THE DEVELOPMENT OF AESTHETIC GUIDELINES FOR SHORT AND MEDIUM SPAN TEXAS BRIDGE SYSTEMS

by

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THESIS

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THE DEVELOPMENT OF AESTHETIC GUIDELINES FOR SHORT AND MEDIUM SPAN TEXAS BRIDGE SYSTEMS

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ABSTRACT

THE DEVELOPMENT OF AESTHETIC GUIDELINES FOR SHORT AND MEDIUM SPAN TEXAS BRIDGE SYSTEMS

by

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The University of Texas at Austin, 1995

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The Texas Department of Transportation (TxDOT) has been building successful bridges for many years. In addition to their proven economy, safety, and durability, their use of precast pretensioned girders alleviates construction congestion which is typical of cast-in-place construction. It can be said that Texas pretensioned girder bridges represent the state of the art in ways such as economy, constructability, safety, and durability. The only area not extensively explored by the Department of Transportation is the area of aesthetics. Recent strides in bridge aesthetics has shown that improvements in the appearance of bridges not only need not be costly, but can result in beneficial public acceptance of state and federal bridge projects. TxDOT has recognized these benefits and initiated Project 1410 to explore methods of enhancing the appearance of substructures, and bridge systems as a whole.

This thesis describes the preliminary work done on the development of the *Aesthetic Guidelines,* a manual of techniques for enhancing the appearance of Texas bridge systems. Relevant information was gathered in four main ways: a literature review of bridge aesthetics, building of a photographic database of existing Texas systems, an informal survey of Texan public opinion, and experience gained through work on an example project. This thesis describes the origins and evolution of the *Aesthetic Guidelines* through the above mentioned major topics and other relevant minor topics. A version of the preliminary draft of the *Aesthetic Guidelines* is included.

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INTRODUCTION

1.1 Introduction

The Texas Department of Transportation(TxDOT) has been building successful bridges for many years. The TxDOT precast, pretensioned girder bridges represent the state of the art in short to moderate span bridges (50' to 140')(15 m to 43 m) in ways such as economy, constructability, safety, and durability. In addition, the use of precast girders reduces the congestion which is typical of cast-in-place construction. The only area not extensively explored by TxDOT is the area of aesthetics.

Certain Texas bridge projects possess a substantial aesthetic emphasis. Examples of this would be the San Antonio Y with its graceful segmental box girders (Figure 1.1), and the US 183 project, currently under construction in Austin, with its sculptural piers supporting a segmental box girder superstructure (Figure 1.2).

Figure 1.1: Graceful Box Girders of the San Antomio Y Project

Figure 1.2: Sculptural Piers of the Austin US 183 Project

Also, a new safety rail type was developed to provide an aesthetic alternative to the standard rails typically used (Figures 1.3, 1.4, and 1.5). Even Reinforced earth retaining walls have been designed for an aesthetic appeal (Figure 1.6). However, the bulk of the bridges built are highly standardized and do not appear to have a specific aesthetic emphasis (Figure 1.7). Obviously, these comprise the bulk of bridges to which the public is exposed.

Figure 1.3: Typical T501 Rail

Figure 1.4: Typical T4 Rail

Figure 1.5: Aesthetic Rail

Figure 1.6: Aesthetic Reinforced Earth Retaining Wall

Figure 1.7: Typical Short Span Texas Bridge

Project 1410 is an effort by TxDOT to explore improving the aesthetics of typical short and medium span bridges. Its purpose is to develop guidelines which would assist designers to produce bridges which are as attractive as they are efficient, safe, durable, and constructible.

1.2 Existing Guidelines

It would be untrue to state that there is no addressing of aesthetics in the TxDOT design process. The TxDOT Bridge Design Guide Section 3.4 actually is a section devoted entirely to aesthetics [1]. This section states as follows:

> **3.4 Aesthetics**
>
> Architectural harmony has been subordinated to economy for the majority of Texas' bridges. Early bridge engineers built some of their aesthetic preferences into railing and the shape of bents and piers. That which was beautiful for one generation became archaic to the next. Even among contemporaries there are usually diverse opinions of what looks good in a bridge. Arguments about aesthetics were often compromised to the most economical solution.
>
> There has been a conscious effort by the Bridge Division to make economical bridges look as good as is practical. Clean lines have been considered the most important feature in this regard. End blocks were removed from prestressed concrete beams and stiffeners removed from the outside of steel girders. Bents have smooth round columns with neat cap lines. A few tailored aesthetic items, such as sloping soffit on bent cap cantilevers and shadow lines on parapet railing, are incorporated into the standards.
>
> From the roadway, the bridge is most aesthetic when it is least noticeable to approaching traffic. For a short period of time a few shoulder width bridges were constructed with asphaltic concrete overlay and railing that carried the approach guardrail continuously across the bridge. This was the ultimate in bridge roadway-aesthetics.
>
> As urban highway work increased, elevated structures became more complicated. It was soon evident that the "forest of columns" and conspicuous bent caps presented an aesthetic affront and social barrier to the bisected community. The Bridge Division concession to this was the inverted tee bent cap. The deeper caps allowed fewer columns without losing the handy erection procedures for precast prestressed beams. The additional cost was reasonable. Isolated projects used more severe measures to limit the number of columns under the bridge.

There have been a few attempts to improve the appearance of concrete bridges by painting them different colors. Strange looking structures were the result. The Bridge Division position is that concrete is endowed to be gray and any attempt to change that will result in discord.

As a result of increasing influence of local environmental organizations and neighborhood groups on the construction of highways, engineers are demanding more aesthetic structures. To date, their efforts have resulted in single cell concrete box girders. Indicators are that other embellishments may now be desirable.

BRIDGE DESIGN GUIDE (TxDOT, 1990)

At the time the first edition was written in 1990, the bridge design division's approach to aesthetics was to "make economical bridges look as good as is practical." The suggested strategy for achieving this goal is to design bridges containing "clean lines,"through removing end blocks from prestressed girders (Figure 1.8), and stiffeners from the outside of steel girders (Figure 1.9).

Figure 1.8: Pretensioned Girder With and Without End Blocks

Figure 1.9: Structural Steel Girder With and Without Web Stiffeners

Other suggestions made in this document include sloping soffits on bent cap cantilevers (Figure 1.10), shadow lines on parapet railing (Figure 1.11), and even the use of the inverted tee bent cap to avoid the "forest of columns" effect (Figures 1.12 and 1.13).

Figure 1.10: Sloping Soffits on Bent Cap Cantilevers

Figure 1.11: Shadow Lines on Parapet Railing

Figure 1.12: Transparency of Inverted Tee Bent

It is very important to acknowledge that relative to the above mentioned goals and suggestions, contemporary Texas bridges are very successful. The standard Texas systems of today do possess clean lines and look more acceptable than earlier systems. They have proven their economy.

Figure 1.13: Forest of Columns

The Design Guide Section on Aesthetics concludes with the acknowledgment that "other embellishments may now be desirable." Project 1410 was developed to address some of those desires. It is only one of the efforts TxDOT is making to improve aesthetics. The initiation of Project 1410 is in no way a judgment or admission that Texas bridges have been aesthetic failures. Under the current prescribed objectives of the Bridge Design manual, Texas bridges are aesthetic successes. This project is meant, first, to define improved aesthetic objectives consistent with modern Texas society and technology, and second, to suggest economical and practical ways to achieve these objectives.

1.3 Project 1410

Project 1410 is a cooperative research program undertaken by the University of Texas at Austin Center for Transportation Research under the sponsorship of TxDOT and Federal Highway Administration (FHWA). The official title of the project is:

PROJECT 0-1410
Aesthetic and Efficient New Substructure Design
for Standard Bridge Systems

It is noted in the Project 1410 problem statement that there is "great potential for upgrading visual aesthetics of current superstructure systems by more sensitive treatment of substructures."[2] Project 1410 is an effort to explore ways to achieve this upgrade. The methods discovered are to be assembled into a manual which is to be accessible to roadway and bridge engineers. This manual, referred to as the *Aesthetic Guidelines,* should be composed of practical and economical ways to improve bridge aesthetics.

In addition to this manual, Project 1410 intends to deliver several example applications of the guidelines. These example applications will include illustrations, presentation drawings, and study models of solutions for bridges of varied lengths, widths, configurations, and settings. Example solutions for specific trial sites will also be produced.

Although substructures are specifically referred to as the focus of the project, it is important to acknowledge all possible methods which could potentially be used to enhance the aesthetic qualities of short and medium span bridges.

1.3.1 Background of Project 1410.

Throughout the United States, the increased attention which has been paid to bridge aesthetics has been met with enthusiastic responses. TxDOT has recognized the possible benefits of increased aesthetic emphasis, and has implemented several improvements. The more attractive railings and reinforced earth retaining walls have shown dramatic payoff in enhanced visual appearance. Further studies indicate there is great potential for upgrading the visual appearance of the substructures, and of the highly efficient Texas bridge systems in general.

There has been a large amount of literature produced on bridge aesthetics, covering a broad range of topics. However, only a modest portion is dedicated to typical short and medium span bridge systems. Most publications focus on more "monumental" long span bridges. In addition, there are not many publications which cite examples utilizing current technologies for substructures such as precasting and high-performance materials.

It was proposed that it should be possible to give specific practical design guidance to future Texas bridges which combine proud Texas traditions such as independence, strength, and frugality, with new material and technological developments to achieve more attractive bridges while still maintaining affordability.

1.3.2 Objectives

The objectives of Project 1410 are as follows [2]:

1. To develop conceptual plans and visual guidelines for improving the aesthetics and efficiency of widely used moderate-span bridge systems;
2. To introduce more attractive structural forms and textures in substructures through increased use of precasting or, where appropriate, in-situ casting utilizing improved form systems similar to those used in precasting;

3. To reduce construction time, cost of traffic delay and rerouting during construction, and field concreting problems by increased precasting of bridge substructures;
4. To develop conceptual plans for several demonstration projects, and to refine those plans based on field experience and observations; and
5. To provide useful design guidelines and examples for improving the aesthetics and efficiency of substructures for Standard Bridge Systems.

1.3.3 Scope

Because the existing Texas pretensioned girder and cast-in-situ deck system is so economically efficient, major changes to the existing superstructure design and construction process would likely add cost to the structures. The specific scope of this project is to suggest methods of improving aesthetics that are also economically practical. One specific aspect is to produce guidelines which can be implemented without major changes in the standard precast girder systems.

In addition, the suggestions must be easy to understand, thus practical to implement. This implies guidelines which contain ideas which are clear both verbally and visually. Thus, in addition to clear rhetoric, the guidelines must contain diagrammatic and pictorial examples.

A third major aspect is that the guidelines must be practical and easily implemented within the TxDOT design process. This means they must take into account all of the primary design participants and the constraints under which they are working. For example, it is not reasonable to suggest that a bridge designer arbitrarily raise the level of a bridge deck for aesthetic reasons if that height has already been set and finalized in another section as a requirement for traffic routing or safety. The guidelines must be available and implementable from the earliest stages of the project by those responsible for roadway geometry, land use, and project planning as well as those doing detailed bridge design.

1.3.4 Precast Alternate Emphasis

Exploration into precasting substructures is an important aspect of Project 1410. One reason existing Texas superstructure systems are so successful in economics is the use of precast, pretensioned girders (Figure 1.14). This not only allows girders to be produced economically and under stricter quality control conditions, but it also provides for more efficient superstructure construction.

Figure 1.14: Typical Pretensioned Girder

A goal of Project 1410 is to increase the success of Texas bridges by increasing the use of precast substructures. Ideally, precasting substructures should have the same effect on improved quality, cost and construction process as precasting the girders. As part of project 1410, potential strategies of fabrication, construction, and connection of precast elements is being explored. More control over finishes due to precasting may prove to be a way to improve aesthetics of the bridge without significantly increasing cost.

Although precasting will be a major focus, the guidelines will be presented in such a way as to be able to be implemented for both precast and cast-in-place construction techniques.

1.3.5 Implementation Benefits

As observed in the project proposal, the highly efficient pretensioned girder bridge systems now used have both the span range and slenderness ratios to be solid foundations for an attractive bridge system. Christian Menn observes in Prestressed Concrete Bridges [3], that if span ranges do not need to be reworked, "substantial aesthetic improvements can, through more attractive and efficient structural forms, higher quality materials, and pleasing textures, actually produce savings."

Also, the dramatic enhancement of the appearance of the bridge should reduce the resistance of the public to future projects even in sensitive locales. The guidelines are intended to provide the designer with the visual tools to achieve that enhancement.

Finally, the implementation of precast substructures will reduce on-site construction and thus reduce traffic disruptions, accidents, and again, public opposition (Figure 1.15).

Figure 1.15: Traffic Disruption Due To On-Site Construction

1.4 Thesis

1.4.1 Objectives

The primary objective of this thesis is to present a thorough state of the art of the development of the *Aesthetic Guidelines*. This thesis should be a reference for Project 1410 and not only include the most recent draft of the aesthetic guidelines, but supporting material explaining in detail their evolution to the point of that draft.

1.4.2 Scope

The scope of the thesis is simply to present and document ideas in development. The ideas, organization, and format are only the basic draft proposal and not the final version of the *Aesthetic Guidelines*. It is acknowledged that the guidelines have evolved to this point and will continue to evolve until the final product at the completion of Project 1410.

In the development of the guidelines, an effort was made to brainstorm, in rough form, as many ideas relevant to bridge aesthetics as possible. As the ideas were developed, issues not relevant to Texas systems started to be weeded out. Ultimately, the final product will contain only relevant topics thoroughly explored and reorganized to reflect the actual TxDOT design process. This thesis was written in late 1994 and early 1995 at the end of the information gathering stage of Project 1410.

1.5 Summary of Following Chapters

The body of this thesis is organized in the following way:

Chapter 2 contains the evolution of the aesthetic guidelines from initial ideas, to their development up to the time of the writing of this thesis. Besides including the development of ideas, Chapter 2 includes the development of organizational and formatting systems.

Chapter 3 contains a summary of available literature on the subject of bridge aesthetics.

Chapter 4 includes a review of existing Texas bridge systems. Included in this review will be a brief discussion of a few systems no longer used. Following will be a more in depth discussion of frequently used contemporary systems. Finally, a brief discussion will be presented of possible future bridge systems.

Chapter 5 contains the contents of and conclusions drawn from an informal survey focused on Texas bridge aesthetics.

Chapter 6 outlines the trial use of several of the guidelines on a very rush basis on an actual project in San Angelo, Texas.

Chapter 7 contains a brief summary of the work contained in this thesis and offers conclusions and recommendations based on the information attained through the process of producing this thesis.

Appendix A contains the proposed guidelines as they exist at the time of the writing of this thesis.

CHAPTER 2:
THE EVOLUTION OF THE GUIDELINES

2.1 Introduction

The purpose of this chapter is to chart the evolution of the guidelines into the draft included in this thesis. The sections of this chapter are organized as follows: Section 2.2 discusses preliminary work done; Sections 2.3 summarizes major resources contributing to the guidelines which will be discussed in greater detail in the following chapters; Section 2.4 gives a detailed account of minor areas which contributed; Section 2.5 summarizes the development of drafts; and finally, Section 2.6 contains concluding comments.

2.2 Preliminary Work

Preliminary work refers to the early developmental work for Project 1410. A literature review was initiated using the resources of the Center for Transportation Research and the computerized search services of the Transportation Research Information Services to acquire a preliminary bibliography of existing literature. In addition, the Project 1410 project statement was finalized, a summary of which is included in Section 1.3. Most importantly, however, the basic framework for the *Aesthetic Guidelines* was developed at this time. In the beginning of February, 1994, a seminar was given by Dr. Breen to TxDOT on precasting potential in substructures. In addition to discussing precasting, aesthetic issues were also addressed. The preliminary aesthetic ideas presented at the seminar were adopted from Fritz Leonhardt's Bridges: Aesthetics and Design [4]. These 9 principles and relevant sub-principles as presented at that meeting are listed below.

1. ***Clarity of Function*** - Efficient Appearance, Clear Form and Impart Feeling of Stability.
2. ***Proportion*** - Balance and Harmonious Relationships Between Elements.

3. ***Order*** - Symmetry, Repetition and Limited Number of Directions, Lines and Edges.
4. ***Refinement of Form*** - Optical Corrections (Tapered Columns and Beams), Light and Shadow and Skew angle View.
5. ***Integration into the Environment***
6. ***Color*** - Harmonious Coloring
7. ***Texture*** - Break in Monotony of Large Expanses of Concrete.
8. ***Character*** - Deliberate Effect on User and Positive, User-Friendly Impressions, Rather than Brutal.
9. ***Complexity*** - Limited Variety to Evoke Interest and Order Must Still Be Maintained.

These nine issues were referred to as the Leonhardt 9 and became the basis from which aesthetic ideas obtained through the literature review and other sources were evaluated.

2.3 Major Sources of Information

The major work contributing to this draft of the guidelines was obtained in four ways. These were: the literature review, the documenting of existing Texas bridge systems, an informal survey on public opinion of Texas bridges, and the observation of an actual TxDOT design project. These sources of information are discussed in more detail in chapters 3 through 6 respectively. A brief summary is presented here.

A substantial amount of time was spent on reviewing and taking notes on the literature acquired. Although the bulk of the articles reviewed were acquired during the Fall 1993, a steady trickle of new literature was constantly obtained and reviewed. This information not only included articles on bridge aesthetics but relevant technical data, award winning bridges, and architectural articles.

In addition, trips were taken around Texas to build a data base of existing Texas systems. These excursions focused not only on bridges encountered in Austin, but also San Antonio, Houston, Corpus Christi, Dallas-Fort Worth and rural areas in between. These trips were used to build an extensive slide library of existing Texas systems, with which to evaluate aesthetic ideas. A particularly important lesson learned through these excursions was that the effects of wear and maintenance of a bridge are important to its appearance. An additional principle referred to as *Lifespan* or *Aging* was added, changing the Leonhardt 9 to the Leonhardt 10.

Another important source of information for development of these guidelines was an informal survey used to evaluate Texans' opinions on bridges and aesthetics. This survey, its development, implementation and results are discussed further in Chapter 5.

Finally, during the latter stages of the development of the guidelines, an opportunity arose to give aesthetic input on an actual project located in the Concho River Park in San Angelo, West Texas. This project was an important aid in understanding the TxDOT design process, and indicating areas where the guidelines could be tailored to it.

