INNOVATIVE PRESTRESSED CONCRETE ALTERNATES FOR THE VESTAVIA HILLS PEDESTRIAN BRIDGE

Christopher J. Waldron, PhD, PE, Department of Civil, Construction, and Environmental Engineering, University of Alabama at Birmingham, Birmingham, AL

ABSTRACT

Several innovative precast, prestressed concrete alternates are being developed for a proposed 142 ft long pedestrian bridge over US-31 in Vestavia Hills, AL. Fully precast superstructure options are investigated to meet the project goals of minimizing the impact to traffic along US-31 during construction, minimizing the structure depth to limit the length of the ramps required for ADA access, and maintaining the aesthetics of the structure. Alternatives explored include modified, prestressed U-beams with the deck cast as a secondary pour but prior to detensioning allowing the entire cross-section to be effective for all loads; prestressed U-beams with an FRP deck to reduce dead load; and AASHTO girders utilized in a through girder system. The use of lightweight (or specified density) concrete is also explored to maintain reasonable shipping weights for the various alternates, and the lightweight concrete options are compared to their normal weight counterparts. The quantitative comparison of the alternatives resulted in the selection of the modified, prestressed U-beam with an integral deck as the most appropriate structure type to move forward into full design development.

Keywords: Lightweight Concrete, High Strength Concrete, Pedestrian Bridge, Accelerated Bridge Construction

INTRODUCTION

The City of Vestavia Hills, Alabama (Figure 1) is undertaking several initiatives to improve the quality of life for city residents. With the goal of becoming a more pedestrian friendly community, Vestavia Hills is adding sidewalks along the majority of public rights-of-way, including along Montgomery Highway (US 31). Vestavia Hills also recently completed a new, LEED certified, public library to ensure that city residents continue to have ready access to educational programs, government information, public access computing, and public access meeting spaces. As shown in Figure 2, the new library is located at the intersection of Montgomery Highway and Round Hill Road in a wooded area adjacent to the Boulder Creek Nature trail. Located across Montgomery Highway from the new library is Wald Park, which features five baseball fields, a walking track, the Vestavia Hills Swimming Pool, picnic areas, the Civic Center, the Senior's Lodge, the Community Playground and the Skatepark. Adjacent to Wald Park is Vestavia Hills Elementary School West. To connect the park and the elementary school on the west side of Montgomery Highway with the library on the east side, and to continue efforts to make Vestavia Hills a more pedestrian friendly community, the City has proposed constructing a pedestrian bridge crossing Montgomery Highway.

