DESIGN FIRST FLORIDA I BEAM BRIDGE WITH GRS ABUTMENT

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ABSTRACT

To replace a rapid deteriorated timber bridge, the GRS-IBS abutment – one of the renovated ideas championed in 2010 by the FHWA's EDC initiative, was implemented to overcome a series of challenges developed during bridge design process. Instead of using a concrete cap supported with piling, the GRS-IBS provides a great settlement tolerant shallow foundation and approach. This paper addresses some new practices in the Florida Department of Transportation: 1) integral diaphragm for an intermedium single span bridge resulting in the elimination of traditional bearing pads; 2) the elimination of expansion joints at roadway surface; therefore, minimizing bridge life time maintenance.

INTRODUCTION

The Department of Environmental Protection's (DEP) Division of Recreation and Parks proposed to replace a timber bridge due to inadequate bridge capacity and rapid deterioration of structural elements. Although existing bridge construction plans were unavailable, additional information emerged identifying the existing bridge as a historic structure to further complicate the design. A series of challenges developed during bridge design; such as where and how to relocate the historic structure, how to protect the historic timber bridge from impact of the new construction if it is not relocated, and where the new bridge would be located to avoid overshadowing the historic structure.

One of the renovated ideas championed in 2010 by the Federal Highway Administration's (FHWA) Every Day Counts (EDC) initiative is the geosynthetic reinforced soil-integral bridge system (GRS-IBS) (1, 2). Instead of using a concrete cap supported with piling, the GRS-IBS provides a great settlement tolerant shallow foundation and approach. Because of the system's lower cost, short construction time, and smooth transition from roadway pavement to bridge, it is accepted by several State DOTs and local governments (3) for single span bridges up to 140 feet long.

Bridge Location and Some Challenges

The existing timber bridge over Zipprer Canal is an undivided two-lane road in Lake Kissimmee State Park in Polk County, Florida, USA. The existing bridge was built in 1964 utilizing timber for both the superstructure and substructure. Due to rapid deterioration of structural elements, it was closed to traffic. The original proposed bridge plans were designed to replace the existing structure with a three-span precast concrete slab bridge. Because of its unique characteristics and service age, the existing bridge was registered as a historic structure during the design process by the Federal Highway Administration (FHWA) and the State Historic Preservation Office (SHPO), and it fell under the provisions of 4(f) for protection. Because of the difficulties to relocate the historic structure, the way to protect the existing bridge and the location of new bridge presented a new challenge for the project; such as pile driving impacts on the historic bridge and the possible overshadowing of the historic bridge in the Park environment.

To avoid overshadowing the historical bridge, a series of bridge locations and several types of superstructure have been investigated. The final location of the new bridge has been established at about 44 feet east of the existing structure. Through the bridge development process, 36-inch Florida I Beams (FIB-36) spaced at 6.75 feet were selected for the bridge superstructure. Compared to pile driving, the GRS abutment was studied and selected for the bridge foundation, which mitigated the risk of possible damage to the historic structure.

To eliminate the bump at the begin/end of bridge, the feasibility of integrating superstructure deck with 36-inch deep Florida I Beams was investigated with a grillage model. Based on FHWA GRS-IBS Abutment Design Index, a 2.5ft bearing width "b" was the minimum required for bridge beam seat. The finite element analysis indicated that a size 2.5'x4' integral abutment would be adequate to transfer the superstructure load into its foundation. Because of the soil condition and the bridge length, a 4'x4' integral abutment was chosen for the final bridge development and construction. The increased bearing seat area brought the service load pressure on the bearing seat under 3.5TSF. To enhance the stability and construction, an 18"x11"x8" CMU (facing block) was selected instead of the recommended ones listed on FDOT Design Index D6025. While the types of superstructure and foundation had been selected, the following project requirements determined the bridge and roadway typical section as well as hydraulic limitations.

PROJECT REQUIREMENTS

The total length of the existing bridge is about 104 feet and consists of seven approximately 15ft spans supported with timber piles. The width of existing bridge deck is 30'-0" with approximately 4 feet of shoulders at each side. The bridge has been closed to traffic due to the significant deterioration of its superstructure and substructure.

