Final Report

ALTERNATIVES TO THE CURRENT AASHTO STANDARD BRIDGE SECTIONS

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Abstract

The main objective of this study was to evaluate feasible alternatives to the current AASHTO bridge girders used in Indiana. This evaluation included prestressed concrete girders for spans from 30 to 120 feet with girders spaced between 5 and 10 feet and up to 12 feet for the longer spans. Other criteria included girder design concrete compressive strengths up to 7000 psi, 8" total concrete deck thickness with design strength of 4000 psi, grade 60 steel for slab reinforcement and stirrups and 1/2" special grade 270 low-relaxation strand for prestressing steel. Post-tensioned and prestressed box girders were outside the scope of the study.

Approximately 100 alternate sections were reviewed for various departments of transportation, consultants, and precasters in the United States. The girder cross sections were then evaluated for their structural efficiency and cost effectiveness. This was done using the computer program, PCEM, developed by Professor Robert H. Lee at Purdue University and currently used by INDOT.

The AASHTO I, II, & III girders were found to be economical for spans 30 to 70 feet. No alternate sections were therefore recommended in this span range. In the range from 70 to 90 feet the Illinois 54" section is considered the most economical. This section is currently being used as the only alternate section in Indiana. Other alternate sections were found to be more economical for spans over 90 feet. The Kentucky Bulb Tens were recommended for use in spans from 90 to 130 feet to provide considerable savings over the standard AASHTO girders. This would result in a savings of as much as 20 to 25 percent of the bridge superstructure for the longer spans.

Design Aides were created for these Kentucky Bulb Tens as well as for the AASHTO standards and the Illinois 54" section. The use of these sections is supported by this research study and recommended to INDOT. Adopting these alternate sections would result in considerable savings in Indiana's bridge construction.
The objective of this study was to evaluate feasible alternatives to the current AASHTO bridge girders used in Indiana. This evaluation included precast pretensioned bridge girders for spans from 30 to 130 feet with girder spacing between 5 and 10 feet and up to 12 feet for the longer spans. Post-tensioning and pretensioned box girders were outside the scope of the study. Approximately 100 alternate sections were evaluated for their structural efficiency and cost effectiveness.

The AASHTO I, II, & III girders were found to be economical for spans from 30 to 70 feet. No alternate sections are therefore recommended in this span range. In the range from 70 to 90 feet the Illinois 54" section is considered most economical. This section is currently being used as an alternate section to the AASHTO IV girder in Indiana. Alternate sections were found to be more economical for spans over 90 feet. The Kentucky Bulb Tees are recommended for use in spans from 90 to 130 feet to provide considerable savings over the standard AASHTO girders. This would result in a savings of as much as 20 to 25 percent of the bridge superstructure for the longer spans.

Design Aids were created for these Kentucky Bulb Tees as well as for the AASHTO standards. This was done in metric (SI) and inch-pound units to simplify design of the existing sections and implement design of the proposed Kentucky sections.
The Kentucky sections are currently being produced by local precasters in Kentucky. They have variable forms with webs from 6 to 8 inches and depths from 60 to 78 inches. The use of these sections is supported by this research study and recommended to INDOT. Adopting these alternate sections would result in considerable savings in Indiana’s bridge construction.
1.1 Background

When designers first began using prestressed concrete for bridge girders, they developed their own ideas of optimal bridge girder sections. Producers soon realized that it was too expensive to continuously design new forms for these customized girders. This led to the adoption of a series of AASHTO standard bridge girders in the late 1950's and early 1960's. As a result, prestressed concrete design became more widespread and efficient.

Since the development of these standard sections, there have been significant advances in materials as well as changes in design specifications relevant to applications of prestressed concrete. This created a need for changes in the original sections. Many state highway departments have thus revised the original AASHTO bridge girders or created their own standards to incorporate the advances in prestressed concrete. The Indiana Department of Transportation has not yet adopted a complete revised set of alternate bridge sections. However, considerable need for
re-evaluating existing standard sections is indicated by the use of alternate sections such as the Illinois 54" Prestressed Precast Concrete I-Beam as well as the consideration given to other possible alternate sections. Indiana is therefore in need of a systematic evaluation of alternate sections for improved efficiency and economy in bridge construction in the state.

1.2 Objective and General Scope

The objective of this investigation is to evaluate feasible alternatives to the current standard AASHTO bridge girder sections. This includes precast pretensioned bridge girders for spans from 30 to 130 feet with girder spacing between 5 and 10 feet and up to 12 feet for the longer spans. Other criteria includes girder design concrete compressive strengths up to 7000 psi, 8" total concrete deck thickness with design strength of 4000 psi, grade 60 steel for slab reinforcement, and 1/2" diameter special grade 270 low-relaxation strand for prestressing steel.