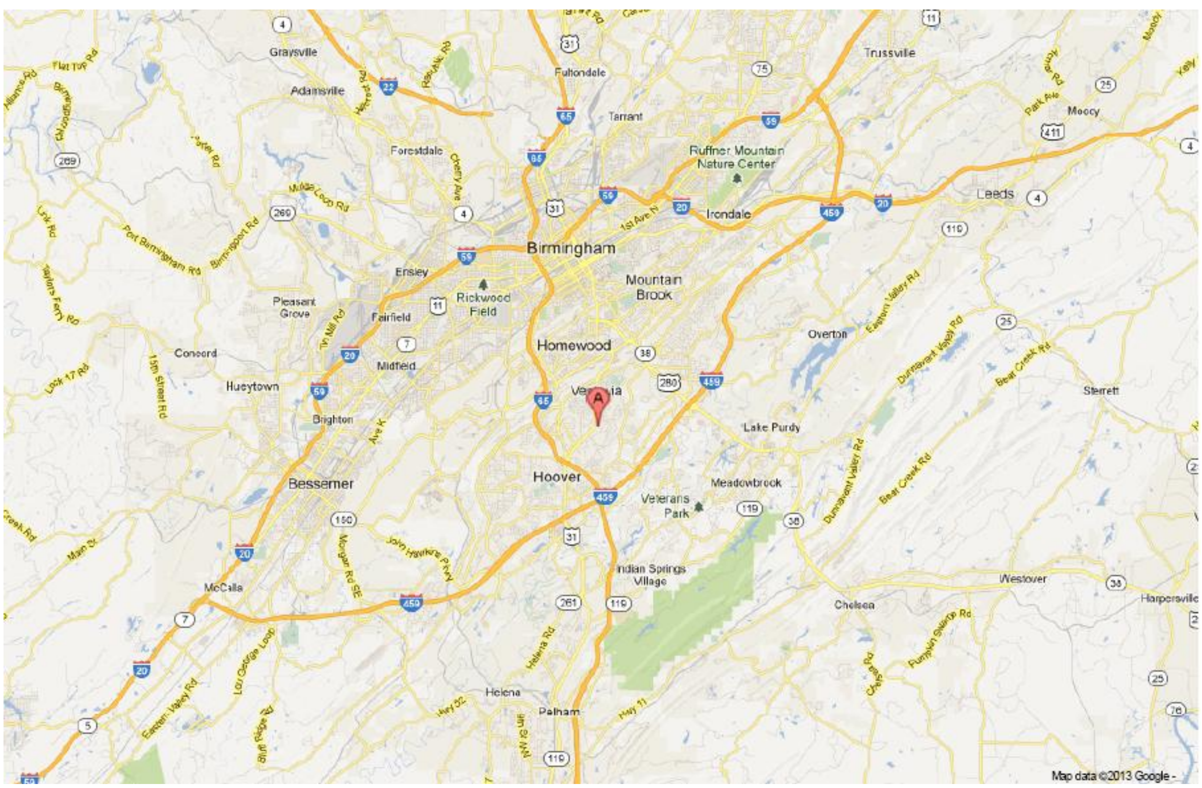


Fig. 1 Location map (map data courtesy of Google © 2013)

Fig. 2 Bridge site (imagery courtesy of Digital Globe, USGS, USDA Farm Service Agency; map data courtesy of Google, © 2013)

The design of the Vestavia Hills Pedestrian Bridge is being completed through a unique partnership between the City, academia, and a local engineering firm. The academic particiapnts are tasked with developing innovative concepts that minimize traffic disruption along Montgomery Highway during construction, minimize structure depth to limit the length of ADA compliant ramping that is required, minimize long term maintenance, and incorporate non-traditional materials such as high strength concrete; lightweight, high strength concrete; and fiber-reinforced polymers, as appropriate. The engineer-of-record is under contract to the City to serve as the responsible party in charge of the overall project ensuring that the innovative features comply with safe and efficient design practices, and as such, has final responsibility for all designs, plans, specifications, and estimates, including those for any innovative concepts or materials proposed. This creates an interesting opportunity for the academic participants to focus on truly practical and constructible innovations to be included in the final structure. This paper focuses on describing the precast, prestressed concepts developed to meet the design objectives. To meet the city's demand for aesthetics, all the precast options examined utilize a box beam or U-beam shape providing an uncluttered, clean, appearance for the underside of the bridge.

PRELIMINARY DESIGN CRITERIA

To begin detailed concept development, the span arrangement of the bridge must be determined along with design criteria for the innovative concepts. The design team decided the best place for the bridge is south of the library where a bluff to the west of Montgomery Highway allows that side of the bridge to be tied into the existing sidewalk with minimal ramping. Placing the bridge as far north on this bluff as possible minimizes the distance to the bridge from the library and from the elementary school, but places the bridge near a median crossover, which the city desires to maintain. Thus, the preliminary layout for the bridge consists of a single, simply-supported span over Montgomery Highway, as shown in Figure 3, with ADA compliant access on the east side of Montgomery Highway. The exact final length of the main span depends on the final structure depth, which controls the tie-in location on the west side slope; however, for structure depths up to 7 ft, the clear span across Montgomery Highway is never longer than 140 ft. Therefore, the design team decided to develop all innovative concepts for a 142 ft, simple span to gauge the practicality of and compare each concept.

