Structural Design Package for the Replacement of a County Bridge

Abstract

All engineering students of our university are required to complete a year-long, industrially-sponsored senior design project prior to graduation. In the project described below, a team of four students worked under the supervision of two liaison engineers from a local county and a university faculty advisor on the design of a bridge requiring replacement. In fall quarter, the students prepared a written proposal for the county outlining the project, scope and plan of work, project deliverables, schedule and budget. The design was done in winter and spring quarters and culminated in a report describing the design methods, engineering drawings, calculations and recommendations. The team made oral presentations to the county at the end of fall, outlining the project approach, and in spring quarter, describing their final design.

A local county identified one of its bridges as structurally deficient and not in compliance with current standards for lane width and pedestrian access. In addition, the bridge had several design challenges: the center support and abutment had experienced severe scouring and erosion; the site had a high pressure artesian aquifer located 48 feet below the road surface; the roadway profile had both a horizontal and vertical curve.

The county requested the student team to submit a structural design package for a single span, pre-stressed concrete bridge superstructure, substructure and roadway approach slab. In response, the team designed a 70 ft long, 49 ft wide bridge superstructure using decked bulb tee girders. The bridge has two-12ft vehicle lanes, two-5ft bike lanes and two-5 to 7ft sidewalks. The substructure consists of 18” diameter cast-in-place concrete piles. The team also designed the abutment consisting of sheet pile walls.

The student team prepared a structural design package for the client consisting of structural plans and details using AutoCAD 2007, construction specifications including special provisions, a construction sequence memo, construction cost estimate and design calculations. The team submitted 30%, 60%, 90% and 100% submittals to the county.

During the academic year the student team met with the faculty advisor weekly and with the liaison engineer biweekly or weekly, to discuss team progress. Because the sponsor was located 30 miles away from the university, some of the sponsor meetings were held via videoconferencing. Each team member served as the project manager during the year, running team meetings, setting agendas, assigning tasks to members and following up on action items. The project strengthened the team’s ability to apply their technical knowledge to a practical problem, to work as a team, to communicate effectively, to learn and practice project management and leadership skills and to meet the clients’ needs.

The county submitted the preliminary design package to the state department of transportation in the summer of 2008 requesting funding. This was the only bridge within the county approved for full replacement.

STRUCUTURAL DESIGN PACKAGE FOR THE REPLACEMENT OF A COUNTY BRIDGE

INTRODUCTION

A local county public works department has found one of its bridges to be structurally deficient and not in compliance with current standards for lane width and pedestrian access. Therefore, the bridge was slated for replacement.

The bridge, shown in Figure 1, was built in 1966. It is a two-span concrete structure with a center pier consisting of nine timber piles. The bridge has been subjected to seasonal scour and erosion behind the abutments and below the center pier pilings; floating debris has been collecting on the center pier as shown in Figure 2a. In 1986, a severe storm event caused scour behind the abutments, which resulted in a two-foot settlement of the roadway slab. Another storm in 1996 washed away the leading pile of the center pier. A 2007 storm resulted in heavy debris build up at the center support. The load-carrying capacity of the bridge is compromised due to structural damage and, therefore, the county has posted a ten-ton limit on the bridge. In addition, removal of debris is an added expense. Therefore, the county is considering replacing the bridge with a single span bridge.

Figure 1. Bridge alignment (looking south)

The county approached our university to carry out the preliminary design for the replacement bridge as a senior capstone project. At our institution, all engineering students are required to complete a year-long, industrially sponsored project. Three to four students work on a real life project under the supervision of a liaison engineer from the sponsoring agency and a faculty advisor from the university.

BACKGROUND

The original bridge has undergone some modifications over the years. The area surrounding the bridge has transformed from rural land to a residential neighborhood in recent years. To accommodate the increased traffic, a narrow pedestrian walkway was added and can be seen in Figure 1. Measures have been taken to alleviate the scour and erosion damages at the embankment and at the center pier. Rip-rap has been added to mitigate the scour behind the abutments and to stabilize the stream bed. The center pier has been retrofitted with a concrete ecology block and supplemental framing and shims. These can be seen in Figure 2b.