2.4 Other Sources of Influence

During the course of this project, meetings of the Project 1410 research team were frequently held to exchange ideas and discus relevant topics. The Project 1410 team is a multi-disciplinary group of both architects and engineers. There were nine participants on this team. These were:

1. J. E. Breen, CTR Project Director, structural engineer specializing in structural concrete bridges and a leader in the development of the aesthetic guidelines.
2. J. O. Jirsa, structural engineer focusing on precast and connection alternatives for substructure systems.
3. Dan Leary, architect focusing on aesthetic finish alternatives.
4. Andrew Vernooy, architect focusing on the development of the aesthetic guidelines.
5. Norman Friedman, architect and structural engineer, bridge designer and the TxDOT Project Director.
6. Sarah Billington, B. A. Architecture, M. S. C. E. and Ph.D. candidate in Structural Engineering, focusing on the development of the aesthetic guidelines.
7. Robert Barnes, B. S. C. E. and M. S. C. E. in Structural Engineering candidate focusing on precast alternatives for substructures.
8. Carl Holiday, Masters of Architecture candidate focusing on development and illustration of the aesthetic guidelines.

9. Scot Listavich, B. A. E. D. Architecture, and M. S. C. E. in Structural Engineering candidate focusing on the research and development of the aesthetic guidelines.

Although initial meetings focused on reviewing data attained through the literature review and Texas excursions, later meetings discussed a variety of topics relevant to the aesthetic guidelines. A summary of important topics covered is presented in this section.

2.4.1 Architectural versus Checklist Approach

Engineers tend to treat aesthetics as an item on a checklist, or as the function of several variables. A more architectural approach tends to focus on understanding the complicated relationships between different visual characteristics of a structure. The architectural method involves sets of ideas which are to be combined by the designer to suit the specific situation and purpose of the bridge. However, since there are so many variables involved in any given situation, there are infinite possible solutions. Thus the designer thoroughly examines every aspect of the problem and develop the unique solution.

Obviously, the *Aesthetic Guidelines* presented in this architectural manner may not be as user friendly due to the unfamiliarity of engineers with this approach, and amount of effort required to process the ideas. A simple check list would be more easily used and thus probably be used more frequently. However, this checklist approach would also be less flexible in the variety of possible situations.

It was decided to tailor the guidelines to needs of the bridge design engineer. This would mean to provide clear, usable techniques to enhance the aesthetics of typical bridges. Of particular importance is that the specific guidelines are to be written in ways which “de-mystifies” historically architectural ideas, and present them in simple usable terms. At the same time, they should inspire a curiosity for the topic which will encourage the reader to experiment with the ideas presented. Thus the guidelines can potentially accomplish the goals of both approaches based on the interest of the user.

2.4.2 Organizational Proposal

As ideas were obtained through the literature review and categorized via the Leonhardt 10, it became obvious that a logical organizational system which takes into account the relationship between the principles was necessary. A proposed organization of these topics was made by Architect Andrew Vernooy [5].

Professor Vernooy's proposal asserted that due to the confusion of technical and aesthetic program in today's world, aesthetic aspects of basically technical efforts, such as a bridge, are treated as components of a larger technical process. This process can be thought of as a mathematical function which seeks a solution to the aesthetic "problem" in terms of established variables such as material and systematic requirements. Professor Vernooy also asserts that these aesthetic guidelines must help the designer create solutions in which "aesthetic logic of a structure must stand alone."

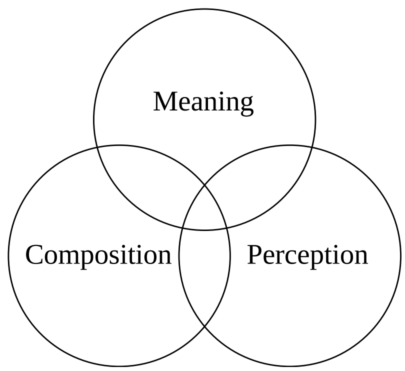

Figure 2.1: Semiotic Model

With this in mind, he proposed the semiotic model shown in Figure 2.1. This model uses as its three main subdivisions the headings of *Meaning*, *Composition*, and *Perception*. As illustrated by the diagram, this model is a potential strategy for representing the inter-related and overlapping nature of the aesthetic ideas. Semiotic theory is an accepted tool often used in design. However, the commonly used terms associated with it are Semantic, Syntactic, and Pragmatic. In the above model, the terms Meaning, Composition, and Perception are used respectively for ease of understanding.

2.4.2.1 Meaning

Meaning is concerned with straight forward interpretations of an element. These interpretations may be technical, economic, or cultural. Decisions made referring to these issues would directly affect the dimensional shape of an element of the structure. The issues proposed under this heading include:

- Historical associations
- Structural principle
- Process of construction
- Contextual associations

2.4.2.2 Composition

Compositional issues deal with how different elements relate to each other to create the larger image of the bridge. These issues represent decisions which affect the overall organization of the bridge. The issues proposed were:

- Expression of force system
- Composition-interlock, or unity in relationship among pieces
- Composition-scale, hierarchy of parts
- Composition-Figure, symmetry/balance, repetition
- Proportions
- Optical corrections
- Light and shadow
- Continuity-transition, coherence of form or line
- Imageability or clarity of the aesthetic intention
- Color-entropic (colors tending towards decay or without apparent order) vs. thematic (relating to a theme, central idea, or intention)

2.4.2.3 Perception

Perception is meant to address bridges as artifacts that represent the cultural and political nature of their time. The issues involved in this category represent decisions on how the bridge is perceived by the public. These issues are:

- Safety
- Economy or efficient use of materials
- Empathy or sympathy for users needs
- Symbolic
- Ecological

Although this organizational system is based in apparent logic, its relation to the larger scope of the *Aesthetic Guidelines* of Project 1410 had not been thoroughly developed at the time of the writing of this thesis. Although this systems validity as an organizational system is not in question, what is debatable is its accessibility to the intended users of this study in its present state. Before this system can be successfully implemented, it must be tailored to be easily understood and used with respect to the needs of the TxDOT bridge design engineers.

This proposed organizational system was important as inspiration for another way to interpret and categorize the ideas raised through the literature review. Although the ideas were still categorized under the original Leonhardt topics, they were loosely organized into three groups, **Form, Composition,** and **Entity**, within each of the Leonhardt categories. This organization was meant to separate out ideas which related to individual pieces of the bridge, the bridge as a whole, and the bridge as an entity respectively. The three groupings were distantly related to the Vernooy proposal as follows:

Form

-*Refinement of Form*

-*Proportion*

-*Complexity*

Composition

-*Order*

-*Color*

-*Texture*

Entity

-*Integration into the Environment*

-*Clarity of Form*

-*Character*

-*Lifespan (Aging)*

Certain ideas related to, thus were categorized in, more than one group. In this organization, all possible relations were explored. Not all would end up being relevant, but it was deemed important to present all ideas in order to systematically and objectively refine the ideas into the final aesthetic guidelines.

2.4.3 Format of Topics

A consistent format for each idea within a principle which included relevant illustrations was required. Ching's Architecture, Form Space and Order [6] was suggested as a potential formatting system. Each architectural idea Ching discusses is formatted to include:

1. **Idea** - Title of specific idea.
2. **Diagram** - Illustrative diagrams.
3. **Discussion** - Definition of idea.
4. **Summary** - Brief discussion of relevant issues.
5. **Reference** - Visual Examples of existing structures.

An example topic from facing pages in Ching's book is presented in Figure 2.2 and 2.3. The separate components of this topic are presented in Figures 2.4-8. Using this format, Ching introduces an idea, defines and discusses it, then illustrates it clearly through diagrams and actual examples. The aesthetic guidelines could follow a similar format with the definition and discussion focusing on issues applicable to Texas systems. Additionally, the ***Reference*** illustrations should reflect actual or modified Texas systems.

This format was tested at a TxDOT short course seminar. Example pages were produced following the Ching format and placed on a page which had a landscape orientation. This enabled maximum room to be available for illustrations on facing pages.

Figure 2.2: Example Topic From Ching “Point” [From Ref. 6]

Figure 2.3: Ching's "Point" Continued [From Ref. 6]

Figure 2.4: Ching Topic *Idea* [From Ref. 6]

Figure 2.5: Ching Topic *Diagram* [From Ref. 6]

Figure 2.6: Ching Topic *Discussion* [From Ref. 6]

Figure 2.7: Ching Topic *Summary* [From Ref. 6]

Figure 2.8: Ching Topic *Reference* [From Ref. 6]

2.4.4 The TxDOT Design System

The fragmented nature of the TxDOT design process can have negative effects on the appearance of a bridge. The design process begins with a district deciding a road is necessary in a particular location. The geometry of the road is set in the form of a plane traveling through space. If this plane encounters an obstacle such as a river, gorge, existing right of way, or railroad crossing, the obvious resolution is to bridge that obstacle. A schematic of the road plane is then sent to the TxDOT Bridge Design Division with support locations and geometric constraints such as on-off ramps either already decided upon or recommended. At this stage the design division's job is to design a bridge which supports the road plane with as little deviation from the proposed geometry as possible. Even the landscapers, who can have a dramatic effect on the bridge aesthetics, seem to be involved in a completely separate process. The final design solution must then be approved by the district.

It became obvious that in this process several crucial decisions are already made before the design division becomes directly involved. Since local district engineers are often quite resistant to adjusting the road plane once the basic geometry has been set, small obstacles which the local engineers did not consider, such as railroad clearances, can become significant problems for the bridge designers. It became apparent that in order to improve the over all appearance of bridges, aesthetic issues must be considered from the earliest design phases of the project. In addition, the different departments involved must communicate and work together.

2.4.5 Practical Constraints of Precasting

In an effort to understand better the constraints of implementation of a precast substructure system, a study was made of the U. S. 183 project. During the early stages of this project, June 1994, the construction of the US 183 piers had started. These piers were originally intended to be precast, yet ultimately were constructed in a cast-in-place method. Several reasons were discovered as to why it was in the contractors best interest to cast-in-place as opposed to precast.

The first, and potentially most important reason, was that the contractor did not want to involve post-tensioners. This would mean involving another trade who would have to wait around until their skills were needed and apparently mean a substantial cost increase. Another reason given was that the contractor did not want to congest further the already full precast yard with the column pieces. He was very limited on yard space. He was using 10 casting machines for the superstructure elements and the precast piers would require several more. Also, since the pier segments were to be connected by post-tensioning, they had to be designed as prestressed concrete structures as opposed to reinforced concrete structures. The contractor indicated that apparently there was more secondary reinforcing steel such as ties and minimum reinforcement bars required to satisfy prestressed concrete code requirements than reinforced concrete code requirements. In addition, a quick start could be made on cast in place piers and the contractor was eager to mobilize his forces. He pointed out that the long extent of cleared right of way was a free work space for assembling cages and falsework. He had experienced great difficulty in leasing appropriate land for his precast yard. All these aspects combined to make cast-in-place construction more attractive to the contractor.

The direct result of that situation, as far as Project 1410 was concerned, was the realization that the recommendations made must not only explore precast units and connections, but also be applicable to cast-in-place construction techniques.

2.4.6 Surface Treatment

An important benefit of precasting is quality control and control over finishes. Finishes can dramatically affect the appearance of the bridge while at the same time cut maintenance costs by negating the need for painting. A meeting was held with Mr. Thomas D'Arcy, of the Consulting Engineering Group to explore different finish options which would be practical for use on Texas bridges. Mr. D'Arcy specializes in precast construction and utilizes several types of surface treatment strategies. He pointed out that there are few precast firms who do both structural and architectural concrete. The main difference between the two types of plants is that a the concern for finish consistency of the architectural plants does not usually exist in the structural precast plants

He made the following recommendations for potential finishes which might apply to the Project 1410 situation [7]:

1. **Sand Blasting** - Mr. D'Arcy stated that sand blasting is the easiest finish done with structural precasting. Sand blasting can be used with tinted as well as standard concrete. The concrete can be retarded until blasted to expose aggregate, or there can be just a light sandblasting which does not expose aggregate. Sand blasting is universally available and seems like the most feasible and easily accessible possibility for Project 1410 recommendations.
2. **Exposed Aggregate** - Mr. D'Arcy observed that there are not a lot of exposed aggregates used in Texas, probably because structural plants are not laid out for this type of finishing work. However, one possibility he mentioned for exposed aggregates was the use of water blasting to expose quartz aggregates.
3. **Tinted Concrete** - This can be done by using tinted cement, or by using aggregate of specific colors. Mr. D'Arcy also pointed out the possibility of using white concrete with a acid etching to create a limestone finish.
4. **Form Liners** - There have been many types of form liners used. In addition to the great deal of variety possible with form liners, they can be economical if reused properly.

5. **Staining** - A stained finish can penetrate into concrete and be quite durable. This has the potential of being a relatively maintenance free finish.
6. **Facings** - Brick and tile facings can be expensive. Again, structural precast plants are not likely to be set up for this kind of complex operation.
7. **Dummy Joints** - Finally, Mr. D'Arcy points out that dummy joints or accentuated joints can be used to hide effectively or improve the appearance of actual joints. This may be a useful strategy in precasting substructures.

2.5 Evolution of Drafts of the Guidelines

This section presents a brief outline of the evolution of the drafts of the guidelines as presented in this thesis. The first rough draft of the guidelines was produced in June 1994. Information obtained from the Texas excursions, and notes taken on the articles obtained from the literature review were organized into categories which roughly followed the aesthetic principles presented by Leonhardt. The first draft included all ideas on bridge aesthetics and not just ideas relevant to Texas bridge systems. The intention was to present as many aesthetic ideas as possible in an effort to cover all issues then refine and tailor them to Texas systems at a later date. In addition, this first draft included a section referred to as Scenarios. This section identified different bridge types, and different types of settings in which they occur as identified during the Texas excursions. The example settings include urban, rural, and environmentally sensitive. Some example types of bridges include overpasses, interchanges, and raised freeways. These scenarios can have implications on a bridge's aesthetic treatment and will be addressed in the *Aesthetic Guidelines*.

The second draft of the guidelines took the first draft and separated out individual ideas. These ideas, along with additional ones were then organized into specific topics under the Leonhardt categories, and formatted using the Ching method. Although this draft did not include specific illustrations, explanations of possible figures were included. In this draft, however, the Leonhardt 10 was organized into the groups labeled **Form, Composition** and **Entity**. These principles were organized in terms of ease of understanding for the engineer, not necessarily in terms of how issues are addressed in the process of bridge design.

The third draft included the landscape orientation and topic format changes reflecting lessons learned from the TxDOT short course presentation. Also included in this draft were sketches of illustration ideas, and an effort to tone the rhetoric down to a more easily understandable level. Also included in this draft was a refinement, reorganization and condensation of the principles and topics. The principles stayed the same except for the *Complexity* principle which was left out and its relevant topics re-distributed to more appropriate chapters.

The fourth draft was the final major revision of the guidelines for the version presented in this thesis. The emphasis of this draft was the illustration strategy, the practicality of the suggestions, and the organization of the topics. An effort was made to make these illustrations more clearly reflect familiar Texas systems. Examples of actual and modified Texas systems were used to illustrate aesthetic ideas. Also, specific examples of topics such as slenderness ratios, span lengths, rail alternatives and finishing information were incorporated into the draft. The final reorganization of the guidelines reflected a topical list of ideas ranging from specific issues of **Form**, to global issues of the bridge as an **Entity**. Finally, a draft of support chapters was produced including an explanation of the guideline organizational system.

2.6 Summary

The period of development of the guidelines described here emphasized the acquisition and processing of information. This information came from areas such as literature, actual Texas bridges, and even the TxDOT design process itself. The result was the accumulation of a substantial amount of aesthetic ideas. The evolution of the guidelines represents the condensing of these issues into a topical set of ideas which can be applied to Texas bridges. The final product produced by Project 1410 will not only be the *Aesthetic Guidelines*, a topical set of ideas further refined and tailored to the TxDOT design process, but a well organized reference library containing relevant information in the form of literature, slides, and technical papers.

CHAPTER 3:
BRIDGE AESTHETICS

Figure 3.1: The Golden Gate Bridge

3.1 Introduction

Aesthetics is defined by Webster as "a particular theory or conception of beauty or art."[9] It is also defined as "a pleasing appearance or effect." Thus the notion of bridge aesthetics is interpreted as the traits or qualities of a bridge design which enhances the overall appearance of the structure.

It was the original assumption of the author that in exploring bridge aesthetics, or the combination of bridge structure and architecture, this project would be exploring unexplored ground. This was of course not true, nor was the notion that the combination of aesthetics and bridges was an awesome uncharted frontier. Even the aesthetics of typical short and medium span

Figure 3.2: The Carquinez Bridge, California [From Ref. 27]

bridges has already been explored by experts in the field of design. Not only has a large amount of literature been written on these topics, but many bridge projects have been built with aesthetics as part of the design emphasis. In fact, to date, CTR Project 1410 has acquired roughly 180 separate articles or design examples related to this topic. However, the area of aesthetics and typical Texas bridges is practically unexplored. In addition, the notion that no work had been done in this field of structural aesthetics, has interesting implications about the "state of the art." Since there seems to be so little emphasis on aesthetics of common structures in the press and other media, it is reasonable to assume that the public believes that there is no "state of the art."

Architecture and structural engineering are inevitably intertwined. Even though architects are the primary designers of buildings and have direct responsibility for building aesthetics, it is obvious that the structural engineers role in building design is not only vital for life safety but is often important in contributing to aesthetics. Addressing aesthetics is not the most important functional requirement of bridge design, in which engineers have the primary design role. However, the success of a bridge, as perceived by the public, has a tendency to be largely a result of its aesthetic qualities. The Golden Gate bridge (Figure 3.1) and Carquinez Bridge (Figure 3.2) are located practically within sight of each other in the San Francisco Bay area. Obviously, the impact of the structures are related to the visual qualities which define their aesthetics. By far, the Golden Gate is on more postcards and T-shirts, and is one of the most widely photographed tourist vistas in the Bay area. Post cards and T-shirts, of course, are contemporary objective indicators of a projects aesthetic success.

This chapter presents an overview of information acquired in the bridge aesthetics literature review. This overview is formatted in such a way as to highlight briefly authors whose work has had significant impact on the current project. However, these are by no means the only authors whose work contributed to the Project 1410 process. This topical overview is presented in the following sections titled Architecture/Structural Aesthetics, General Bridge Aesthetics, Short and Medium Span Bridges, Design Award Winners, and Texas Examples.

3.2 Architecture and Structure

3.2.1 Definitions of Visual Perceptions

Since architectural aspects of an object are generally understood through that object's visual characteristics, it is necessary to define and understand the nature of those characteristics. Francis D. Ching's Architecture: Form, Space and Order [6] was used extensively as a reference of visual qualities of forms and space. Ching, is a registered architect, but a faculty member at the University of Wisconsin. His other works, Architectural Graphics [10] and Building Construction Illustrated [11], are also widely used references. In Architecture: Form, Space, and Order, Ching's discussions range from "primary elements", such as point, line, plane and volume (Figure 3.3), to more complex topics of form, spatial organizations, structural system and enclosure (Figure 3.4). Within each topic are series of ideas which he defines, discusses and illustrates.

Certain sub-topics were used to define the tools bridge designers can access when dealing with the notion of a bridge's appearance. The ideas of shape, how shape is explained through form's silhouette, and how articulation can be used as a way to highlight certain aspects of the form are specifically referenced. In addition ideas such as proportion and ordering systems were examined with respect to how they can be used to enhance a bridge's appearance.