The exact layout of the ADA compliant access is not yet established and will likely depend on the final configuration of the main span over Montgomery Highway. The effective structure depth, i.e., this distance from the walking surface to the bottom of the superstructure will play a key role in the height of the required access on the east side. Therefore, this paper focuses on the innovative design alternates for only the main span of the bridge.

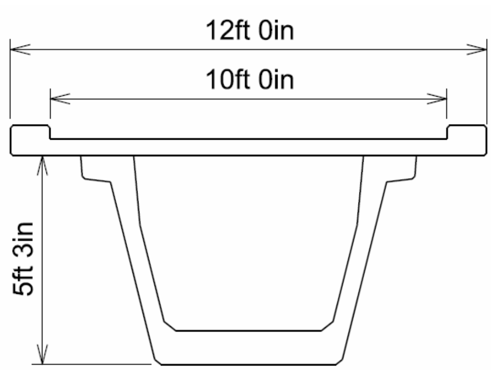
Fig. 3 Preliminary bridge layout (imagery and map data courtesy of Google © 2013)

The design team established the AASHTO LRFD Bridge Design Specifications[1] and the LRFD Guide Specifications for the Design of Pedestrian Bridges[2], as the governing design criteria for the project. Other design criteria for the innovative concepts are as follows:

- Live load = 90 psf, no vehicular live load, no equestrian load
- 10 ft curb-to-curb width
- Live load deflection limit of L/360
- 60 plf allowance per side for railings and fencing
- Allowable concrete stresses in accordance with AASHTO LRFD, expect no tension allowed under Service III in the precompressed tensile in accordance with the ALDOT Structures Design Guide[3].
- 0.6 in, 270 ksi, low relaxation strand ($A = 0.217$ in^2)
- $f'c \leq 10$ ksi for normal weight concrete
- $f'c \leq 8$ ksi for sand lightweight concrete (LWC) with unit weight (γ) ≥ 120 pcf

BASELINE TRADITIONAL DESIGN

In order to have an effective baseline structure to compare the innovative concepts against with regard to structure depth, speed of erection, and durability, a traditional preliminary design for the bridge was completed following the project aesthetic guidelines, AASHTO LRFD[1,2] and the ALDOT Structures Design and Detail Manual[3] as closely as possible. The shallowest baseline structure feasible utilizes a Florida U 63, and is shown with its design details in Figure 4, where f'c is the 28-day compressive strength of the concrete, f'ci is the required concrete strength at transfer of prestressing, f'cd is the 28-day compressive strength of the deck concrete, and F_{pj} is the total jacking force. This structure meets all requirements of the design specification except those establishing debonding limits for the prestressing strand. To control end stresses, 38% of the strands must be debonded, exceeding ALDOT's limit of 25%; however, no row has more than 38% of its strands debonded.



- 5 in. thick CIP deck, composite for live load
- 4 in. high, 12 in. wide curb
- f'c = 7.0 ksi
- f'ci = 5.5 ksi
- f'cd = 5 ksi
- 64 strands (24 debonded at girder ends)
- F_{pj} = 2,800 kip
- 104 ton girder weight

Fig. 4 Baseline traditional structure

INNOVATIVE DESIGN CONCEPTS

To improve upon the baseline design, innovative superstructures were developed to reduce the structure depth, speed erection, reduce long term maintenance, and/or incorporate non-traditional materials. The four precast, prestressed alternatives that are discussed in this paper are as follows:

- U-beam with FRP deck
- U-beam with yard cast concrete deck on shored beam
- Modified U-beam with deck cast in bed prior to release of prestressing
- Modified AASHTO beams with bottom flange mounted concrete deck

Each of the options discussed in this paper and the associated preliminary cost estimates have been developed through discussions with several precasters in Alabama, Georgia, and Mississippi, who have experience working with the specific types of superstructures presented and/or experience working with high strength, specified-density concrete. Based on the interaction with these precasters, the design team believes that each of the options can be successfully and economically produced in the Southeast.

