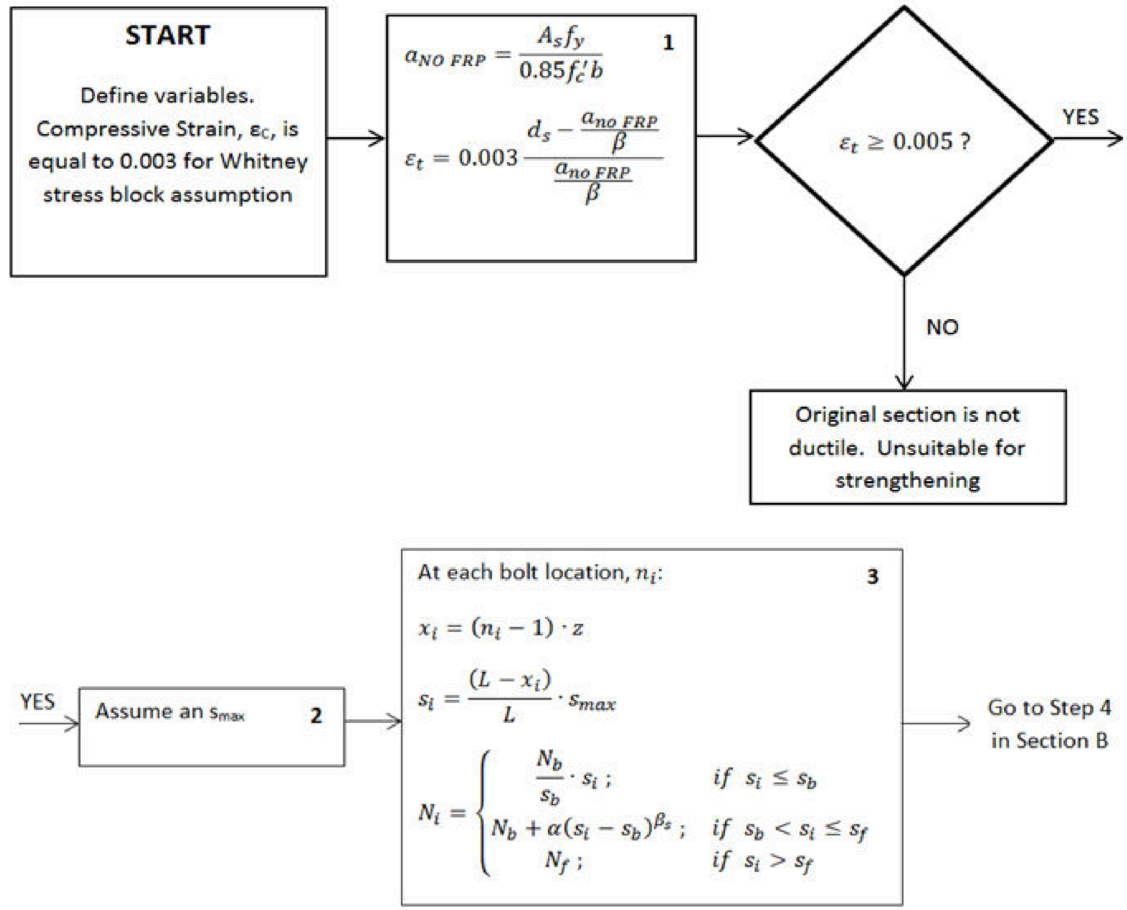

Fig. 5—Section A: Nominal Moment Capacity Analysis – Determination of Force per Bolt from Slip Model

