4-29-2011

The Civil Engineering Balancing Act

Elena M. Rodriguez

University of South Florida

Follow this and additional works at: http://scholarcommons.usf.edu/honors_et

Part of the American Studies Commons

Scholar Commons Citation


http://scholarcommons.usf.edu/honors_et/4

This Thesis is brought to you for free and open access by the Honors College at Scholar Commons. It has been accepted for inclusion in Outstanding Honors Theses by an authorized administrator of Scholar Commons. For more information, please contact scholarcommons@usf.edu.
The Civil Engineering Balancing Act

by

Elena M. Rodriguez

A thesis submitted in partial fulfillment of the requirements for graduation of the Honors College
University of South Florida

Advisor: A. Gray Mullins, Ph.D.
Committee Members: Rajan Sen, Ph.D. & Julio Aguilar

Date of Approval:
April 29, 2011

Keywords:
Civil Engineering, Bridge Design, Anna Maria Island Bridge,
Engineering Design Considerations

Copyright © 2011, Elena M. Rodriguez
# Table of Contents

List of Tables ................................................................................................................................. iii

List of Figures ................................................................................................................................ iii

ABSTRACT ................................................................................................................................... iv

1. Introduction ..................................................................................................................................1

2. Planning .......................................................................................................................................1

2.1 The Debate .............................................................................................................................1

2.2 Studies ....................................................................................................................................2

2.3 Proposal ..................................................................................................................................6

3. Design ..........................................................................................................................................6

3.1 Sustainability ..........................................................................................................................6

3.2 Loads ......................................................................................................................................7

3.3 Superstructure .........................................................................................................................9

3.3.1 Deck .................................................................................................................................9

3.3.2 Girders ...........................................................................................................................10

3.4 Substructure ..........................................................................................................................12

3.4.1 Pier .................................................................................................................................12

3.4.2 Footing ...........................................................................................................................13

4. Construction ...............................................................................................................................14

5. Conclusion ..................................................................................................................................15

References ......................................................................................................................................16

Rodriguez
List of Tables

Table 1: Alternatives Analysis Matrix ........................................................................................................... 4

List of Figures

Figure 1: Location of Environmental Study for Anna Maria Island Bridge .................................................. 3

Figure 2: Holmes Beach Bridge Approach ..................................................................................................... 5

Figure 3: Existing Anna Maria Island Bridge ................................................................................................. 5

Figure 4: Characteristics of the Design Truck ............................................................................................... 8

Figure 5: Superstructure ................................................................................................................................ 9

Figure 6: Thermal Cracking of a Concrete Slab ............................................................................................. 10

Figure 7: Bending in a Beam .......................................................................................................................... 11

Figure 8: Recommended Bridge Substructure Cross Section ....................................................................... 11

Figure 9: Substructure .................................................................................................................................... 12

Figure 10: Profile of the Bayside Bridge Spanning Old Tampa Bay, FL ...................................................... 13

Figure 11: FLpier Simulation .......................................................................................................................... 13

Figure 12: Truck Collision Along I-90 in Minnesota ..................................................................................... 14
The Civil Engineering Balancing Act

Elena M. Rodriguez

ABSTRACT

The capstone design project for the civil engineering students at the University of South Florida involved designing a replacement bridge for the current Anna Maria Island Bridge in Anna Maria, Florida. The new bridge would replace the current low-level, two-lane drawbridge with a high-level fixed bridge. As part of a group of learning engineers, the task at hand was to develop an economically optimal design proposal and then carry this design to a refined stage. However, it is a common misconception among the members of society that designing is the civil engineer’s only obligation to a project. In order to ensure public welfare, civil engineers cannot only concern themselves with the design phase of a project, but they must also consider and stay actively involved in the planning and construction as well. A case study of the Anna Maria Island Bridge project will enlighten readers of the many tasks and design considerations a civil engineer must entertain when developing a project.
1. Introduction

The American Society of Civil Engineers (ASCE) describes civil engineering as “the design and maintenance of public works such as roads, bridges, water and energy systems as well as public facilities like ports, railways and airports.” Although these structures facilitate human existence, an engineer’s foremost duty is to ensure public health, safety, and welfare. Engineers are not only responsible for the structural design; they must also consider the environment, public opinion, public wellbeing, efficiency and the sustainability of a design. One such instance is the design of a replacement bridge for the current two-lane Anna Maria Island Bridge in Anna Maria, Florida. Many citizens of Anna Maria Island were concerned with the construction of the proposed replacement bridge, while others were in complete disaccord. A careful analysis of the planning, design, and construction of the bridge, as well as an examination of the debate among citizens of Anna Maria Island and the Florida Department of Transportation (FDOT) concerning the construction of this new bridge is presented to highlight the struggles civil engineers face during the lifespan of a project.