Figure 3.3 Ching: Point Line and Plane [From Ref.6]

Figure 3.4: Ching, Spatial, Structural, and Enclosure Systems [From Ref. 6]

Throughout the literature review, many aesthetic ideas were encountered. By using Ching's reference framework, these ideas could be broken down into basic terms and reconstructed into ideas appropriate to Project 1410. Even the way Ching formatted his ideas contributed to the eventual format of the guidelines. Most importantly though, Ching suggested that a complex idea such as “attractiveness” can be broken down and analyzed in terms of simple tools. These tools can be used to construct general strategies, such as the *Aesthetic Guidelines*, for enhancing appearance. This break down, however, is not meant to understate the difficulty inherent in the aesthetic problem. Although the tools are simple, to achieve their appropriate combination with respect to aspects such as program and context is quite a complex undertaking.

3.2.2 Structural Implications

Clovis Heimsath, while a professor of architecture at Rice University in Houston, observed in his article *Architecture* [12] that a building’s structural characteristics can affect how it is perceived. He describes the situation of a house in Houston which was to be torn down (Figure 3.5).

Figure 3.5: Houston House without Balcony Columns [From Ref. 12]

Although a balcony over an entrance had had its supporting columns removed, it stayed safely suspended in space supported by its cantilevering beams. Although it was perfectly stable, people tended not to walk under the balcony to enter the building. This situation implies that viewers intuitively knew that this was not how the balcony was intended to perform, thus they did not trust it. Heimsath asserts that the typical observer has an intuitive feel for structural performance even if not an intricate knowledge. He additionally points out that an inherent long span structure such as a folded plate system would be disturbing to the viewer if used on a clearly short span (Figure 3.6).

Figure 3.6: Long Versus Short Span Folded Plate System [From Ref. 12]

Thus Heimsath asserts that the viewer's intuitive feel for structural systems configuration and capabilities affect the level of confidence in the structure. This idea becomes important in trying to produce bridges which are aesthetically pleasing by being structurally comfortable.

3.2.3 Technology + Architecture = Structural Aesthetics

The idea of structural aesthetics can be thought of as the sum of pleasing visual ideas and structural implications. In his article *Structural Aesthetics* [13], Mario Salvadori takes the idea of structural aesthetics a step further by making the connection between architecture and technology. Salvadori, a Professor Emeritus of Civil Engineering and Architecture at Columbia University, speaking primarily of buildings, observes that today's architecture is a result of a "collaboration of large teams of architects and consulting technologists," and that although the architect is responsible for aesthetics, "the structural engineer exerts a strong influence followed by that of the mechanical consultant." New frontiers in architecture are results of advances in technology, whether they are the ability to handle larger lateral loads caused by the combination of increasing height and winds or earthquakes, or the ability to transport people to greater heights, or even the ability to efficiently span great distances. Designs resulting from technological advancements and structural logic have resulted in structures with great visual impact. The technological advancement of the elevator would ultimately make practical high-rise structures such as the World Trade Center (Figure 3.7). The Eiffel tower, which was made possible through advances in metal construction and a form based on the moment diagram produced by wind loads, has become the symbol of France (Figure 3.8). The Hancock Building in Chicago is based on expressing the same structural message of efficiently addressing wind loads (Figure 3.9).

Figure 3.7: World Trade Center   Figure 3.8: Eiffel Tower   Figure 3.9: Hancock Building

[From Ref. 13]

Because of its use of external bracing, it has become an important building in the state of the art in skyscraper design. Salvadori concludes that the future of great architecture requires both “great architects and technologists willing and capable of understanding each other.”

3.2.4 Structure as Art

Once it is accepted that structure and aesthetics are tied together in architecture, it takes only a small step to de-emphasize architecture and allow structure to stand alone as an art. This is easily validated by the study of numerous engineered structures which had little, if any, influence from architects. These structures, such as towers and bridges, have the potential to become overwhelming aesthetic feats. Professor David Billington has become one of the most influential authors on the subject of structure as an art form through his works such as The Tower and the Bridge: The New Art of Structural Engineering, [14], and the Dexter Award winning Robert Maillart’s Bridges: The Art of Structural Engineering [15].

In Billington's *Bridges and the New Art of Structural Engineering* [16], he traces the developments in the structural art of bridges from 1885 to the 1980's through the works of a series of bridge designers. He starts with Gustav Eiffel and his iron truss work bridges of the late 1800's (Figure 3.10). He then discusses John Roebling and his state of the art suspension bridges of the late 1800's (Figure 3.11). Next is Robert Maillart and his sculptured reinforced concrete bridges of the early-mid 1900's (Figure 3.12). Billington closes with the modern prestressed concrete bridges of Christian Menn (Figure 3.13). A common characteristic of all these designers and their bridges is that they used the state of the art material and technology of the time to produce bridges which were visually impacting through their efficiency and logic.

Figure 3.10: Garabit Viaduct By Gustav Eiffel [From Ref. 16]

Figure 3.11: Cinncinati Bridge By John Roebling [From Ref. 16]

Figure 3.12: Schwandbach Bridge By Robert Maillart [From Ref. 16]

Figure 3.13: Ganter Bridge by Christian Menn [From Ref. 16]

Billington's overall objective is to illustrate that the "new" art form is not new at all. It has been practiced since the late eighteenth century, and evolved "parallel to and fully independent from architecture." Also, the pleasing aesthetics of the bridges of these particular designers are inherently a result of their "minimum use of materials consistent with safety" and "minimum cost consistent with performance." Finally, products of the art of structural engineering, if built within "the laws of nature and rules of society", have the potential to "become symbols of the reality of the recent past and the potential for the near future."

3.2.5 Additional Architectural Aspects of a Bridge's Nature

One architectural aspect of a bridge is how its setting is, or is not addressed. The question of a bridge's relation to its setting becomes an important issue unique to each case. Specifically, because bridges span obstacles, they are often in natural locations where they bridge valleys or bodies of water. Robert Venturi observes in Complexity and Contradiction in Architecture [17] that the optimum solution for a bridge is one which compromises the inherent order of the bridge's program, to address the order of the setting such as an uneven ravine (Figure 3.14).

Another architectural aspect is the use of the material of which the bridge is constructed. For Project 1410, the dominant material is concrete. As R. Lopez Palanco observes in *Aesthetic Expression in Concrete* [18], concrete's most important aesthetic traits are its ability to be manipulated both in form (Figure 3.15) and finish (Figure 3.16).

Figure 3.14: Poggettone and Pecora Viaducts [From Ref. 17]

Figure 3.15: Manipulation of Concrete Form [From Ref. 14]

Figure 3.16: Manipulation of Concrete Finish [From Ref. 19]

Although dramatic manipulations are possible, subtle manipulations can draw much favorable attention. In *Who Says Concrete is Beautiful?* [20] an announcement was made inviting readers to submit examples of beautiful concrete. Many of the examples were minor manipulations. These included examples such as a cantilevered seating area on an urban bridge in Grand Rapids (Figure 3.17). Even the modifying of a form lined pier to achieve a fractured fin finish (Figure 3.18) has dramatic effects. It is obvious that the sculptural manipulation of form and finishing potential of concrete is an important aesthetic tool. Since these manipulations need not be dramatic, they need not be expensive.

Figure 3.17: Cantilevered Seating Area
[From Ref. 21]

Figure 3.18: Fractured Fin Finish
[From Ref. 19]

3.3 General Bridge Aesthetics.

Much has been written about bridge aesthetics in general and potential benefits are also being realized. However, much of the information on bridge aesthetics is more easily applied to larger, more monumental structures. Possibly this is because the extra cost of aesthetic improvements becomes less noticeable the larger the project. Two designers who are famous for producing highly aesthetic bridge projects are Fritz Leonhardt and Christian Menn. Their writings [3, 23, 4, 24]have also initiated the acceptance of bridge aesthetics as a discipline. Modern designers, such as Jean Muller[25], are using their ideas coupled with modern technology and construction techniques to enhance the state of the art of bridge aesthetics.

3.3.1 Social Implications

One reason for the advancement of bridge aesthetics as a discipline is the benefit of public acceptance. Frederick Gottemoeller, an architect and engineer who frequently advises on bridge projects, wrote of these benefits in *Aesthetics and Engineers: Providing for Aesthetic Quality in Design* [26]. He describes a link between bridges and public policy. This link is exemplified by the fact that bridges can either be civic symbols of public pride (Figure 3.19), or symbols of urban plight (Figure 3.20).

Figure 3.19: Symbol of Public Pride: Brooklyn Bridge [From Ref. 22]

Although typical bridges seem to have less immediate impact than monumental bridges, this tends to be offset by the large number of typical bridges to which the public is exposed on a daily basis. He observes that the responsibility for aesthetically pleasing bridges rests on the design engineers, and that there is no economic reason to not act on that responsibility since small modifications

Figure 3.20: Symbol of Urban Plight

tend to have large impacts. Gottemoeller's observations are particularly important when the influence of public acceptance or rejection is considered with respect to state and federal bridge projects.

3.3.2 Aesthetic Goals

One of the most influential modern bridge designers is Christian Menn. He recently retired as Professor of Structural Engineering at the Swiss Federal Institute of Technology in Zurich and has been a consultant on many large bridges in Switzerland and throughout the world. He is one of only a few structural engineers to have a show of his major bridges exhibited in an art museum. Important bridges of his include the Ganter Bridge (1980) (Figure 3.21), the arch Reichneau Bridge (1964) (Figure 3.22), and the haunched box girder Felsenau Bridge (1974) (Figure 3.23).

Figure 3.21: Ganter Bridge by Menn, 1980 [From Ref. 23]

In his article *Aesthetics in Bridge Design,* [23] Menn outlines specific goals of bridge design in their conventional order of importance. These are:

1. **Safety**
2. **Serviceability**
3. **Economy**
4. **Aesthetics**

He observes that although there is little immediate economic value in aesthetics, the conceptual value is considerable. Since people predominately live in constructed surroundings, he asserts that the quality of life is strongly influenced by visual aspects of civil engineering structures.

Figure 3.22: Reichneau Bridge by Menn, 1964 [From Ref. 23]

He further asserts his opinion that poor planning of these structures leads to environmental disruption and public hostility towards technology.

Menn lays out a framework he refers to as “Fundamentals of Aesthetics in Bridge Design.” The first major component is the integration of the bridge into the surroundings. Since overall route selection can generally not be controlled by the bridge designer, it is the bridge professional's challenge to favorably manipulate this integration through advice on the selecting of horizontal alignment and vertical profile. Many of the basic aesthetic qualities are set by the geometrical layout. It is essential that the roadway designer and the bridge designer interact at the project's earliest stages.

Figure 3.23: Felsenau Bridge by Menn, 1974 [From Ref. 16]

Menn goes further to suggest issues to consider while in the process of the "design of bridge as a structure." These issues are transparency and slenderness (Figure 3.24), simplicity and regularity (Figure 3.25), and artistic shaping (Figure 3.26). In Figure 3.26 the artistic shape he refers to is actually symbolic of the structural shape of cross bracing of a lateral force resisting system. All of these issues involve the direct form of the bridge elements and composition. He asserts that all of these aspects must be involved, at least partially, to create an aesthetically successful bridge.

Figure 3.24: Transparency and Slenderness [From Ref. 23]

Figure 3.25: Simplicity and Regularity [From Ref. 23]

Figure 3.26: Artistic Shaping [From Ref. 23]

In conclusion, it is important to recognize the idea that Christian Menn is perhaps most known for, which is the correlation between economy and aesthetics. He asserts that although enhancing aesthetics will potentially add cost to the bridge, for a bridge with fixed span lengths, the added cost may only be 1 or 2% of the total construction cost. Finally, he recommends that as far as aesthetics is concerned, designers should focus on "adapting structural shape" while "developing their own feel for aesthetics." He hopes discussions of aesthetics will promote heightened awareness of the subject for engineers and "further the level of expertise in this area."

3.3.3 Aesthetic Guidelines

The most influential source of information, as far as Project 1410 is concerned, is Fritz Leonhardt. He is Professor Emeritus of Civil Engineering at the University of Stuttgart, Germany, and a practicing consulting engineer. He has been active as a bridge designer since 1934 and has written 12 books in addition to numerous scientific papers and research reports. His recent book Bridges: Aesthetics and Design [4] is recognized world wide and has established him as an expert in the field.

The basic framework of the aesthetic guidelines for Project 1410 was adopted from Professor Leonhardt's *Developing Guidelines for Aesthetic Design* [24]. These guidelines were treated as ideas which were modified and refined to tailor to Texas bridges. As suggested by Leonhardt, the guidelines are:

1. **Fulfillment of Purpose-Function**
2. **Proportion**
3. **Order**
4. **Refining of Form**
5. **Integration into the Environment**
6. **Surface Texture**
7. **Color**
8. **Character**
9. **Complexity-Stimulation by Variety**
10. **Incorporating Nature.**

In addition to describing how each relates to bridge aesthetics, he warns that simple application of these ideas will not necessarily lead to beautiful bridges. He suggests that the designer must consider the individual circumstance of the bridge and attempt to perfect "imagination, intuition and a sense of both form and beauty." The guidelines, however, do provide a better sense of departure and help in critical appraisal of design solutions.

He goes on in his article to illustrate the application of these guidelines to different types of bridge systems. These include masonry and concrete arch bridges, suspension bridges, truss bridges, cable stayed bridges, and most importantly for Project 1410, beam bridges. He extensively discusses such important subjects as slenderness (Figure 3.27), cross section design (Figure 3.28), and substructure configuration(Figure 3.29) possibilities.

Figure 3.27: Leonhardt’s Slenderness Ratios [From Ref. 24]

Figure 3.28: Leonhardt’s Cross Section Design [From Ref. 24]

Figure 3.29: Leonhardt’s Substructure Configuration [From Ref. 24]

Although guidelines provide a valuable framework for addressing aesthetics, he acknowledges that foremost, the functional requirements of bridges must be met. Also, although the inherently artistically gifted may produce masterpieces without any reference to rules, today’s structures “demand that work must include a significant degree of conscious, rational, and methodical reasoning.”

3.3.4 Aesthetics and the State of the Art.

Before closing the subject of general bridge aesthetics, it is important to acknowledge the work of modern pioneers. Jean Muller is one such pioneer taking advantage of modern technology and construction methods to produce aesthetically stunning as well as technologically “state of the art” bridges. Jean Muller was a founding partner of the Figg and Mueller firm, and now is the technical director of J. Muller International, a consulting firm that specializes in major prestressed structures. In *Aesthetics of Concrete and Segmental Bridges* [25], he gives a summary of different bridge systems, their applications, and aesthetic issues associated with them. Although his designs emphasize segmental box bridges (Figure 3.30), some variations include long-span concrete truss bridges (Figure 3.31), and cable stay bridges (Figure 3.32).

Figure 3.30: Sallingsund Segmental Concrete Box Girder Bridge by Muller [From Ref. 25]

Figure 3.31: Long Span Concrete Truss Bridge [From Ref. 25]

Figure 3.32: Sunshine Skyway Cable Stay Bridge [From Ref. 25]

In addition, he discusses varied settings for the bridges such as over water and urban viaducts. He observes that before prestressed concrete, bridge designers used arches to span long distances by taking advantage of compression stresses induced by gravitational forces. With the advent of prestressing technology, the designer can manipulate the application of compression forces to his advantage. The direct result of this is more slender, longer spanning bridges.

He asserts that although the primary concern of a designer is to fulfill functional requirements, one must also consider a bridge as a work of art. He quotes the words of Sejourne, “no one is allowed to build ugly.” It is also important not to let the quest for aesthetics lead the designer to burden an inherently pleasant form with unnecessary ornament. Ideally, the smooth lines of the logical structural form will posses its own aesthetic appeal as illustrated in the Coatzacoalcos Bridge in Mexico (Figure 3.33). Additives such as textures will merely compliment it. J. Muller’s work is particularly important because segmental construction appears to be the construction method of the future due to its economic and constructable advantages. His work potentially lays the groundwork for bridge aesthetics of the future.

Figure 3.33: Coatzacoalcos Bridge [From Ref. 25]

3.4 Short and Medium Span Bridge Aesthetics.

There was much more material available on the aesthetics of short and medium span bridges than originally expected. These articles were very helpful in interpreting general bridge ideas with respect to specific applications for more typical bridge systems.

3.4.1 Conceptual Building Blocks

California is a leader in short and medium span bridge aesthetics. Arthur L. Elliot retired in 1973 after spending 20 years as a Bridge Engineer with the California Department of Transportation. He is widely known for his interest in increasing the compatibility of highways and bridges. In his essay, *Creating a Beautiful Bridge* [8], he describes his building blocks for structural beauty as developed through 20 years of highway bridge design. These blocks are:

1. **Quality** - Craftsmanship and artistic perfection.
2. **Artistic Proportions** - Spatial relations thought out and well executed.
3. **Attractive Forms** - Judicious amount of decoration and subtle manipulation.
4. **Future Acceptance** - Considering future generations and not following fads.
5. **Compatibility** - Appropriate integration into surroundings.

It is particularly interesting to observe where the similarities and differences are between authors coming from a monumental bridge background, versus a more routine smaller highway bridge background. Both emphasize integration into the environment, attractive forms, and artistic proportions. However, Elliot places particular emphasis on craftsmanship and future acceptance.

A reason for this could be that since these smaller highway bridges are not only experienced daily, but are experienced for relatively long periods of time daily due to commuter traffic delays, their long term impact on the user becomes an issue. Elliot acknowledges that it is difficult to be inspired by 90% of the settings in which these bridges happen. Thus it is important to use sketches and study models (Figures 3.34 and 3.35) to test out many designs and optimize the solution for even typical settings.

Figure 3.34: Design Sketches [From Ref. 8]

Figure 3.35: Study Models [From Ref. 27]

3.4.2 General Approach

In his article *Aesthetics for Short and Medium Span Bridges* [28], Edward P. Wasserman acknowledges that most projects are small and issues of aesthetics tend to be overwhelmed by issues of cost and scheduling. In addition, Mr. Wasserman, the Director of the Division of Structures for the Tennessee DOT, points out that architecture is not an exact science for which incontrovertible rules can be laid down. Mr. Wasserman's recommendation for dealing with highway bridge aesthetics involves focusing on a few general aesthetic issues. One such idea includes continuity which emphasizes continuous and flowing lines. Another includes the use of proportioning to affect how the superstructure is perceived. This could include adjusting span lengths or even the section of the bridge. Finally, he asserts that substructures make or break a bridge and specifically suggests that tapered shafts and hammerhead or "T" columns (Figure 3.36) are better than multi-column bents. Wasserman closes with the assertion that "bridge aesthetics have a vast effect on the public, and every opportunity should be used to provide attractive structures."

