REHABILITATION OF THE HISTORIC BRIDGE OF LIONS

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EXPERIENCE | Transportation

INTRODUCTION

The Bridge of Lions was built by the City of St. Augustine, Florida in 1926-1927. It was designed to be a civic amenity as well as a link from the city to its developing barrier islands. While it is not an early or nationally distinguished example of the rolling lift bascule technology, the bridge ranks as one of the aesthetically most important spans in the state. The bridge dominates the St. Augustine waterfront, reflecting the "good taste, daring optimism, and faith of the people of this progressive community" (St. Augustine Record, Feb. 27, 1927). The significance of the bridge was acknowledged by its 1982 listing in the National Register of Historic Places for its significance in the areas of architecture, engineering, and transportation. In 1976, the Florida Section of ASCE recognized it as one of the two most significant bridges built in the 1920s in the state of Florida.

The Matanzas River Bridge derives its moniker from the two marble lion statues donated by Dr. Andrew Anderson, a wealthy resident and civic booster. Figure 1 shows the rendition of a 1950's artist. The bridge is exceedingly well proportioned and detailed. Its appearance was a successful attempt to revive the style and culture of other east coast resort cities. Executed in the popular, eclectic Mediterranean Revival style, the bridge was built to be as much public architecture as a transportation facility. It was ably designed to be an extension of the architectural character of the city, and its appearance is its most significant historic feature. The designers achieved the arched appearance by using steel, arch-shaped girders. The motif was repeated for the bascule span that is set between massive concrete bascule piers . Its octagonal-ended bays are topped by slender octagonal towers with barrel tile roofs that provide a pleasing textural contrast with the concrete. The attenuated towers integrate the bridge very well into the cityscape. It is this integration of the bridge into the cityscape, and its visual relationship to and from the city, that are important to preserve. The sheer size of the bridge, which is over 1,500' long, the arched spans and the open substructure provide a lively and graceful rhythm that needs to be maintained for the bridge to retain its historic significance. The bridge is meant to be appreciated, and that fact serves as the measure for evaluating the effect of all rehabilitation options and gives guidance on historic issues.

TYPICAL SECTIONS

The existing bridge deck is 22'-0" from curb to curb. There are two 5'-0" sidewalks which run the full length of the bridge. The cross section is substandard because of the narrow lane widths and the lack of protection for pedestrians and bicyclists. See Figure 2. Additionally, the railing height and configuration do not meet the AASHTO requirements for pedestrian or bicycle railings.

Figure 1: Artist's view of the west bridge approach.

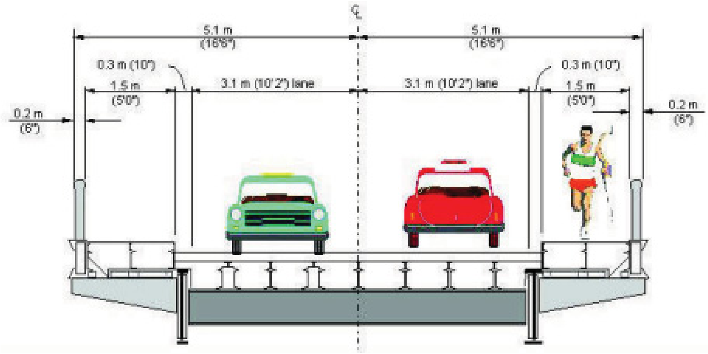


Figure 2: Existing bascule span cross section.

The scope of the rehabilitation included increasing the roadway and shoulder widths on the approach spans to 25', including two 11' travel lanes, two 1'-6" shoulders, and separation of the sidewalks from the roadway using two 1'-2" traffic barriers. On the bascule span, the roadway would be widened to 25', and vehicular and pedestrian traffic would be separated by including a 1'-2" traffic barrier. To accommodate the widened roadway and traffic barriers, the sidewalks would narrow to 3' wide on the bascule span. See Figure 3.