Hydraulic Requirements

Based on bridge hydraulic study and the requirement of South Florida Water Management District (SFWMD), a minimum 80ft opening under the bridge is required and will be provided. The future canal bottom at elevation of 45.29 feet (NAVD 88) will be 48ft wide with 1:2 (V:H) bank slopes on both sides at the bridge. The minimum low chord member elevation of 57.0 feet NAVD is required to meet the minimum vertical clearance.

Roadway Typical Section

Based on the traffic data, the proposed bridge cross section consists of two 11ft travel lanes and one 5'-0" wide raised sidewalk on the west side and 2'-0" shoulders on each side with 1'- 1" wide standard 32" vertical traffic barriers. The overall width of the proposed bridge is 33'-2". The bridge deck is crowned with a cross slope of 0.02 to both sides of the bridge coping.
Following sections summarize the geotechnical investigation and the bridge selection.

GEOTECHNICAL CHALLENGE AND GRS-IBS SOLUTION

Subsurface Investigation and GRS-IBS Abutment Solution

Two 150-ft deep soil borings were taken by the Department in vicinity of the proposed bridge. The results of the borings indicated the presence of sands, sand-silt mixtures and clayey sands. Ground water elevation was recorded at about 1.0ft below the ground surface.

Steel piles (both pipe piles and H-piles) and prestressed concrete piles were investigated in the Geotechnical Report. Due to the lack of a hard layer of soil and the requirement of long shafts, the study of drilled shaft foundations was not warranted. Based on the Geotechnical Report, steel piling is a possible alternative but it is not expected to be economically viable due to the extremely aggressive environment. Precast prestressed concrete piles are considered suitable for the support of foundations at this location; however, close monitoring of the existing bridge will be required during pile driving. Based on the soil boring information, GRS abutments are feasible for this project. Because the use of the GRS abutment will eliminate pile driving and mitigate the risk of damaging the existing historic structure, the GRS bridge abutment has been further evaluated and selected for the single span bridge alternatives.

Constructability

With deep foundations, all the alternatives studied can be designed and constructed in a single phase. Because of the concern of differential settlement, a multi-span bridge option on GRS piers was not investigated. Due to the close distance between the new bridge and the existing historic bridge, eliminating pile driving activity and its impact on the existing bridge was preferred. Otherwise, close monitoring of the existing bridge during pile installation would be required because of its qualification as an FHWA historic structure. Preforming of pile holes would be needed at this location to reduce the pile driving vibrations. Long piles requiring multiple splices may be required because of the limitation of access.

Compared to the multi-span bridge alternatives, single span bridges could take advantage of GRS-IBS application, which not only resulted in lower construction cost but also minimized the construction impact on the historic bridge. Due to required bridge length, further route analysis was conducted to confirm beam delivery would be possible.

BRIDGE SELECTION

The key factors that influenced the Cow Camp Road bridge alternative evaluation and selection were the construction cost, and the risk mitigations associated with pile driving adjacent to the existing historic structure. Constructability, accessibility, construction time, maintainability, durability, and aesthetics were also considered in the selection of the most desirable bridge alternative for this project. It was established that span arrangement and the risk mitigation associated with the bridge construction were critical in controlling the overall cost and success of the project. To meet the minimum requirements of SFWMD for its ultimate canal widening and to mitigate the risk of pile driving impacts, three-span structures with span arrangement of 30’-30’-30’ was studied and dropped out, and only single span bridges were selected for further investigation.

Because of the adjacent historic bridge, single span Florida I beams (FIB-36), steel girders and prefabricated steel truss with GRS abutments were considered in the BDR study. As a result, the GRS bridge abutment with FIB-36 was selected in the final recommendation. To accommodate the beam seats of GRS abutments and based on soil information, the final bridge length for single span options was set at 91’-4”, which brought the bearing pressure under 7,000psf on reinforced soil bearing for each beam. Based on the BDR recommendation, a single span bridge with prestressed concrete FIB-36 was implemented in final design for this project.