Figure 3.36: Hammerhead of "T" Columns [From Ref. 28]

3.4.3 Specific Approach

Paul Harbeson is an Emeritus Partner of H2L2 Architects/Planners. He was the architect in charge of architectural consultation with engineering firms and other agencies in the design of bridges and other transportation structures. He was also commissioned by the Federal Highway Administration to develop Highway Bridge Aesthetics. In his article, *Architecture in Bridge Design* [30], he states that "truth and beauty can be reconciled with other necessary objectives of design and that strength and grace are fully appropriate to each other in ordinary structures as well as major ones." To achieve these objectives of strength and grace he suggests a complex set of guidelines for highway structures.

He describes a set of factors in design. These include:

1. **Nature of materials** - Visual characteristics inherent in a specific material.
2. **Form and Space** - Volumes modeled in light and shadow.
3. **Line and Plane**
4. **Texture** - Appeal to sense of touch.
5. **Color** - Cosmetic and/or visual manipulator.
6. **Proportion**
7. **Scale** - Function of relative size as perceived in components of a structure relative to its overall entity.
8. **Rhythm** - Ordered though not monotonous repetition.

Harbeson illustrates ways to implement these ideas on separate "elements of design" such as structure types, alignments, piers, spans, abutments, parapets, and bearings. Particularly interesting, however, is his consideration of the position of the viewer as an element of design. He points out that viewers fall into two categories, those viewing and those using the bridge. Those using the bridge will primarily have views of it while passing over as in the small rural bridge in

Figure 3.37 or under as in the interchange in Figure 3.38. Mr. Harbesen emphasizes the importance of considering all these views for a successful design. Finally, he also includes the context of a bridge as an element of design.

Figure 3.37: View while Passing Over a Bridge [From Ref. 30]

Figure 3.38: View while Passing Under a Bridge [From Ref. 30]

3.4.4 Pitfalls

In his essay *Aesthetic Considerations for Bridge Overpass Design* [31], Roger Dorton identifies specific areas of concern for highway bridge aesthetics. Dorton recently retired as the Manager of the Structural Office of the Ministry of Transportation and Communications, Downsview, Ontario, Canada and now is a bridge consultant. He observes that certain evolutions in highway bridge designs are the result of some problem. For example, rigid frame bridges ceased to be constructed because of the closeness of the frame to the roadway (Figure 3.39) and potential dangers to wayward motorists. This resulted in a move to prestressed and precast beams (Figure 3.40) which dramatically changed the visual appearance of bridges. Some design decisions made in the interest of safety, such as abutments have being pushed back as far as possible or supports near road removed (Figure 3.41), create the positive by-product of further increased visibility.

Figure 3.39: Frame Bridge [From Ref. 31]

Figure 3.40: Precast Girder Bridge [From Ref. 31]

Figure 3.41: Increased Visibility Through Fewer Supports [From Ref. 31]

However, consequences of design choices are not always positive. Cast-in-place construction can achieve a pleasing continuous bridge, but at the expense of inhibiting traffic during construction. Steel box girders are less inhibiting, but there are other negative economic consequences of painting, or aesthetic consequences of weathering steel rusting onto other portions of the bridge.

Other concerns include how rehabilitation can affect the appearance of a bridge. Examples given include the addition of New Jersey Barriers or cathodic equipment where none existed before (Figure 3.42). These may become visual detractors. Dorton concludes with recommendations that an attempt should be made to keep abutments to a minimum and an alternative be sought to the New Jersey Barrier. He also states that color and texture are useless and highway bridge aesthetics must rely on clean form, balance, and proportion.

Figure 3.42: Cathodic Equipment [From Ref. 30]

3.4.5 Public Opinion and Its Influence.

Colin O'Conner presents the results of a survey done by Crouch in 1974, in *Empirical Assessment of Bridge Aesthetics: An Australian View* [32]. In this survey, a group of engineers, a group of architects and a control group of philosophy students were shown sketches of typical highway bridges illustrating different slenderness, spans, camber, and beam vs. column thickness (Figure 3.43). Interestingly enough, the study showed (a) that the opinions of the three groups were generally the same, and (b) that all three groups had strong opinions on the preferred configurations

(Figure 3.44). The obvious conclusion of this study was that the public does notice and have opinions about bridges, refuting the commonly held belief around transportation departments that they do not.

Figure 3.43: O'Conner Survey [From Ref. 32]

Figure 3.44: Preferred Configurations [From Ref. 33]

Transportation departments are taking notice of that opinion and making attempts to address it. California, which seems to be a front runner in the highway bridge aesthetics field, has design teams made up of architects and engineers as described by John Ritner in *Bridges Produced by an Architectural Engineering Team* [33]. Some Departments of Transportation without in-house architects are making efforts to publish aesthetic handbooks such as the Maryland DOT Aesthetic Handbook [34]. The Texas effort to establish its own aesthetic tradition is certainly timely and appropriate. TxDOT Design Division has several engineers with architectural education or interest which has produced a heightened awareness of the opportunities. Designers such as Norman Friedman are experimenting with improving the overall appearance of pretensioned girder bridges through enhancing the aesthetics of the substructures (Figure 3.45).

Figure 3.45: Aesthetic Pretension Girder Substructure

3.5 Award Winning Designs

An increased emphasis on bridge aesthetics is being set and recognized through various award programs. Two such examples of award programs are those of the PCI journal and ASCENT magazine. These award winning bridges, as collected through the literature review, become references to provide ideas in almost all areas of bridge aesthetics. Some example bridges are:

1. **Fairoaks Bridge, Sutherland Oregon** - This 256 ft. bridge uses precast arch segments and illustrates how easily new technology can adapt to old ideas and make pleasing forms constructable (Figure 3.46) [36].

Figure 3.46: Fair Oaks Bridge, Sutherland Oregon [From Ref. 36]

2. **S-1369/Watauga River, Washington County, Tennessee** - The use of box beams and simple substructures exemplifies why simple systems and clean lines are attractive (Figure 3.47) [37].

Figure 3.47: S-1369/Watauga River, Washington County, Tennessee [From Ref. 37]

3. **Glenwood Canyon Bridges, Glenwood Springs, Colorado** - Figg and Muller illustrate the potential that top down construction has to protect the environment. The environmental sensitivity can be read through the light way the bridge touches the ground (Figure 3.48) [38].

Figure 3.48: Glenwood Canyon Bridges, Colorado [From Ref. 38]

4. **Ramp B Bridge over US 23, Pike County, Kentucky** - Although this structure was precast, its lines are so smooth and joints so hard to see that it appears cast in place. Its continuity is enhanced by its light color and simple piers (Figure 3.49) [39].

Figure 3.49: Ramp B. Bridge over U. S. 23, Pike County, Kentucky [From Ref. 39]

5. **Interstate 110, US 90, Biloxi, Mississippi** - This precast segmental box bridge has particularly interesting pier shapes (Figure 3.50) [21].

Figure 3.50: Interstate 110, U.S. 90, Biloxi, Mississippi [From Ref. 21]

6. **The Linn Cove Viaduct** - This dramatic bridge combines interesting pier shape, precast top down construction, and concrete tinted the color of the natural rock to create a spectacular bridge that looks as if it grew there (Figure 3.51) [40].

Figure 3.51: The Linn Cove Viaduct, North Carolina [From Ref. 40]

3.6 Texas Examples

In addition to Texas efforts to improve aesthetics through this research, there have been several actual projects which emphasize aesthetics. A highly notable project is the US 183 segmental box girder project currently (1994-5) being constructed in Austin. The innovative design suggested by Dean VanLanduyt uses precast segmental box girder construction for the superstructure (Figure 3.52), supported on interestingly shaped piers (Figure 3.53).

Figure 3.52: U. S. 183: Precast Segmental Box

Figure 3.53: U.S. 183 Sculptural Piers

The use of this state of the art construction method was to allude to the contemporary high tech emphasis of Austin industry. This state of the art in bridge technology meant a construction system which would have little congestive effect on the busy existing highway. It also meant an innovative, aesthetically pleasing pier design. The aesthetic motivation behind the pier design as presented by VanLanduyt was to capture an essence of Texas culture. In an informal survey, he asked for adjectives to describe Texas culture. The most frequently used words were proud, strong, and friendly. His design was intended to incorporate these traits as well as other aesthetic goals.

These goals were to provide variety but to maintain harmony, integrate human scale, and manifest human presence. So far the public reaction to his design has been quite favorable.

Figure 3.54: San Antonio Y [From Ref. 41]

Another example of a special project was the San Antonio Y (Figure 3.54). It also was meant to be erected using precast segmental box construction to lessen impact on existing traffic patterns. The original idea for the piers as designed by the Figg Engineering Group was particularly interesting. A window was placed through the pier transversely removing unnecessary material (Figure 3.55). This resulted in graceful slender columns to accentuate the streamlined precast box girders.

Figure 3.55: San Antonio Y Windowed Support

A final example is the Texas U-Beam substructure design proposals presented by bridge engineer Norman Friedman (Figures 3.56 and 3.57).

Figure 3.56: U-Beam Substructure Design Proposal [From Ref. 35]

The move to U-Beams not only provided a longer spanning competitive alternative to pretensioned I-Girders, but also the opportunity to enhance aesthetics through removing the need for a bent cap (Figure 3.58).

Figure 3.57: U-Beam Substructure Design Proposal [From Ref. 35]

Figure 3.58: U-Beam Supports Without Bent Caps [From Ref. 42]

3.7 Concluding Comments

The notion of aesthetics and bridge design is a vital link between architecture and structural engineering. Although it has been suggested that engineering can stand alone as an art form, the engineering field would be just as foolish to disregard the aesthetic knowledge and capabilities of architects, as architects would be to disregard the structural talents of the engineer. These two fields, which diverged at the end of the age of the master builder, in many ways have been forced to stop merely co-existing and to start communicating in order to access and find use for progressing technology. Just as skyscrapers are opportunities for architects to access the expertise of engineers, bridges are opportunities for engineers to use the ideas of architects.

Figure 3.59: Hagia Sophia [From Ref. 43]

The notion of aesthetics in bridges is no more new than the notion of structural aesthetics in buildings, which has been evident even before such structures as the Hagia Sophia (532-37 A.D.) (Figure 3.59)[43]. It is important that architects and engineers stop congratulating themselves for finding this ancient art form of structural aesthetics and start working towards defining it in terms of the capabilities of modern times. Bridge designers such as Christian Menn and Fritz Leonhardt not only produced modern pieces of structural art, but established the new definition of bridge aesthetics. With this definition, designers such as T. Y. Lin (Figure 3.60), with the Ruckachucky Bridge, and Jean Muller, with the Hanging Lake Viaduct, apply modern technology to and test the bounds of possibility (Figure 3.61).

Figure 3.60: Ruckachucky Bridge by T. Y. Lin [From Ref. 44]

Figure 3.61: Hanging Lake Viaduct by Jean Muller [From Ref. 25]

What should be celebrated is the discovery of a previously little charted area of bridge aesthetics, the typical highway bridge. In previous years only a few states, such as California and Tennessee, had concentrated on this area. Now the idea has filtered down to states like Florida, Illinois, New Mexico, Maryland, and Texas. Although short and medium span highway bridge aesthetics is still young in terms of architecture and engineering, theories are flourishing and progress is being made.

Although many aesthetic theories abound, one commonly agreed upon point is that there are no aesthetic absolutes, there are only rough frameworks of ideas which can be massaged to suit the specific situation. These frameworks do have common ideas such as the use of proportion and order. Additionally, all theorists seem to agree that an optimum solution addresses the environment in some way. However, the most important common belief is that the public *does* notice these structures. The advantages to be gained by addressing the public's need for aesthetically tolerable structures far outweighs the amount of effort needed to explore the possibilities (Figure 3.62).

Figure 3.62: Manhattan Bridge [From Ref. 3.33]

CHAPTER 4: EXISTING TEXAS BRIDGE SYSTEMS

4.1 Introduction

In an effort to produce guidelines most relevant to Texas short and medium span concrete girder bridge systems, a study was made of the existing types of such Texas bridges to understand better the aesthetic aspects of the past, the current, and the potential Texas bridge systems of the future. Several trips were taken around Texas, photographs were taken to document example systems encountered, and an extensive slide library was developed containing examples of all types of typical concrete bridges. From this slide library conclusions were drawn about Texas systems and their relationship to information attained on bridge aesthetics in the literature review. Section 4.2 briefly describes the information gathering process. Section 4.3-5 summarizes the older, modern, and potential future systems encountered on the excursions. Section 4.6 discusses reinforced earth retaining walls encountered. Finally, Section 4.7 contains concluding comments on observations made through this process.

4.2 Information Gathering.

During the months of March and April 1994, several trips were taken around Texas. Many photographs were taken and compiled into a library of over three hundred slides. The areas focused on were Austin, San Antonio, Houston, Dallas-Fort Worth, and Corpus Christi. In addition, many photographs were taken of bridge examples encountered on the way to and from these cities.

The general purpose of the slides was to document pictorially the aesthetic qualities of typical concrete bridges with respect to several different variables. These variables included the type of superstructure, type of substructure, type of structural materials used, type of setting, and type of functions. The bulk of the functions encountered included overpasses, interchanges, and raised freeways.

In addition to bridge examples, many photographs were taken of reinforced earth retaining walls. It was decided that retaining walls typically are associated with bridge systems, even if not directly connected to them.

4.3 Older Systems.

Many systems were encountered which are rarely or no longer used. Two main systems are particularly relevant to this project.

4.3.1 Early Precast Pretensioned Girders

The first system is the early precast pretensioned girders. These girders are distinctive because of end blocks at either end of the beam (Figure 4.1). The end blocks were originally incorporated into the design to control tension forces due to transfer of prestressing at the ends of the beam.

Figure 4.1: Early Pretension Girders with End Blocks

Although advancement in available technology has made the need for these blocks obsolete, it is important to note that aesthetics were an issue for the removing of these blocks. These end blocks were singled out as interrupting the clean lines of the bridge, thus, were thought to be an aesthetic problem. Their removal represents an effort by TxDOT to improve aesthetics.

4.3.2 Cast-in-Place Haunched Beam Girders

The second type of bridge is the cast-in-place haunched reinforced concrete beam bridge. Several of these bridges dot I-35 between Austin and the Dallas-Fort Worth area (Figure 4.2).

Figure 4.2: Cast-in-Place Haunched Girder Bridge

This system used a set of standardized forms to cast in place the continuous beams. Most bridges of this type were used in rural overpass situations and typically involve three beams supported by sets of single columns. In some cases the angle of the rip rap slope protector was decreased creating longer end spans than the standard forms would allow. This situation would typically be resolved in one of two ways. The first was to extend the abutments out to the end of the standard span (Figure 4.3).

Figure 4.3: Haunched Girder Bridge with Extended Abutments

The second strategy was to create a small span connecting the end of the standard beams to a typical abutment (Figure 4.4). These extra spans were connected to the main bridge through pinned joints in contrast to a continuous joint (Figure 4.5).

Figure 4.4: Haunched Girder Bridge with Additional Spans

Figure 4.5: Pinned Connections of Additional Spans

These systems have been replaced by the more popular prestressed girder systems. However, there are many ways that haunched beams can be used to express different aesthetic issues. Although suggestions for the use of haunched beams are not very practical for today's pretensioned girder systems, some ideas will be presented anyway. This presentation will not only be relevant to these older systems, but also to potential future systems which may use haunches, such as post tensioned segmental box girders.

4.4 Modern Systems

There are multiple systems being used today. Most of these systems tend to be related to the commonly encountered precast pretensioned girder. In addition to the girder, also commonly used are precast pretensioned box beams, and mixed material bridge systems using steel plate girders with concrete decks.

4.4.1 Modern Pretensioned Girder Bridge

The modern pretensioned girder system is by far the most commonly used system in Texas, thus the guidelines will focus on aesthetic solutions that best apply to it.

Because of their status as highly standardized structural members, the girders have become very economical to use. They are fabricated in precasting yards and then can be transported to the site via truck. The columns and bent caps are generally cast-on-site, after which the girders are placed by crane (Figure 4.6). Then either precast panels, permanent steel forms, or temporary wood forms are put between the girders (Figure 4.7).

Figure 4.6: Placing of Pretensioned Girders

Figure 4.7: Precast Panel Formwork

The bridge deck slab is then cast in place. This girder precasting process makes the erection of the superstructure far more efficient than cast in place solutions such as the haunched beams mentioned above. These prestressed beams have been used in many widely varying situations from overpasses, to interchanges, to environmentally sensitive areas. In all cases they have been safe, durable, and successful systems.

One interesting note is that these beams have a cross section dictated entirely by the nature of their use (Figure 4.8).

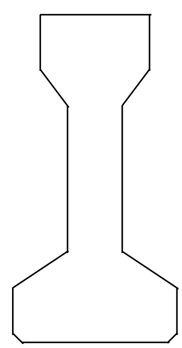

Figure 4.8: Pretension Beam Cross Section

The material is concentrated at the top and bottom of the section. This makes the most efficient use of the concrete's compression capacity at the top, and the steel tendon's tensile capacity at the bottom (Figure 4.9).

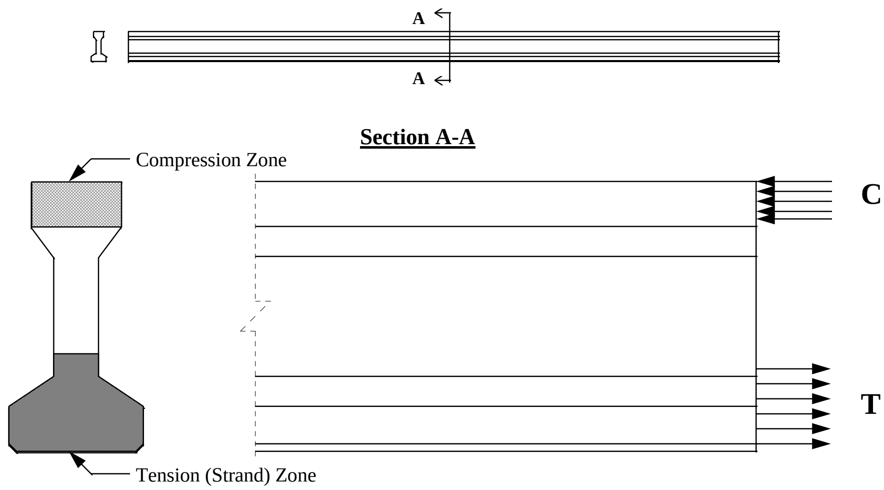

Figure 4.9: Diagram of Tension and Compression Zones

Material is then removed in the middle of the section where it is efficient to do so. This efficient use of material produces a section and elevation that is distinctive to pretensioned girders (Figure 4.10). It is interesting to notice the relationship between that section/elevation and the trademarked section/elevation of typical concrete and steel girders (Figure 4.11).