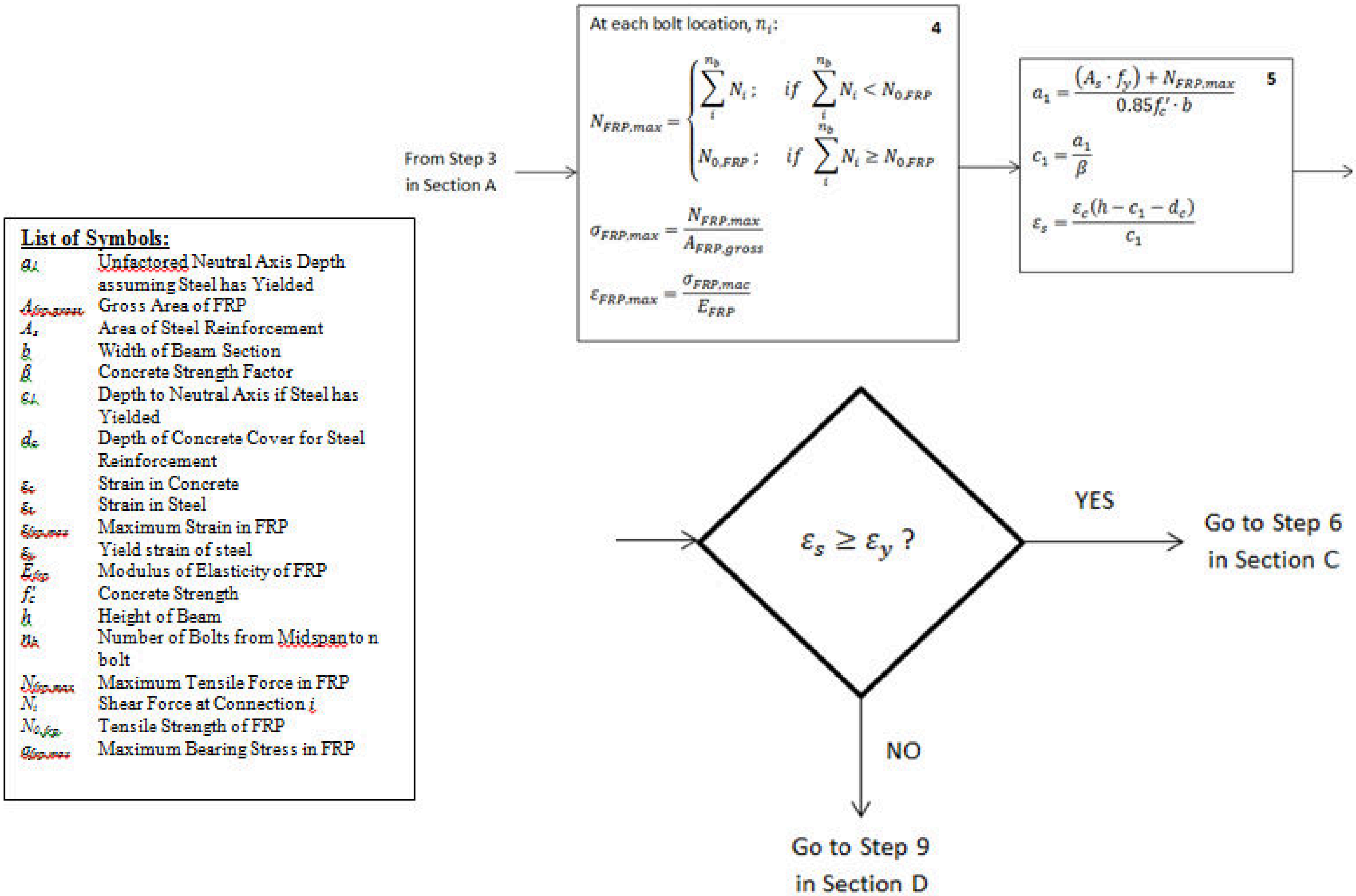

Fig. 6—Section B: Nominal Moment Capacity Analysis – Location of Neutral Axis Assuming Steel Yields