BRIDGE SUPERSTRUCTURE DESIGN AND INTEGRAL ABUTMENT ANALYSES

Bridge Design and Superstructure Load (4)

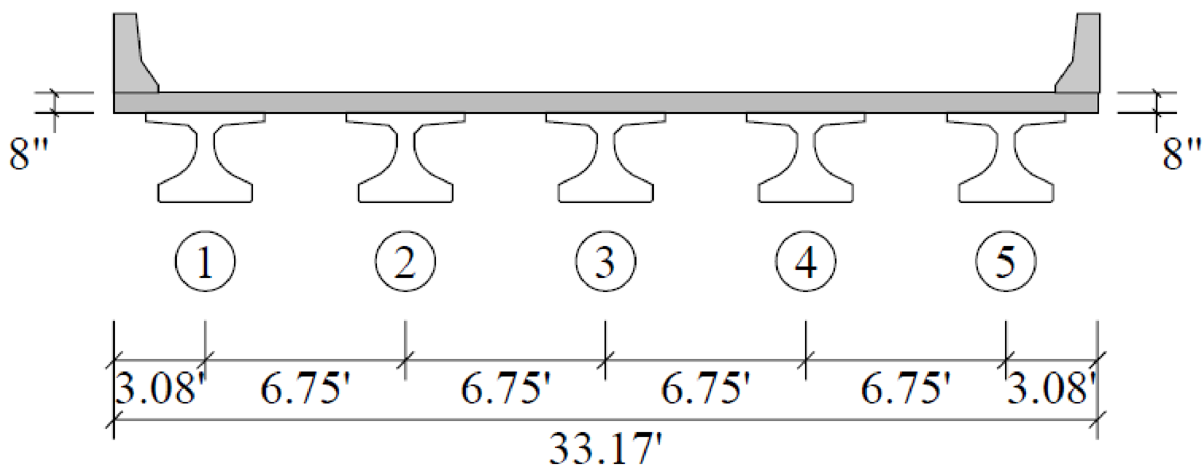
Smart Bridge Suite has been used in beam design and load rating. Based on the output, the maximum load at beam end bearing is 254.06kips factored load and the 169.49kips service load. See the table below.

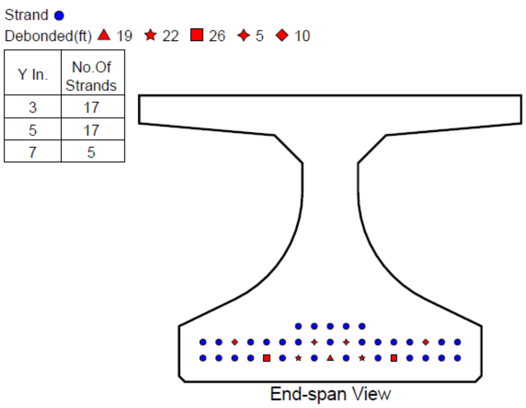
Reactions at the start and end of each girder are summarized in the following tables.

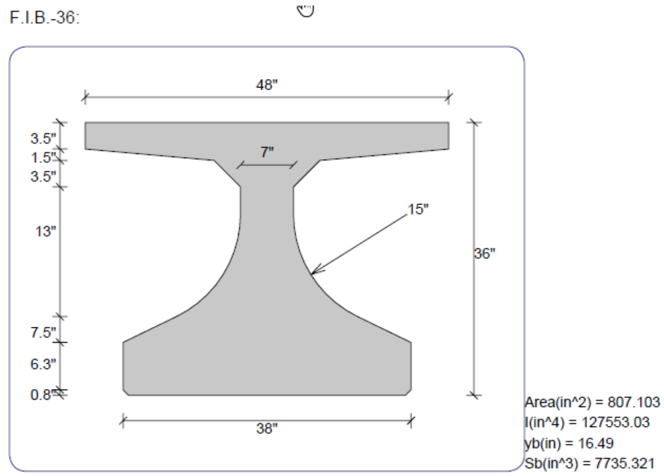
DesignVehicle	Girder 1		Girder 2		Girder 3	
	Start	End	Start	End	Start	End
Factor dead load reaction(kips)	106.87	106.87	110.23	110.23	110.23	110.23
Factor live load reaction(kips)	132.21	132.21	143.83	143.83	143.83	143.83
Factor total reaction(kips)	239.08	239.08	254.06	254.06	254.06	254.06
Serviced dead load reaction(kips)	84.79	84.79	87.30	87.30	87.30	87.30
Serviced live load reaction(kips)	75.55	75.55	82.19	82.19	82.19	82.19
Serviced total reaction(kips)	160.34	160.34	169.49	169.49	169.49	169.49

DesignVehicle	Girder 4		Girder 5		-	
	Start	End	Start	End	-	
Factor dead load reaction(kips)	110.23	110.23	106.87	106.87		
Factor live load reaction(kips)	143.83	143.83	132.21	132.21		
Factor total reaction(kips)	254.06	254.06	239.08	239.08		
Serviced dead load reaction(kips)	87.30	87.30	84.79	84.79		
Serviced live load reaction(kips)	82.19	82.19	75.55	75.55		
Serviced total reaction(kips)	169.49	169.49	160.34	160.34		

Beam layout and strand pattern as well as beam concrete are shown in the following.