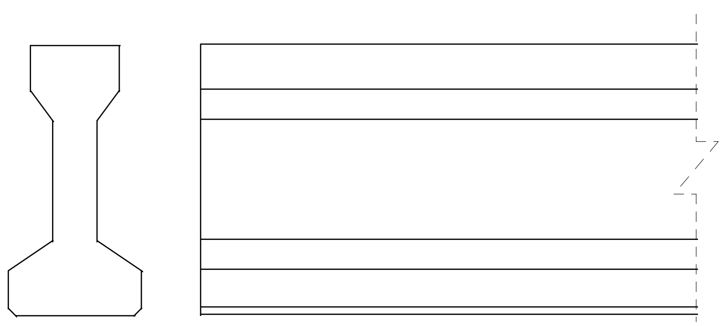

Figure 4.10: Elevation and Section of Type IV Pretensioned Girder

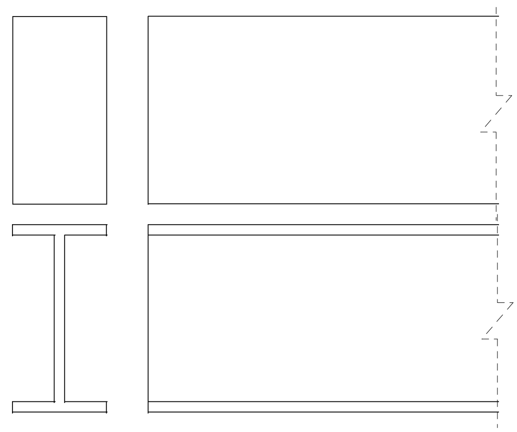

Figure 4.11: Rectangular Concrete Girder and Steel I-Girder Section and Elevation

The typical sections associated with reinforced concrete are the rectangle and the T-section. The typical section associated with structural steel is the I-section. The prestressed girder section is an interesting compromise between the rectangular concrete section and the steel I-section. The larger number of shorter lines in cross section produce more surfaces to catch the eye than the rectangular section. However, the angles between the surfaces are less brutal than with the steel I-section. The end result is a section that is appropriately substantial for concrete, yet possessing efficient aspects of the steel section.

4.4.2 Precast Pretensioned Box Beam.

The prestressed box beam is a modification of the typical girder. It may be thought of as being produced by splitting the girder longitudinally down the middle, spreading the material out, and adding some flange material to form a box (Figure 4.12).

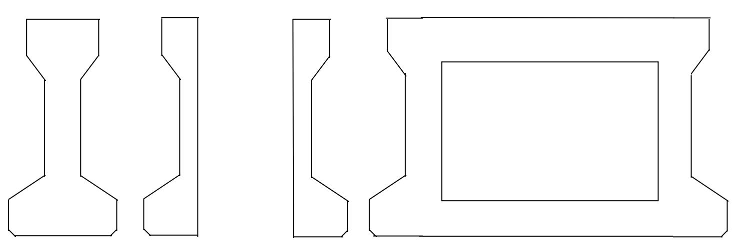

Figure 4.12: Box Beam Section from Pretensioned Girder Section

The result of using the box girders is a bridge which has a smooth underside for its superstructure (Figure 4.13). This smoothness is similar to that attained for many box girder or slab bridges using cast-in-place construction (Figure 4.14).

Figure 4.13: Underside of Box Beam Bridge

Figure 4.14: Underside of Cast-in-Place Bridge

According to certain theories of bridge aesthetics, cast in place bridges have surfaces that are smoother and more continuous and thus more visually attractive. The prestressed box beam represents an effort to close the gaps between the girders and produce a more aesthetically pleasing bridge when viewed from below.

In addition to a different cross section, box beam bridges have a distinctive elevation different from that of the girder bridges (Figures 4.15 and 4.16). Because of the width of the box beams, there is typically less overhang of the bridge deck. As a result, a less harsh shadow is cast and even up close, the girder and facia are perceived more as a unit than in the girder bridges. However, from a distance both bridges tend to appear as a unit instead of as separate girders and facia.

Figure 4.15: Elevation of Box Beam Bridge

Figure 4.16: Elevation of Pretensioned Girder Bridge

An interesting side note about the pretensioned box girder is that it is an attractive habitat to bats. The small gap between girders on the underside of the bridge becomes an ideal roosting place for migrating bat colonies. These bat colonies provide a valuable ecological service by consuming from 10 to 30 thousand pounds of insects nightly. Although initially this seems to have no aesthetic implications, it is important to note that the bat population can become a tourist attraction. Many Austin residents and visitors venture nightly to the Congress Avenue bridge to witness the dusk flight of the bat colony which resides there during the summer months. [47]

4.4.3 Mixed Use Bridges

Often, both prestressed concrete girders and structural steel girders are used in the same bridge. This seems to be done for two main reasons. First, steel plate girders are generally used for spans longer than the 130-140' (40-43m) maximum typical span of pretensioned girders. Sometimes geometric or other constraints require that the piers be spaced farther apart than 140’ (43m). Because pretensioned girders longer than this span become difficult to handle and transport, it becomes more practical to span the distance with a configuration of structural steel plate girders. One instance where this situation might occur is to facilitate on and off ramps from an access road to a highway interchange (Figure 4.17).

Figure 4.17: Steel Plate Girders Used to Span a Highway Entrance

Figure 4.17 (continued): Steel Plate Girders Used to Span a Highway Entrance

The second reason steel is used is for its horizontal curvature capabilities (Figure 4.18). As of now, no horizontally curved concrete beams are being used in Texas systems. Horizontal curves in prestressed girder bridges are being handled by a series of straight girder spans placed as chords on the curves. These spans then have a curved deck placed on them (Figure 4.19). However, in some instances the combination of a tighter radius of curvature and limitations on pier position result in it being more practical to use structural steel plate girders.

Figure 4.18: Horizontally Curved Steel Girders

Figure 4.19: Horizontally Curved Pretensioned Girders

Steel girders used in Texas bridges can be categorized into two types, painted steel and weathering steel. In the past, steel girders were painted in a variety of different colors. Some steel sections were painted to mimic the coloring of the concrete used in the bridge. This was done in such a way that it is difficult at first glance to distinguish between the concrete and the steel girders.

More often in recent times, weathering steel is being used in bridge structures. Weathering steel is supposed to lessen long term maintenance costs by developing a protective surface rust which forms a barrier and protects the interior steel from rusting. However, experience and manufacturers' literature show that weathering steel is not a maintenance free material. In fact, some states have experienced problems due to excessive corrosion. These problems can be caused by contamination of the steel due to regional factors such deicing as salts, shore breezes carrying sea salt, and extended wetness in areas of persistent high humidity. The most common cause of excessive corrosion is due to runoff water leaking through the bridge deck and wetting the steel superstructure. Additionally, some steel shapes such as I-girders are prone to trapping moisture in ponds which also cause excessive corrosion. [48]

In addition to the structural problem, the runoff water can cause an aesthetic problem. During travels throughout Texas, it has been noted that the use of weathering steel often produces rust which can stain the concrete parts of the structure (Figure 4.20). Cleaning the stained parts of the bridge also adds to the long term cost of the structure.

Figure 4.20: Weathering Steel Staining Bridge Supports

One consequence of using steel in a predominately concrete bridge structure whatever the reason is the lack of consistency in the type of material. In addition, each type of steel has consequences associated with its use. Although the use of painted steel can hide this lack of consistency, the painting must be maintained. If the steel is not kept painted, its life of usefulness may be cut short through rust. This continual maintenance adds long term cost to the life of the bridge.

In conclusion, it always seems better to exercise consistency in the choice of superstructure material. However, functional requirements and available technology may not make this practical. If steel has to be used, aesthetic consequences and maintenance costs must be considered in choosing the between painted or weathering steel.

4.5 Future Texas Systems

Although there are many possibilities for the future of Texas bridges, two particular systems were encountered during the information gathering phase of this thesis. These systems were the U-Beam and the Segmental Box Girder.

4.5.1 U-Beam Girder

The U-Beam system is currently being developed to compete with the most frequently used pretensioned girder system. Although no completed systems were encountered on the Texas excursions, the first U-Beam bridge was in the process of being constructed as the Louetta Road Overpass in Houston.

The principle of the U-Beam is much the same as the prestressed box beam. However, the construction of these beams allows for smoother lines (Figure 4.21). The second major impact is the potential configuration of the substructures. Although conventional bents may be used, there is an opportunity to use single columns to support the beams, doing away with the need for bent caps. Finally, these beams have a span length 10 to 15% longer than typical type IV pretensioned girders.

Figure 4.21: Computer Rendering of U-Beam Bridge

The Louetta Road Overpass not only utilizes the U-beam, but also high performance concrete and slender hollow-core post tensioned pier segments. The use of high performance concrete meant the span lengths could be stretched to 136’ (41m). The longer/fewer spans not only lowered initial construction costs, but will produce a lighter, more streamlined appearing structure. The high performance concrete will also reduce long term maintenance costs and possibly reduce adverse effects on the appearance of the bridge due to the aging process. Although the Louetta project is being built with precast substructures, no work is being done on precast substructures with bent caps which are currently the most common type of substructure to use with pretensioned beams. It is important to note, however, that the U-beam project was conceived with definite aesthetic issues in mind. The low bid on the Louetta structure was 27$ per sq. ft., as opposed to 30-32$ per sq. ft. for typical pretensioned girder bridges. The U-beam project is a good example of how economy and aesthetics are not necessarily mutually exclusive. [42]

4.5.2 Segmental Box Girders

Segmental Box girders are not only being used to construct bridges all over the United States, but all over the world. Box girders may be cast-in-place (Figures 4.22), or precast (Figure 4.23).

Figure 4.21: Cast-in-Place Segmental Box Girder

Figure 4.23: Precast Box Girders Segments

The San Antonio Y and the US 183 projects are examples of precast. The precast process involves precasting segments of the bridge superstructure in a casting yard and transporting the segments to the site to be assembled. The segments are tied together by post tensioning on site and can utilize internal, external, or combined internal and external tendons, and can be erected using any one of many construction techniques developed specifically for segmental construction (Figure 4.24).

Figure 4.24: Segmental Construction Technique

There are several advantages to using this sort of construction technique. First of all the bridge itself can be used to support its own construction equipment. This relieves traffic congestion in urban settings. Secondly, stricter quality control can be exercised in a precast setting. Finally, this method produces a more stream lined continuous looking bridge which may be a desired visual characteristic.

As of yet, precast segmental box bridges are rare in Texas relative to the established prestressed girder systems. However, this technique has been used on a few high profile projects. In fact, the first precast segmental concrete bridge in the United States was built in Texas in 1972-3.

A widely admired recent example is the San Antonio Y. This project is just completed (Figure 4.25).

Figure 4.25: San Antonio Y Project

Another high profile project is the US 183 project in Austin (Figure 4.26). This project not only uses the precast segmental construction method, but also showcases an unusual pier design meant to reflect the latest in bridge technology. As of May 1, 1995, many piers have been constructed and segments cast. Also, ten spans of the east bound lanes have been erected.

Again, the major aesthetic impact of these bridges is their continuous graceful profile. There is also potentially more freedom in pier design because of the lack of the functional requirement of a pier cap. Many design award winning bridges have been constructed using this technique. This technique is becoming more frequently used in other states and could possibly be a construction method of the future for Texas. While used to date in long spans and viaduct (highly repetitive number of spans) crossings, it could be standardized and used for several span overpasses.

Figure 4.26: U. S. 183 Project

4.6 Reinforced Earth Retaining Walls

In recent years there has been substantial effort made to improve the aesthetics of reinforced earth retaining walls. The effect of this effort was so noticeable throughout the excursions that it became important to note.

In the past, retaining walls and rip rap meant large, empty expanses of concrete (Figure 4.27). Not only were these expanses visually monotonous, but they were also attractive to graffiti artists. Additionally, stains resulting from normal weathering were accentuated on these barren expanses.

Figure 4.27: Expanse of Concrete Rip Rap

In recent years, TxDOT has been experimenting with a variety of colors and textures to make these retaining walls more interesting. The use of precast technology has made this experimenting easier to do. Textures range from fine grains such as exposed aggregate, to larger textures imposed on whole units of retaining wall panels (Figures 4.28 and 4.29).

The overall effect of these experiments has been retaining walls which are visually more interesting and attractive. They also do not show the affects of the aging process as harshly.

Figure 4.28: Aesthetic Reinforced Earth Retaining Wall

Figure 4.29: Aesthetic Reinforced Earth Retaining Wall

4.7 Concluding Comments

A wide variety of bridge systems were encountered during the excursions throughout Texas. Although both older and newer systems were seen, the pretensioned girder system was encountered by far the most frequently. This system is well established and any recommendations must be easily applied to Texas girder systems.

The first conclusion drawn is that as time passes, modern Texas systems are more successfully achieving the present aesthetic goals of the TxDOT design manuals. More recent Texas bridges seem to posses cleaner lines than older systems. As previously mentioned, specific examples of achieving this goal have been implemented. For example, prestressed girders with end blocks do not appear in more recent Texas bridges, and bents tend to have smooth columns and neat cap lines. Recently built structures, such as the Mopac-183 interchange in Austin, have more dramatic chamfers on the columns which tend to emphasize the smooth lines of the bent (Figure 4.30). In many cases, texture has been used on substructures, facia, and even on the ends of bent caps (Figures 4.31 and 4.32). This indicates an implementation of the last sentence of the design handbook which states, “Indicators are that other embellishments may now be desirable.” Potential future Texas systems such as the U-Beam and the Precast Segmental Box will make even further advances towards clean lines.

Figure 4.30: Dramatic Chamfers on Mopac-U. S. 183 Interchange

Figure 4.31: Texture Used on Substructure

Figure 4.32: Texture Used on End of Bent Cap

The second conclusion drawn from these trips was that the signs of aging have a dramatic effect on the way the bridge is perceived. These signs include staining due to rain drainage and deterioration of joint material (Figure 4.33), paint peeling and exhaust staining (Figure 4.34), and even graffiti (Figure 4.35). The excursions made it obvious that no matter how extensively aesthetics were emphasized in the initial design, these effects can be lost over the lifetime of the bridge if these age related issues are not directly addressed.

Figure 4.33: Staining Due to Rain Drainage

Figure 4.34: Paint Peeling

Figure 4.35: Graffiti

The final and most important conclusion is that there is ample room to improve the aesthetics of these bridge systems. Any deviation noticed from the normal design tends to have dramatic effects on the visual perception of the bridge. This deviation can have positive effects such as the use of texture on typical retaining walls. Not only does the texture make once was once a monotonous expanse of concrete more interesting, it can downplay the effects of staining. Because Texas bridges are so minimal in the use of materials and form, there is great opportunity to introduce subtle changes which can have positive impacts. This is particularly possible in the substructures (Figure 4.36). It is likely that even minor changes to the substructures will achieve the same aesthetic success as the contemporary reinforced earth retaining walls have achieved.

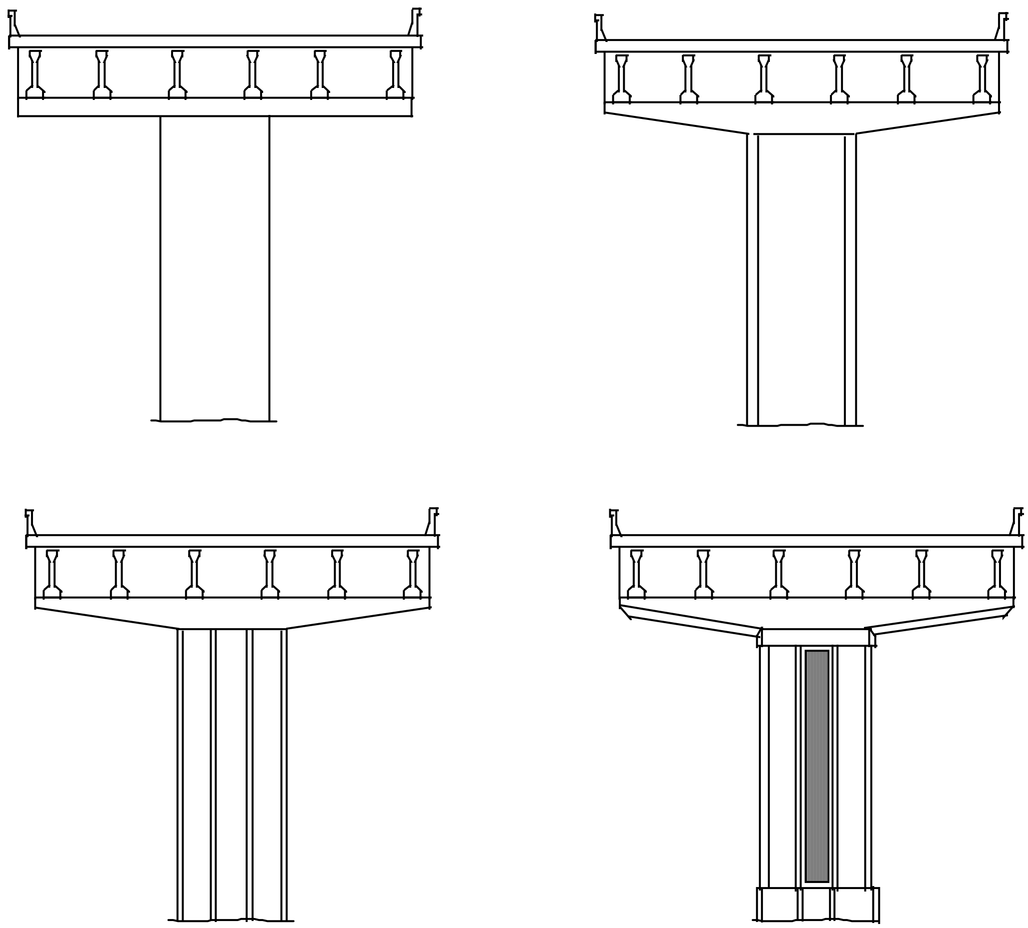

Figure 4.36: Possible Modifications to Typical Substructures

CHAPTER 5:
THE INFORMAL SURVEY

5.1 Introduction

The obvious client for Texas bridge systems is the Texas public. Not only are they the primary users, but they are also the primary funders. Therefore, it is important to develop some sense of the public's opinion and input on the issue of typical highway bridge aesthetics. To do this, an informal survey was developed and implemented.

5.1.1 Objective

There were four main objectives to the informal survey. These were:

1. To see if the public actually notices and has an opinion of Texas bridge aesthetics.
2. To see if the public thinks bridge aesthetics is important and why.
3. To see what the public feels are important aspects in bridge aesthetics and how they suggest these aspects may be achieved. Basically, the question was how would the public improve Texas bridges.
4. To get a feel of the public's attitude on spending some tax funds on bridge aesthetics.

5.1.2 Scope

To get highly specific unassailable information from a survey it must be crafted like an experiment by someone knowledgeable in the field of surveys. For this thesis, it was decided to try merely to achieve an informal sense of public opinion and not rigorous data. Therefore, the survey contained fairly open ended questions. The answers to these questions were interpreted and summarized by the author into the results given herein. It is acknowledged that these results are only interpretations and are not intended to be evaluated as hard data.