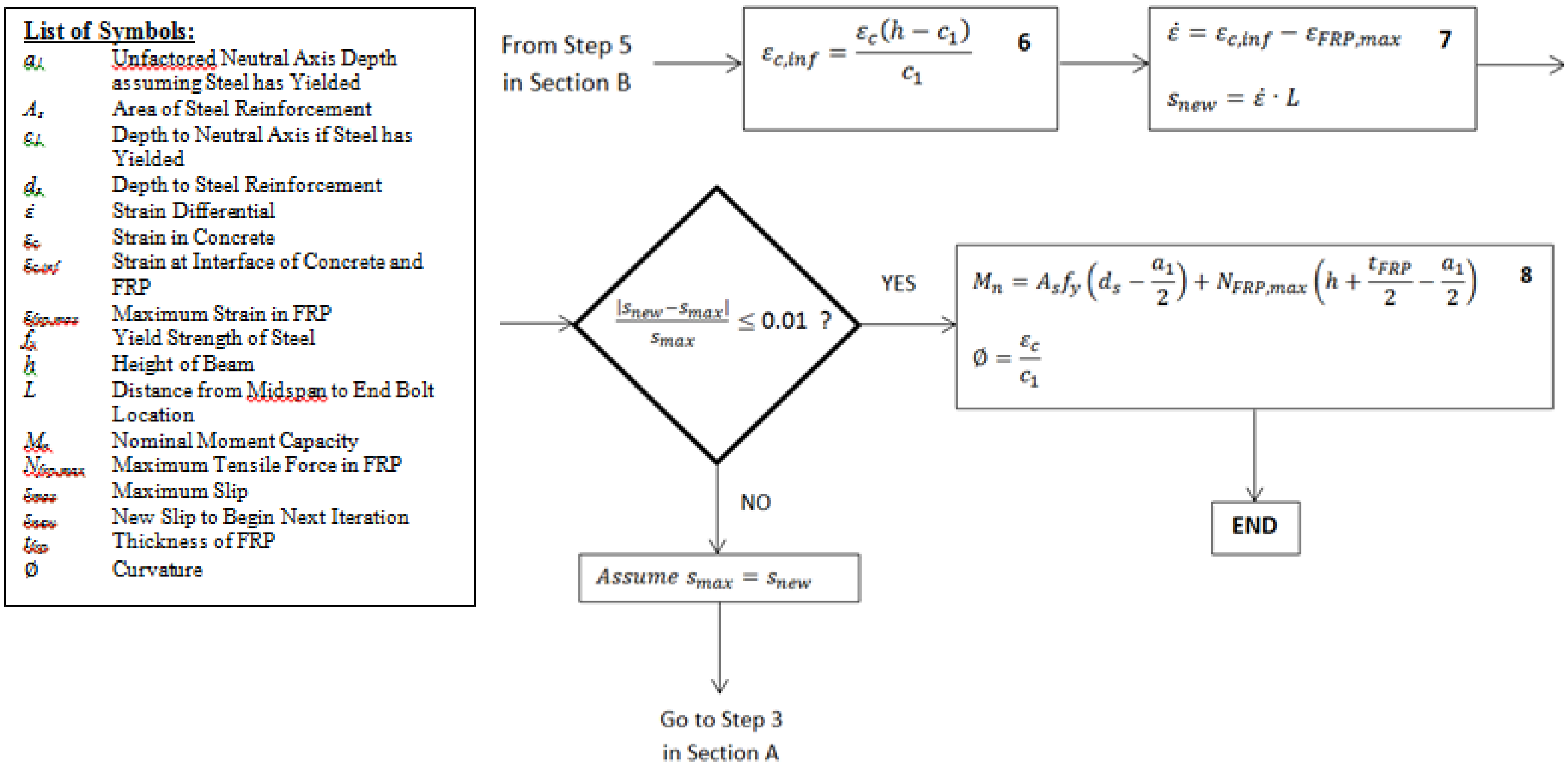

Fig. 7—Section C: Nominal Moment Capacity Analysis -
Convergence to Actual Bolt Slip and Calculation of Ultimate Moment for Sections where Steel Yields