(a) (b)

Figure 2. State of Center Pier, a) Condition after a Storm, b) Structural Retrofits

The public safety issue related to seismic vulnerability of the bridge is of concern to the county as the seismic standards have changed considerably since 1960's. The county has slated the bridge for replacement because of the structural deficiencies, escalating maintenance costs and the potential seismic vulnerability.

The replacement bridge design had several other site-specific challenges and constraints:

- A two-foot diameter conduit consisting of fiber optic cables is attached to the bottom deck of the existing bridge. Relocating this or interrupting service to the customers during construction was not an option.

- Subsurface exploration at the bridge site revealed a high-pressure artesian aquifer at approximately 48 feet below the roadway. The county required that the foundation system should be selected such that it avoids puncturing the aquifer as this would result in significant construction delays and added cost of construction.

- The roadway profile has both a vertical and horizontal curves making the design challenging.

- Because the stream flows at an angle beneath the bridge, one of the abutments had to be skewed at an angle of 45^{o} to the longitudinal axis of the bridge.

COUNTY'S DESIGN STIPULATION

The county required the team to design the superstructure, substructure and the roadway approach slab. The bridge had to be pre-cast, single span with two vehicle lanes, two pedestrian walkways and two bicycle lanes. The design had to be submitted at 30%, 60%, 90% and 100% completion on predetermined dates.

The design package had to consist of the following:

- Structural plans, details and engineering calculations: design plans for the structural elements had to be done in AutoCAD 2007; electronic and hard copies were required.

- Specifications with special provisions: the county provided a pick list from which the team was required to put together the specifications for the bridge. Special provisions had to be added for items not appearing in the pick list.

- Construction sequence memo: this had to outline the construction sequence.

- Construction cost estimate: a preliminary cost estimate was required.

The county provided the team with the hydrologic and geotechnical analysis. The county was responsible for the civil site design.

TECHNICAL DETAILS

The team designed the superstructure, the substructure and the approach slab, as requested. The new bridge is 70 ft long and 49 ft wide. The bridge has two-12 ft vehicle lanes, two-5 ft bike lanes, two sidewalks ranging between 5 and 7 ft. The approach slabs to the bridge is 25 ft long and the slope of the stream banks up to the bridge abutment is 2:1. An elevation view of the bridge is shown in Figure 3. Some of the important technical details are described below.

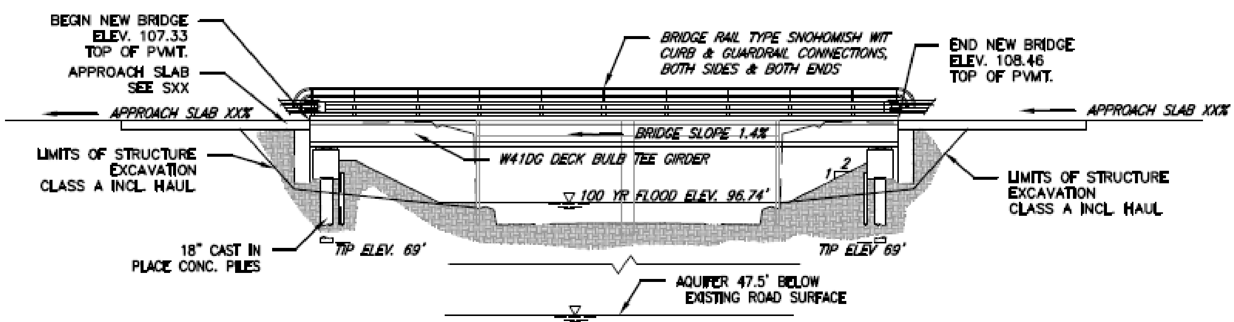

Figure 3. Elevation View of Proposed Bridge

a) Superstructure

The bridge deck consists of seven 41 in. decked bulb tee girders at 7 ft spacing as shown in Figure 4. At both ends of the bridge, end diaphragms are used to tie all the girders together and provide structural continuity. The end diaphragms are required to resist gravity and seismic loads.