U-BEAM WITH FRP DECK

Fiber-reinforced polymer (FRP) decks for bridges and other structures are becoming more readily available. An example of an FRP deck with an integral curb, manufactured by Composite Advantage, LLC is shown in Figure 5. Although the primary advantage of the FRP deck for this bridge is the reduced dead load allowing a shallow girder, FRP is also generally low maintenance, and is expected to have a service life at least as long, and most manufacturers would argue longer, than the CIP concrete deck of the baseline structure.

Fig. 5 Example FRP deck (image courtesy of Composite Advantage, LLC, © 2013)

By replacing the CIP concrete deck (850 plf) of the baseline structure with the much lighter FRP deck (120 plf), the total dead load that must be carried by the prestressed girder is significantly reduced. However, all of the savings in reduced dead load does not translate directly into reduced load on the girder, because the FRP deck is non-composite with the girder for all loads, meaning that all live load and superimposed dead load is now carried on the non-composite section along with the girder self-weight. Reducing the dead load and increasing the concrete compressive strength of the concrete does, however, allow a Florida U 48 to be used as shown and detailed in Figure 6. This design meets all the requirements of the proposed design criteria for the innovative options and nearly meets the ALDOT requirements for limits on strand debonding, exceeding those limits by only 1%.

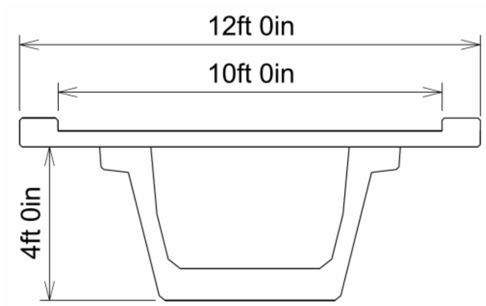


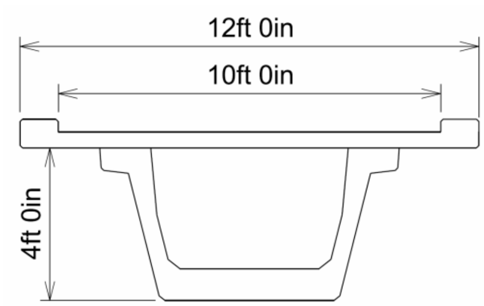
Fig. 6 U-beam with FRP deck

- FRP deck, non-composite for live load
- FRP curb, integral to FRP deck
- f'c = 9.0 ksi
- f'ci = 7.0 ksi
- 68 strands (18 debonded at girder ends)
- F_{pj} = 3,000 kip
- 92 ton girder weight

This alternate has several advantages and disadvantages over the baseline structure. The structure depth can be effectively reduced 15 in., reducing the length of the required ramps by as much as 25 feet on the east side of the bridge. Due to the light weight of the FRP deck, the deck can potentially be assembled on the girder at the prestressing plant while adding less than 10% to the shipping weight of the girder. The 142 ft span over Montgomery Highway can then be erected in one piece without the need to assemble the deck while working over the highway. The biggest disadvantage over the baseline structure is the additional cost of the FRP deck. The estimated cost of the FRP deck is between $35 and $55 per square foot compared to an estimated cost of $15 to $25 per square foot for a CIP concrete deck, although a portion of this cost difference is likely to be offset by the smaller girder and shorter duration of construction of the highway.

U-BEAM WITH YARD CAST DECK ON SHORED BEAM

This structure type alternate reduces the structure depth by allowing the composite section to carry all superimposed dead load, including the deck weight, and live load by casting the deck at the prestressing plant while the girder is shored. This approach allows the girder to be removed from the casting bed as soon as the release strength is reached, but requires the plant to provide additional shoring in storage beyond the supports at the ends generally provided, so that the girder is not supporting the weight of the fresh concrete when the deck is cast. The precast plant must also take on the additional task of forming and placing the deck, although this eliminates this operation onsite potentially reducing the duration of construction over Montgomery Highway. To keep the shipping weight of the full girder reasonable, LWC with a dry density of 120 pcf is necessary. Under these conditions a Florida U 48 can be used as shown and detailed in Figure 7. This design meets all the requirements of the proposed design criteria for the innovative options, except the ALDOT requirements for limits on strand debonding. To control stresses at the end of the girder, 35% of the strands must be debonded, with no more than 38% of each row debonded.