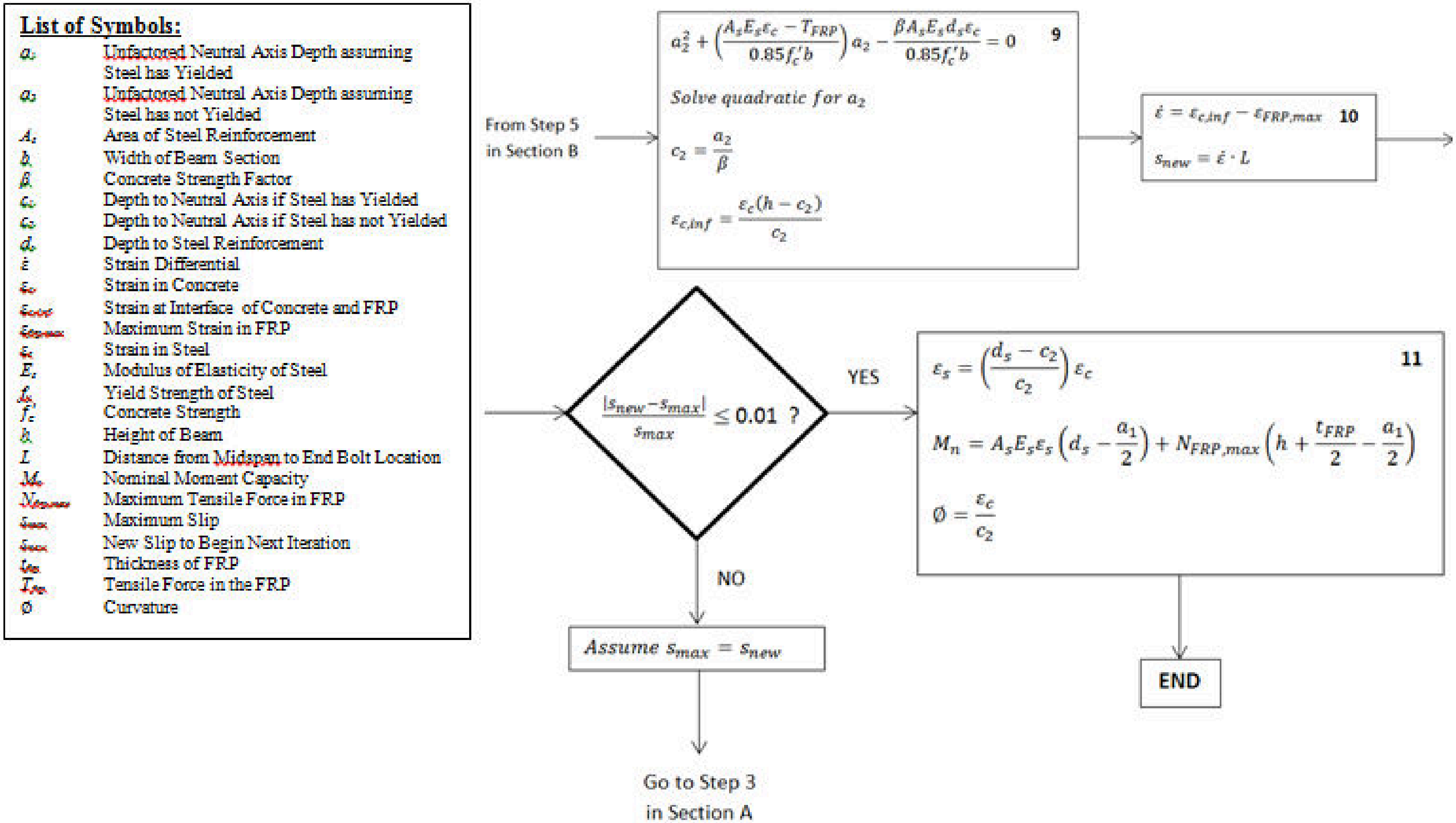

Fig. 8—Section D: Nominal Moment Capacity Analysis -
Location of Neutral Axis, Convergence to Actual Bolt Slip, and Calculation of Ultimate Moment for Section where Steel does not Yield

