4 CASE STUDIES OF SHORT TO MEDIUM SPAN BRIDGE DESIGN

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Master's Report

Presented to the University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

May 1997

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CASE STUDIES

INTRODUCTION

This section applies the TxDOT Aesthetic and Efficiency Guidelines to the design of four bridges. Each bridge consists of a few short to medium spans, and the sites differ widely. These case studies aim to offer an illustrative application of the guidelines and to show the cost impact of design decisions based on aesthetics. The first two case studies deal with ongoing TxDOT projects. The last two are imaginary scenarios.

The sites for the four bridges represent most of the typical land use patterns in Texas. The first case study presents a bridge design for a sensitive rural location, a low water crossing in Bell County near Waco. The second case study discusses the design of a bridge for a suburban freeway crossing in Richardson, a Dallas suburb. An urban site, the southern part of Downtown San Antonio serves as the location for the third case study. The final case study concerns an environmentally sensitive site, Zilker Park in Austin.

The case studies follow the organization of the Guidelines. Each case study begins by “visiting the site” through a description, photos and a site plan. The text then discusses site conditions and constraints and presents a vision for the design of the bridge. The case study then offers design possibilities for layout, superstructure, substructure, and non-structural details. The case study then examines a few of the options in greater depth and compares price estimates for the various options.

Price estimates appearing in the Case Studies result from conversations with TxDOT personnel, except where indicated. The figures listed are not absolute and will vary by location within the state and also over time. They represent an attempt to show the relative economic effect of design decisions. The cost listed for TxDOT Project 1410 precast substructure results from research and estimation based on the premise of standardization. In other words, the prices listed assume that this substructure is already in production and precast plants possess the formwork. Engineers would be able to specify standard precast piers just as they now do for standard I-beams or box beams.

CASE STUDY 1: FM 1123 OVER SALADO CREEK

The first case study concerns a rural site. FM 1123 crosses Salado Creek at a picturesque location in Bell County near Waco (Fig. 1). The crossing lies approximately six miles southeast of Belton. Tall pecan trees line the banks of the Salado there, and an historic grist mill stands roughly a hundred yards upstream (Figs. 2 and 3).

Currently, a low water crossing spans the creek, but flooding closes the bridge several times each year (Figs. 4,5). Local landowners have resisted past attempts to construct a more serviceable bridge out of fear it would disrupt the scenic area. The well-maintained fences and buildings clearly demonstrate the appreciation of the residents for the location (Fig. 6).

The bridge for FM 1123 over Salado Creek would carry approximately 500 vehicles per day. The design would require one lane going each way, a single shoulder in case of breakdowns, and a foot on each side for the rail--a total width of 11.6 meters (38’). The two dashed portions shown on the site plan in Figure 7 represent two options for the proposed bridge. The dashed lines mark the entire distance that the road surface would be higher than existing topography. In other words, moved earth or abutment may support some of the 236 meter (775’) distance shown. The 100 year flood plain rises 7.3 meters (24’) above the average level of the creek (Fig. 8). The topography is asymmetrical about Salado Creek.

Site Conditions and Constraints

The picturesque site presents several interesting issues for the engineer. First, the design has to win the approval of local landowners. In addition, the low traffic requirements justify little extra funding. Thus only relatively inexpensive options can receive consideration.

Another issue particular to the Salado site is the existing bridge. The cheapest alternative would probably involve demolishing it and saving money on future maintenance. Leaving it in place, however, would have many benefits. First, walkers, horseback riders, and bikers could use the low water crossing and enjoy its proximity to the creek and its view of the mill. Second, getting riders and walkers away from the vehicular traffic on the new bridge would probably increase safety. Third, the older bridge is an existing piece of history. Limiting the use of the bridge to pedestrians and bicyclists would substantially reduce the maintenance cost because most damage to bridges is vehicular. Interested local groups may agree to assume maintenance costs for the bridge, so the engineer can explore this possibility at advance meetings. The State Historical Commission could also save the bridge by designating it an historical landmark, so it may be worthwhile to contact them. Low posts or bollards across the roadway which would permit passage of bikes or pedestrians are a more pleasing option to block vehicles from the bridge than dumping fill or tearing out approach spans.

Vision

A bridge over Salado Creek should fit harmoniously into its scenic site and blend with the pastoral and nicely maintained area. If possible, the proportions of the bridge should continue those of the other built objects in the area, such as the residences, the mill, and the fences. Possibly the nicely maintained fences could inspire the design. All over the Salado area, residents lavish care on their fences. In addition to maintaining them nicely, some even embellish them with such features as electric lights on posts at regular intervals.

Layout

The site plan shows two options for the layout of the roadway (Fig. 7). Both options have the advantage of a curve, which allows drivers a view of the bridge before they cross. If the existing bridge is saved, roadway layout option 1 is recommended. Roadway option 1 would move the new bridge a comfortable distance away from the older one. Roadway option 2, on the other hand, would result in a bridge that looms over sightseers or bikers on the existing bridge. Option 1 continues the curve of FM 1123.

If the existing bridge is demolished, Option 2 is suggested (Fig. 7). Crossing Salado Creek at close to a right angle improves the bridge in two ways. First, Option 2 shows sensitivity to Salado Creek by changing the to fit its geometry. Second, making a special curve forces motorists to realize that this is a distinct place. Making drivers slow down slightly to navigate the curve would reinforce the individual nature of this site. The curve in Option 2 would, of course, have to meet the demands of traffic safety. However, emphasizing the unique character of the site with the roadway layout would help win the approval of local landowners. The parallel roadway layout of Option 2 allows the existing bridge to remain open during construction.

The bridge should completely span the creek at normal high water because a pier in the river would collect debris. Figure 8 shows the 15.2 meter (50') minimum width to span. In addition, placing piers in the stream could give the impression the designer was unaware of the presence of Salado Creek, something local residents may already suspect.