The bridge deck has a 2% grade from the centerline to facilitate drainage. Because of the complex geometry of the bridge, the asphalt depth ranges from 2 to 8 inches, with an average depth of 5 inches.

The superstructure was designed according to county engineering design and development standards and the American Association of State Highway and

Transportation Officials (AASHTO) bridge design specifications. In addition, bridge design manuals developed by the state Department of Transportation (DOT) and Precast Concrete Institute (PCI) were used, when necessary. The state DOT's PGSuper software was used to design the girders.

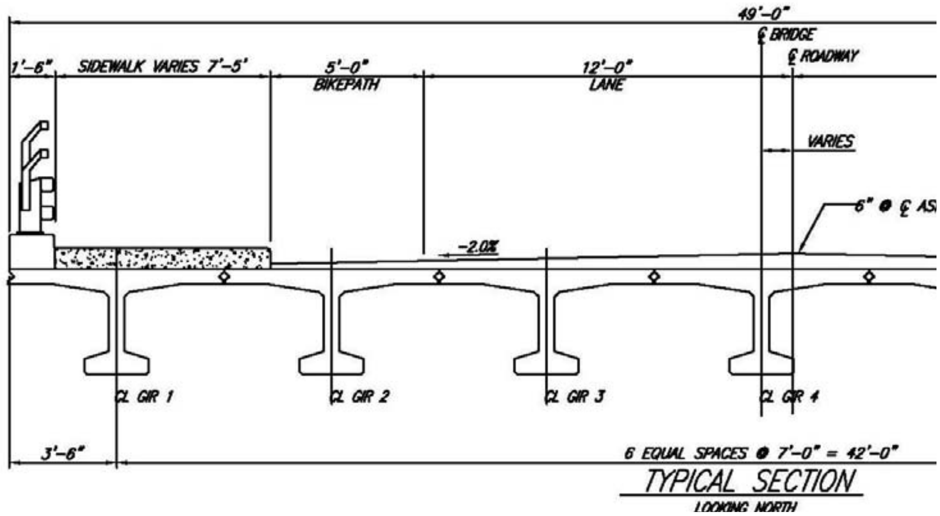

Figure 4. Typical Section of proposed bridge

b) Substructure and Approach slabs

The bridge foundation consists of fourteen 18 in. diameter cast-in-place concrete piles with 6 ft center to center spacing at each end of the bridge. The length of the pile is limited such that it does not penetrate the aquifer. A 4'3" wide, 3' deep, 82' long concrete beam serves as a pile cap at the top of the abutment.

A sheet pile wall was designed at the two abutments to contain the soil around the piles and below the approach slabs. These were designed as anchored sheet pile systems using the method of moment reduction. Figures 5 and 6 show the foundation system and the sheet pile wall system. The skew in the abutment can be seen in Figure 5.

The foundation was designed according to AASHTO standards. The bridge approach was designed according to the state DOT standards with modifications made for the skew of the abutments. SAP2000 (software) was used to determine the maximum moment, shear force and deflection of the piles. PCACol (software) was used for pile reinforcement design and LPile (software) was used for lateral pile capacity analysis.

c) Design package

i) Structural Plans and Calculations

Part of the design package consisted of the following ten 11"x17" sheets of engineering drawing developed in AutoCAD2007:

1) Cover page: title page, vicinity map, sheet numbers and titles
2) Bridge plan and elevation: horizontal and vertical datum, survey stations
3) Bridge replacement – typical section and general notes

4) Foundation Plan, Abutment Section including details (3 sheets)
5) Girder Details (2 sheets)
6) Diaphragm details
7) Approach slab and details