HISTORIC ELEMENTS

RAILING, BRIDGE LIGHTING AND TRAFFIC GATES

The original railing on the bridge was replaced sometime in 1971. The newer railing is substandard as a traffic barrier. The rehabilitation includes the construction of traffic barriers at the curb lines to allow for reproduction of the original wrought and cast iron railing. The new traffic barrier needed to be a clean, contemporary design like the Kansas corral railing, which is relatively open and unobtrusive. The color of the concrete would compliment that which predominates on the bridge. An important goal of the bridge rehabilitation project was to return lost elements, when those elements were well documented, in order to enhance the historic character of the bridge. The original wrought and cast iron railings, light standards, and luminaires were all removed and replaced with aluminum elements in 1971. The rehabilitation includes removal of the 1971 features and their replacement with reproductions from the original plans.

The design team met with the State Historic Preservation Office (SHPO) to present the alternatives for the sidewalk railing. Because of the heavy bicycle usage, we recommended installing a 4'-6" railing emulating the characteristics of the original 3'-6" sidewalk railing. The SHPO was in agreement, and all the details, except the height, of the original railing met the current AASHTO guidelines for pedestrian and bicycle railings.

The original design for the light standards and luminaires would be used to replace the modern aluminum light standards.

There is excellent documentation for the original traffic

Figure 3: New bascule span cross section. Approach spans have 5'-2" sidewalks.

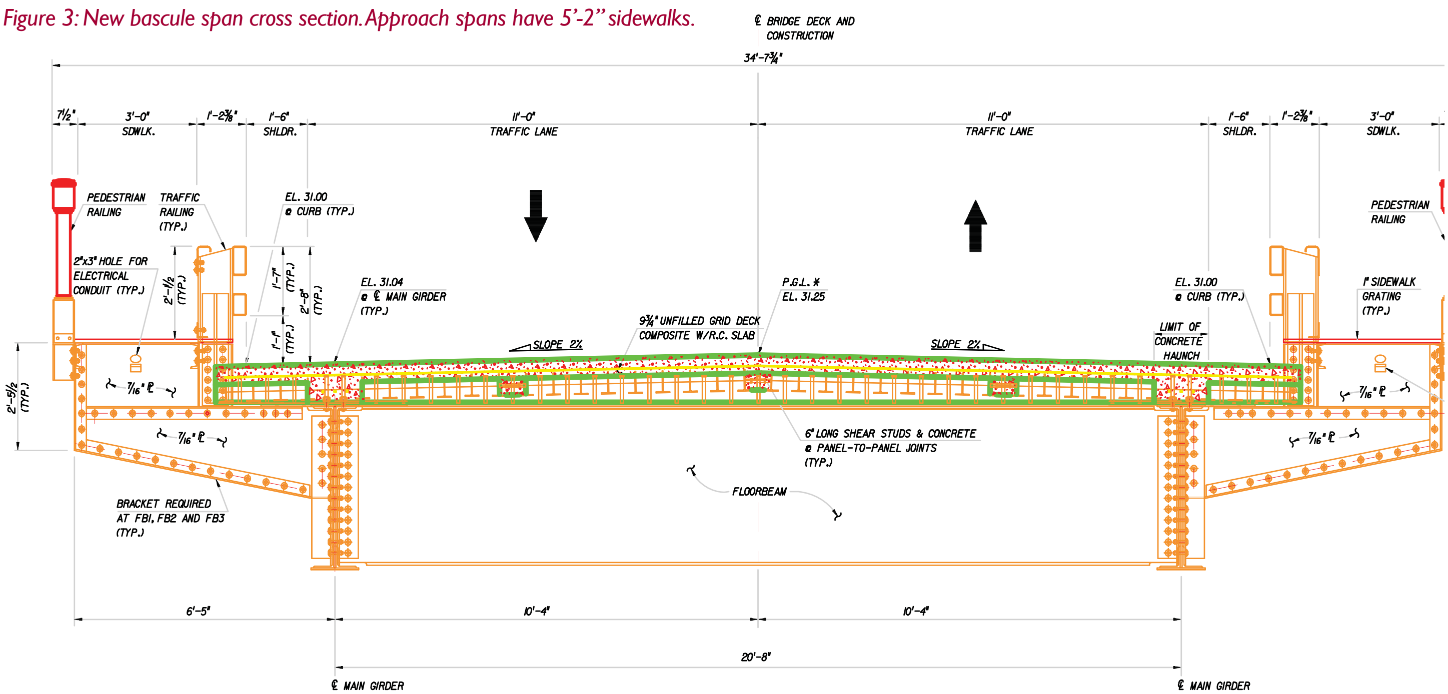


Figure 4: 1927 photograph showing ornamental traffic gates, railing, and observation towers.

gates for the bascule span, and given the high level of pedestrian use of the bridge, their reproduction and reinstallation as pedestrian barriers would enhance the historic character and experience of the bridge. See Figure 4 for original construction.