Figure 9a illustrates a conventional bridge layout for this crossing. The constant 30.5 meter (100') bent spacing shown uses prestressed beams at an efficient length. Another positive aspect of this layout is that the spans would result in a fairly transparent substructure. One drawback of this configuration is that it necessitates fairly deep beams. These spans would require 1370 mm (54") deep Type IV I-beams, for example. These large members and the long spans overwhelm the scale of the other built objects in the area, such as the house, the mill, and the fences. Type IV I-girders fit the scale of a major highway or heavily built up urban area much better than they do the "fence scale" dominant at Salado Creek.

Figure 9b shows a layout of approximately constant 15.2 meter (50') spans. These spans would require Type A beams which are 710 mm (28") deep. The smaller members would blend with the scale of the area better.

Figure 9c shows a layout that keeps a relatively constant ratio of span to average vertical clearance. Layouts with spans proportional to heights can have a pleasing appearance when topography varies because the spaces formed by the columns have the same shape. The layouts in Figure 9b, for example, look stiff in comparison. In addition, the wider main span visually emphasizes Salado Creek.

The layout shown in Figure 9c has two problems. First, the 36.6 meter (120') span requires deep beams which do not fit the scale of the area, as discussed above. Second, the varied spans require beams of different depth. Therefore, the design would have to use large beams at far below their capacity, or it would have to switch beam sections, which can be an ugly transition. Figure 10a shows the awkward transition from a Type IV beam to a

Type A beam, which is sharply noticeable. This switch interrupts the horizontal line of the bridge, and creates a less graceful design. The switch from a Type B to a Type A I-beam in Figure 10c is not as jarring.

Figure 9d shows a fourth option: a 19.8 meter (65') wide span over Salado Creek and 15.2 meter (50') spans for the rest of the bridge. The main span requires 865 mm (34") deep Type B beams, while the other spans would require 710 mm (28") deep Type A beams. The wider span over Salado Creek makes it obvious the designer took special care in crossing the Salado. The transition between the two beam depths would not be too extreme (Fig. 10c).

Figure 9e shows a fifth option: a 27.4 meter (90') wide span over Salado Creek and 19.8 meter (65') spans for the rest of the bridge. Like the layout shown in Figure 9d, this layout has a transition between beams with only a 6 inch difference. The 1015 mm (40") deep Type C beams required by the main span, however, make the scale of the bridge clash with the scale of the rest of the area.

Superstructure

The low budget dictates a choice between I- and U-beams. The state average price for I-and U-beam bridges are approximately $29 and $28 per square foot of deck respectively. An 11.6 meter (38') wide standard bridge would require 5 prestressed I-beams or 3 U-beams. An advantage of I-beams for this site is their smaller proportions. Consider I- and U-beams of the same depth. The bottom flange of a Type C I-beam is 560 millimeters wide, while the bottom of a U40 beam is 1400 millimeters wide--two and a half times wider. The top flange of the I-beam is 180 millimeters (0.59') wide, while the top of the U-beam is 2264 millimeters (7.43 feet)--more than twelve times broader! From beneath a bridge, U-beams are mammoth members. Their hollowness and relatively thin walls are hidden from a viewer.

The advantages of U-beams do not play a crucial role at the Salado site. U-beams create an underside that is better for natural light than I-beams, but pedestrian traffic underneath the bridge is fairly limited. U-beams, unlike I-beams, offer no ledges for birds, but this holds little significance for this location.

One drawback of I-beams for this site results from the curve of the roadway. The overhanging bridge deck creates scalloped shadows on them.

Substructure

A typical substructure system for FM 1123 over Salado Creek might involve multi-column bents with rectangular caps.. This economical and reliable solution may clutter the view for sightseers by the creek, however. Single column bents would offer much more transparency. "Inverted tee" bents also increase transparency of the substructure (Fig. 11). The state average for inverted tees is $480/cubic meter of concrete ($370/ cubic yard), slightly more than the $420 per cubic meter ($320/cubic yard) for rectangular caps.

Single columns would be quite large members, roughly 4 feet by 6 feet. The scale of such large columns could overwhelm the pedestrians by the creek. Smaller members would better fit the scale of the built objects in the area. Double column bents could strike a compromise between the demands of transparency and appropriate scale (Figs. 11a, b).

Several options are also available for the shaping of the columns. The designer can choose between circular, rectangular, or octagonal cross sections. The characteristics of the other components of the bridge may help make a selection between these.

Non-Structural Details

Many rail options deserve consideration for the Salado crossing (Fig. 12). The T501 concrete rail presents the least expensive option (Fig. 13). However, it offers no transparency and blocks some of the picturesque view for the drivers. The T101 w-beam rail offers much more transparency at a slightly higher price. The T101's exposed steel I-shape posts clash with the proportions of the concrete slab, however. The attractive T4 (S) combines a slender closed rail with a concrete parapet, which helps to blend the proportions of the steel with those of the rest of the bridge. The T411 Texas Classic rail might blend nicely with the historic mill and the old bridge if it is preserved. The T421 post rail with steel pipe also offers a fairly high level of transparency. The T421 would require paint, unlike the T101 and T4 (S) rails which use galvanized steel.

The Salado Creek crossing would require no electric lighting.

Design Options

Figure 14a shows Option A, a conventional I-girder bridge over the Salado Creek with a T501 rail. The substructure consists of multi-column bents with rectangular caps. Option A uses the layout shown in Figure 9a. The spans would require Type IV I-beams, which, in combination with the T501 rail, would have an apparent slenderness of 13. This ratio is slightly below the recommended slenderness range of 15 to 30. Table 1 below compares the costs of three different designs for the FM 1123 bridge over Salado Creek. The $642,000 cost of Option A serves as a baseline cost by which to measure the design changes made to improve the aesthetics.

Figure 14b shows Option B, an improved design. Option B uses smaller Type A I-girders which are a more coherent design for the scale of the site. Type A beams are approximately half as deep as Type IV beams. In addition, the double-column bents used in Option B do not disturb the scale of the surroundings as much as massive single column bents would. Option B uses the layout shown in Figure 9b. The C202 rail also blends with the scale of the fences and buildings much better than the Jersey Barrier of Option A. The shorter spans also help to minimize the unattractive scalloped shadows created by FM 1123's curve. Twelve short beams approximate the curve better than six long ones. This improved design results in a tiny increase over the cost of Option A.