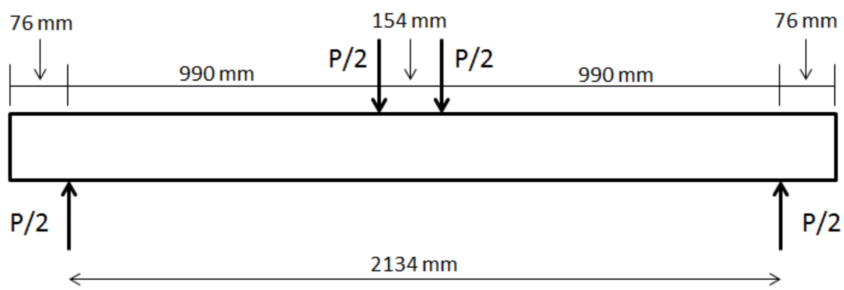

Fig. 9—Beam Load Diagram
Note: 1 mm = 0.039 in

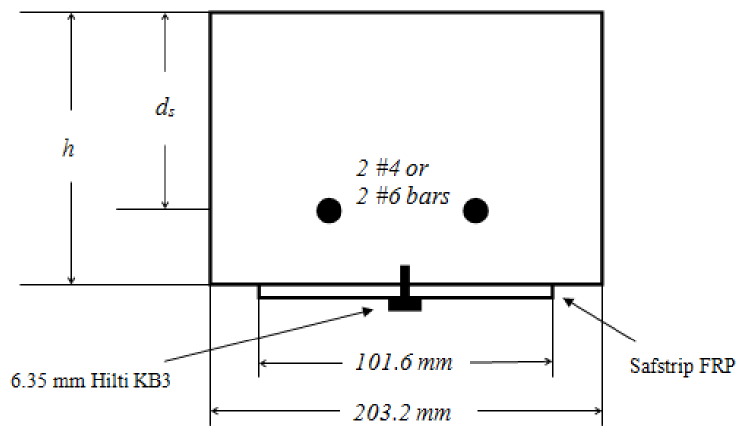

Fig. 10—Typical Beam Cross-Section
Note: 1 mm = 0.039 in

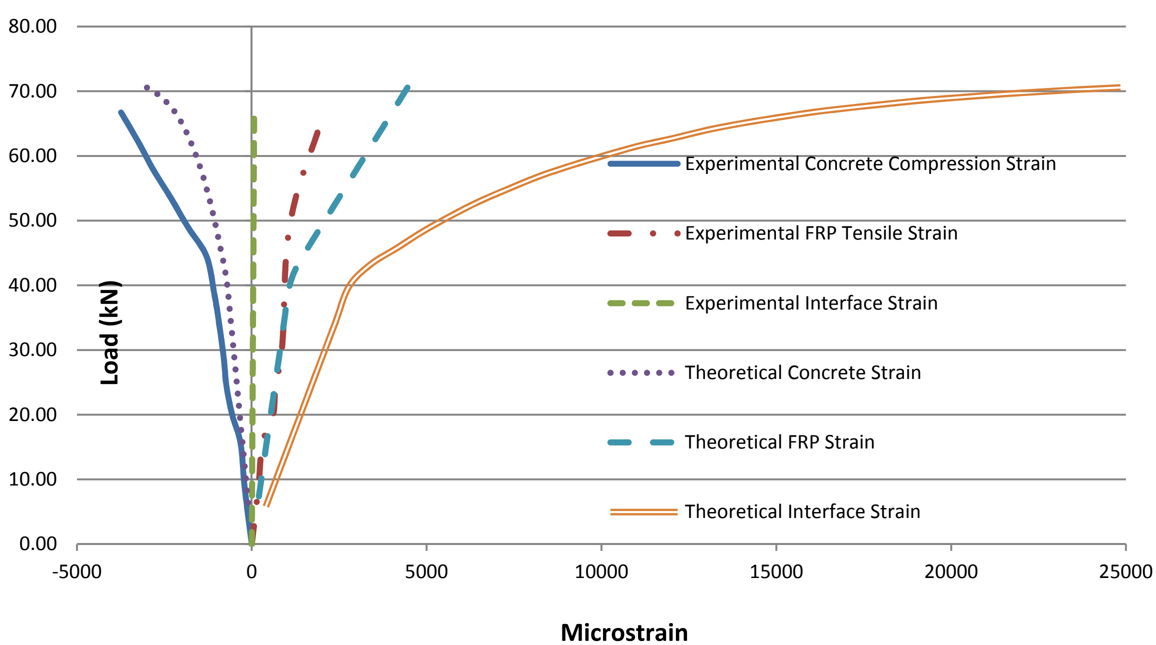

Figure 11—Beam 1 Strain Comparison
Note: Interface Strains Not Measured on Beam Centerline; 1 kN = 224.8 lbs

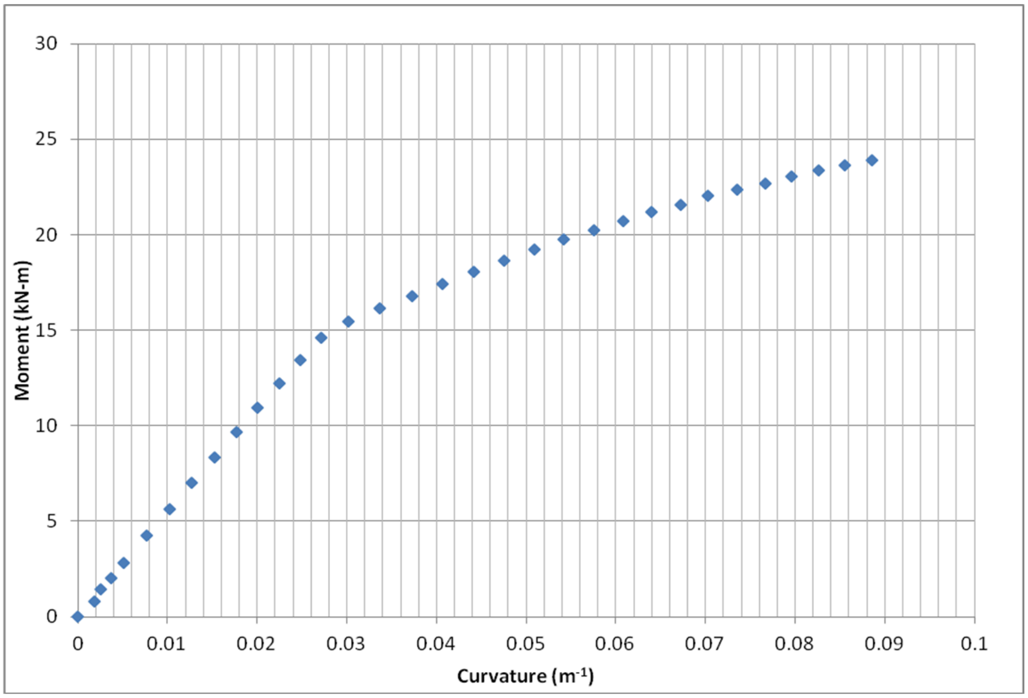

Figure 12—Moment-Curvature Diagram for Beams 3-1 and 4-1
Note: 1 kN-m = 737.6 lb-ft and 1 m^{-1} = 0.305 ft^{-1}