OBSERVATION TOWERS

There are several preservation issues related to the towers, which are very important historic details of the bridge because of their visual prominence. The towers are those elements extending from the sidewalk level upward. The bascule pier is considered to be the structure below the sidewalk level. The towers link the bridge with the St. Augustine skyline and place it within the local architectural genre. They also contribute greatly to making the bridge one of the prominent landmarks in the community. The towers are truly character-defining features of the bridge.

Along the entire length of the bridge, except the bascule span, the bridge is being widened, and includes traffic barriers separating the roadway from the sidewalks. Consideration was given to increasing the width of the sidewalks on the bascule span to maintain a 5' wide sidewalk across the length of the structure. To open the bridge in this configuration, some modifications would need to be made to the towers (moved outward). It was considered very important for the historic appearance of the bridge that the towers be changed as little as possible and that they maintain their current mass.

During Environmental Impact Statement (EIS) development and Bridge Development Report-phase meetings, it was decided that the bascule span cross section would not be widened to allow the 5' sidewalks, so no moving of the towers was required. The sidewalks on the bascule span are 3' wide.

The upper levels openings of the observation towers have been open to the weather and birds. Weatherproof windows are being installed. First level (at the roadway) fenestration is being replaced in accordance with the original plans. The towers are to be reroofed, using materials which are similar to the original construction, including the framing and finish materials. The roof tiles will be placed in accordance with the original plans.

The towers require varying degrees of concrete repairs. Hollow areas, spalls, pop outs, cracks, and exposed reinforcing are present. The roofs have not been well maintained, so there is considerable damage to the cornices. See Figure 5.

The Secretary of the Interior's standards and treatments for rehabilitation of historic structures are the criteria against which the effect of the project on the historic value of the bridge will be judged. They call for the conservation of original fabric whenever possible. It is thus important to retain as much of the towers as

Figure 5: Typical condition of interior of towers where windows have been left uncovered.

possible to conform to the standards and treatments. Our in depth inspection and testing program, discussed below, showed generally isolated areas of deterioration, at the NW and SW towers. More extensive deterioration is evident at the NE and SE towers.

The towers are prominent features of the bridge that are visually accessible from near and far. The deteriorated areas, identified and measured as part of the condition report for the bascule span, are to be repaired in accordance with generally accepted National Park Service conservation standards for concrete buildings. This includes carefully removing deteriorated areas to sound concrete, treating rusted steel, and placing new concrete to match the existing. All work will be blended with surrounding sound concrete. Specifications include the requirement for this work to be preformed by skilled masons with demonstrated experience in concrete restoration. Approval of a test patch for the concrete finish coating is part of the project specifications.

APPROACH SPAN MAIN GIRDERS

There are two primary features of the bridge that define its historic character, the towers and the arched steel girders, with their deep bracketed overhanging deck sections supported on piers composed of concrete column and web wall bents. The structural system of the approach spans consists of two main girders supporting transverse floorbeams which support a reinforced concrete deck. The arch-shaped girders establish the overall aesthetics of the bridge and, with open substructures, provide the characterdefining visual rhythm that the bridge achieves. See Figure 6. The retention of the approach span arched girders contributes greatly to the overall effectiveness of the rehabilitation of the bridge. Since a project requirement is to provide a wider roadway over the bridge, the girders are being moved outward rather than adding a wider cantilevered deck section on new, larger brackets.

Figure 6: Elevation of existing bridge. Note arched girders and open approach pier configuration.