Figure 14c shows Option C, which resembles Option B except that its bents have inverted tee caps. The inverted tee caps increase the transparency of the substructure. This change alone results in a 12.5% increase in cost of the project over Option A (Table 1). The low level of pedestrian traffic beneath the bridge does not warrant such an expenditure.

The bridge in Figure 14d, Option D, shares many of the features of Option B above, but it also has steel rails and a 19.8 meter (65') span over Salado Creek. The design uses a T421 steel pipe rail painted white. Option D uses the layout shown in Figure 9d. Type A I-beams support most of the deck, but the main span would require Type B beams. The wider main span emphasizes the creek visually. Like Option B, Option D uses double column bents with rectangular caps. The T421 rails are highly transparent, so the girders and the deck have an improved slenderness of 17.

The fences in the Salado area are striking because their crisp white color contrasts highly with the darker ground. If there is no substantial price difference, the designer could specify a darker aggregate than, for example, limestone. Octagonal columns would fit the vision of the bridge the best. The white fences contrast with the land, and the rails should contrast with the bridge. Round columns would echo the shape of the steel pipe and blend the rail with the bridge on which it sits. Octagonal columns resemble the chamfered flanges on the I-beams. The different shapes can increase the contrast between the rail and the rest of the bridge.

Recommendation

Option D is recommended. It is the best choice because it offers a much improved bridge for a relatively small cost increase of 8%. The T421 rail painted white continues the idea of crisp white fences on the land that is prevalent throughout the Salado area. The transparency of the rails increases the apparent slenderness of the bridge. The relatively small Type A beams fit the scale of the area. In addition, the shorter beams minimize the scalloped shadows resulting from the curve. The wider span emphasizes the creek visually and shows courtesy toward the site. The small increase in cost for Option D would reflect the residents’ obvious investment in aesthetics in the area.

CASE STUDY 2: U.S. 75 CROSSING AT RICHARDSON

The second case study concerns a suburban site with a major highway running through it. The community of Richardson, a Dallas suburb, has proposed an extension of Greenway Drive over U.S. Highway 75. The highway dominates the site with four lanes of freeway and three lanes of frontage road running in each direction (Fig. 15). Richardson residents know this area as the “Telecom Corridor.” Businesses such as MCI, Nortel, and Northern Telecom line U.S. 75 here (Figs. 16,17). In addition to the highway, the Greenway Bridge would span a planned High Occupancy Vehicle lane and a rail line operated by Dallas Area Regional Transit (Fig. 18).

The bridge for Greenway Drive would require two lanes each way to carry traffic projections of 7000 vehicles per day eastbound and 4500 westbound. The 16.5 meter (54’) wide crossing would include 0.6 meter (2’) shoulders on each side but would not require pedestrian facilities. U.S. 75 carries 76,000 vehicles per day in each direction. As mentioned in the previous case study, the dashed portion shown in Figure 19 represents the entire distance the roadway would be higher than current topography (440 m, 1435’).

Site Conditions and Constraints

Because of the high vehicular flow of U.S. 75, minimization of interference with traffic during construction is a key issue for the Greenway Crossing. The bridge stands out sharply in this relatively flat area, and will enjoy high visibility. Principal vantage points of the bridge include the view of workers in the surrounding buildings and those of drivers on the highway and from the bridge itself. Perception of this bridge at close range will be limited. The site has no special cultural or historical significance. Thus little extra funding for aesthetics should be required. The wide highway will constrain the geometry of the layout.

Vision

The construction method of the bridge over U.S. 75 should disrupt traffic as little as possible. The scale of the buildings and highway are large enough that a bridge of large dimensions should fit in well. Long distance aesthetic issues such as pier spacing, slenderness, and design of the abutments and slopes will be of importance. Possibly the high-tech character and sleek architecture of the telecom companies in the area can serve to inspire the design of the bridge.

Layout

The layout for Richardson should attempt to maximize transparency of the substructure for traffic safety as well as aesthetic reasons. Figure 20 shows two possible layouts for the U.S. 75 crossing.

The layout in Figure 20a was primarily set by site constraints. Placing bents in the center of existing medians between U.S. 75 and the frontage roads created 3 spans of 24.4 meter (80’). The rest of the layout simply continued this rhythm. The layout in Figure 20a uses twelve bents. The proximity of the parking garage makes a retaining wall necessary, which is marked by a dark line at the lower right corner of Figure 20a.

The layout shown in Figure 20b uses longer spans in order to use prestressed beams at efficient lengths. This arrangement uses 30.5 meters (100’) spans for every span except for one 36.6 meter (120’) span forced by the position of the DART tracks. As a result, the layout in 20b uses only nine bents.

Superstructure

A 16.5 meter (54’) wide standard bridge would require 7 prestressed I-beams or 4 U-beams. As mentioned above, I- and U-beams average approximately $29 and $28 per square foot of deck respectively. U-beams have several advantages over I-beams aesthetically. U-beams have a less blockish profile (Fig. 21). They lack the projecting bottom flange of I-beams, and the web is inclined away from the light. This is important because the edge is the most visible part of the bridge to the drivers on U.S. 75. In addition, U-beams form a more pleasant underside because they create fewer dark spaces between them than I-beams do. Although natural lighting underneath a bridge is not a high priority on a car dominated site, a brighter underside is still more pleasant for drivers. The large proportions of U-beams present no problem for this site with its huge buildings and highway.

Balanced cantilever construction offers the advantage of disturbing the traffic very little, but it costs a great deal more for spans in this range. A balanced cantilever bridge completed in Surfside in 1995 cost $73 per square foot of deck. Although the Surfside bridge had longer spans, 105 meters (350’) and 59.5 meters (195’), the cost figure should be fairly accurate for the scale of the Richardson project. The moderate budget for the Richardson bridge would not justify this higher cost.