2. Planning

2.1 The Debate

The FDOT first proposed the redesign of the Anna Maria Island Bridge during the 1990’s. The proposal was terminated by court order after numerous complaints from the residents of the island resulted from a lack of civilian involvement and disapproval of the proposed redesign. In 2008, a bridge replacement was again proposed, but this time the FDOT was careful to include the public and their opinions. Citizens pay thousands of tax dollars each year to fund public projects such as the replacement of the Anna Maria Island Bridge and thus
have a rightful part in the decision making process. Major concerns for the citizens of Anna Maria Island included the effect the new bridge would have on their lifestyles and its environmental impact.

2.2 Studies

After the second Anna Maria Island Bridge proposal, public hearings were held so citizens could voice their positions and points of view; additionally, several opinion surveys were conducted. In the 2008 proposal several alternatives were considered: no action, rehabilitation repairs to the existing drawbridge, a drawbridge replacement, a high-fixed bridge alternative, and even a tunnel alternative. With a rising concern for the health of the natural environment, pollution worries, and a push for a “green” planet among the world’s population, engineers must consider future generations and popular opinion. It is not surprising that the citizens of Anna Maria Island became concerned with the new plans for construction and their effect on the environment. The FDOT, in conjunction with the U.S. Department of Homeland Security, specifically the U.S. Coast Guard, attempted to damper civilian inquietude by including an environmental assessment of the area along State Road 64 connecting Holmes Beach and Perico Island in the public information workshop (see Figure 1). This analysis included a two mile stretch, encompassing the bridge alternatives and its surrounding area. This study was conducted to ensure that the bridge would fit properly into the landscape and would be as environmentally friendly as possible.
Figure 1: Location of Environmental Study for Anna Maria Island Bridge (U.S. DHS & FDOT 2009)

In the Project Development and Environmental study, the FDOT recognized this bridge as an “arterial” road connecting Holmes Beach and Perico Island. It was concluded that the impacts of no build, rehabilitation, and re-placement alternatives would not significantly impact “wetlands, floodplains, threatened and endangered species, water quality, hazardous materials, recreational sites, historic structures and archaeological sites,” (FDOT 2008). The matrix of alternatives analysis in Table 1 summarizes the environmental impacts as well as the cost for each of the alternatives. It should be noted that the “No Build” and “Rehabilitation” alternatives, while the costs are significantly lower, are only temporary solutions to the deterioration of the Anna Maria Island Bridge. Both these alternatives will require future work and ultimately the replacement of the bridge; saving a little now will only cost more in the end. The FDOT
additionally analyzed a tunnel alternative, with an estimated cost of $370 to $535 million not including design and inspection costs. Aside from the excessive cost, the impact on the environment could be detrimental, thus this alternative was eliminated.

Table 1: Alternatives Analysis Matrix (FDOT 2008)

<table>
<thead>
<tr>
<th>Life of Alternative</th>
<th>No-Build *</th>
<th>Rehabilitation **</th>
<th>North Alignment</th>
<th>South Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Low-Level Bascule</td>
<td>2 Mid-Level Bascule</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>25</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

Right-of-Way Impacts

<table>
<thead>
<tr>
<th>Number of Parcels Impacted</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>3</th>
<th>3</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neal Preserve (ac)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.38</td>
<td>0.38</td>
<td>0.42</td>
</tr>
<tr>
<td>Submerged Lands (ac)</td>
<td>0</td>
<td>0</td>
<td>0.13</td>
<td>0.13</td>
<td>0.09</td>
<td>0.55</td>
<td>0.55</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Natural, Environmental and Physical Impacts

<table>
<thead>
<tr>
<th>Species/Habitat (Potential Impacts)</th>
<th>None</th>
<th>None</th>
<th>Low</th>
<th>Low</th>
<th>Low</th>
<th>Low</th>
<th>Low</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential Contamination Sites</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wetlands (ac)</td>
<td>0</td>
<td>0</td>
<td>0.82</td>
<td>0.82</td>
<td>0.84</td>
<td>1.07</td>
<td>1.07</td>
<td>1.11</td>
</tr>
<tr>
<td>Seagrass (ac)</td>
<td>0</td>
<td>0</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>1.80</td>
<td>1.80</td>
<td>1.81</td>
</tr>
<tr>
<td>Archaeological Sites (ac)</td>
<td>0</td>
<td>0</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Estimated Capital Costs (2008 Dollars)