- LWC girder and deck with γ = 120 pcf
- Yard cast deck, composite for SIDL and LL
- f'c = 8.0 ksi
- f'ci = 6.0 ksi
- 68 strands (24 debonded at girder ends)
- F_{pj} = 3,000 kip
- 125 ton girder weight

Fig. 7 U-beam with yard cast deck on shored beam

Compared with the baseline structure, this alternate allows the structure depth to be reduced 15 in., thus shortening the required access ramps. Also, since the deck is cast at the prestressing plant, the duration of construction over Montgomery Highway is reduced, thus creating a smaller impact on traffic. The biggest disadvantage of this alternate is the high shipping weight even when using LWC, and the additional cost that is likely to be incurred due to the high weight and use of high strength LWC.

MODIFIED U-BEAM WITH INTEGRAL DECK

With the goal of reducing total girder weight below that of the U-beam with the yard cast deck, the design team developed a modified U-beam cross-section where the deck slab and curbs are cast prior to transfer of the prestressing force allowing the entire bridge cross-section to be effective in resisting all load and resulting in a smaller, lighter section. To keep the fabrication of this alternate as familiar as possible to the area precasters, the open-top U-beam is cast using the standard steel outer and inner forms and allowed to cure until the inner form can be safely removed. Then, the deck slab and curbs are formed and cast as a secondary pour before the strands are released and the entire beam is removed from the casting bed. To reduce the weight of the cross-section, the portion of the top flanges outside the webs is blocked-out of the standard forms, and the bottom flange of the Florida U-beam is thinned from 10 in.to 8 in. by blocking-out 1 in. at the top and bottom of the bottom slab.

The thinning of the bottom flange is achievable because the Florida U-beams provide a spacing from the edge of the flange to the center of the top and bottom row of prestressing of 3 in. So, although the bottom flange is thinned, three rows of prestressing on a 2 in. grid spacing are still provided with the top row centered 2 in below the top of the flange and the bottom row centered 2 in. above the bottom of the flange, matching the spacing and cover of the AASHTO I-beams and AASHTO Bulb T girders[4].

Blocking-out the edges of the top flanges not only creates a lighter structure, but creates a cleaner corner where the deck meets the girder web, giving the girder a less cluttered look from underneath. Figure 8 depicts a CIP trapezoidal box girder pedestrian bridge in Birmingham, AL with a similar shape, illustrating the look of the proposed cross-section.


Fig 8 Pedestrian bridge over University Blvd. at UAB

With the proposed modifications to the basic Florida U-beam forms, a modified Florida U 48 can be used as shown and detailed in Figure 9. The dashed line represents the Florida U 48 form, and the solid line represents the final outline of the modified box girder. The entire bridge span is complete upon detensioning the prestressing strands, and is shipped to the bridge site and erected as a single piece, thus reducing the duration of construction over Montgomery Highway.

The details in Figure 9 assume that LWC with a dry density of 120 pcf is again used to keep the shipping weight reasonable, although because of the reduction in girder cross-section a specified density concrete with a unit weight above 120 pcf may be feasible. This design meets all the requirements of the proposed design criteria for the innovative options, including the ALDOT requirements for limits on strand debonding. The design requires debonding 24% of the strands at the end of the girder to control stresses, with no more than 38% of the strands in each row debonded.