Because of the overall importance of the arched girders, they are being rehabilitated and reused. The girders will be removed from the site, deteriorated material replaced in kind using button head bolts, the steel painted in the shop, and then returned to the site and installed on new piers. The bridge is large enough that moving each girder outward approximately 3 feet to accommodate the bridge widening, will not adversely affect the historic appearance if the substructure is replaced in kind. In elevation, the bridge will be unchanged. The bridge will appear as it presently does from the shorelines.

Multi-beam superstructures (structurally redundant) are preferred over a two girder/floorbeam system typified in the existing bridge. Longitudinal stringers are being added to support the deck. The longitudinal beams are no deeper than the shallowest point of the existing girder, and the rehabilitated girders and brackets will carry the sidewalk loads. Using functioning historic members is preferable over non-functioning members.

APPROACH SPAN PIERS

The in-depth inspection and testing program revealed that the approach span substructures were severely deteriorated and highly contaminated with chlorides. There has also been undermining and severe scour damage. As the bridge is being widened, the elephantine columns and partial web wall bents will be replicated and redesigned to accommodate the widening. The design of the existing open substructure, which is important to achieving the graceful arcaded rhythm of the bridge, lends itself well to the widening by repeating the column detail and making the plain web

Figure 7: Existing approach span underside and piers.

walls wider. See Figure 7. The in-kind replacement is in accordance with various Secretary of the Interior's standards and treatments and will compliment the reuse of the existing girders.

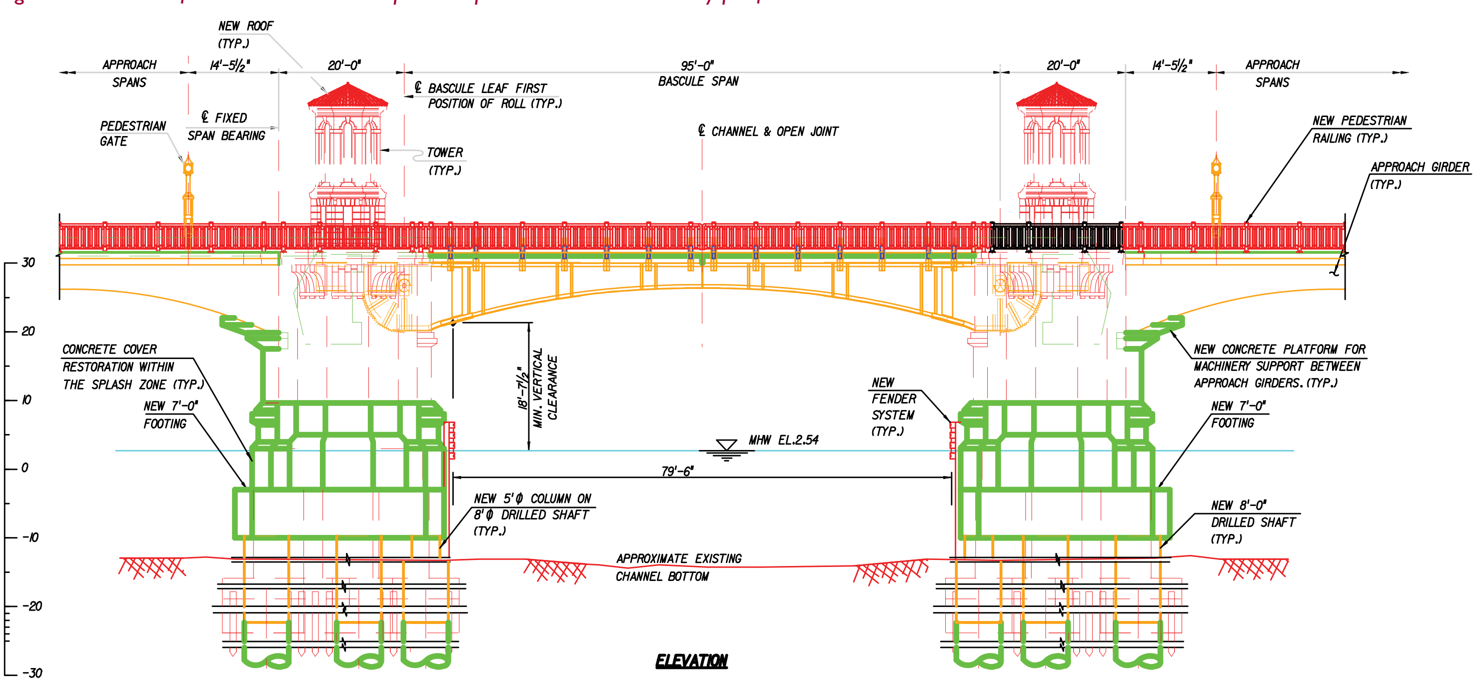
Again, it is the overall aesthetics of the bridge that are important to retain in order to preserve what is historically significant about the bridge, and keeping the relationship of the arched girders bearing on the open, stylized column bents will do that. The rehabilitated bridge will be wider, but the original relationship between dominant elements, like the superstructure and the substructure, will be maintained.