<table>
<thead>
<tr>
<th></th>
<th>Design (15% of Construction)</th>
<th>Roadway Right-of-Way</th>
<th>Roadway Construction</th>
<th>Structure</th>
<th>CEI (15% of Construction)</th>
<th>Operation and Maintenance</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$353,185</td>
<td>$7,911,063</td>
<td>$13,367,147</td>
<td>$14,566,144</td>
<td>$11,637,882</td>
<td>$13,398,782</td>
<td>$14,597,775</td>
</tr>
<tr>
<td></td>
<td>$0</td>
<td>$0</td>
<td>$19,100</td>
<td>$19,100</td>
<td>$19,100</td>
<td>$150,100</td>
<td>$150,100</td>
</tr>
<tr>
<td></td>
<td>$0</td>
<td>$0</td>
<td>$33,118,929</td>
<td>$35,827,422</td>
<td>$29,464,089</td>
<td>$33,469,270</td>
<td>$36,177,739</td>
</tr>
<tr>
<td></td>
<td>$2,354,568</td>
<td>$52,740,423</td>
<td>$55,995,386</td>
<td>$61,280,204</td>
<td>$48,121,790</td>
<td>$55,855,943</td>
<td>$61,140,761</td>
</tr>
<tr>
<td></td>
<td>$353,185</td>
<td>$7,911,063</td>
<td>$13,367,147</td>
<td>$14,566,144</td>
<td>$11,637,882</td>
<td>$13,398,782</td>
<td>$14,597,775</td>
</tr>
<tr>
<td></td>
<td>$1,500,000</td>
<td>$4,225,000</td>
<td>$10,781,250</td>
<td>$10,781,250</td>
<td>$1,406,250</td>
<td>$10,781,250</td>
<td>$10,781,250</td>
</tr>
<tr>
<td></td>
<td>$4,560,938</td>
<td>$72,787,550</td>
<td>$126,648,959</td>
<td>$137,040,264</td>
<td>$102,286,993</td>
<td>$127,054,127</td>
<td>$137,445,401</td>
</tr>
</tbody>
</table>

* Followed by Rehabilitation or Replacement of Bridge
** Followed by Replacement of Bridge

Prior to design, engineers must also become familiar with the construction site. It is indispensable that an engineering firm go on a site visit to the existing Anna Maria Island Bridge to observe and photograph the bridge and its surroundings to become acquainted with the area.
and role of the bridge within the landscape and within the lives of Anna Maria Island residents. An on-site visit gives an engineer critical information concerning the placement of a structure and whether there are any obstacles that may complicate construction. Introductory information about the soil conditions of the site can also be obtain during an on-site visit so that future geotechnical tests can be performed adequately, especially in areas of major or visible concerns. Lastly, a field visit and an inspection of the condition of the existing bridge will enlighten an engineer on problematic areas and causes of deterioration in the existing structure. These observations will aid in the future design of a more durable bridge that will significantly eliminate or retard the deterioration process. Figure 2 shows the bridge approach from Holmes Beach and Figure 3 is a photograph of the existing two-lane drawbridge at Anna Maria Island.

With environmental and pollution concerns increasing among citizens, engineers must consider future generations and popular opinion. The preferred course of action seems to be the high-level fixed bridge, but many citizens are still in favor of keeping the existing bridge. The high-level fixed bridge will allow the passage of vessels without the inconvenience and delays of a drawbridge. Citizens, unfortunately, often times do not consider public welfare as a whole; they merely regard themselves and their families. The construction of a replacement bridge for
Anna Maria Island “is a vital link connecting Anna Maria Island and Longboat Key to the mainland and serves as a primary evacuation route during major storm events,” (White 2009). Engineers must find a consensus that satisfies everyone and still develop a successful design because millions of dollars are spent on civil engineering projects to better the community.