Substructure

Multi-column bents with rectangular pier caps are a time-tested substructure system for the spans required by the Richardson bridge. Single or double column bents are a better option for preserving the view beneath the bridge than are three or four column bents, however. In addition, many small columns would be out of scale with the site, which has only a few huge buildings and roads. Two options to consider for substructure are rectangular pier caps and inverted tees. The inverted tees confer greater transparency of the substructure, but as mentioned earlier, they cost somewhat more than rectangular caps.

Several options are also available for the shaping of the columns. The octagonal shape blends better with either I-beams or U-beams than the circular or rectangular cross sections do. Neither U- nor I-shapes have right angles like the rectangular column, or curves like the round one. The octagonal column would make a more coherent design.

Precast substructure reduces construction time, a distinct advantage for the Richardson site. Precast substructure is faster because fabrication and curing takes place off site and out of the way [1]. In addition, fewer trips to the site are required by concrete trucks. Precast also offers superior control over finish. Figure 22 shows TxDOT Project 1410’s prototype precast substructure. The precast pier shown uses concrete more efficiently than cast-in-place versions, which results in a more pleasing appearance. For example, the underside of the ledge of the inverted tee cap is angled, which saves material and expresses the decreasing moment of the ledge cantilever (Fig.

22). Elimination of unneeded material and aesthetics are interrelated. The width of the bridge would necessitate double column bents as shown in Figure 22b for Project 1410's precast piers.

Non-Structural Details

The T501 presents the least expensive rail option. Figure 13 from the Salado Creek case study above compares the prices of several different types of rails. The T101 offers a much more transparent rail at a slightly higher price (Fig. 12c). The exposed steel I-shape posts clash with the proportions of the concrete slab, however. The attractive T4 (S) combines a slender and smooth closed rail with a concrete parapet, which helps to blend the proportions of the steel with those of the rest of the bridge (Fig. 12d). Ornamental rails, such as the T411 Texas Classic, would be out of place in this site because the architecture and the highway have minimal decoration (Fig. 12b).

Designing the slopes of the abutments presents many alternatives. Using concrete slope protector for all abutment inclines is one solution. The rip rap would stain over time, however, and offer a canvas for graffiti. Limiting the use of rip rap to the area under the bridge and planting vegetation everywhere else presents a much more pleasant option.

The maximum soil slope for seeding is 4:1, unless mesh reinforcement is used, in which case the slope can be as high as 3:1. A slope of 5:1 is necessary for wildflowers to grow, which uses more soil. The Richardson site has enough right of way to allow for the 5:1 slopes except for the area adjacent to the parking garage, which requires a retaining wall. One drawback to grass and wildflower seeding is that a backup watering plan is necessary in case of drought. In addition, advance planning is necessary because the best planting times are mid-March to the end of May.

Design Options

Figure 23a shows Option A for Richardson, an I-girder bridge with a concrete barrier rail. The substructure consists of four-column bents with rectangular caps. Concrete rip rap covers the slopes. The slow pace of the construction of the cast-in-place columns results in a large time delay cost of the traffic. Option A uses the layout shown in Figure 20a. The combination of Type IV I-beams with the T501 rail would result in an apparent slenderness of 10, considerably below the recommended range of 15 to 30. Table 2 below compares the costs for the Richardson options.

Figure 23b shows Option B, an aesthetically improved bridge which has U54 beams and T101 rails. Single column cast-in-place piers and inverted tee caps improve the transparency of the substructure in comparison to Option A. The layout also reduces the number of piers. 4:1 slopes on the abutment inclines allow for the seeding of grasses, a much better alternative than the concrete slope protector used in Option A. The vegetation will renew itself and create a more pleasant surface. The transparency of the T101 rail increases the apparent slenderness of the bridge to 19, well within the recommended range.

Figure 23c shows Option C, which uses TxDOT Project 1410's precast frames for substructure. As mentioned above, these bents use concrete very efficiently, which creates an attractive form. The smooth surfaces of the precast piers combined with the U-beams reflect the detailing of the Nortel building's sleek exterior. The faster construction times of the precast piers result in a significant cost savings due to the reduced traffic delay. The spans would require U54 beams, which, in combination with the T101 rail would have an apparent slenderness of 19. Finally, the wildflowers growing on the abutment slopes change with the seasons and make the area much more pleasant.

Figure 23d shows Option D, which is similar to Option C except that it has T4 (S) rails, which offer good transparency and superior aesthetics. The T4 (S) rails would reduce apparent slenderness to a ratio of 15, but this still falls within the suggested range.

Recommendation

Depending on the budget for the project, Options C or D are recommended. Both use U-beams, which are appropriate for the Richardson site because their profile is less blockish, their underside is brighter, and their scale fits the area. Options C and D also use TxDOT Project 1410's prototype precast substructure system. The faster construction times of the precast frames save traffic delay and re-routing costs. In addition, the detailing of the U-beams and frames blends with the architecture of the area. Finally, both designs feature wildflowers on the slopes of the abutments which will change with the seasons and add interest to the whole area.

Option D also features more expensive T4 (S) rails, which attractively combine steel's transparency with a small concrete parapet. If funding will not permit, the T101 rail of Option C will provide transparency for a lower cost.

CASE STUDY 3: RIVERWALK CROSSING IN SAN ANTONIO

The third case study involves an imaginary scenario in a culturally significant urban location. The site lies at the southern edge of Downtown San Antonio. Walkways for the popular Paseo Del Rio, or Riverwalk, run alongside the banks of the San Antonio there (Figs. 24-25). High-rises lie just north of the location of the proposed bridge, but most of the buildings in the immediate area are one or two stories (Figs. 26,27). Administrators at the City of San Antonio predict that if developers build on empty lots in the area, it would become necessary to connect Old Guilbeau Street and Tolle Place with a bridge (Figs. 24-27).

The bridge would require two lanes in each direction and pedestrian walkways on both sides. The width would total 19.5 meters (64'). Motorized traffic would probably amount to 2000 vehicles per day in each direction. Depending on the layout, the bridge would cross between 40 to 61 meters (130'-200') (Fig. 28).