The work described in this report supports more efficient alternate sections for use in the State of Indiana as replacements for the current standard AASHTO sections.
The evaluation is divided into four main tasks consisting of evaluation of bridge girder sections, structural efficiency and cost-effectiveness, final beams and recommendations, and design charts.

1.3 Project Tasks

This section describes the tasks which comprised this research study.

1.3.1 Task 1: Evaluation of Bridge Girder Sections

The work conducted during this task included surveying the current use of precast pretensioned bridge girders from various departments of transportation, consultants, and precasters in the United States. Surveys were conducted through mail, telephone, and site visits. This survey provided information on alternate sections that are being utilized by other states. Cross sections of girders were obtained as well as information relevant to their design and use.
1.3.2 Task 2: Structural Efficiency and Cost-Effectiveness

This task included evaluating the structural efficiency and cost effectiveness of the alternate sections obtained in Task 1. These alternate sections were then compared to the standard sections which Indiana is currently using. The computer program, PCEM, developed by Robert H. Lee at Purdue University and currently used by INDOT was used for structural evaluation of the alternate sections. Relative costs were obtained through Task 1 and employed as a further comparison of the alternate sections with the current standards.

1.3.3 Task 3: Final Beams and Recommendations

This task included selecting the best beams in each span range for additional evaluation. Selection was based on least relative material costs as well as comparing criteria influencing the production of these girders. Cross sections and properties of the selected beams were sent to several precasters to obtain comments on their production.
Recommendations were then made for the final girders to be used in each span range.

1.3.4 Task 4: Design Charts

This task included preparing design aids for the final girders and the standard sections used by INDOT. The design aids were prepared for both simple and continuous spans as well as 6000 and 7000 psi girder concrete. They consist of three steps to select and design prestressed bridge girders. This includes choosing the appropriate girder for a given span range, and determining the required number and layout of prestressing strands.

1.4 Summary

In summary, Indiana is in need of a systematic evaluation of alternate sections for improved efficiency and economy in bridge construction in the state. The research described in this report evaluates alternate sections for use as replacements for the current standard AASHTO sections that Indiana is using. This includes precast pretensioned
bridge girders for spans between 30 and 130 feet. The evaluation is divided into four main tasks consisting of evaluation of bridge girder sections, structural efficiency and cost-effectiveness, final beams and recommendations, and design charts. The next chapter reviews the history of prestressed bridge girder design and relevant literature regarding optimization of these sections.
CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter will give a brief history of current design practices for precast prestressed bridge girders as well as review literature relevant to this study. A concise discussion of the history and development of the precast prestressed bridge girder is followed by examples of current design philosophies in use today. Summaries of two reports pertaining to the optimization of highway bridge girders will also be reviewed. The first report is a thesis written by Kathryn Lynn Geren at the University of Nebraska in 1992. The second report is a nation wide survey done by Basile G. Rabbat and Henry G. Russell in 1982.

2.2 Historical Background

In the early 20th century the invention of prestressing changed the design world forever. The first use of prestressing in the United States was for confinement of hoop stresses that were developed in circular storage tanks. This technique soon led to linear prestressing for use in
the design of bridge girders. The first bridge constructed in the United States utilizing linear prestressing was the Walnut Lane Bridge in Philadelphia in 1949.

The successful construction of the Walnut Lane Bridge brought about an increase in the use of prestressing in the design and construction of bridges. The versatility and cost efficiency of prestressing made it a popular choice over the conventional reinforced concrete. The ability to make larger and more efficient bridges encouraged more contractors to enter the design business. Each designer used what he thought was the best girder design for each task. This involved making custom forms for each bridge constructed. It soon became obvious that the cost of producing new forms for each bridge would increase the overall expense of the project.

The cost increase became a major factor in the use of prestressed girders. The American Association of State Highway Officials (AASHO) and the Prestressed Concrete Institute (PCI) were prompted to begin work on standardizing girder design. The girders that were decided upon are still in use today. These girders include the original AASHO, today referred to as AASHTO Standard Sections Type I through IV, (designed in the late 1950's) and Types V and VI (developed in the early 1960's).
Since their acceptance, the use of the standard AASHTO-PCI sections greatly reduced the cost of the design and construction of prestressed bridges. It became possible to set up plants to mass produce the beams. This was accomplished using permanent forms instead of having to fabricate new forms for each series of beams being produced. In the beginning, this made prestressing a very popular design alternative. However, with standardization often comes stagnation.

The disadvantage behind standardization of the prestressed precast bridge girders was the reluctance of the industry to implement new alternate designs. The precast plants in their unwillingness to try new beam designs were as much at fault as the practicing engineers. The precasters made large initial investments in material as well as employee training in the mass production of the current beams. They felt that changes in their plants to accommodate new beams would have to bring significant economic potential. Some of the practicing engineers were hesitant because they were comfortable with the design and use of the current girders and did not want to deal with the nuances and expected performances of new girders. An example of this is the Washington Bulb Tee developed by Art Anderson in 1959. This series of beams was not used
nationally until 1988, the 30 year time span illustrates at least in part the universal reluctance to change [4].