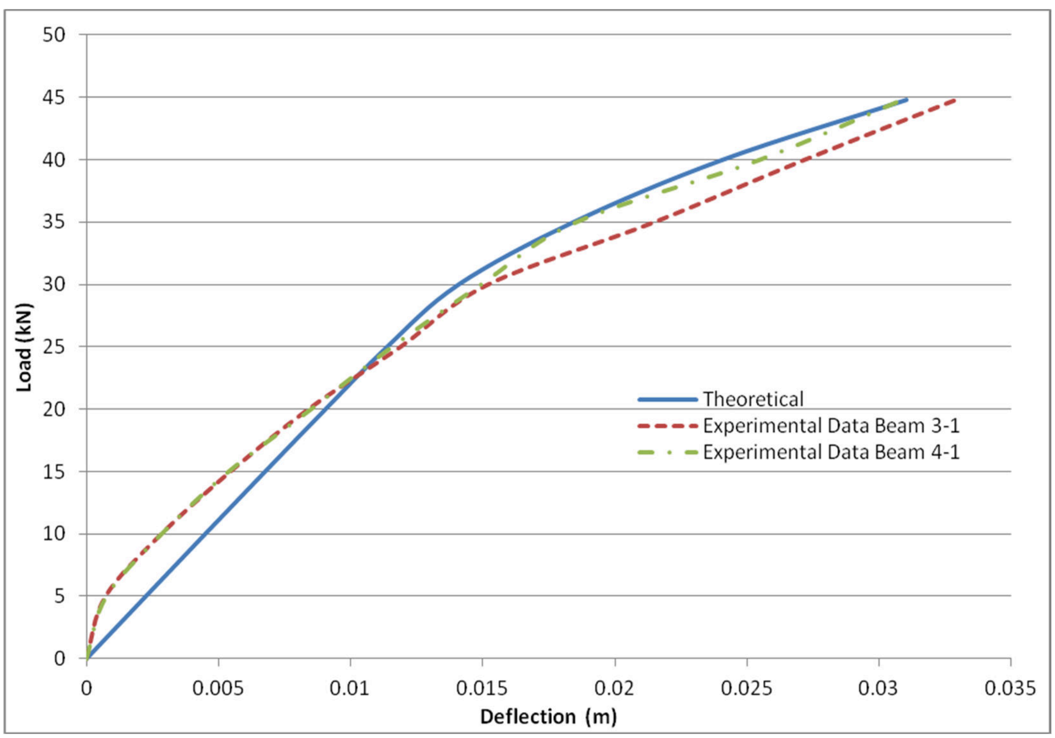

Figure 13—Beams 3-1 and 4-1 Midspan Deflection Comparison
Note: 1 kN = 224.8 lbs and 1 m = 3.28 ft

Use of Self-consolidating Concrete and High Volume Fly Ash Concrete in Missouri Bridge A7957

E.S. Hernandez, and J.J. Myers

Synopsis: Self-consolidating concrete (SCC), as defined by ACI 237R-07, is a very flowable, non-segregating concrete that can spread into placed, fill the formwork and encapsulate the reinforcement without any mechanical consolidation. SCC, compared to traditional concrete mixtures, has primary benefits that include a reduction in equipment and labor associated costs as well as higher construction effectiveness. Innovative materials such as high volume fly ash concrete (HVFAC), represent a substantial advantage to producing stronger, more durable cast-in-place (CIP) concrete members. A level of 50% fly ash to cement proportion, as well as both normal strength self-consolidating concrete (NS-SCC) and high strength self-consolidating concrete (HS-SCC), were employed in the implementation project for Missouri Bridge A7957. The objective of this research was to provide an implementation test bed and showcase for the use of these materials. The serviceability and structural performance, both short-term and long-term, of the concrete members within the bridge were monitored in an effort to investigate the in-situ performance of not only SCC but also HVFAC. The initial instrumentation program consisted of obtaining the temperature, strain, and deflection data for the different components within the bridge's structure, from casting through service conditions. The results obtained from this two-year monitoring program will lead to propose certain specification requirements that can be used for future project implementations.