Additionally, no specific types of interviewees were targeted. The degree to which subjects have been exposed to bridges in their occupations was kept in mind. However, a structural bridge engineer's opinion was treated with the same validity, no more, no less than a hotel bellmen's. As Colin O'Conner illustrated through a survey by Couch in *Empirical Assessment of Bridge Aesthetics: An Australian View* [32], trends in engineers and architects opinions mirrored trends in the control group which was made up of philosophy students.

In conclusion, it is important to re-emphasize that this informal survey was intended to get a general feel for public opinion and does not claim to have achieved anything more. There is the possibility that what is learned through this study will lead to a more elaborate survey in the future.

5.2 Survey

After exploring example questions and possible survey sites for several months, the final first draft was produced. This draft involved 29 questions. It included these topics:

1. Location of the subject's home and how frequently they travel Texas highways.
2. Whether they notice and/or think about bridges, how they would describe them, and how they would improve them.
3. Whether they think any other states have more attractive bridges, where and why.
4. Whether they think the appearance of buildings and bridges affect how they feel and why.
5. Whether they have favorite buildings or bridges, and why they are their favorites.
6. How they feel about spending some tax revenue on bridge aesthetics, and how much revenue would be acceptable.
7. How they would describe Texas culture, and how to make Texas bridges reflect that culture.
8. How they feel about the Austin US 183 project.
9. How they feel about the particular bridge near the site of the survey, and what they would do to improve it.

This survey was originally meant to be a five minute interview. However, even though all the questions had merit, this brainstorm of ideas produced a lengthy survey. Actual interviews averaged much longer.

The first draft was tested by giving ten surveys in and around Austin. Ten surveys were given to people whose occupations ranged from bridge engineer to first grade teacher. Non-engineers were just as enthusiastic, if not more than the engineers. However, it was noted that the survey was not only too long, but redundant in some places. The survey was then further refined. The information attained in these test surveys was still considered valid.

The refinements to the first draft included taking out questions which proved to be confusing or redundant, and organizing the survey questions in a more logical and smooth manner. Questions on the subjects occupation and place of origin were added. Finally, an area where the person being surveyed could further comment was added at the end of the survey.

The final draft of the survey is presented below:

1.0 CONTEXT

1.1 WHAT IS YOUR OCCUPATION?

1.2 WHERE WOULD YOU SAY THAT YOU ARE FROM?

1.3 WHERE IS YOUR CURRENT RESIDENCE ? (City, State)

1.4 HOW FREQUENTLY DO YOU TRAVEL TEXAS HIGHWAYS?

1.5 WHAT OTHER STATE (S), IF ANY, HAS MORE ATTRACTIVE BRIDGES AND WHY?

2.0 AESTHETICS AND STRUCTURES

2.1 DO YOU THINK A BUILDING’S APPEARANCE AFFECTS HOW YOU FEEL ABOUT WHERE YOU LIVE/WORK/SPEND TIME?

2.2 DO YOU THINK THE APPEARANCE OF A COMMON BRIDGE CAN HAVE THE SAME EFFECT AND, IF SO, WHY?

2.3 DO YOU HAVE A FAVORITE BRIDGE AND WHY IS IT YOUR FAVORITE?

2.4 DO YOU HAVE A FAVORITE BUILDING AND WHY IS IT YOUR FAVORITE?

3.0 TEXAS BRIDGES

3.1 WHEN YOU TRAVEL TEXAS HIGHWAYS, DO YOU NOTICE THE BRIDGES?

3.2 WHAT ARE THREE WORDS OR PHRASES YOU WOULD USE TO DESCRIBE TEXAS BRIDGES AND WHY**?**

3.3 PICTURE A TEXAS BRIDGE; WHAT SPECIFIC THING(S) COME TO MIND?

3.4 IF YOU COULD CHANGE TEXAS BRIDGES, WHAT WOULD YOU DO?

4.0 SPECIFIC EXAMPLES

4.1 WHAT DO YOU THINK OF THAT BRIDGE AND WHY? (Location and type)

4.2 HAVE YOU NOTICED THE NEW CONSTRUCTION ON US 183 BETWEEN BURNET AND I-35? (IF YES) WHAT IS YOUR OPINION OF THOSE BRIDGE SUPPORTS?

5.0 TEXAS

5.1 WHAT ARE THREE WORDS OR PHRASES YOU WOULD USE TO DESCRIBE TEXAS CULTURE?

5.2 HOW WOULD YOU CHANGE TEXAS BRIDGES SO THAT THEY WOULD BETTER ACHIEVE THOSE QUALITIES AND WHY?

6.0 THE MONEY QUESTION

6.1 DO YOU THINK THE STATE WOULD BE JUSTIFIED IN SPENDING SOME TAX FUNDS TO MAKE THE BRIDGES MORE ATTRACTIVE?

6.2 (IF YES) IF WE ASSUME THE PRESENT COST OF A BRIDGE IS 100, HOW MUCH MORE WOULD YOU THINK IT WOULD BE O.K. TO SPEND ON IMPROVING THE SHORT AND LONG TERM APPEARANCE?

7.0 ADDITIONAL COMMENTS

5.2.1 Carrying Out

The initial results presented here are processed from a total of 103 surveys. These surveys came from two different sources. The bulk, 91 surveys, were administered by members of a structural concrete bridge class taught by Dr. J. E. Breen. 18 students were asked to take a survey themselves, and administer 4 or 5 additional surveys at various sites around Austin. The other 12 surveys included in this sample are from test surveys given before and after the refinement of the survey. Although the results are not included here, further surveys were given at a later date. 25 surveys were administered in the San Antonio area, and 25 more at a rest stop along I-10 between San Antonio and Houston.

5.3 The Results

The results of the initial 103 surveys are presented in this section. It is important to note that in addition to previously mentioned limitations, the results will be affected by the fact that 19 separate people administered the survey. To get the most accurate information, the survey would have to be administered the same way every time. Since this survey was given by so many different people, the quantity of information recorded varied from surveyor to surveyor. There are 2 numbers in the lower right hand corner of each chart of the results. These numbers are meant to give an idea of the amount of information received for each question. An example of these two numbers is *78% responded/ 114 comments.* The first number indicates the percent of the 103 surveys which answered the question. The second number represents how many separate ideas were recorded by those who answered the question. Some people who answered the question only mentioned one idea. Others answered more thoroughly touching on several different ideas. This number is meant to reflect how many total ideas were presented.

The results section is comprised of two parts. The first set is results of the total 103 surveys. The second set identifies certain questions and compares how structural engineers answered compared to non-engineers.

5.3.1 Total Survey Results

As indicated by the results of Question 1.1, the bulk of the surveys were given to white collar occupations. Students, including structural engineering students, comprised 32% of those surveyed and made up the second largest portion of those surveyed.

All of these surveys were given in and around Austin. The results of Question 1.2 reflect how diverse the origins of Austin residents are. More than half, 51%, of those surveyed were from outside of Texas.

The answers to Question 1.5 were broken down by region of the U.S. **None** indicates that the person surveyed believes that Texas has the most attractive bridges. The **None** answers are not included in the South Central region where the state of Texas would have been considered located.

As indicated in Question 1.5a, those surveyed thought that a bridges ability to blend with its surroundings, or the effects of the bridges environment were the leading factors adding to the bridges attractiveness. The type of structure (ex: suspension or arch bridge) and material was the second factor. Also second was the bridges historic or symbolic implications. Older, rustic bridges were popular, along with bridges symbolic of a place, or a period in history.

As indicated by the results of Questions 2.1 and 2.2, those surveyed overwhelmingly thought that a building's or a bridge's appearance can have an effect on how one feels. However, fewer surveyed felt that a bridge had as much of an impact as a building.

Through Question 2.2a, many of those surveyed stated that a bridge not only can make you feel better, but many linked feeling to the bridge's appearance. Also, many observed that a bridge can make one feel better about their circumstances such as sitting in traffic, or surroundings such as their residence or place of work.

Question 2.3 indicates that the Loop 360 Bridge at Town Lake in Austin was the favorite. This may be attributed to the fact that it is the highest profile bridge in the Austin area and such a large percent of the people surveyed reside in Austin. The Golden Gate Bridge was the close second as far as fame. Bridges which were mentioned at only twice include: New York Bridges, Louisiana Bridges, The Sunshine Skyway, The London Bridge, The George Washington Bridge, The Tappanzee Bridge, The Salginatobel Bridge, The New River Gorge Bridge, The Crossing of the Mississippi at Memphis, The New Orleans Bridge, and two people had a favorite style of bridge.

In Question 2.3a, **Structure Type, Feat or Material** is the reason mentioned most often for a bridge being a favorite. This not only includes favorite structure types such as suspension or arch, but structural feats such as long spans. Also included is material type such as stone, wood, concrete or steel. The second most impacting reason involved the environment around the bridge, the view from the bridge, or the location in general. Tied for second was the appearance of the bridge. Often mentioned was how picturesque, graceful or how well designed the bridge is. Also specifically mentioned was how unique the bridge is, how well it blends with its surroundings, and how symbolic of history or place it is.

The most frequently mentioned favorite building mentioned in Question 2.4 was the Texas Capitol. This is indicative of the sample taken from Austin. The second favorite was a **Favorite Style** such as gothic or rustic. Buildings getting two votes include: Notre Dame, Gaudi's Barcelona architecture, The U. S. Capitol, The U. T. Tower, The Empire State Building, and "My House."

The results of Question 2.4a indicate that as far as buildings are concerned, the its symbolic nature is the most popular reason for being a favorite. The second most popular reason is if it is unique or interesting, if it stands out, or if it is big. **Architectural Features**, such as atriums or architectural style, was the third most mentioned reason.

Also, Question 3.1 indicates that more than half of those polled said they notice Texas bridges as they drive by, over, or under them.

The words most frequently used to describe Texas bridges, in Question 3.2, were **Old or Plain**. **Utilitarian or Functional** was the second most mentioned descriptor. **Ugly or Dull** was mentioned third most frequently. Relative to these three sets of ideas, **Attractive or Well Designed**, **New or Clean**, or **Unique or Interesting** are mentioned fairly infrequently.

The idea behind Question 3.3 is similar to the previous, but the question is asked in a different way. **Old or Plain**, or **Ugly or Dull** are still mentioned more frequently than **Attractive or Well Designed**, or **New or Clean**.

Although a large amount of those responding to Question 3.4 suggested "**Do Nothing**," many more wanted safer, more interesting designs. Often mentioned along with safety were ideas such as widening roads, adding guardrails, and not making the bridges so tall. Interestingly, specifically improving aesthetics was mentioned as often as doing nothing.

Figure 5.1: U. S. 183 Project

The responses to Question 4.2 are organized such that opposing views similar in magnitude are next to each other. These opposing views are **Good** vs. **Negative**, **Attractive** vs. **Not Attractive**, **Safe** vs. **Unsafe**, **Ornate** vs. **Too Fancy**, and **Unique** vs. **Nothing Special**. In all cases, the more positive response occurred more frequently than the negative response. Additional comments included **Classical**, **Big**, and many responses mentioned different traffic concerns.

Question 5.1 was intended to get an idea of people's perception of Texas culture. **Friendly or Hospitable** was mentioned the most frequently. However, many Austinites associate diversity, the Old West, a laid back attitude, and independence with Texas culture.

Do nothing was mentioned frequently for this Question 5.2. However, more respondents wanted the bridges to reflect more of a connection with Texas. A good example of this is the Texas inlays being used on reinforced earth retaining walls. Also, many respondents wanted more diversity and variety, more relation of the bridge to the location, and more unique and interesting designs.

The responses to Question 5.2 were interpreted a second time and that data is presented below.

Even in this interpretation, being unique and relating the bridges to Texas were the main suggestions. Safety is also mentioned often in this analysis.

In responding to Question 6.1, 62% of those asked said that the state would be justified in spending tax revenue to improve aesthetics. However, 3% only feel spending funds would be justified on new bridges.

When asked how much additional could be spent in Question 6.2, even some of those surveyed who said "no more money should be spent," in the previous question, suggested an amount. The above chart shows a distribution of what each person surveyed suggested. Only one third of those surveyed said no additional funds should be spent. Almost half, 46%, suggested between 1 and 15%.

Only 29% of those surveyed actually provided additional comments in Question 7. It is important to note that of those who did, safety was a concern.

5.3.2 Engineers Opinions

In an effort to compare the Structural Engineer's opinion with the rest of those surveyed, the surveys were divided into two groups; Engineers and Non-Engineers. The Engineers group was comprised of 21 University of Texas Structural Engineering students and bridge engineers. The Non-Engineers group was made comprised of the other 82 people surveyed. They were then analyzed taking note of what percentage of each group responded in which way. 10 questions were analyzed in this way and the results presented below.

Charts of results of Questions 2.1 and 2.2 indicate that the same percentage of Engineers as Non-Engineers believe that both buildings and bridges affect how one feels.

The chart of Question 2.3a indicates that Engineers are less impressed with structural types or feats and are more interested in picturesque and unique designs. Roughly the same percentage of Engineers and Non-Engineers thought the environment, view and location were important factors in a favorite bridge.

As indicated through the results of Question 3.1 higher percentage of engineers notice bridges than Non-Engineers. It is understandable that engineers would be more observant of structures. Other than that the distribution of percentages between the two groups is similar.

There were a variety of differences between the two groups with respect to Question 3.3. The largest percentage of Engineers thought that Texas bridges were **Ugly or Dull**, or the **Same All Over**. The largest percentage of Non-Engineers thought of size, material, or that Texas bridges were old or plain.

As Question 3.4 indicates, more Non-Engineers than Engineers thought nothing should be changed in Texas bridges. With respect to those who suggested changes, the largest percentage of Engineers, and the second largest percentage of Non-Engineers, thought there should be more interesting designs. The same percentage of Engineers and Non-Engineers thought aesthetics should be improved overall. Non-Engineers were more concerned about safety than other possible changes. Engineers were more aware of the sub-structure appearance than Non-Engineers.

As Question 4.2 indicates, the differences between the positive and negative responses to the US 183 project were similar for both Engineers and Non-Engineers.

As in Question 3.4, a higher percentage of Engineers than Non-Engineers thought changes should be made to improve the looks of Texas bridges in Question 5.2. Of the changes suggested, both groups thought adding Texas flavor and variety were the main changes necessary. Engineers also focused on more unique and interesting designs. The same percentage of Engineers and Non-Engineers thought that relating to nature and location were important. Overall, the distribution of Engineer percentages was similar to that of Non-Engineers for this question.

Although in Question 6.1 more Engineers thought additional tax revenue should be spent, the distribution of engineers and Non-Engineers was similar for this question.

As indicated in Question 6.2, the largest percentage of Engineers thought between 10 and 15% additional should be spent, while the largest percentage of Non Engineers thought no additional funds should be spent. However, larger percentages of Non-Engineers were in the 20 to >100% range. This possibly indicates a lack of knowledge by the public of the cost of a bridge project. The 0 to 10% range seems more realistic.

5.4 Summary

5.4.1 Results of the Whole Survey

The sample population for these survey results are primarily white collar workers or students. About half of those polled originated in Texas. All of those polled live in Texas, and most live in and around Austin. Two thirds of those polled said they traveled Texas highways daily to once every two weeks. The largest number of those polled believed Texas has more attractive bridges than other regions of the U. S.. Finally, those polled believe both buildings and bridges can affect how one feels.

Those surveyed were asked both why they considered bridges in a certain region attractive, and why a certain bridge was their favorite. The reasons most often mentioned involved favorite bridge types such as arch or suspension bridges. Another reason mentioned frequently was the interaction of the bridge with its surroundings. This included not only how it fit in to its surroundings, but the view from the bridge, and the scenic nature of its location. Also mentioned frequently was the bridges symbolic nature. This means the bridge's association with history, such as rustic bridges, or a location, such as the Golden Gate Bridge in San Francisco. Often those polled referred to bridges which were symbolic of their home. The Loop 360 bridge at Town Lake in Austin was the most popular. Its popularity reflected the fact that the residence of most of those polled was Austin. Also, unique, interesting or picturesque designs were popular with those polled. When asked why a particular building was their favorite, the largest number of those polled referred to its symbolism of history or location.

59% of those polled stated that they do notice bridges as they drive by, over or under them. When asked for words describing Texas bridges, the words mentioned most often were old, plain, utilitarian, functional, ugly, and dull. When asked what specifically comes to mind when thinking of a bridge, most of those polled mentioned descriptors such as big, tall, concrete, and steel. The next most frequently mentioned descriptors included ugly, dull, old, and plain. Of those who suggested changes, safety was mentioned most often. Safety suggestions included adding guardrails and widening roads. More interesting designs was mentioned just as often as safety. Improving aesthetics in general was mentioned next most frequently. Also mentioned was both incorporating surroundings and using different structure types. The desire for more interesting and unique designs is reflected in those surveyed responses to the US 183 project. The US 183 project is composed of substructure forms which are unusual with respect to other bridges in the Austin area. The general opinion was overwhelmingly positive.

When asked to describe Texas culture, the words most frequently used were friendly, hospitable, diverse, and varied. Also, many associate the Old West, laid back attitudes, and independence with Texas. When asked how bridges could be changed to reflect Texas culture, those who suggested changes most often wanted to see more Texas or Southwestern flavor in the bridges. An example mentioned often was the Texas inlays being used on reinforced earth retaining walls.

Figure 5.2: Texas Inlay on Reinforced Earth Retaining Wall

Those polled also often suggested more diversity and variety in the bridge designs. Also mentioned was not only making bridges safer, but relating the bridge to its location and using more unique and interesting designs. 29% of those polled had additional comments. Safety was mentioned most often as a concern. Mentioned almost as often as safety was the desire not to spend more money on bridges. Other comments included making bridges less dull, and somehow increasing their relationship to Texas. Also mentioned were concerns about traffic.

When asked if more money should be spent on improving the appearance of bridges, 59% of those polled said yes. When asked how much the state should spend, only a third said no more money. 46% suggested between 1 and 15%.

5.4.2 Comparisons Between Structural Engineers and Other Occupations

Structural Engineers and Non-Engineers opinions were almost the same when asked about if a bridge or building affects how one feels, whether or not they notice bridges and if money should be spent to improve aesthetics. In addition, the Engineers and Non-Engineers opinions on the US 183 project were almost identical.

The Engineers and Non-Engineers had similar opinions as to reasons why a bridge is their favorite. Non-Engineers favored specific structural types such as arches or suspension bridges, structural feats such as long spans, and specific materials such as stone, wood, or steel. As many engineers favored picturesque, unique and interesting designs as structural types, feats, or materials. Both groups thought the environment, view or location was equally important.