Concrete:

	For Prestressed Concrete Application			
	At transfer		At service	
Concrete 8.5	**fci'**	6.00 ksi	**Allow. tension (inv)**	0.55 ksi
	Eci	4506.27 ksi	**Allow. tension (opt)**	0.69 ksi
	Allow. comp	3.32 ksi	**Allow. comp. (permanent load)**	3.83 ksi
	Allow. tension (Center 70%)	0.45 ksi	**Allow. comp. (0.5 permanent +LL)**	3.40 ksi
	Allow. tension (Outer 15%)	0.89 ksi	**Allow. comp. (permanent +LL)**	5.10 ksi

Bearing to Bearing (ft)	87.33	Precast Length (ft)	89.00
Haunch Thickness (in)	0.50	Concrete Age at Transfer (days) *	1.00
Concrete Age at Deck Placement (days) *	120.00	Concrete Age at Final Stage (days) *	20000.00
Friction Factor U *	0.60	Cohesion Factor C (ksi) *	0.08
K1 *	0.20	K2 (ksi) *	0.80
Min Dist.Between Longitudinal Reinforcement (in)	2.00	Min Side Cover Depth of Longitudinal Reinforcement (in)	2.00
Min Bottom Cover Depth of Longitudinal Reinforcement (in)	2.00	End Cover Depth of Shear Reinforcement (in)	2.00

*: For LRFD only

Integral Diaphragm Analyses

Based on AASHTO GRS Design Guidelines and bridge superstructure design outputs, the preliminary dimensions of the integral diaphragm were decided to be: 4' (W) x 4'(D) x 33'-2" (L) cast-in-place concrete. A grillage model was used in checking the integral diaphragm. See Figure 1 for the finite element model.

Phase Bearing Analyses

For the bearing stress before casting concrete, the analysis is based on AASHTO 5.6.5 – Bearing (4)

$P_r = FP_n$

$P_n = 0.85f'_c A_1 {*} m$

Per AASHTO 5.5.4.2 for shear and torsion in reinforced concrete section of normal weight concrete, take F= 0.9

Use m = 1.0 to be conservative in the capacity calculation, which results in P_r = 1652kips (>> P_u = 47kips).

The bearing stress checks after casting diaphragm are not required because the integral diaphragm is sitting on the GRS abutment where soil bearing capacity is required to be checked.

The Developmental Design Standards (Index D6025 GRS-IBS) (5, 6) limits the maximum service load on bearing to 2.0 TSF which is lower than the calculated bearing pressure in the beam end. To increase the bearing capacity in the beam seat, woven geotextile with minimum strength of 4800 lb/ft (both machine and cross directions) and size No. 57 stone aggregate were specified for the GRS backfill after geotechnical analyses.

Bridge Expansion Concern

For 91'-4" single span, two expansion joints located at bridge ends designed to accommodate the total extension due to temperature change ranging from 35 degrees to 105 degrees were evaluated. The expected total expansion/contraction based on calculation is approximate 0.460 inches which is not significant enough to cause cracks at the interface between integral abutment and roadway approach. Therefore, expansion joints were not included in the final plans. For a detailed discussion of the concern of possible cracking at the roadway surface due to beam expansion/contraction, see the Section 6.3 of Publication No. FHWA-HRT-11-026, June 2012 (1).

DETAILING PLANS AND CONSTRUCTION

Per the FDOT Plans and Preparation Manual (7), figures 2 through 5 present some detailing plans of the GRS-IBS bridge abutment for the Cow Camp Road bridge. Picture No. 1 presents the GRS-IBS bridge abutment construction and challenges. Picture No. 2 shows the erected beams and integral diaphragm reinforcement. Finally, Picture No. 3 is the completed bridge.