Keywords: bridge superstructure, extended service life, high volume fly ash concrete, long-term monitoring, self-consolidating concrete.

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INTRODUCTION

One of the advantages of using high-strength self-consolidating concrete (HS-SCC) is the possibility to place additional mild or prestressing steel within a reinforced concrete (RC) or precast, prestressed (PC/PS) concrete member. This benefit comes with a strength gain that reduces the number of longitudinal members and/or interior supports of a structure in transportation infrastructure. HS-SCC reduces labor and equipment costs, maintenance expenses, and, thus, the overall project costs. Furthermore, the flowable characteristic of SCC produces better consolidation and placement, with fewer voids and honeycombing problems as compared to conventional concrete mixtures [1]. A more condensed microstructure increases the concrete durability properties, leading to a longer service life. Despite all these benefits, several concerns are related to HS-SCC's mechanical behavior due to its constituent materials and proportions. Myers et al. [2] reported that the effect of the larger paste content and the smaller coarse aggregate size employed in the mixture is of particular interest. The effects of using HS-SCC in PC/PS girders must be monitored by examining its response to prestress losses, shear capacity, creep, shrinkage, thermal gradients, mechanical properties development, and serviceability in full-scale infrastructures under varying loads [3]. High volume fly ash concrete (HVFAC) offers an alternative to typical concrete mixtures, producing stronger, more durable, and, therefore, longer lasting structures. Material specifications have typically restricted the amount of fly ash to 25 or 30 percent of portland cement replacement. Volz et al. [4] demonstrated that higher cement replacement percentages, even up to 75 percent, can produce an enhanced concrete in terms of strength and durability. Several limitations and concerns, however, are related to the application of HVFACs in full-scale structures. When the fly ash replacement content is increased, it generally slows down the setting time and hardening rates of concrete at early ages. This is especially important in the presence of cold weather conditions, and when less reactive fly ashes are used. An instrumentation plan was designed and implemented during the construction stage to investigate the previously mentioned concerns and structural performance, both short-term and long-term, associated with several of the RC and PC/PS members within Bridge A7957. This plan included the monitoring of strains and stress variations at critical locations of selected PC/PS members. In addition, temperature changes of some PC/PS girders, CIP RC deck, and bents from casting through service life were monitored during the same stage. This project enabled comparing the behavior of the three different concrete mixtures used to fabricate the PC/PS girders. The behavior of the two different concrete mixtures employed in the bents of Bridge A7957 under the same environmental conditions was also compared.

RESEARCH SIGNIFICANCE

During the last two decades, self-consolidating concrete (SCC) has grown in use in infrastructure projects around the world because of its primary benefits to produce stronger and longer lasting infrastructure. Similarly, within very recent years, high volume fly ash concrete (HVFAC) has seen its initial transformation from the laboratory to the field. In the United States, important efforts have been made by the Federal Highway Administration (FHWA) and their respective department of Transportation (DOT's) to implement these materials in infrastructure projects. The results presented with this paper are part of an on-going research program whose main objective was to provide an implementation test bed and showcase for the use of SCC, HS-SCC and HVFAC. This stage of the study investigated the in-situ performance of both SCC and HVFAC employed in Missouri Bridge A7957, the first implementation project, built by the Missouri Department of Transportation (MoDOT) using these innovative type of materials. The study also included monitoring the serviceability and structural performance both short-term and long-term of the concrete members of Bridge A7957. The results from this stage of the research are being utilized to establish a load rating of the bridge through diagnostic field load testing.