2.3 Proposal

For a proposal, the design process begins with a request for the conceptual design of new infrastructure or re-design of an existing structure. This invitation can be extended by an individual, a firm, or a government agency. In the case of the Anna Maria Island Bridge, the request for the re-design of the existing drawbridge was initiated by the FDOT. All design professionals that desired to send a proposal to the FDOT were given a set of guidelines and criteria that must be met when designing the replacement bridge. All candidates received the same information, so that no single company had an advantage. The design engineers then submitted preliminary designs as well as cost estimates. Past trends within the engineering profession estimate that a 10% increase is added to the overall design cost to compensate for error during the execution phase.

3. Design

3.1 Sustainability

Construction and design technology are moving in a more innovative and environmentally friendly direction. Everywhere we turn, people are using the word “sustainability.” But, what does it mean? According to the Brundtland Commission, sustainability is “development that meets the needs of the present without compromising the
ability of future generations to meet their own needs.” (U.N. 2007). Three factors are measured in a sustainable product or design: economics, social needs, and pollution. A sustainable design must serve public needs, as it is a civil engineer’s job to provide for and protect the common welfare. This design must also take care to not harm the environment by complying with all regulations set forth by the U.S. Environmental Protection Agency, while simultaneously serving its purpose and being cost effective. Many producers, designers, and contractors fail to use life cycle planning. Life cycle planning encompasses considerations for the entire life of a project or product from start to finish: site preparation, material accumulation, construction, use, durability, and end of life disposal. This kind of thinking is vital in keeping our planet healthy and suitable for human life. More often than not, this balance is hard to attain. This is particularly true when the public is not well informed about a project or the design considerations.

3.2 Loads

In the United States, as in the rest of the world, civil engineers use building codes when designing to ensure that buildings, bridges, roadways, and other structures are safe for people to use. A common design code for bridges was developed by the American Association of State Highway and Transportation Officials (AASHTO). Different codes exist depending on the engineer’s / owner’s desired method of design. This analysis of the Anna Maria Island Bridge meets the code requirements of the *AASHTO LRFD Bridge Design Specifications, Fifth Edition*.

When designing, engineers develop load situations that mimic the loads applied to the structure both during and after construction. AASHTO provides rules and regulations on the development of these loads for a particular situation. All design loads are additionally amplified in accordance with AASHTO to provide a factor of safety that will ensure the welfare of
Engineers consider two general types of loads: dead loads and live loads. Dead loads, typically, are loads due to the weight of the structure; these loads remain constant throughout the life of the structure. Live loads, however, are in continual action and are slightly more difficult to estimate; thus they are associated with larger factors of safety. For a bridge, live loads include but are not limited to forces applied to the bridge by traffic, ship impact, seismic movement, and the wind. For instance, a portion of the live traffic loading on Anna Maria Island was developed per *AASHTO LRFD Bridge Design Specifications, Fifth Edition* section 3.6.1.2, denoted as HL-93 loading. HL-93 loading traces the movement of a 3-axle truck along the length of the bridge and determines the position at which the truck will impose the largest reactive force on the bridge. Figure 4 exhibits the spacing and magnitude of these truck loads, where 1 kip is equivalent to 1000 pounds of force.

![Figure 4: Characteristics of the Design Truck (AASHTO 2010)](image)
3.3 Superstructure

The superstructure of a bridge is largely composed of the deck, i.e. the roadway, and its immediate support, the girders. The limitations of the superstructure as well as its components can be seen in Figure 5.

Figure 5: Superstructure

3.3.1 Deck

The bridge deck has several components: the concrete slab, safety barriers, street lamps, and any other above pavement elements. All these deck elements contribute to the dead weight of the structure. The width of the deck is determined by the number and size of the lanes, sidewalks, and shoulders desired for the completed project. The main design portion of the deck is the concrete slab. The slab is designed to support the dead loads as well as the cyclical live loads of the traffic under normal service conditions. The concrete slab is limited to a minimum
thickness of 7 inches per *AASHTO LRFD Bridge Design Specifications, Fifth Edition* section 9.7.1.1. Slab thicknesses typically range from 8 – 12 inches, contingent upon the size and loading of the bridge. Furthermore, the concrete slab is designed with steel rebar reinforcement. An issue of major concern when designing the concrete slab is the quantity and placement of steel to combat temperature fluctuations. Concrete expands when exposed to heat and shrinks when subjected to cold weather. These freezing and thawing cycles cause thermal cracks in the concrete slab if it is not properly reinforced (see Figure 6). If properly placed, the steel will create a “gripping” effect on the concrete to mitigate excessive thermal expansion and shirking.