ACKNOWLEDGEMENTS

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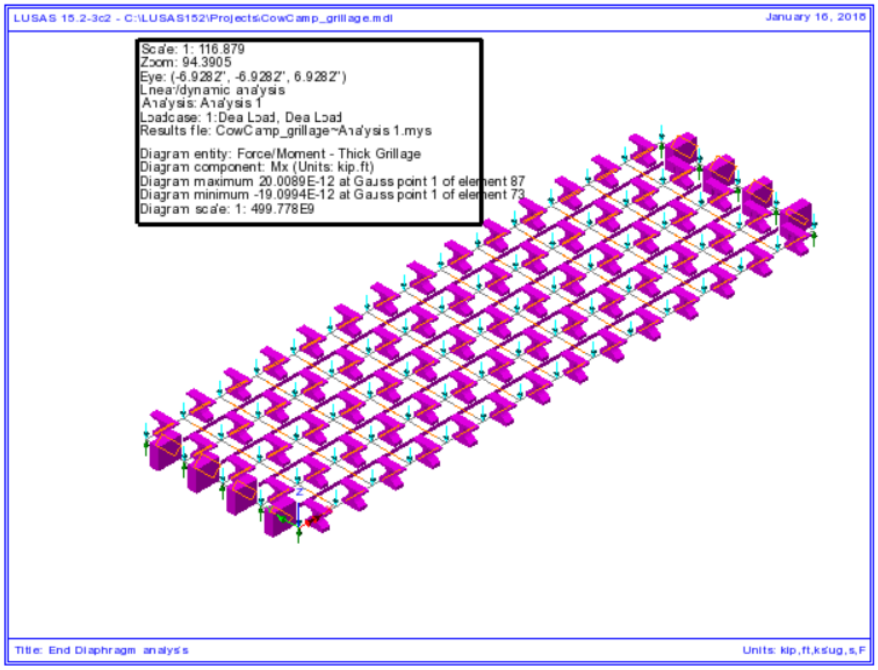