Site Conditions and Constraints

Pedestrians on the Riverwalk would see the bridge in profile and from underneath. The other main vantage points are those of the drivers and walkers on top of the bridge. Some additional funding would probably be available for enhanced aesthetics because of the location on the Riverwalk.

Due to the topography, the deck would rise only 4.9 meters (16') above the typical level of the river. Thus the bridge would create an extremely long and narrow space 19.5 meters (64') feet wide and 3 to 4 meters (10'-13') high depending on the section depth.

Although a large tunnel diverts water from the San Antonio River during flooding, employees of the City of San Antonio indicate that the river would rise up to its banks during 100 year flood stage (Fig. 29).

Vision

A bridge that accommodates walkers above and below would blend nicely with the pedestrian character of Downtown San Antonio and the Riverwalk. The design should brighten the underside with natural light, and keep the section depth shallow in order to make the space beneath as high as possible. The concrete should also be nicely finished because walkers have more time to observe detailing than drivers. If possible, the detailing should respond in some way to the urban location.

Layout

Figure 29a shows a conventional layout for the San Antonio River crossing. The two 30.5 meter (100') spans use prestressed beams at cost efficient lengths. The single intermediate bent is also an economical choice. However, the bent in the river would collect debris. In addition, placing a bent in the water creates an impression of indifference toward the uniqueness of the river and the Paseo del Rio.

A second option is to have full-height abutments and a single 130 foot span (Fig. 29b). However, the large earthworks would block views along the Riverwalk corridor. This seems an unnecessary disruption of a pleasant area. The spill-through abutments in Figures 29a and 29c leave the views along the Riverwalk much less changed.

Figure 29c shows a third option. It has a longer span over the river and two unequal side spans. The bents in this configuration block neither the river nor the walkways on either side of it. The significantly longer span over the San Antonio River shows courtesy toward the river and the Riverwalk. Although this arrangement is asymmetrical as a whole, the bents are symmetrical about the San Antonio River. Each bent stands approximately 2 meters (6.6') away from the edge of the sidewalk.

Another option to consider for a bridge with heavy pedestrian traffic underneath is splitting it into two in order to bring in a shaft of light. This configuration would work well to get natural light underneath the bridge, but it would probably leave the bridge less versatile for the city in the long run.

Superstructure

I-beams are a typical choice for superstructure and would support the deck quite economically. U-beams have several advantages for this site and are also inexpensive. U-beams form a more pleasant underside because they create fewer dark spaces between them. In addition, U-beams have a less blockish profile than I-beams (Fig. 21), and they create no ledges for birds. A 19.5 meter (64') wide bridge would require eight prestressed I-beams or five U-beams.

Box beams deserve consideration for the San Antonio River site for several reasons. First, they form a flat underside. The smooth underside reflects light extremely well and would brighten the underside of the bridge for Riverwalkers. Box beams create no dark spaces between them like I-beams. In addition, the flat surface would catch light reflections from the San Antonio River. Dancing reflections could help to make passing beneath the bridge magical.

Box beams have shallower section depths than other prestressed beams. The 30.5 meter (100') span would require an 865 mm (34") deep box beam. I- or U-beams, on the other hand, would have to be 1370 mm (54") deep to span the same distance. Thus box beams raise the "ceiling" for pedestrians on the Riverwalk by 505 mm (20"). The increase in height would also allow more natural light into the space.

Finally, box beams offer no ledges for pigeons, an advantage for walkers below. Disadvantages of box beams include a blockish profile that does not express the flow of forces nicely and a tendency to stain the substructure. Another drawback is economic: whereas the state average price for I-and U-beams is below $30 per square foot of bridge deck, box beams average $42 per square foot.

Substructure

A common design for substructure for a bridge of this size involves cast-in-place multi-column bents with rectangular caps. Having an uncluttered space is crucial for the Riverwalkers beneath the bridge. Minimizing the number of columns per bent would increase the transparency of the substructure. Single column bents, however, would be undesirable because of their massive scale in the space beneath the Riverwalk. Inverted tee caps would "raise the ceiling" for the pedestrians beneath the bridge. As mentioned in previous case studies, inverted tees cost slightly more than rectangular caps.

Octagonal cross sections form longitudinal lines that increase a viewer's perception of slenderness. This would help to decrease a pedestrian's impression of the massiveness of the columns and lend the columns human scale.

Precasting the substructure allows a high degree of control over the finish of the concrete, as mentioned above. The 19.5 meter (64') width of the bridge would necessitate double column bents for the TxDOT Project 1410's precast substructure system (Fig. 22b). The efficient use of material, as discussed further in the Richardson case study, creates a pleasing appearance.

Non-Structural Details

Figure 30 shows several ways the San Antonio bridge could accommodate pedestrians. A simple 3 meter (10') shoulder with a Jersey barrier is a conventional way to serve alternate forms of transportation on a bridge, such as bikers or walkers (Fig. 30a). The raised sidewalk at the edge of the bridge in Figure 30b is termed partial accommodation because the walkers are raised 150 mm (6") above the traffic and the curb gives some protection against traffic. Including a second barrier and rail between the traffic and the walkers offers full pedestrian accommodation (30c). The rail contributes to the peace of mind of the strollers. Figure 30d shows a raised walkway that has a rail also. Such a configuration may be desirable in the case of high speed traffic or a curving bridge.

Several pedestrian rails merit consideration (Fig. 31). The PR1 steel pipe pedestrian rail offers walkers a rail at hand height, and it also reduces a viewer's perceived slenderness of the bridge because of its transparency. The C101 rail's combination of a W-beam and thin steel pipe rail lacks coherence (Fig. 31b). The proportions of the C101's W-beam dwarf those of the slender steel pipe. The C4 (S) option combines the proportions of steel and concrete in an elegant way (Fig 31c). The T411 Texas Classic rail could possibly blend with some of the architecture of San Antonio, but the immediate area lacks particular historical character.