Both groups had similar opinions on how bridges should be changed. Fewer percentage of Engineers thought nothing should be done. The largest percentage of the public suggestions focused on safety, while the largest percentage of engineers wanted more interesting and unique designs. The distributions of percentages for the rest of the suggestions were similar. The same percentage of Engineers as Non-Engineers believed aesthetics should be improved in general. Other suggestions often mentioned were incorporating surroundings, structure types, and variety. When asked how to change bridges to reflect Texas culture, more Non-Engineers felt nothing should be done. The distributions of percentages for the suggestions made were similar for both groups. The suggestions mentioned most often for both groups involved relating bridges to Texas, and having more diversity and variety in designs. The same percentage of both groups suggested relating the bridge to nature and the surroundings.

Both groups had similar ideas of how much money should be spent on improving aesthetics. However, Non-Engineers suggestions ranged from 0 to more than 100%, with 0% being mentioned most often. The range of Engineers suggestions was not as wide. The largest percentage of Engineers felt between 10 and 15% should be spent.

Engineers and Non-Engineers had slightly dissimilar opinions when asked what specific things come to mind when thinking of Texas bridges. Engineers most often responded that bridges were ugly, dull and the same all over. The next largest percent of Engineers described bridges as big, tall concrete, steel, and post and beam construction. The largest percentage of Non-Engineers described bridges as big, tall, concrete, and steel. The second largest percentage described bridges as ugly dull, old and plain. The only percentages that were slightly similar between the two groups were that bridges were big, tall, concrete and steel. The percentage of Engineers and Non-Engineers was exactly the same when thinking of bridges as new or clean. However, only 3% of each population thought of bridges that way.

5.5 Conclusions

Although Texas bridges are very successful with respect to their safety, economy and durability, the public perceives them as basically utilitarian, plain and dull structures. Around 80% of the public thinks the appearance of Texas bridges should be improved. Structural Engineers are more critical of bridges and about 96% feel changes should be made. About 60% of those polled are even willing to have tax funds spent on improving aesthetics.

Several issues were frequently mentioned. Many of those polled favored bridges which blended or incorporated the environment in some way. The location and view from a bridge were mentioned frequently. Many thought that bridges in scenic settings should be more open to enhance the view. Those polled were interested in designs which blended with or added to the surroundings.

Also frequently mentioned was the need for more unique and interesting designs. Many favored arch and suspension bridges. This reflects the fact that these systems are more commonly used for longer, more monumental spans, thus have a greater impact on the viewer. Although arches or suspension systems would not necessarily be appropriate for typical short and medium span bridges, enhancing the uniqueness and variety of these typical bridges should have favorable results. The US 183 project is unique for the area and the over all public opinion of it is positive.

The most frequently suggested change was incorporating Texas flavor into bridges. The Texas inlays are a good example and were mentioned frequently. Texans associate the old west, Southwestern, and Spanish influences with Texas culture. Possibly these influences can be incorporated into the architectural style of the structure in some way. Texans also associate independence with their culture. This is probably why more unique, diverse, and varied designs were often suggested.

Safety was mentioned consistently. Although Texas bridges have a successful safety record, a portion of the public still has concerns. This is potentially because the pretensioned girder bridges have very slender profiles. Most often mentioned as a safety concern was the width of the bridge. Also mentioned was height and lack of, what some surveyed considered, adequate guardrails. Some surveys also mentioned lack of pedestrian access. The results of this survey indicate that the publics confidence in the safety of the bridge, on a variety of levels, are indicators of the bridge's aesthetic success. More robust and sturdy appearing bridges seem very popular.

The analysis of the Structural Engineers surveys with respect to Non-Engineers indicates that the opinions of both are quite similar. Engineers tend to be more critical and want to see more improvements.

Finally, the survey indicated that public pride is a significant issue in a structure's aesthetic success. Almost all of those surveyed reside in Austin. Consequently, the most popular bridge, Loop 360, and building, Texas Capital, are located in Austin. Many suggested that a bridges symbolic nature, both of history and place, added to its success. The popular suggestion of relating bridges to Texas more, and having unique designs are also indicative of this pride. This helps confirm the theory that aesthetically successful bridges tend to become civic symbols.

CHAPTER 6:
THE SAN ANGELO PROJECT

6.1 Introduction

One of the objectives of Project 1410 is to implement the information developed on actual trial projects. The project staff were given an opportunity to observe and comment on a bridge design project already well underway in San Angelo, TX. The San Angelo project had interesting constraints and a challenging site which made it an excellent opportunity to make aesthetic recommendations.

The objectives of this chapter are to examine the San Angelo situation in terms of how it relates to the development of the aesthetic guidelines. Therefore, an overview of the process will be presented and not a detailed account of the project.

6.2 Scenario

San Angelo is a town approximately 4 hours driving time north-west of Austin, in the heart of West Texas. 20 years ago, a plan was developed to expand the existing North Concho River, US 87 and ATSF RR Overpass in Tom Green County. The district laid out a road surface geometry, but the project was stalled until recently. As the project started moving again, the road geometry was sent to the Design Division of TxDOT in Austin and preliminary bent positions were laid out.

The target bridge was partially funded by the Federal Government to be a multi-state experiment in the use of high performance concrete with pretensioned concrete girders. The use of concrete with higher than typical compressive strength enabled the girders to span up to 150' (46m). As part of this project, Center for Transportation Research study number 9-589, the design called for the substructure to be an aesthetic shape since the bridge will be adjacent to an urban park [49]. The use of high performance concrete in the substructures was an ideal opportunity for implementing a precast strategy. The Research Project Statement dictated that the contractor be given a option of either precast or a cast in place alternative. Since Project 1410 was developing strategies for precast substructure techniques, they were requested to offer advice. At the same time, it was decided to explore the San Angelo project as a trial site for enhancing the aesthetics of the bridge, also a Project 1410 emphasis.

However, the most important constraint was time. The project needed to be let in June 1995, which meant that the design needed to be finalized in January 1995. While the project had been in various stages of planning for 20 years, the effective opportunity to input advice regarding the improving of bridge aesthetics was about four weeks in late November and early December 1994. The input of Project 1410 was volunteered as an indication of what might be done and as an attempt to become more familiar with the overall design process and constraints.

6.3 Site.

The San Angelo site was quite complex. The existing highway is intended to become access roads for the new freeway. On the site, the new bridge will actually be two bridges raised above the access road and access road bridges (Figure 6.1).

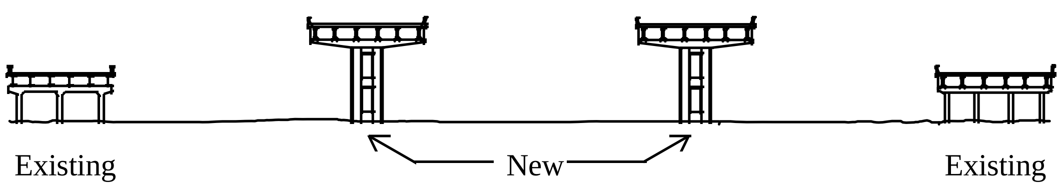

Figure 6.1: Concho River Park Site Section

They will begin at a reinforced earth wall to the west of the site, span a section of the Concho River Park, the Concho river, the intersection US 87, and a set of railroad tracks before ending at a reinforced earth wall at the east end of the bridge (Figure 6.2).

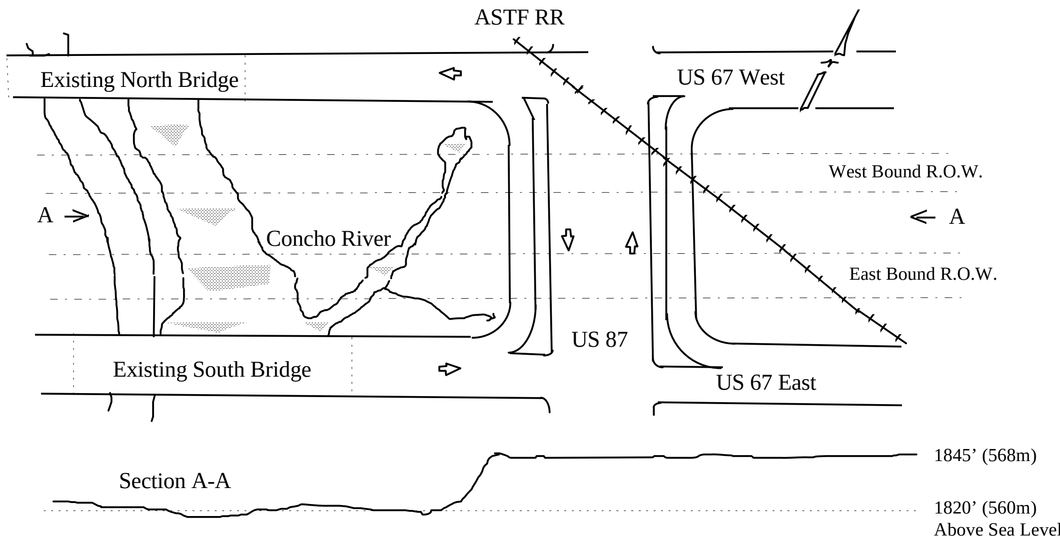

Figure 6.2: Concho River Site Plan with Proposed Bridge Right of Way

There were several significant aesthetic concerns on this project. First, the integrity of the river park was important (Figure 6.3). Next was the resolution of the crossing of the bridge and the intersection and railroad (Figure 6.4). The railroad and the road geometry created a difficult problem due to safety and clearance requirements.

Figure 6.3: Concho River Park Site

Figure 6.4: ASTF RR Railroad and Highway 87

The interaction of the new bridge, and the existing bridges was a concern (Figure 6.5 and 6.6). Finally, the fact that the users of the existing bridges will be around fifteen feet below the new bridges and would get a close up view was to be taken into account.

Figure 6.5: Existing North Bridge

Figure 6.6: Existing South Bridge

In addition to suggested pier layouts, the original design proposed a reinforced earth retaining wall virtually right against the road in the river park at the west end of the bridge. Also, a 30' high reinforced earth retaining wall ran along and very close to the train tracks at the east end.

6.4 Project 1410's Preliminary Involvement

In order to best develop suitable suggestions for the San Angelo situation, Project 1410's preliminary involvement consisted of three actions. These were a trip to the project site, a brainstorming work session to develop ideas, and a resolving of Project 1410's role and interest in the San Angelo situation. From these actions, suggestions on enhancing the aesthetics of the structure were developed and later presented to the TxDOT Design Division.

The first part of Project 1410's strategy for attacking this problem was visiting the San Angelo site. A trip was taken to the intended location of the bridges and information gathered. This information included a video tape of movement through the site, slides from multiple angles of characteristics of the site, and notes on important features and distances (Figures 6.7 and 6.8)

Figure 6.7: View of Site Looking East from West End

Figure 6.8: View of Site Looking West From East End

In addition, an exploration of the intended location of the freeway and the rest of the Concho River Park was made and photographically documented. (Figures 6.9-12).

Figure 6.9: Concho River Park Hike and Bike Trail South of Site

Figure 6.10: Concho River Park Hike and Bike Trail North of Site

Figure 6.11: Southern Concho River Park

Figure 6.12: Community Bridge at South End of Concho River Park

Figures 6.11 and 6.12 contain pictures of other bridges along the Concho River. When compared to the existing bridges already on the site of the proposed new bridges, it is interesting to note that all are unique. Although all are about the same over all size, they reflect both a variety of different aesthetic intentions and the era in which they were built. For example, Figure 6.6 shows the existing bridge on the proposed site. This bridge was built in the 1930's and has a concrete railing similar in shape to suspension systems of more monumental bridges built at that time. Figure 6.12 illustrates a pedestrian bridge close to the rivers surface. This bridge is covered with plaques honoring community members who contributed to the park beautification project. While they do it in different ways, both symbolize civic pride.

Five days after the visit to the San Angelo site and surrounding areas, a meeting of the Project 1410 team was held to explore the possibilities of Project 1410's involvement in the San Angelo project. At this meeting, it was decided that primary issues to be explored were layout, precasting and form of the substructures. After exploring of these topics a set of suggested improvements were developed for changes to the original layout and strategies for the precasting.

Also at this meeting, it was decided that Project 1410's principal interest in this project would be the observation of the TxDOT process. Ideally, a trial project would involve Project 1410 at a much earlier stage than was possible in this project. However, it was also decided that the ideas developed at this meeting would be presented to the TxDOT design division as suggestions which they could decide either to use or not. These would be presented at a TxDOT meeting three days later. Whether to pursue making suggestions about substructure form and surface treatment would be decided after that meeting.

6.5 Presented Suggestions

Preliminary suggestions, presented at the TxDOT meeting, were of two types; layout and precasting. Later, suggestions for substructure form were also submitted.

6.5.1 The Layout.

A new layout comprised of several suggestions was presented. It is illustrated in Figure 6.14 contrasted with the original and final layouts (Figures 6.13 and 6.15).

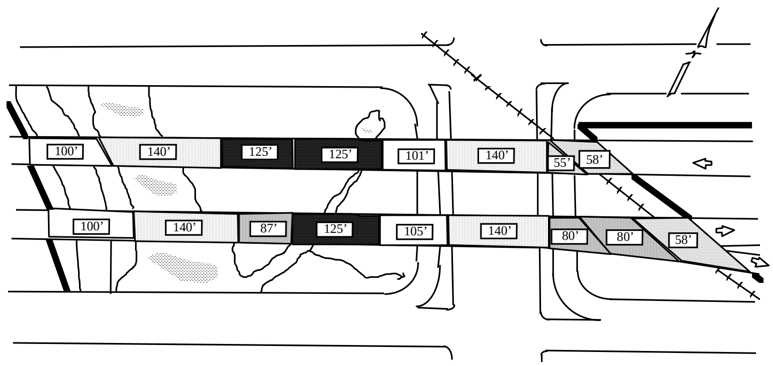

Figure 6.13: Original TxDOT Span Layout

Bold Lines Indicate Retaining Wall Positions

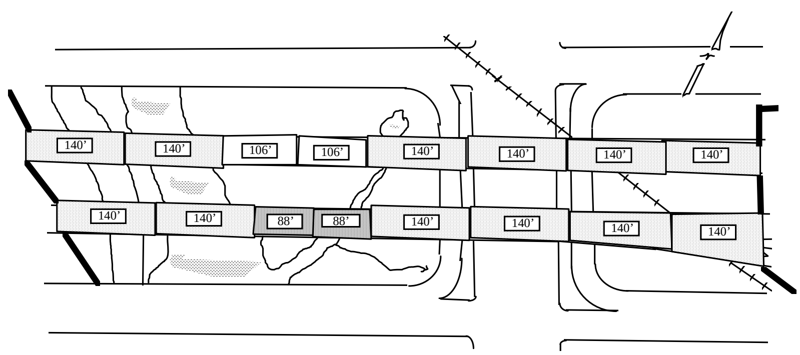

Figure 6.14: Project 1410 Proposed Span Layout

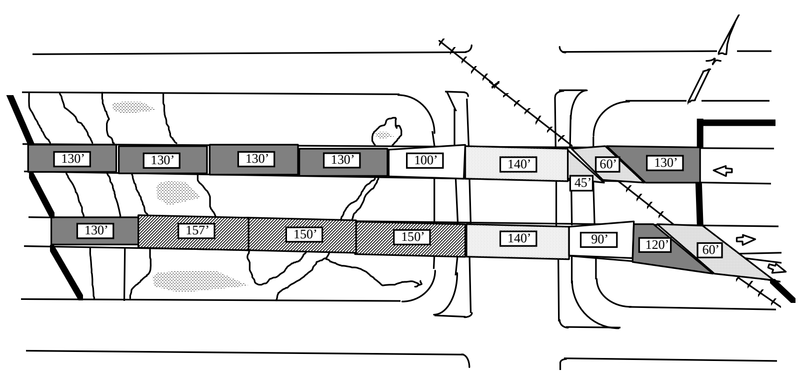

Figure 6.15: Final TxDOT Span Layout

The first suggestion involved lengthening the westerly approach span enabling the retaining wall, which dominated the river park on the west end of the bridge (Figure 6.16), to be moved back.

Figure 6.16: Computer generated Rendering of West Retaining Wall

It was moved back away from the river road to preserve as much of the river park space as possible. The second suggestion offered a way to make the span lengths more regular and rhythmic than the original TxDOT discordant layout which had a very irregular span arrangement. The third suggestion involved adding an additional long span, on the eastern end, in order to move the retaining wall back away from the railroad tracks, which in turn would open up that area. The area along the railroad appeared very “cave” like in artist renderings of the original layout (Figure 6.17).

Figure 6.17: Artist Rendering of Original East Retaining Wall Position

Not only did this openness reduce possible hidden crime scenes, but it also provided more visibility of the train tracks for the westbound lanes of Highway 67, improving traffic safety. This proposal also would allow more rhythmic spans to occur on that end of the bridge. However, because of clearance constraints over the railroad, the geometry of the road would have to be raised about 20 inches. This is because thicker beams would be necessary to span the distance over the tracks to the new retaining wall position. The benefits of these suggestions were, aside from a more harmonious layout, more standardization of the precast pieces in both the sub- and superstructure. However, to optimize the standardization in the substructure systems, an off-ramp would need to be re-configured.

The intention of these suggestions was to take advantage of both the site and the proximity of the existing older access road bridges to express the structure as the new generation of bridge design. This proposal used regularity of longer spans and the thin profile of the super- and substructure to accentuate the height of the bridge through the way the ground dropped away at the river. Traffic on the existing bridges would view the new bridge from mid-height, a vantage not usually available to users. The intentions of addressing the site and reflecting the moderness of the new bridge motivated aesthetic decisions suggested for this project.

The suggestion of moving the west retaining wall back from the park was well received and it was decided that this retaining wall could and should be moved back. Also, the span lengths on the west end of the bridge were modified, to achieve more standardization of span lengths and rhythm. The suggestions about the east end were more controversial because of the need to re-configure the road geometry in order to use higher depth sections over the railroad. These suggestions were received as logical, but in the end, because of time constraints the district would not allow the earlier established geometry of the road surface to be re-configured. Since the road surface was not raised, the change in girder depth remained (Figure 6.18).

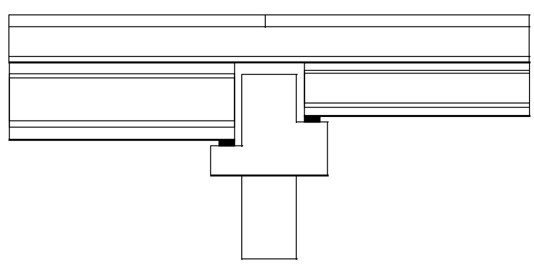

Figure 6.18: Change in Girder Depth at Pier

However, the district did decide to move the retaining wall back from the railroad quite a bit on the north east corner.

Ultimately, the layout was finalized as is illustrated in Figure 6.15. The final layout moved away from the more repetitious Project 1410 proposal of Figure 6.14. However, when compared to the original layout (Figure 6.13), the final layout appears to be an improved compromise. A change from the more rhythmic layout suggested by Project 1410 was largely because it was decided to use the longer span high strength pretensioned girders only in the south structure. Although the retaining wall on the west end was moved back, it was not moved back quite as far as originally recommended.