BRIDGE DESCRIPTION

The Missouri Department of Transportation (MoDOT) built Bridge A7957 during the summer and fall of 2013. This bridge, located on Highway 50 in Osage County, Missouri, is a three-span, PC/PS concrete bridge made continuous via a CIP deck (**Fig. 1** and **Fig. 2**). The PC/PS concrete NU53 girders in each span were designed with concrete mixtures of different compressive strength [5]. The first span (between bents 1 and 2) is 30.48 m [100 ft.] long, and the PC/PS girders are comprised of a conventional concrete (CC) mixture designated by MoDOT as Class A-1. The target 28-day compressive strength was 55.2 MPa [8,000 psi], and the specified release strength was 44.8 MPa [6,500 psi]. The second span (between bents 2 and 3) is 36.58 m [120 ft.] long. Girders on the second span were fabricated with HS-SCC with a target 28-day compressive strength of 68.9 MPa [10,000 psi] and a release compressive strength of 55.2 MPa [8,000 psi]. The third span (between bents 3 and 4) measures 30.48 m [100 ft.] long. It contains girders fabricated with NS-SCC with target 28-day design strength of 55.2 MPa [8,000 psi] and release strength of 44.8 MPa [6,500 psi]. The girders of the first and third spans were prestressed with thirty 15 mm [0.6 in.] diameter Grade 270 low-relaxation prestressing strands of twenty straight strands and ten strands harped at double harping points as shown in **Fig. 3**(a) and **Fig. 4**(a). The girders of the second span were prestressed with the same type of prestressing strands; however, twenty eight straight strands and tend strands harped at double harping points were used as illustrated in **Fig. 3**(b) and **Fig. 4**(b). Within the top flange of each girder (spans 1 through 3), four additional 9 mm [3/8 in.] diameter prestressing strands were added for crack control. The mixture proportions employed in the fabrication of the PC/PS girders of each span are listed in **Table 1**. PC/PS concrete panels, were fabricated of conventional concrete (MoDOT's Class A-1) with a target compressive strength of 41.4 MPa [6,000 psi]. These panels extend between the top flanges of the girders in the transverse direction of the bridge and underneath a CIP RC deck (**Fig. 5**). The CIP deck was cast from a conventional concrete mix (MoDOT modified Class B-2) using a 25 % fly ash replacement of portland cement. The target design strength of this concrete mix was 27.6 MPa [4,000 psi]. Two intermediate bents and two abutments support the superstructure (**Fig. 2**). Both abutments and intermediate bent 2 were built with a conventional concrete mixture (MoDOT Class B) using a 20% fly ash replacement of portland cement with a design compressive strength of 20.7 MPa [3,000 psi]. Intermediate bent 3 was cast from HVFAC with a 50% fly ash replacement of portland cement; it was designed with a specified compressive strength of 20.7 MPa [3,000 psi]. The mixture proportions employed in the supports and CIP deck of Bridge A7957 are listed in **Table 2**.

MONITORING PLAN

During the preconstruction of Bridge A7957, structural elements instrumented included: intermediate bents (**Fig. 6**), two PC/PS NU53 girders per span, and two PC/PS panels located at mid-span (**Fig. 7** and **Fig. 8**). These two instrumented PC/PS panels were set in span 2, between girder lines 2 and 3, and girder lines 3 and 4, respectively. A high-performance automated total station (ATS) was employed at the precast plant so that the girder's camber could be obtained immediately after the prestressing force was transferred to the PC/PS girders (
Fig. 9). The type of sensors employed and details on their installation are described in the following subsections.

Intermediate bents

Thermocouple sensors were installed within bents 2 and 3 so that the temperature and thermal gradients could be obtained once casting was complete. The bent sections at which these sensors were located are illustrated in **Fig. 6**. The ambient temperature was measured to adjust for any difference between concrete mixtures under similar exposure conditions. One thermocouple was placed within each bent at the center line of each column 0.92 m [3 ft.], from the bottom edge of the pier cap [sensors NC and SC in **Fig. 6**(a) and **Fig. 6**(c)]. A second set of thermocouples was installed in the web wall, 2.74 m [9 ft.] from the center line of each column [sensors NW and SW in **Fig. 6**(a) and **Fig. 6**(b)] within the same horizontal plane. One exterior and three interior thermocouples were placed at section C [**Fig. 6**(a)], located 0.30 m [1ft.] from the pier cap's south end according to the detail illustrated in **Fig. 6**(d).

Precast prestressed girders

Vibrating wire strain gauges (VWSG)–A total of 86 vibrating wire strain gauges (VWSG) with built-in thermistors (type EM-5) were used to monitor the strain and stress variations, as well as temperature changes in the PC/PS girders, and the RC deck from fabrication through service life. A total of 62 VWSGs were installed in all spans within the PC/PS girders of lines 3 and 4 before the casting was begun. The PC/PS girder's cluster locations at which the VWSG were placed are illustrated in **Fig. 7**. Within each girder of span 1 and span 3, the instrumentation clusters were located at two cross-sections. One section was located at mid-span, and the other section was placed at approximately 0.61 m [2 ft.] from the support centerline of bents 2 and 3. The instrumentation clusters for span 2 were arranged at three different cross-sections: one at the mid-span and two at approximately 0.61 m [2 ft.] from each support centerline. Several details on VWSGs installed at the girders'