Figure 1 Grillage Model

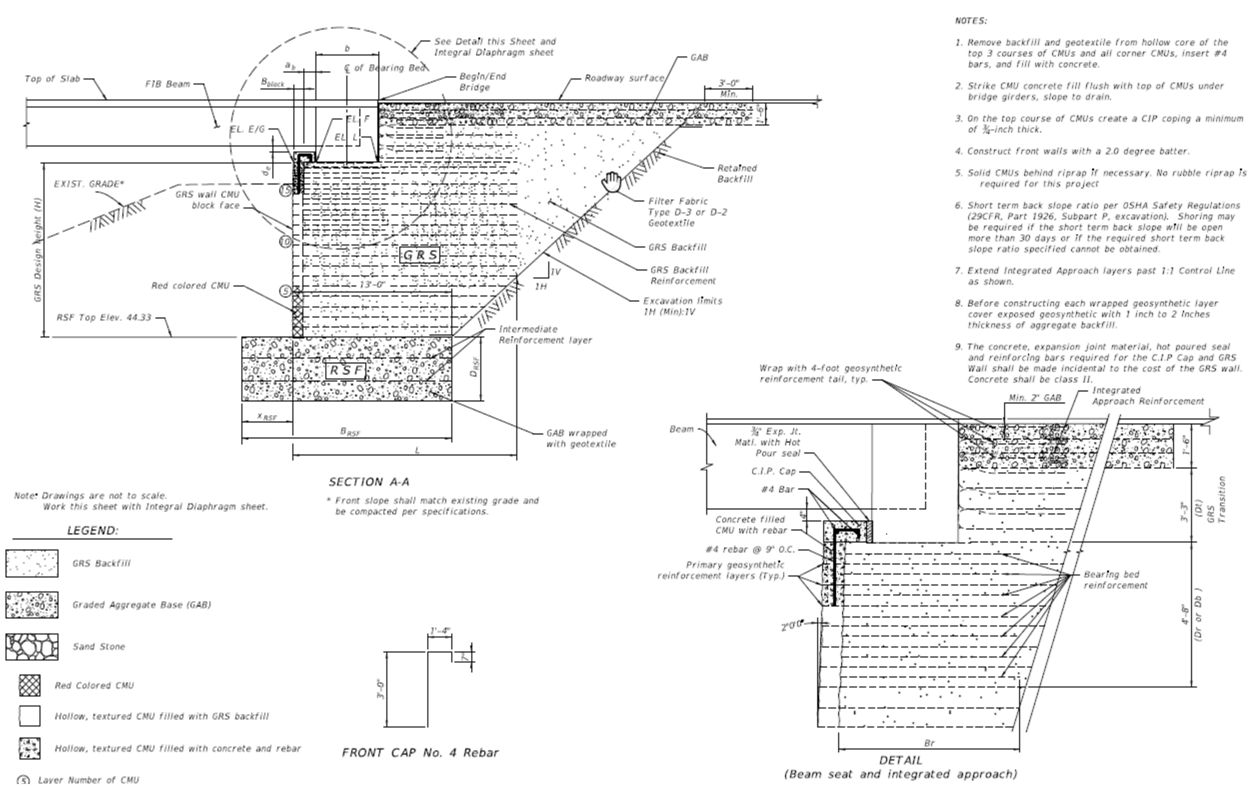


Figure 2 – GRS Abutment Details

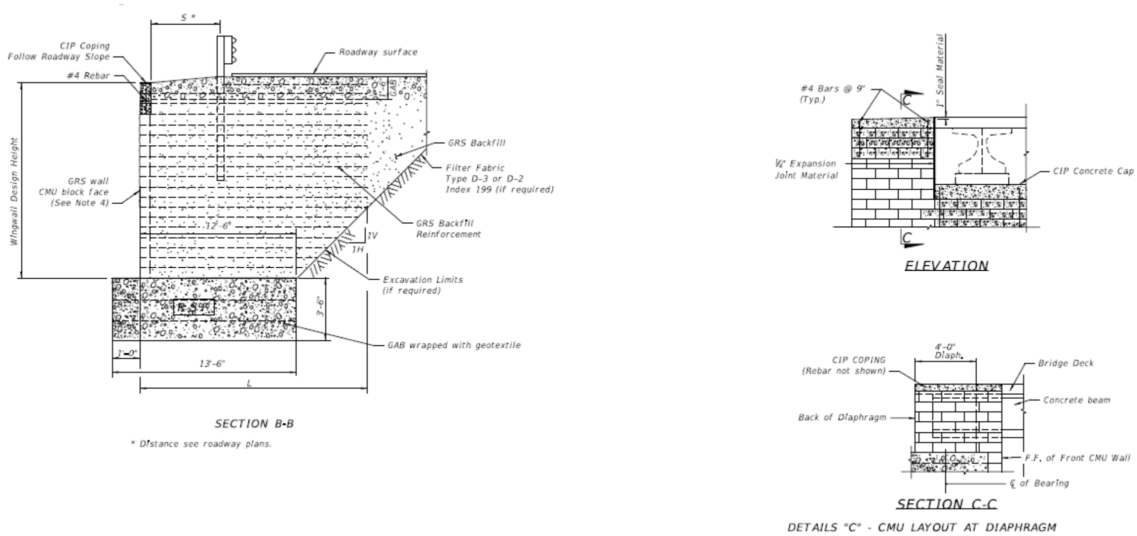
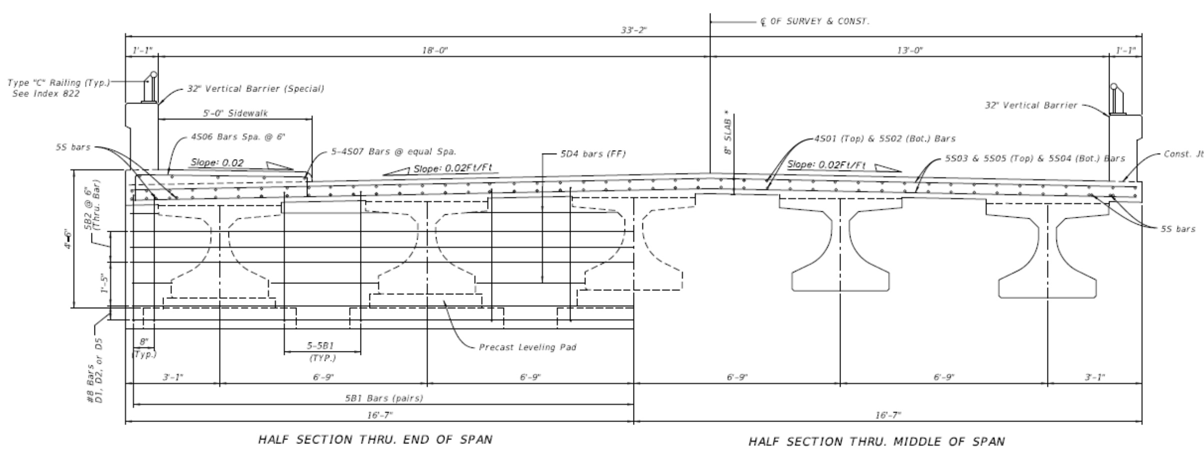