BASCULE PIERS

As noted above, one of the defining characteristics of the bridge is the shape and style of the massive concrete bascule piers. It is important that neither the shape nor details of the piers be changed. The concrete cantilever brackets at the upper levels of the piers will be preserved to maintain the look and feel of the bridge. Changes at the top of pier where the bascule girders on the channel side, and the flanking span girders in the back, extend through are acceptable, since they are mostly hidden from view. The changes required include moving the supports for the flanking span outward to accommodate the widening, and installation of a new cantilevered concrete platform to accommodate the new span drive machinery. See Figure 8.

Repair of concrete on the bascule piers will be done to the same matching procedures as the towers. Our inspection and testing program revealed large spalls, hollow areas, inadequate cover, chloride contamination to a depth of 6", and ettringite crystals, which in the presence of

Figure 8: Elevation of rehabilitated bascule span and piers. Note new machinery platforms.



water, are detrimental to the concrete due to its expansiveness over time. Within 8' of the waterline, the chloride contaminated concrete is being removed to a depth of 6 inches. Additional thickness is being installed to allow for increased cover and the installation of an impressed current cathodic protection system. The band of extra thickness is continued around the entire pier with careful detailing at the plinth in the middle of the pier. Additionally, the openings in the counterweight pit are being sealed, and the exposed pier surfaces are being coating. These treatments should keep water from reacting with the ettringite crystals.

BASCULE SPAN AND MACHINERY

The movable span is not a technologically significant example of the rolling lift bascule type, which was first built in 1892. Because the more significant approach girders are being reused, and the bascule girders are heavily deteriorated, the bascule span superstructure is being replaced in its entirety. The new leaves reproduce the shape of the existing leaves, and they are made of built up members (angles and plates) to keep the appearance of the bridge the same. In order to keep the visual rhythm that the bridge presents, the spacing of the sidewalk brackets is kept the same as the existing bridge. Both rolling lift and trunnion bascule leaves were evaluated and the rolling lift chosen because it requires fewer modifications to the piers. The machinery is being placed off the moving leaf.

INSPECTION AND TESTING

Prior to making recommendations for the rehabilitation of the structure, we completed an in-depth inspection and testing program. Elements anticipated to remain, in accordance with our historical evaluation of important elements, received a hands-on inspection. We removed concrete core samples from selected approach piers and several critical areas of the bascule piers. We used a barge mounted lift to inspect the piers and superstructure. This way no traffic control was needed on the narrow bridge.

The piers typically had large spalled and hollow areas, zones of map cracking, and large open cracks due to corrosion of embedded steel. See Figure 9.

Figure 9: Typical condition of bascule piers.

Spalls typically had exposed and corroded reinforcing steel. Tests performed on the concrete core samples were compressive strength testing, petrographic analysis, air content testing, and chloride-ion analysis.

The concrete compressive strength test results indicated that the existing bascule pier concrete has a compressive strength near 4000 psi, as shown in the table of results below:

Compressive Strength Test Results	
Location	Compressive Strength (psi)
West Bascule Pier Wall	3930
East Bascule Pier Wall	4488

The results of the petrographic analysis indicate that the bascule pier concrete is poor to fair in quality, exhibiting non-uniform and high water/cement ratios, up to 0.65. Some air voids in the samples contained ettringite crystals, which are detrimental to the concrete due to its expansiveness over time, which may cause spalling and cracking.