![Figure 6: Thermal Cracking of a Concrete Slab (Online Civil Engineering 2009)](image)

3.3.2 Girders

The bridge girders run parallel to the roadway and are designed to support the deck and all of its corresponding dead and live loads. Girders are large beams that must be designed for flexure and fatigue. Fatigue in the girders is the result of repetitive loading and unloading that the bridge undergoes when subjected to daily traffic loads. Flexure occurs when loads are placed on a beam and moments are formed. These moments cause the beam to bend as seen in Figure 7.
In the case shown, the moments have created tension or pulling in the upper portion of the beam (blue) and compression or pushing in the lower section (red).

Bridge girders can be made of concrete, steel, aluminum, wood, etc. Concrete girders must be reinforced with steel in areas of tension because the material properties of concrete hinder its ability to resist tensile forces; however, concrete functions well in compression. Prestressed concrete girders were used in the recommended design of the Anna Maria Island Bridge. Figure 8 is a diagram of a proposed superstructure design for the bridge.

Figure 7: Bending in a Beam

Figure 8: Recommended Bridge Substructure Cross Section (U.S. DHS & FDOT 2009)
3.4 Substructure

The substructure of a bridge transfers all the applied dead and live loads into the soil. Figure 9 depicts the substructure of a bridge and corresponding elements.

![Figure 9: Substructure](image)

3.4.1 Pier

The bridge pier is composed of two main parts: the pier cap or hammerhead and the columns. The load carried by the girders is transferred onto the vertical columns by the hammerhead. The hammerhead runs perpendicular to the roadway and is designed for flexure, much like the girders. Designed primarily for axial compression, it is to be expected that vertical columns are typically made of concrete and marginally reinforced with steel for bending. The vertical columns vary in height forming the profile of a high-fixed bridge to allow vessels to pass.
under the characteristically taller and wider main span of the bridge, as evident in Figure 10 of the Bayside Bridge spanning Old Tampa Bay, Florida.

![Figure 10: Profile of the Bayside Bridge spanning Old Tampa Bay, FL](image)

### 3.4.2 Footing

Last but not least, an engineer must design the footing. The footing is composed of a footing cap and a group of either prestressed piles or drill shafts. The concrete footing cap serves to join the group of piles or shafts. Pile and shaft groups are a collection of columns that transfer all the dead and live loads into the ground. Prestressed piles are typically driven into the soil. In contrast, drill shafts are constructed by drilling giant holes that are filled with concrete. Design software, such as FLpier, is readily used among engineers to mimic load cases on structures. FLpier uses geotechnical soil properties as well as building material properties to aid design professionals in determining the required layout and length of soil embedment for a group of piles or shafts by reproducing deflections and stresses in a bridge footing for a particular load case. Figure 11 is a screen shot of FLpier simulating the deflections of a shaft group.

![Figure 11: FLpier Simulation](image)
When designing a bridge footing, all design load combinations are considered, but it is common that vessel impact loads will control the design. In the extreme event of a ship impact or truck collision, engineers are mainly concerned with avoiding the complete failure of the bridge. Small deflections and cracks are no longer of concern; those can be repaired, but complete failure of the bridge leading to the loss of human lives is unacceptable. One such instance of good design for extreme events occurred when a truck in Minnesota buckled a landbridge column along I-90, and quick responding authorities were able to support the bridge prior to its collapse.

![Image of truck collision on I-90](image)

Figure 12: Truck Collision Along I-90 in Minnesota (Wilkins 2003)

4. Construction

Most people believe that as soon as the plans are permitted by the building department the project is now in the hands of the contractor. This is far from the truth; an engineer has an
obligation to visit the job site many times after the final structural plans are drawn. Structural inspections are scheduled throughout the erection of the project to ensure that all elements of the design are being constructed as specified. Additionally, as soon as something goes wrong on the job site, be it the discovery of an obstacle or an error in construction, the engineer is the first person called to the site. The engineer must now attempt to fix the problem in the least costly manner, sometimes resulting in hundreds of unpaid hours of re-design.

5. Conclusion

The FDOT will spend an estimated $102.5 million on the Anna Maria Island Bridge in design, research, planning, approval, construction, and demolition. In this balancing act, engineers must consider costs, necessity, the environment, citizens, temporary routes of travel, ease of construction, sustainability, and future changes in population and development. Never once can they neglect public health, safety, or welfare. As civil engineers, it is in our best interest to provide citizens with information so they understand the considerations that engineers undertake when designing a project of this magnitude and thus realize that it is not always a win-win situation.
References