Figure 3 – Abutment Details



Notes:

1. For reinforcement at span ends see Integral Diaphragm Details.
2. Top 5B2 rebars shall be field bent as necessary to meet slope.
3. Rebars 5D3 & 8D1 in leveling pad not shown for clarity. For details see Integral Diaphragm Details sheets.
4. See Roadway Plans for raised sidewalk transition details.

* A minimum 2" cover shall be provided for top steel and bottom steel at deck.

Figure 4 - Bridge Section

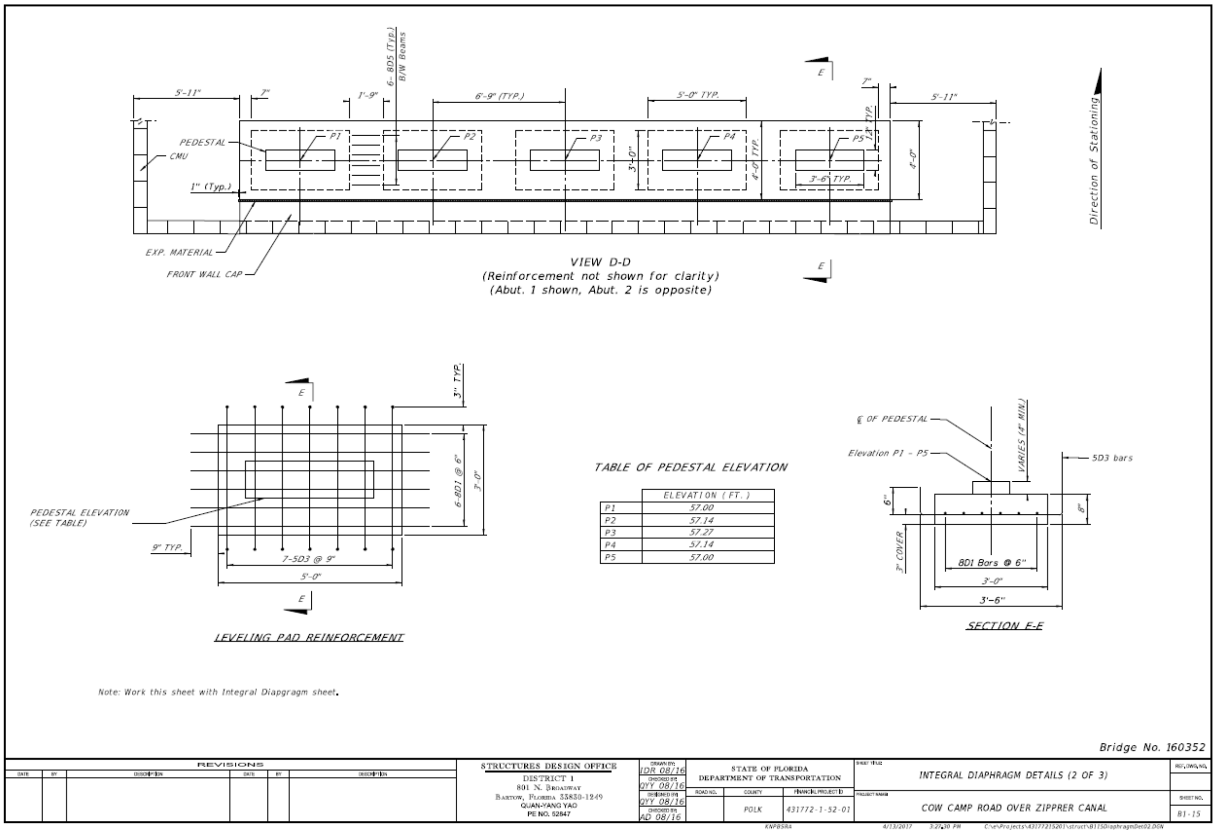


Figure 5 – Bearing Details

Picture No. 1 - GRS Abutment Construction and Challenge

Picture No. 2 - Erected Beam and Integral Diaphragm Reinforcement

Picture No. 3 - Finished Bridge