A typical electric lighting design spaces the fixtures according to the manufacturer's specified range. This approach, however, can make them inconsistent with the bridge design. Lighting should be placed according to the geometry of the bridge. Here, placing the electric lighting to either side of the abutments creates a coherent design. Interested local groups can help to decide which fixtures blend with their area, but the engineer decides the spacing of the lights.

A lighter color of concrete than gray would have a higher reflectivity and brighten the underside of this bridge. White concrete would have the highest reflectivity. White cement costs approximately twice as much as ordinary cement due to increased expenses from formwork, truck cleaning, and transport. However, the price increase for the beams due to white cement may not be significant [2]. The cost of cement is a small proportion of the cost per linear foot of prestressed beams. Colored concrete is maintenance free, unlike paint. One difficulty of white concrete is that marks on it tend to be highly visible. Other drawbacks of colored concrete include matching from batch to batch and reproducing the color for patching.

Another option is fly ash cement, which creates buff colored concrete. The price difference of buff colored cement compared to regular cement should be minimal because fly ash is cheaper than cement [2]. An additional advantage of buff concrete for this site is that it could relate the bridge to some of the tan limestone architecture prevalent in San Antonio.

Superelevation is one option for drainage, but this can stain the superstructure and the substructure. A 2% vertical slope that brings rainwater back to the banks offers a better solution, because it would not stain the bridge.

A projecting pedestrian “stop” can be a pleasant option on a bridge. However, the view here offers no special justification for a scenic overlook. In addition, 1.8 meter (6’) pedestrian walkways proposed above allow enough space for walkers to pass while sightseers linger.

Design Options

Figure 32a shows Option A. A five-column cast-in-place bent in the center of the bridge supports two 30.5 meter (100’) spans, the layout shown in Figure 29a. The design features Type IV I-girders and T501 rails. A shoulder allows space for pedestrians. The I-beams, in combination with the Jersey Barrier rail would have a low apparent slenderness of 13. Table 3 compares prices for all four San Antonio options.

Figure 32b shows Option B, a design based on the single long span layout illustrated in Figure 29b. The design features Type IV I-girders and T501 rails. Option B results in a 5% savings over Option A. However, the large abutments significantly block the view along the Riverwalk corridor.

Figure 32c shows a much improved bridge which uses the layout shown in Figure 29a. The river is crossed by a 30.5 meter (100’) span, and spill-through abutments preserve the view along the pleasant Riverwalk corridor. 1370 mm (54”) deep U54 beams serve as superstructure. As discussed earlier, U-beams create a brighter underside and offer less blockish edge profile. U-beams here will seem massive to pedestrians on the Riverwalk, however. TxDOT Project 1410’s precast frames serve as substructure. Their chamfering and superior finish significantly improve the experience of walking alongside them. Because this bridge will be straight and carry relatively slow traffic, the raised sidewalk and a PR1 rail will suffice for pedestrian accommodation. An additional rail between the traffic and walkers would be unnecessary. The pedestrian rail and the U54 beams result in an acceptable slenderness of 18 for the main span. Buff colored superstructure, shadow rip rap, and bents both brighten the underside of the bridge and blend it with local architectural materials.

Figure 32d also uses the layout shown in Figure 29a, but it employs 865 mm (34”) deep box beams. The box beams are 510 mm (20”) less deep than the Type IV or U54B beams used in Options A and B above. Inverted tee bents, combined with the box beams, result in raising the vertical clearance of the bridge 740 mm (29”). The raised ceiling and flat underside of the box beams brighten the underside of the bridge. A PR1 rail and a raised sidewalk accommodate pedestrians as in Option C above.

In order to minimize the staining that often occurs with box beams, the slab is increased to 150 mm (6”) thick instead of the more typical 100 mm (4”). In addition, the raised sidewalks are sloped to drain toward the roadway. This configuration will prevent the box beams, which are flush with the road deck, from staining. The deck itself has a 2% vertical slope to shed water toward the banks.

The deck, raised sidewalk, and box beams combined result in a slenderness of 26 for the main spans and 16 and 10 for the side spans. Option D, like Option C, uses buff colored concrete.. The placement of light fixtures at the sides of the abutments helps to integrate the whole into a coherent design.

Recommendation

Option C is recommended. Although Option D offers the best design of the four aesthetically, its significantly higher price would probably place it out of consideration for this site. The precast substructure will offer good finish, human scale, and efficient detailing to the pedestrians who pass beneath the bridge. U-beams will improve natural lighting under the bridge and offer no ledges for birds. Tan fly ash concrete will also brighten the underside. In addition, the six inch high sidewalk will raise pedestrians on the bridge above traffic, and the PR1 rail will increase the bridge’s apparent slenderness.

CASE STUDY 4: ROAD CROSSING IN ZILKER PARK

The final case study focuses on an imaginary project set in an environmentally sensitive site. Austin's popular Zilker Park is home to athletic fields, Barton Springs Pool, and many other attractions (Figs. 33-35). Zilker Park is much beloved by Austinites, and construction in the Barton Creek Watershed has already caused many conflicts between lovers of the outdoors and builders.

Stratford Lane ends into Barton Springs Road in an extremely busy tee intersection (Figs. 36,37). Barton Springs Road separates the park's large athletic fields from Barton Springs Pool, and Stratford Lane divides the fields from the Austin Nature Center. Left turning traffic backs up a great deal at this intersection on pleasant days when park attendance is high. In addition to fraying the tempers of drivers, the heavy traffic creates a hazard for the park-using pedestrians who attempt to cross it. An overpass for the southbound Stratford Land vehicles desiring to turn left to go east on Barton Springs Road would greatly alleviate this traffic snarl. In addition, a pedestrian lane would allow park-goers on foot easy access to Barton Springs from the rest of Zilker Park.