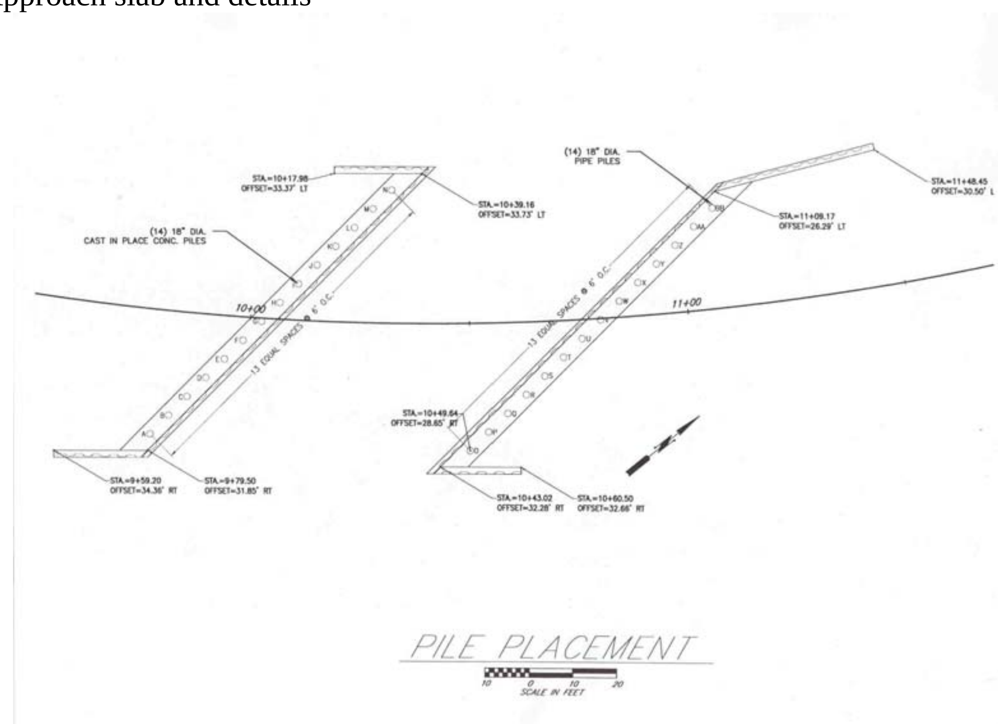

Figure 5. Plan View of Bridge and Substructure

Figures 3 through 6 are excerpts from the design package. All engineering calculations supporting the design were submitted as an appendix to the final report and completed by students.

ii) Specifications with Special Provisions

The team completed the specifications for the bridge using the standard pick list provided by the county. The team submitted special provisions for non-traditional structural elements included in the design such as the sheet pile wall embankments.

iii) Construction Sequence Memo

The team submitted a memo to the county outlining the construction sequence of the bridge. The purpose of this document was to demonstrate the team’s understanding of the construction process and to show that the design is constructible.

iv) Construction Cost Estimate

The team used the state DOT’s cost sheet to estimate the cost of construction of the bridge. It arrived at a cost of $1.8 million for the structural elements of the proposed bridge. Based on this value, the unit cost for the construction of the new bridge was $530/sq. ft.