The air content test results indicate that the bascule pier concrete has air void contents ranging from 1.7% to 4.1%, with entrained air contents of 1.2% and 2.6%, and entrapped air contents of 0.5% and 1.5%. An air void system would help diminish damage due the expansion from ettringite crystals.

The chloride-ion tests were performed to determine the potential for future reinforcing steel corrosion and subsequent damage to the bascule piers due to spalling and cracking. Determining the chloride ion content within the existing concrete at various depths helps to determine the viable alternates for rehabilitation, particularly the decision to repair individual defects or replace the cover concrete throughout. The results of the

Chloride-Ion Analysis Results				
Sample Designation		Chloride Ion Content		Threshold for Chloride Ions Facilitating Corrosion (Lbs. per yd ^{3} of Concrete)
Sample Number (Location)	Depth (inch)	% by weight of Concrete	Lbs. per yd ^{3} of Concrete	
1 (West B. Pier)	2	0.0923	3.61	1.02
	4	0.0607	2.37	1.02
2 (East B. Pier)	2	0.1234	4.83	1.02
	4	0.1437	5.63	1.02
3 (West B. Pier)	2	0.1014	3.97	1.02
	4	0.0813	3.18	1.02
	6	0.0418	1.64	1.02

chlorideion analysis (above) indicate that the concrete at both bascule piers is saturated with chloride ions which will facilitate corrosion of the reinforcing steel.

REHABILITATION

Rehabilitation of historic elements was discussed above. The design life of the rehabilitation is 75 years. Although the original scope of work did not include strengthening of the bascule piers for ship impact or to resist the design scour, given the historic value of the piers and towers, and the design life, it was determined that the bascule piers should be strengthened.

A scour analysis for the bascule piers was performed by a specialty firm and resulted in estimated scour values which would completely undermine the existing timber piles, which extend to an approximate elevation of -57.0 feet. The existing channel bottom is approximately at elevation -22.5 feet. As the theoretical scour would resulted in very costly foundations for the bascule and approach piers, a model was constructed and tested in a flume at the University of Colorado. The resulting scour depth at the bascule piers was estimated to a depth of -50.0 feet.

Following is a summary of the rehabilitation scope for the bascule span and piers:

BASCULE PIERS

- Spall repairs - removal of contaminated and deteriorated concrete and cover restoration below Elev. +10.0, with individual repairs above that elevation;
- Close counterweight pits;
- New electrical room floors;
- Machinery platform at rear of each bascule pier to accommodate new drive machinery;
- Rear face column modifications; and
- Installation of 5 new drilled shafts at each pier with a new waterline footing built below the existing footing. This strengthening addresses the near loss of the existing foundations during the 100 year scour event and strengthens the foundations for vessel impact. Even though strengthening for scour is substantially more expensive, the strengthening costs are less than the costs for new bascule piers.

SUPERSTRUCTURE

Based on least cost, an exodermic deck on a stringer/floorbeam/main girder system is being built. The exposed sections of the main girders are fabricated from angles and plates and mimic the shape of the original girders. The curved girder section and tread plate of the rolling lift are not visible and are fabricated from welded sections.

MECHANICAL SYSTEM

The mechanical options evaluated include hydraulic cylinder arrangements and the conventional power transmission equipment typically seen on movable bridges.

Despite the lower initial cost for the hydraulic options, these options are not recommended for the following reasons:

- Modifying the counterweight pits for hydraulic cylinder mounts presents a cost disadvantage;
- The horizontal orientation, combined with the length of the cylinder, for hydraulic cylinders mounted behind the rolling leaf, would result in a long unsupported length. Although similar arrangements have worked successfully, it is preferable to avoid this design issue and the potential for resulting problems throughout the life of the bridge;
- The rehabilitation requirements associated with hydraulic installations have proven to be significant compared to conventional power transmission equipment.

Of the three mechanical power transmission equipment options considered, using a single speed reducer configuration mounted on the moving leaf or a multiple speed reducer layout mounted behind the leaf, on the bascule pier were considered more favorable than installing a multiple speed reducer system on the moving leaf, due to the

significant space limitations associated with this option. Maintenance and inspection space would be extremely limited once installation is completed, and installation itself would be difficult. For these reasons, this option was not recommended.