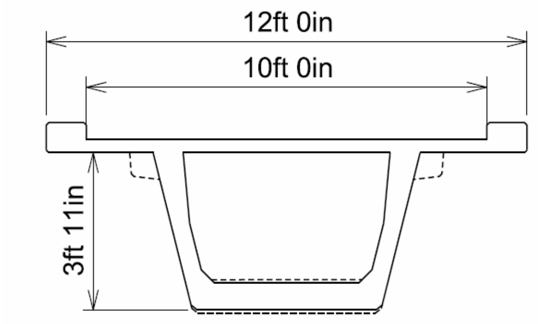


Fig. 9 Modified U-beam with integral deck

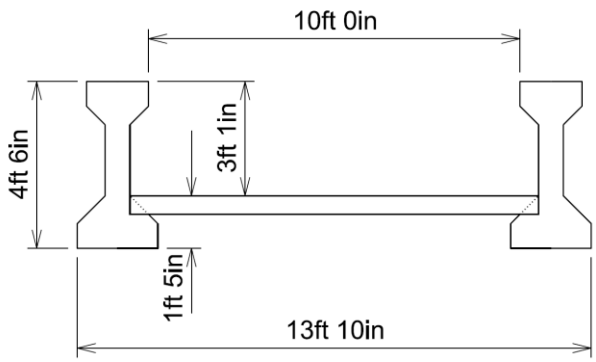
- LWC girder and deck with γ = 120 pcf
- Deck cast prior to detensioing
- f'c = 7.0 ksi
- f'ci = 5.5 ksi
- 54 strands (12 debonded at girder ends)
- F_{pj} = 2,400 kip
- 106 ton girder weight

This alternate has the same advantages as the previous alternate, but accomplishes those advantages at a lower shipping weight. In addition to a shallower structure depth and reduced construction duration over the highway, this alternate contains no un-prestressed concrete in the superstructure. By prestressing the full cross-section and keeping the longitudinal tensile stresses in the entire girder low, the bridge is likely to be more durable than the baseline structure. The biggest disadvantages of this alternate are the additional time the girder must spend in the bed to cast and cure the deck prior to detensioning and the blocking-out of the standard Florida U-beam forms that is required to achieve the desired cross-section.

AASHTO I-BEAMS WITH BOTTOM FLANGE MOUNTED CONCRETE DECK

In keeping with the goal of minimizing the structure depth to limit the required ramp length, the design team developed an alternate cross-section for the bridge consisting of two AASHTO Type IV girders with non-composite precast concrete deck panels supported on a block-out in the bottom flange, as shown and detailed in Figure 10. This design meets all the requirements of the proposed design criteria for the innovative options. Stresses at the ends of the girder are controlled by draping 8 strands rather than debonding strands.

This cross-section provides an uncluttered look from underneath similar to, although not as clean as, the U-beam options. The alternate also has the lowest effective structure depth of all the alternate designs. The distance from the walking surface to the bottom of the girder is less than 18 in, potentially reducing the required ramp length by as much as 76 ft. Also, because each girder is shipped to the site separately, this alternate has the lowest component shipping weights. The biggest disadvantage of this option is that it requires the most construction activity over the highway, and thus represents the option with the biggest impact to the traveling public during construction.



- Precast concrete non-composite deck panels
- f'c = 8.0 ksi
- f'ci = 7.0 ksi
- 44 strands (8 draped)
- F_{pj} = 1,900 kip
- 58 ton girder weight

Fig. 10 AASHTO Type IV Alternate

COMPARISON OF THE ALTERNATE INNOVATIVE DESIGNS

Each of the innovative designs improves in some way on the baseline structure while maintaining appropriate aesthetics for the project. All reduce the structure depth when compared to the baseline structure. The U-beam with the FRP deck and U-beam with the yard cast deck reduce the structure depth by 15 in.; the modified U-beam with the integral deck reduces the structure depth by 16 in., and the AASHTO Type IV alternate reduces the effective structure depth by 46 in. All but the AASHTO Type IV alternate also potentially reduce the duration of construction over Montgomery Highway by allowing the entire main span superstructure to be erected as a single piece.

Each alternate also has one or more disadvantages when compared to the baseline structure. Many of the alternates will likely incur additional cost in the production of the girder due to deviations from standard operations at the prestressing plant or the use of non-tradiational materials like FRP and high strength, lightweight concrete. Some of this additional cost for each alternate is likely to be recovered if user delay costs are accounted for during construction, while some will likely be recouped due to the smaller girder size and, therefore, less quantity of material in the alternate structures.