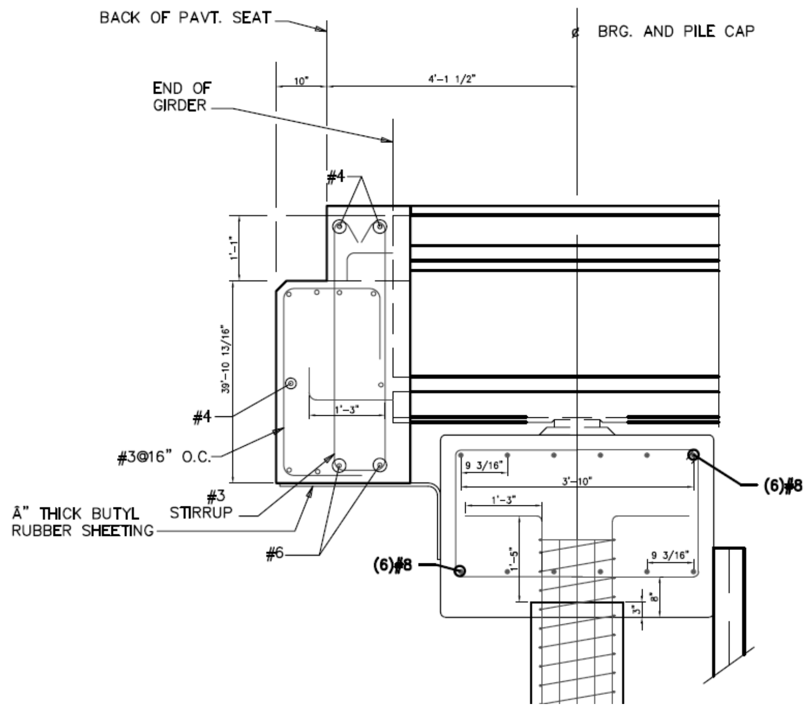

Figure 6. Details of Abutment Diaphragm and Pile

SKILLS DEVELOPED
The project enabled the students to develop the following: technical skills, oral and written communication skills, project management and leadership skills, ability to work in a team setting and to interact with clients.

a) Technical skills
The students learned how to design a bridge from the conceptual stage to the final design. Along the process they acquired the skill to use the following tools:

- Design Manuals: AASHTO bridge design manual, Precast Prestressed Concrete Bridge Design Manual, State DOT Bridge Design Manual, State DOT Standards Specifications for road, bridge and municipal construction
- County Codes: county engineering design and standards, county CADD standards.
- Computer aided drafting (AutoCAD 2007)
- Design Software: PGSuper for girder design, L-Pile for lateral pile analysis, SAP2000 for load distribution analysis, PCACol for pile reinforcement.

Students have had limited exposure to PCACol, SAP2000 and AASHTO bridge design manual in their structural engineering coursework. But they got an opportunity to work with all the above design manuals, codes and design software in much detail with the help of the faculty advisor and the liaison engineers.

b) Communication skills
The students submitted a written proposal to the sponsor at the end of fall quarter, outlining their understanding of the project, scope of work, plan of implementation, and schedule. At the end of spring quarter, they submitted a final report describing the work done, engineering drawing, calculation and other deliverables requested by the sponsor.

The students were required to make oral presentations to their peers thrice a quarter. Each student was required to make at least one presentation each quarter. In addition, students presented their proposed work at the county office at the end of fall quarter. They presented their final design to the county at the end of spring quarter. The academic year concluded with projects day, a conference style event, where the team presented its work to the entire university community, sponsors of all the various senior capstone projects, prospective sponsors, friends, family and alumni.

c) Project Management and Leadership skills
The student team met with the faculty advisor weekly. In addition, the team met with the liaisons bi-weekly or weekly as necessary. Every other meeting with the sponsor was done through video conferencing as the sponsor was about 30 miles away from the university campus.

Each team member served as the project manager for part of the academic year. The project manager was responsible for setting up the team meetings, developing the meeting agenda, conducting the meetings, assigning tasks and following up on action items. He/She was also responsible for contacting the liaison and the faculty advisor in between team meetings, when needed.

SUMMARY
A team of four civil engineering seniors carried out the structural design of a bridge for a local county under the supervision of two liaison engineers from the county and a faculty advisor. The new bridge will replace an existing bridge that is structurally deficient. Through this capstone experience the team learned how to apply the technical skills learned in structural engineering courses to a real life design. Moreover the students developed project management, leadership and communication skills, and client relationships. The students were exposed to various design manuals, design software, oral presentations tools and video conferencing technique. The county presented the preliminary design package prepared by students to the state department of transportation and was successful in getting funding for complete bridge replacement. Both parties involved benefited by this project.