The advantages of mounting the machinery on the bascule pier are significant and include the following:

- This option provides the best access to the machinery for maintenance and inspection.
- Design considerations related to change in orientation of the machinery and machinery supports during operation of the bridge are not a factor.
- The location of the machinery brakes safeguards against mechanical failure of the motors, couplings, primary speed reducer, and the floating shafts.
- This system provides the best access for installation and alignment of the machinery. With this option, it is likely that the majority of the machinery can be assembled in the shop. This will reduce field installation time and the problems frequently encountered with installing and properly aligning machinery in the field.
- This system has a straddle mounted rack pinion. This arrangement limits deflection and ensures more uniform tooth loading than the overhung pinion arrangement associated with mounting the machinery on the moving leaf.

ELECTRICAL SYSTEMS

A 250 amp 480 volt, 3-phase electrical service is being installed for the operation of all bridge motors and sub-systems. The 480-volt utilization voltage is the industry standard for industrial power systems and provides the most efficient and economical means of serving the bridge loads. The majority of FDOT's new designs and rehabilitations use 480 volts as their utilization voltage.

The new emergency generator size 60 KW. The generator is connected to the electrical system via an automatic transfer switch and provided with an exerciser load bank sized at approximately 30 KW.

Variable frequency drives have a proven track record in bridge applications and will be installed for motor speed control. Their advantages lie in the drive's ability to provide torque for seating and control overhauling loads during high wind conditions or lowering without the need for speed feedback from the motor. Redundancy is accomplished with back up motors and drives that will operate in an alternating scheme. The VFD provides the most reliable and logical choice of drive for this project. Individual motor speed controllers are provided for each motor.

The disadvantages to this option are cost and aesthetics. The cost of mounting the machinery off of the moving leaf was estimated to be 16% greater than the cost of the single speed reducer arrangement mounted on the moving leaf. The installation and maintenance advantages of mounting

the machinery off of the moving leaf outweigh the cost implications, and so the machinery is being installed on the bascule pier, behind the moving leaf.

Normal motor control will be accomplished via standard relay logic. All alarm functions will be monitored by the PLC. However, in the event of PLC trouble, bridge operation will continue unaffected. Suitable hardwired controls are provided to allow the bridge tender to initiate bridge operation. The control system is comprised of a control desk and main control panel. The control sequence is semi-automatic with only the leaf operation being automatically sequenced. Operator interface is provided by a series of push buttons, initiated sequentially from left-to-right to open the leaves, and right-to-left to close. The individual leaf drive units control the operation of their respective leaves. The control system provides only "Run" signals while the "Slow down" and "Stop" signals are provided by discrete limit switches.

Due to the location of the tender house in relation to the sidewalks, a closed circuit television system will be installed. The camera system consists of a blemish free, onehalf inch, frame transfer, charge coupled device, image sensor and auto iris lens, and associated electrical circuitry, integrally enclosed in a sealed and pressurized aluminum barrel housing. The camera is capable of unattended, continuous 24 hours per day operation under the environmental conditions present at the bridge.

SCHEDULE AND COST

The rehabilitation project is scheduled to bid on April 28, 2004, and construction is estimated to last 4 ½ years, including the construction and demolition of a temporary movable bridge to carry two lanes of traffic and one sidewalk for the duration of the permanent bridge rehabilitation. Construction was bid at $ 76,810,674.75 including the temporary bridge.

ACKNOWLEDGEMENTS

TranSystems | Lichtenstein Consulting Engineers, Inc. completed the design of the movable spans for the rehabilitation of the Bridge of Lions and the temporary bridge as subconsultants to Reynolds Smith and Hills, Inc. (RS&H) of Jacksonville, Florida. TranSystems | Lichtenstein was also responsible for the historic evaluation of the bridge and recordation. RS&H completed all roadway design and design of the fixed spans of the permanent and temporary bridges as well as public involvement. The work was performed under contract with the Florida Department of Transportation, District 2.

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