To gauge the relative cost of each alternate, a conceptual, comparative cost estimate was developed for each superstructure type using basic cost information contained in the Florida DOT Structures Design Guide[5] and costs for non-standard operations and non-traditional materials based on discussions with several area precasters and material suppliers who have familiarity with the types of structures and fabrication methods proposed as well as familiarity with using high strength, specified density concrete with a unit weight as low as 125 pcf. Table 1 presents the comparative, in-place costs for the main span superstructure for each alternate designed. Additionally, a comparative cost estimate is presented for two, prefabricated, painted, steel truss alternates that are not discussed in this paper, but are presented to the City of Vestavia Hills for consideration. The costs do not represent the total cost of the structure as they do not include the cost of substructure, foundations, or the ADA access structure on the east side. Also, the costs are conceptual in nature, and as such, are only applicable to making relative comparisons between the superstructure types at the conceptual design level.

Table 1 Comparative costs estimates for bridge superstructure

Superstructure Alternate	Girder / Truss	Deck	Railing	Total	Ratio to Baseline
Baseline	$120,000	$30,000	$45,000	$195,000	--
U 48 with FRP Deck	$105,000	$65,000	$45,000	$215,000	1.10
U 48 Yard Cast Deck	$120,000	$35,000	$45,000	$200,000	1.03
Mod. U 48 Box Girder	$160,000	--*	$45,000	$205,000	1.05
Type IV with Precast Deck	$75,000	$30,000	$45,000	$150,000	0.77
Steel Truss with Concrete Deck	$200,000	$25,000	--**	$225,000	1.15
Steel Truss with FRP Deck	$200,000	$60,000	--**	$260,000	1.33

* The deck cost in included with the girder cost for this alternate since the entire superstructure is cast prior to detensioning the strands.

** The cost of the railing is included with the cost of the truss for these alternates as a typical component of prefabricated, steel truss pedestrian bridges.

SELECTION OF THE MOST APPROPRIATE SUPERSTRUCTURE

Clearly, given the conceptual nature of the cost estimates, the expected costs for each alternate are similar, with the AASHTO Type IV through girder option at the low end and the painted, steel truss with an FRP deck at the high end. Each of the other options is within 15% of the baseline cost and can be considered to be the same at this level of refinement.

Therefore, the selection of the most appropriate design to move forward is based primarily on the desired project aesthetics, the speed of construction over Montgomery Highway, and the expected durability of each alternate. Based on these criteria, the design team presented to the City of Vestavia Hills the Florida U 48 with an FRP deck, the modified U 48 trapezoidal box girder, and the steel truss with an FRP or concrete deck as the short list of desirable structure types.

Although the AASHTO Type IV through girder structure is arguably shown to be the least expensive, the design team and the city did not feel this alternate matched the desired aesthetics of the project, and that the impact to traffic on Montgomery Highway would be too great given the multiple erection operations that would need to occur at the bridge site. Also, the U 48 with the yard cast deck was not included on the short list, because it does not compare favorably with the modified U 48 trapezoidal box girder. The conceptual, comparative cost for each of these alternates is nearly the same, while the modified U 48 trapezoidal box girder provides the advantages of a fully prestressed cross-section and a lower shipping and erection weight.

From the short list of alternates, the City of Vestavia Hills selected the modified U 48 trapezoidal box girder, as the design alternate most appropriate to move forward. This option is stiffer than the U 48 with an FRP deck while providing similar durability since the deck is precompressed and a similar duration of construction impact over Montgomery Highway. The steel truss alternate does provide the lowest effective structure depth of the alternates on the short list, thus potentially requiring the shortest east side ramps. However, the modified U 48 trapezoidal box girder eliminates the need for periodic painting that the steel truss alternate would require, and the city did not feel a weathering steel truss met the aesthetic needs of the project. The modified U 48 trapezoidal box girder alternate, therefore, represents the best balance of cost, durability, low maintenance, speed of construction, and structure depth.