The bridge would begin in the right side of Stratford Lane and cross over Barton Springs Road as it turns left (Fig. 38). Drivers on Stratford Lane wishing to turn left onto Barton Springs Road Right would exit to the right to get on the bridge approximately 115 meters (380') before the intersection. Vehicles turning right onto Barton Springs would stay on Stratford and take the separated right turn lane shown on the site plan. The bridge would have to attain a vertical clearance of 4.9 meters (16') for all road crossings (Fig. 39). The bridge would require a single lane for traffic, one shoulder, a pedestrian walkway, and rails at the edge and separating the road and walkway. The width of the bridge totals 10 meters (33'). As mentioned in the previous case studies, the dashed portion on the site plan represents the entire distance the roadway would be higher than current topography.

Site Conditions and Constraints

The environmentally sensitive park setting presents major difficulties for the design of the bridge. As the photographs show, pedestrians swarm Zilker Park. In addition, vehicular traffic at this particular intersection is extremely high. Principal vantage points of the bridge include those of the people on the athletic fields and pedestrians and drivers both underneath and on top of the bridge. With a length in the range of 200 meters (650'), the walkway would be fairly long, so pedestrians will have a long time to observe it. The bridge will curve significantly in plan.

The cultural significance of Zilker Park and Barton Springs Pool for the identity of Austin means that the design of the bridge will receive a great deal of scrutiny. The importance of the site implies that extra funding would probably be available for the construction of the bridge.

Vision

For the benefit of the park-goers who roam every square foot of the grounds, the Zilker bridge should have a pleasant view from the underside and careful detailing of the columns. The walkway should make the several minute long stroll across as safe and pleasant as possible. The construction of the bridge should minimize the disruption of traffic and also leave the natural surroundings little disturbed if feasible.

The bridge should appear to fit into the site harmoniously, and to accommodate the curve of the roadway. Ideally, the design should in some way acknowledge the cultural significance that Zilker Park and Barton Springs hold for Austinites.

Layout

In a natural setting such as Zilker, a bridge should disturb the view of the landscape as little as possible. Figure 39a shows a conventional layout for the Zilker Park Bridge that consists of one 36.6 meter (120') spans and four 30.5 meter (100') spans. These distances use prestressed beams at efficient lengths and can result in a fairly transparent substructure. This arrangement keeps columns 4.5 meters (15') away from the roads at the intersection. Although these distances are large enough to satisfy safety concerns, an improved layout would avoid the placement of a column in the median between Stratford Lane's right turn lane and the rest of the intersection. Crossing the entire intersection would require a span of approximately 55 meters (180'). Figure 39b shows a layout that consists of such a span over the intersection and two 55 meter side spans as well.

Another option to consider for a park landscape is an underpass. An underpass has the distinct advantage of leaving the view largely unchanged, which may win the approval of local residents where no bridge could. Disadvantages for an underpass in this situation include higher costs due earth moving and blasting through solid rock as well as the necessity of constructing a bridge across the gap for Barton Springs road. In addition, the proximity of Barton Springs and Town Lake may create difficulties for underground work. The underpass would require a pump station or a special outfall for drainage.

Superstructure

Type IV I-girders could economically span the 36.6 meter (120') layout shown in Figure 39a. A 10 meter (33') wide standard bridge would require four prestressed I-beams. Although U-beams have advantages over I-beams in edge profile and natural lighting, the geometry of U-beams does not efficiently fit this narrow bridge. Two U-beams would support approximately 8 meters (26'), and three would support 12 meters (40'). In addition, U-beams are more difficult to use on sharply curving bridges. Box beams would not accommodate the curves of the Zilker Bridge either.

The construction of an I-beam bridge presents several problems for this site. First, their construction would cause significant amounts of time delay. Using a gantry system of beam placement would help to reduce the impact of construction on the park landscape, but little of the immediately surrounding area is undisturbed due to the roads already in place. In addition, the gantry technique would still disrupt the flow of traffic on Barton Springs Road, so this expensive technique is probably not justified.

Another drawback of I-beams for this site is that they form a dark and unattractive underside. Furthermore, the curve of the bridge would create strongly scalloped shadows on their sides, especially at the required 36.6 (120') spans. Finally, I-girders have a blockish profile.

Balanced cantilever construction presents a much better option for the superstructure of the Zilker Bridge. Cantilevered box girders would minimally disrupt the traffic flowing beneath the bridge. Although balanced cantilever bridges cost substantially more than I-beam construction, the cultural and environmental significance of Zilker Park may justify the added cost. The statewide average for I-beam bridges was $29 per square foot of deck, but a balanced cantilever bridge with a 105 meter (350') main span completed in Surfside in 1995 cost $73 per square foot.

Cast-in-place box girders have many aesthetic advantages for the Zilker site. First, they form an underside with no dark indentations. Second, box girders accommodate curves gracefully. Instead of breaking a curve down into a few straight lines like I-beams, they curve continuously. Finally, the efficient section of a typical box girder eliminates the need for bent caps and expresses the flow of forces clearly.

Substructure

A typical design for the substructure for a bridge of this size involves cast-in-place double-column bents with rectangular caps. Preserving the view in Zilker Park is a priority for this site, however. Thus single column bents would offer a much improved alternative. "Inverted tee" caps would also increase transparency of the substructure. As stated previously, "inverted tee" caps cost slightly more than rectangular caps due to the greater complexity of the reinforcement detailing.

Precast substructure reduces construction time, a distinct advantage for a high traffic site such as the Stratford-Barton Springs intersection. The Richardson case study discusses the merits of precast and cast-in-place substructure in greater detail (Figs. 11,22). The superior control over finish offered by precast piers will also improve the pedestrian experience of the bridge.

Balanced cantilever box girders requires no caps on the piers.

Non-Structural Details

The curve of the Zilker Bridge would require full pedestrian accommodation: a rail separating the flow of traffic from the walkers. The previous case study in San Antonio presented options for the accommodation of pedestrians on a bridge (Fig. 30). A T501 rail would perform this task inexpensively. The long walk across the bridge would justify a more aesthetic rail, however. The Salado Creek case study discusses rails in greater detail and presents state average costs for several of them (Fig. 13). The PR1 steel pipe pedestrian rail at the edge of the bridge offers walkers a rail at hand height, and it also reduces a viewer's perceived slenderness of the bridge because of its transparency. Rails with a high level of ornament, such as the T411 Texas Classic, would look out of place in the natural landscape of Zilker Park. Of the traffic barriers, the T4(S) would offer the best alternative because it combines transparency with a concrete parapet that makes a transition between the proportions of the bridge to the steel of the rail.