6.5.2 Precast Pier Suggestions.

The precast pier strategy suggested involved using vertically orientated segments of the pier substructure and connecting them with DywiDag post-tensioning bars. Different piece configurations were suggested and illustrated (Figure 6.19). Also, it turned out that the standard cap would be potentially too heavy for an on site crane, so a segmental bent cap configuration was suggested. Finally, match casting and epoxy joints were suggested for the connections.

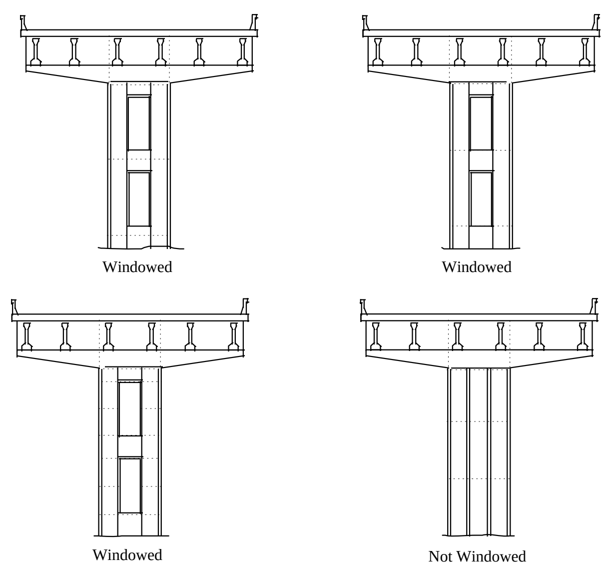

Figure 6.19: Precast Configurations

Dashed Lines Indicate Joints Between Precast Pieces

The precast pier suggestions were received but with some skepticism involving details particularly of the segmental cap. In the end, TxDOT decided not to design a precast alternative to the substructures**.**

6.5.3 Substructure Form Details

The final suggestions made by Project 1410 as of late December 1994, were suggestions on substructure form. These suggestions were made after preliminary feedback was given on the layout suggestions that were presented at the TxDOT meeting. The substructure suggestions are categorized in two ways: the overall substructure form; and suggestions on treatment of the change of girder depth at the railroad crossing.

Preliminary ideas for substructure form were inspired by the existing bridges. The bridges represented two separate generations in bridge design. The bridge to the south was built in the 1930’s and possessed a particularly striking articulated rail (Figure 6.20).

Figure 6.20: Existing Older Bridge

During the time when this bridge was built, this sort of embellishment was economically practical. Since the rail shape is similar to the shape of more monumental suspension bridges built at that time, it appears as though the intention of this bridge was to create something special out of a seemingly ordinary river crossing. In addition, although this bridge is actually constructed using steel girders, extra effort was taken to modify the outer girders to appear as if they were made of concrete thus match the concrete rail and substructure. This bridge can be thought of as a symbol of care and time.

Figure 6.21: Existing Newer Bridge

The North bridge is constructed of modern pretensioned girders (Figure 6.21). The intention for this bridge and other systems like it is efficiency and simplicity. The pretensioned girders are quite economical. The supports and rails are clean and un-embelished. Even the gap between the ends of the outer girders at the supports was filled in to minimize interruptions of the bridges flowing lines. This bridge certainly reflects the intentions of the modern TxDOT aesthetic goals and can be thought of as symbolic of the industry of bridge design and construction.

The original idea for the form of the new bridge supports was a combination of the two existing structures. However, it was decided that since the new structures would be using high strength concrete, thus have longer than usual spans of 140' (43m) or more, they should have their own modern aesthetic presence. Thus, three separate generations of Texas Bridges will be represented, each reflecting the era in which it was built.

Preliminary suggestions for these new substructures were presented by Norman Friedman. Since these piers were to be originally designed for high strength concrete, it became apparent that it would be possible to remove a substantial amount of material from the shafts to better utilize the high strength capabilities. Original suggestions included windows in the shafts of the substructures. In addition, a tapering of the bent cap was recommended. The Project 1410 team picked a design which possessed these qualities from those submitted (Figure 6.22).

Figure 6.22: Suggested Substructure Forms

The consistent window configuration also resulted in a meter which related well to the upper and lower elevations of the site. (Figure 6.23). Integrating the shaft with the bent cap was also explored (Figure 6.24). However, because of forming issues involved for a cast-in-place option, this suggestion was neglected in favor of more economical changes.

Figure 6.23: Substructure Form at Different Elevations

Figure 6.24: Integration of Bent Cap and Shaft Ideas

Because of the railroad clearance requirements, the geometry at the east end of the bridge created some tricky aesthetics problems. These clearance and safety requirements resulted in a change in the depth of the beam over, and heavier column shafts near the railroad. Some recommendations of how to deal with these issues were submitted by Architecture faculty Andrew Vernooy and Dan Leary (Figure 6.25).

Figure 6.25: Architecture Faculty Suggestions for Treatment of Bent Along Railroad Tracks [From Ref. 50]

To resolve the problem of the changing girder depth, a haunched girder solution was suggested. These haunched girders would create a tunneling effect along the length of the railroad. Ideally, this tunnel effect would result in the change of girder depth being perceived as a purposeful decision rather than a result of a oversight in the planning process.

In addition, a heavier column was required near the railroad to fulfill safety requirements of resisting train impacts. It was the opinion of Project 1410 that it would be difficult to effectively blend the form of the heavier column with the forms of the other substructure used for the rest of the bridge. Instead, the proposed solution accentuated the difference. The proposed solution would appear as if a circular concrete safety jacket were wrapped around the piers next to the railroad tracks. The design was meant to convey a sense of a different purpose for those substructures. This purpose was an enhanced strength resulting from proximity to the railroad traffic.

Although no surface treatment suggestions were made as of December 1994, it is likely that Project 1410 will submit some at a later date. During Project 1410's initial explorations, formal issues were a priority because of the need for a detailed design to be completed for letting by June 1995. Surface treatment suggestions could still be effectively made at a later date.

6.6 Lessons Learned

Project 1410’s interest in observing the TxDOT design process was fully achieved through involvement in the San Angelo project. Through these observations and the TxDOT responses to Project 1410 suggestions, several important conclusions were drawn.

The first and most important conclusion was the need for aesthetic consideration at the earliest phases of a project. Had pier placement and potential railroad clearance problems been considered more substantially during the highway geometry layout phase of this project, a consistent rhythm of span lengths and consistency in span depths would have likely been easier to achieve in the design phase.

The second important conclusion was the value in visiting the actual bridge site. Apparently, TxDOT bridge designers rarely have the opportunity to visit the site of the bridge they are designing. They often have only a schematic like that of Figure 6.2 from which to design the structure. In this case, the schematic did not show such important aspects as the style of the existing bridges, or the nature of the Concho River Park area which is similar to a smaller version of the Austin Hike and Bike Trail. Visiting San Angelo allowed the Project 1410 team to walk around and get a “feel” for important aspects of the site such as what it would be like for motorists sitting in traffic on the access roads staring up only 15’ (4.5m) at the underside of the new structure. Finally, the pictures and sample renderings helped illustrate what spaces such as those near the retaining walls would be like. The visit to the site was essential for gaining insight and improving the aesthetics of the project.

The third conclusion drawn is that introducing precast substructures into standard Texas bridge systems will take time. Although precasting of parts of the superstructure has dramatically impacted Texas bridges, there is not a perceived imperative to further increase efficiency and economy through precasting substructures. The experience gained on the San Angelo project indicated that the reason for this is the lack of experience with the design and construction techniques involved. Designers, field personnel, and contractors have become “prisoners of the familiar.” They prefer to stick to known successful solutions and to avoid risks of new solutions. There need to be clearly perceived advantages to encourage them to try precasting substructures. In addition, there is no industrial establishment already set up for producing precast pier segments, as there is for producing pretensioned concrete girders. Until there is, precast substructures will continue to be an unfamiliar, thus uninviting alternative. This was the situation for pretensioned girders in the 50's. Results have shown the decision to try precasting of superstructure brought greatly improved efficiency.

Finally, from an architectural point of view, what makes the existing bridges in the Concho River Park special is the variety of their intentions. Every part of the park is unique, and each bridge contributes to that uniqueness. Project 1410 developed the intention that the new bridges reflect the uniqueness of the site and the moderness of their technology, and made suggestions based on these intentions.

In conclusion, this project reaffirmed that the ultimate goal of TxDOT design is practicality. Thus there will often be practical constraints which may override aesthetic considerations. The already finalized road geometry and the shortness of time in which to affect changes with respect to on/off ramp configurations, resulted in defeat of the aesthetic issue of the change in girder depth at the railroad. Considerations and limitations imposed by the research project concerned with high performance concrete pretensioned girders resulted in a less rhythmic modification to Project 1410's span layout recommendations. Lack of familiarity with, and resulting concern over, precast pier techniques resulted in cast in place substructures, which will possibly ultimately affect the final form of the substructures. However, it is important to acknowledge TxDOT's openness to aesthetic possibilities which is exemplified by the revised layout of retaining walls and of girder spans which can be credited to Project 1410's preliminary suggestions.

CHAPTER 7:
CONCLUSIONS & RECOMMENDATIONS

7.1 Summary

This thesis maps the early stages of development of the *Aesthetic Guidelines*, which contains useful tools for TxDOT bridge designers to be used to enhance the appearance of short and medium span Texas bridges. This manual is one work product of Project 1410 which also will further explore precast alternatives for typical substructure configurations. In a precast situation, aesthetic finishes and interesting forms are more practical and economical than in current cast-in-place practice. The overall goal of Project 1410 is to suggest ways to make future Texas bridges as aesthetic as they will be economical, durable and safe.

The early development of the *Aesthetic Guidelines* involved collecting and processing information in order to organize aesthetic ideas applicable to current Texas short and medium span bridge systems. The major focus of research included reviewing bridge aesthetics literature, collecting and building a database of Texas bridge examples, obtaining the opinion of the public through an informal survey, and observing the TxDOT design process through an example project. Other areas of research included organizational options, precast substructure constraints and surface treatment options.

Ultimately, all information collected to date was compiled into a body of ideas, then refined through a series of drafts into a topical set of aesthetic ideas. This topical set of ideas is the final initial draft of the *Aesthetic Guidelines* as contained in Appendix A. Also included in Appendix A are drafts of potential support chapters. These include an introduction, a brief review of literature on bridge aesthetics, a summary of the evolution of the *Aesthetic Guidelines*, a discussion of appropriate scenarios for use, a discussion of the organization of the topics, and a brief conclusion.

7.2 Conclusions Drawn

Although the information for this thesis was collected through several different methods, the following ideas frequently reoccurred.

7.2.1 Proportion and Order

Many systems of designing aesthetic bridges were revealed during the literature review. Although these systems of design were as diverse as the authors who wrote them, the ideas of proportion and order reoccurred frequently. Several authors discussed the notion of appropriate and logical proportions used the enhance the appearance of bridges. This may mean either the proportions of an element, such as the slenderness of a beam, or even the relative sizes of components such as abutments and substructure.

Along with proportion, order was frequently mentioned. Coherence of design was a consistent theme throughout the literature. This may be achieved through the repetition of forms, span lengths, or textures. Coherence implies a well thought out bridge design.

7.2.2 Addressing the Setting

Many authors felt that the setting is a strong influence in the success or failure of the appearance of a bridge. This influence can occurs in several ways such as the bridges ability to somehow incorporate the surroundings, present the user with a view, or successfully become a contributor to a scenic vista. It is important that a bridge first of all not detract from a site, and enhance it if possible.

Results of the informal survey indicated that the public support this idea. The bridges setting was repeatedly mentioned in answers to various survey questions. Unfortunately, as learned through the San Angelo experience, TxDOT bridge designers frequently do not visit the bridge sites.

7.2.3 Character

Authors repeatedly suggested that bridges should be special events which inspire the user. Although short and medium span bridges may not have as much opportunity to become civic symbols as large structures, it is important that they do not become symbols of urban plight. Even minor aesthetic changes can make dramatic differences. An example of this are the aesthetic reinforced earth retaining walls TxDOT has recently been using. By simply adding texture, what was once an empty expanse of concrete has become an event of interest.

There are many different styles of textured reinforced earth retaining walls. This adds variety to a highway system which many feel is monotonous. Through the informal survey, it was learned that many felt that Texas bridges all looked the same and there needs to be more diversity and variety to better reflect Texas. "More unique and interesting designs" was often suggested in many answers to questions. Even in the San Angelo River Park, there were several bridges of about the same size, but different enough to give each an individual character. Each bridge is a unique event.

7.2.4 Safety

Safety was mentioned often as a concern of the public. Because of modern prestressing and high performance concrete technology, many contemporary bridges have slender profiles which sometimes appear less than substantial. In addition, requests for better pedestrian safety measures and wider roads were made. Bridges should inspire confidence in the user, whether the user is driving over, driving under, or walking across the bridge.

7.2.5 Texas Flavor

Many Texans feel that bridges should reflect Texas' Old West and/or Southwestern nature. The Texas inlays in retaining walls were particularly popular with those polled. By linking the bridge to Texas, the designer is able to access the public patriotism and pride. The overwhelming winners of survey questions on favorite bridges and buildings were both local Austin structures, the Loop 360 bridge and the Texas Capitol. The U. S. 183 project accesses this patriotism through designing the piers to symbolize southwestern architecture as inspired by the Alamo. As indicated by responses to the informal survey, public response to these piers is positive.

7.2.6 Effects of Age

It became obvious through excursions around Texas that no matter how much emphasis may be put on aesthetics in the design phase of a project, these efforts may be lost through effects of wear such as drainage staining, paint peeling and graffiti. Avoiding high maintenance costs and retaining the aesthetics of a structure can be done by the use of finishes which do not require painting, and the use of textures, which downplays the effect of age.

7.2.7 Process and Practicality

Aesthetic issues must be addressed from the earliest phases of the design process and be included in all phases of the process. All parts of the process must include aesthetic discussions from the earliest stage so problems can be identified and addressed promptly. Ultimately, practicality, economy, and safety must be components of any successful design. However, simple efforts such as rhythmic pier placement, and subtle form modifications such as large chamfers, can have dramatic benefits without dramatically increasing costs.

7.2.8 Precasting

Precasting of the substructure pieces would allow dramatic and economical improvements in finishes and forms to take place in substructure design. However, at this point in time, the industry is not as established for mass precasting of substructure pieces as it is for producing pretensioned girders. Until this capability is established, a precasting alternative will not be as attractive to contractors as familiar cast-in-place techniques.

7.3 Recommendations for Further Development

There are five main recommendations for further development of the *Aesthetic Guidelines.*

1. The next stage of refinements of the guidelines should take the current set of guidelines and tailor them to the TxDOT design process. Ultimately, they should be formatted in such a way that the global intention of the structure is resolved first. Then, the guidelines can be used to identify areas where modifications can be made to achieve those intentions. Although these guidelines should be organized in such a way that the different parties participating in the design

can easily access information which is germane to their contributions, they should not be organized in such a way that communication between contributing parties is in any way discouraged.

2. Further development and application of precast substructure systems should be made. Ideally, the advantages of precasting should make it such an attractive option that contractors are encouraged to utilize it.

3. Further emphasis on incorporating Texas flavor into designs should be explored. Example methods suggested included naming bridges after famous Texans or war veterans, or even allowing the public to somehow sponsor a bridge to be named after someone.

4. More research into appropriate aesthetic treatment of different scenarios should be made to give the designer ideas of what has worked in the past for that situation and what definitely hasn't.

5. Finally, research and development of ways to effectively control the problems related to age are needed. Using finishes which do not require painting and continual maintenance will alleviate the peeling problems. In addition, better drainage details and graffiti deterrents are needed.

7.4 Concluding Comments

Although the guidelines provide a useful set of tools for enhancing the appearance of a structure, the most useful and effective tool the designer has is the realization of the intention of the design as a whole. The design process for producing short and medium span Texas bridges has become so efficient that many contemporary bridges appear routine and, the general public responded frequently, "all the same." That a designer possesses a vision of what the design can ultimately represent is obvious to the public, even if the specifics of the vision is not. Even if the public does not immediately understand what is implied by the U. S. 183 aesthetic treatments, the public realizes that it is something special as indicated by the results of the informal survey, and even an editorial exchange which occurred in the Austin American Statesman during the spring of 1995.

The addition of details such as a Texas Inlay (Figure 7.1), a specific precast reinforced earth retaining wall panel (Figure 7.2), or the "Aesthetic Rail" (Figure 7.3), will certainly enhance the aesthetics of a typical bridge.

Figure 7.1: Texas Inlay

Figure 7.2: Precast Reinforced Earth Retaining Wall Panels

Figure 7.3: "Aesthetic Rail"

However, the maximum impact will be achieved through the use of what can be described as an overall concept, vision or intention. This has been exemplified many times by examples such as the Linn Cove Viaduct which is meant to minimally disturb and be subject to the environment (Figure 7.4), or the Salginatoble Bridge wherein sculptural form expresses its structural performance (Figure 7.5).

Figure 7.4: Linn Cove Viaduct

Figure 7.5: Salginatoble Bridge [From Ref. 3]

An excellent Texas example is the rust colored arch of the Loop 360 Bridge (Figure 7.6).

Figure 7.6: Loop 360 - Lake Austin Bridge

Many of those surveyed mentioned that the arch blends into the environment. Even though rusted steel may not be considered a natural material such as wood or stone, the earth tone of rust is associated with decay which is understood as a natural occurrence. This may not have been the specific reason for the choice of weathering steel, and the public may not overtly realize that its symbolism of decay is why the bridge blends so well with the environment. However, the public has acknowledged the Loop 360 Bridge as something special and adopted it as a symbol of Austin.

The U. S. 183 structure is a raised freeway, a commonly occurring situation in cities. It is a good example of how a vision can be applied to a typical situation and not only to monumental structures. Once a vision is established, the *Aesthetic Guidelines* can be used to guide decisions about aesthetic treatments. Thus the most effective use of the *Aesthetic Guidelines* is not as a list of ways to make bridges look more attractive, but as a list of tools that the designer can use to make his/her individual vision a reality.

Appendix A:

THE AESTHETIC GUIDELINES

This Appendix contains a complete version of the finalized initial draft of the *Aesthetic Guidelines*. This version includes both the actual aesthetic principles and the supporting Sections.

The supporting Sections will be preceded by a "G." A summary of the following sections is presented below.

Section G.1 is an introduction to the guidelines.

Section G.2 is a brief discussion of bridge aesthetics.

Section G.3 is a summary of the evolution process of the *Aesthetic Guidelines*.

Section G.4 is a brief discussion of relevant scenarios for application of the *Aesthetic Guidelines*.

Section G.5 is an explanation of the organizational system for the included set of aesthetic topics.

Section G.6 is the set of aesthetic topics.

Section G.7 is a brief set of conclusions and recommendations.

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