SUMMARY

The design team working with several area precasters developed several innovative prestressed, precast concrete alternates for a pedestrian bridge over Montgomery Highway (US 31) in Vestavia Hills, AL. The primary goals of the innovative designs were to reduce the structure depth compared to a baseline conventional design, improve the durability of the bridge superstructure, lower the long term maintenance requirements, reduce the duration of construction over Montgomery highway, and incorporate non-traditional materials, such as high strength concrete; lightweight, high strength concrete; and fiber-reinforced plastics.

Four precast, prestressed concrete preliminary designs were developed meeting the project criteria. Three of the designs utilized a single Florida U 48 girder as the basis for the superstructure and resulted in a main span that can be fully assembled prior to erection at the site to limit the duration of construction activities that must be completed over the highway. The fourth option utilized AASHTO Type IV girders in a through girder configuration to create the shallowest possible effective structure depth. The most feasible of these options, along with the option of a prefabricated steel truss, were presented to the City of Vestavia Hills, where the city selected one option as best meeting the needs of the project.

The alternate selected by the city consists of a modified Florida U 48 lightweight concrete girder with a lightweight concrete deck cast while the girder is still in the prestressing bed, prior to detensioning the strands. This allows the entire cross-section to be effective in resisting all load, allowing a shallower girder to be used compared to the baseline design and allowing the section of the Florida U 48 to be slightly reduced. To minimize the weight of this option and maximize the structural efficiency, the bottom slab of the girder is thinned from 10 in. to 8 in. Additionally, since the deck is cast and prestressed integrally with the girder, the portion of each top flange outside the web is blocked-out, creating a cleaner corner where the girder meets the deck and a less cluttered appearance from underneath the bridge. Finally, by longitudinally prestressing the entire cross-section, the durability of the bridge, and most notably of the deck slab, is improved over the baseline design.

FUTURE WORK

The design team has begun fully developing the design and the final layout of the bridge. This includes establishing the final geometry of the main span and the ADA compliant access on the east side, as well as fully designing and detailing the bridge. As the design progresses the academic participants will also be looking at ways to speed construction of the substructure and any required ramps through the use of prefabricated elements, and at ways to incorporate FRP materials into the non-structural elements of the bridge, like the railing and fencing, as well.

Discussions with area precasters have led the design team to begin working on a second alternate very similar to the selected structure type, but using the Texas U-beam forms as the basis for the cross-section rather than the Florida U-beam forms. Since the precast U-beam is not a standard section typically used in Alabama, and because of the geographic location of Alabama, some area precasters who regularly complete work in Florida have the Florida U-beam forms, while other area precasters who regularly complete work in Texas have the Texas U-beam forms. As the project moves forward the design team intends to prepare designs using each basic form as the basis for the project to allow the maximum competition for the city when the project is advertised. Also, as the design moves forward, the design team will continue to find ways to make the cross-section more structurally efficient and reduce the shipping weight of the precast main span.

Finally, the academic participants will be developing an instrumentation plan for the long term monitoring of the bridge, and will be pursuing sources of funding for the implementation of the instrumentation. The instrumentation will allow the city to monitor the long term performance of the bridge, the lightweight concrete components, and any other innovative, non-traditional, or prefabricated elements that are included in the final design.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), *AASHTO LFRD Bridge Design Specifications,* Fifth Edition, 2010.
2. American Association of State Highway and Transportation Officials (AASHTO), *LFRD Guide Specifications for the Design of Pedestrian Bridges,* December, 2009.
3. Alabama Department of Transportation (ALDOT), *Structures Design and Detail Manual,* January, 2008.
4. Precast/Prestressed Concrete Institute (PCI), Precast *Prestressed Concrete Bridge Design Manual,* October 1997.
5. Florida Department of Transportation (FDOT), *Structures Design Guide: FDOT Structures Manual,* V.1, January, 2013.