As discussed in the San Antonio case study above, one approach for the placement of electric lights is to space them according to the manufacturer's specified range. Positioning lights according to the rhythm of the bridge and its supports, however, creates a more coherent design.

Limiting the use of rip rap to the area under the bridge and planting vegetation everywhere else presents the best option for the abutment slopes. Other aspects of the shadow rip rap to consider include coloring the concrete to match the shade of the vegetation adjacent to it. Rip rap lies on the land and should be consistent with it. Dyeing concrete a darker color costs roughly $40 per cubic meter ($30/cu.yd.).

The Zilker Bridge would require retaining walls parallel to Stratford Lane and possibly also along Barton Springs Road. Many textures and patterns are available to the designer (Figs. 40-42). Figures 40 and 41 are quite ornamental, and would not fit in as harmoniously in a natural setting such as Zilker Park. Ornate bridges fit better in or near urban areas, where they can reflect and blend with the architecture of the area. Figure 42 presents a rougher, less decorative finish which may blend with this site better.

Another option to consider for Zilker is landscaping. Ivy, for example could grow on the retaining walls, and help blend this structure into the greenery of its natural site. Vines present a particularly attractive option for Zilker because the retaining walls along Stratford Drive and Barton Springs Road would face east and northeast respectively. These directions are ideal for ivy, which needs to keep its roots cool. Hot southern and western exposures, on the other hand, are inhospitable for vines. For a typical bridge, an ivy project will add $50,000 to the cost.

Buff colored fly ash concrete could have several advantages for a Zilker Bridge. The lighter tone would brighten the underside of the bridge. In addition, buff concrete would also be a fairly close match to the exposed natural limestone in many areas of the park (Figs. 34,35). Finally, colored concrete needs no maintenance, unlike painted concrete. As mentioned previously, fly ash cement has a minimal price difference from regular cement.

Design Options

Figure 43a shows Option A, a conventional I-girder design for the Zilker site. Double-column cast-in-place bents support one 36.6 meter (120’) spans and four 30.5 meter (100’) spans, the layout shown in Figure 39a. The design features Type IV I-girders and T501 rails with a PR1 pedestrian rail on the outside edge of the walkway. The I-beams, in combination with the Jersey Barrier rail would have a fairly low apparent slenderness of 13 for the 30.5 meter (100’) spans.

Figure 43b shows an improved I-girder design for the Zilker site, Option B. The design features single column cast-in-place bents and Type IV I-beams arranged in the layout shown in Figure 39a. The reduced number of columns supporting the bridge improves substructure transparency. In place of the T501 rails Option B uses T4 (S) rails with a PR1 pedestrian rail on the outside edge of the walkway. The I-beams, in combination with the T4 (S) rail would have an improved apparent slenderness of 15 for the 30.5 meter (100’) spans. Option B raises the sidewalk six inches to separate pedestrian further from the traffic. Ivy on the retaining walls and dye in the rip rap in the shadow of the bridge help to integrate these expanses of concrete into the natural landscape. Finally, buff colored concrete relates the bridge to the exposed limestone throughout Zilker Park.

Figure 43c shows Option C, a design similar to Option B except that it uses precast substructure instead of cast-in-place bents. The faster construction times of the precast piers result in significant cost savings due to the reduced traffic delay. Furthermore, precasting allows a high degree of control over the finish, which improves pedestrian experience of the bridge. The raised walkway separated from traffic by a rail improves the walk across the bridge. T4 (S) rails offer transparency and a nice integration of the proportions of steel with those of concrete. Using a C4 (S) combination with hand rail for pedestrian traffic creates a coherent design. The minimal decoration on this bridge helps to blend it with the lack of decoration of the natural area. Ivy and a rough finish help to blend retaining walls with the land they support. Buff colored superstructure, shadow rip rap, and bents both brighten the underside of the bridge and blend it with the exposed limestone in the park. In addition, the tan color helps to remove this structure from the “highway bridge” connotations of gray concrete. The placement of light fixtures according to the rhythm of the piers also helps to integrate this bridge into a single coherent design.

Figure 43c shows Option D, a balanced cantilever bridge. A cast-in-place box girder leaves the intersection undisturbed with a 55 meter (180’) span. Option D uses the layout shown in Figure 39b. In addition, the balanced cantilever construction technique results in a significant saving in time delay costs because the erection of the substructure will not block traffic. The box girder, in combination with the T4 (S) rails and 150 mm (6”) sidewalk result in a slenderness of 20 for the three spans. The two piers offer an extremely transparent substructure, so the view of the park will be minimally disturbed. The box girder smoothly accommodates the curves and creates a relatively bright underside.

Recommendation

Although Option D is far better aesthetically than the other options, its doubled cost probably puts it out of consideration. Thus Option C is recommended. The 23% increase in cost results in a significantly better bridge for this site. The precast substructure will reduce traffic disruption, and also offer a superior finish, human scale, and efficient detailing to the pedestrians who pass beneath the bridge. In addition, the inverted tee caps and single column bents will significantly increase the transparency of the substructure. The raised sidewalk and T4 (S) rail separating pedestrians from the flow of traffic improves walkers’ experience on the bridge. The T4 (S) in combination with the C4 (S) creates a highly coherent design. The buff concrete, ivy on a rough textured retaining wall, dyed rip rap, and lack of ornamentation all help to integrate the bridge with its natural landscape.

REFERENCES

1. Billington, Sarah. “Aesthetic and Efficient Design of Standard Bridge Systems.” Ph.D. dissertation, University of Texas at Austin, 1997.

2. Carrasquillo, Ramon. University of Texas at Austin, Austin, Texas. Interview, 25 April, 1997.

3. Ratchye, Stephen. “Four Case Studies of Short to Medium Span Bridge Design.” Master’s report, University of Texas at Austin, 1997.