However, an interesting fact is the desire and willingness of states to adopt their own style of girders as noted by the work in this report. Several studies have been done to find the optimal precast prestressed bridge girder. Several states designed and implemented their own style of girder to meet their economic needs and geographic locations. An example of this is the type of girders used in Pennsylvania. These beams are quite short and bulky compared to some of their counterparts, such as the Bulb Tee. The relatively short nature of the beams is due to the clearance problems associated with many of the roadway underpasses [4]. The potential to use these beams made it a viable alternative to steel bridge girders. The bulkiness of the girders is to account for the large prestressing forces that are developed in the beam to span the needed ranges. Other examples of geographical influence are seen in Colorado and Washington State. In these states the superior quality of aggregate enables the fabricators to utilize higher strength concrete which is needed to produce girders with 5" and 6" web thickness [4].
2.3 Studies Related to Optimization of Precast Bridge Girders

2.3.1 Optimized Sections for Precast Prestressed Bridge Girders by Rabbat and Russell

This study was done by Basile G. Rabbat and Henry G. Russell in 1982 in order to determine the most efficient girder type to use for the national or regional standard. The study was limited to bridges constructed using precast prestressed I or T sections for span ranges over 80 ft which utilized concrete strengths up to 7000 psi [7].

The research approach was divided into two phases. Phase 1 was the collection of information from precasters of bridge girders and highway agencies. Phase 2 was the evaluation of the structural efficiency and cost effectiveness of the beams. The standard AASHTO girder types were used as the basis for comparison. The parameters used in the testing were girder spacing, span length, deck thickness and concrete strength.

Once all the surveys were received and evaluated, the structural efficiency of the girders was determined using efficiency factors developed by Guyon and Aswad. The efficiency factor derived by Guyon $p$ is based on maximizing
the section moduli for the top and bottom sections of a
given girder type.

\[ \rho = \frac{r^2}{y_t y_b} \]  

(2-1)

\( r \) = radius of gyration
\( y_t, y_b \) = distance to top and bottom fibers

The efficiency factor developed by Aswad \( \alpha \) is relative to
spans exceeding 75 ft because of the bottom stresses
governing the design of the girders.

\[ \alpha = \frac{3.46 S_b}{Ah} \]  

(2-2)

\( S_b \) = section moduli for bottom fibers
\( A \) = cross-sectional area
\( h \) = height of section

Using this equation, Aswad determined the girders with the
highest efficiency ratio had the lowest cost per square foot
of superstructure [7].

The cost analysis was done on the Bulb Tee's, Colorado,
Washington and AASHTO girders. Consideration was also given
to modified beams of the same type mentioned above with 6”
webs. The parameters considered were girder spacing,
concrete strength, deck thickness and girder span. Due to
the complexity of evaluating each girder, a computer program was developed to help in the calculations. The costs of labor, transportation and material varied greatly for each region so a relative cost of in-place construction was developed. The final cost of each beam was then divided into the deck area to give a relative cost index per square foot of deck.

Once all the results were tabulated, optimum cost curves were generated to determine the most efficient and economic girder. According to the study the Bulb Tee girders were the most economic when compared to the AASHTO girders. The cost savings were an average of 17 percent greater than with the AASHTO girders. The second most economical beams were the Washington series. The overall report stated that the Modified Bulb Tee's should be considered as a national standard over the current Modified AASHTO girders for the constraints established by the study.

2.3.2 Optimization of Precast-Prestressed Concrete Bridge I-Girders by K. L. Geren

This research project partially funded by PCI was the work of Kathryn Lynn Geren at the University of Nebraska in 1992. The objective of this report was to investigate the
potential of a national standard for continuous precast prestress I-girders. The standard girders in use today are primarily used for simple spans, therefore, there are some problems using them in the post-tension continuous area. Some examples of this are limited space in the web for posttensioning strands and an insufficient amount of compressive area in the bottom fibers to accommodate negative moment regions. The scope of the project was not limited to the existing forms on the market today. A review of the existing I-girders and the optimization process used to choose an efficient girder were addressed in this project.

The survey was sent to 200 bridge constructors, state bridge designers, consultants and precast plants. From this survey there were nearly 90 responses. The responses of the poll consisted of structural details, fabrication procedures, handling and erection techniques.

Once all the surveys were obtained a parametric study was done. A computer program was developed to aid in the determination of the most structurally efficient and cost effective girder design. There were four major criteria used in the optimal design process. The parameters were; deflection, shear, prestress anchorage and flexure at critical negative and positive zones. The final goal of
this project was to design a girder that would, under service loads, "approach maximum capability based on ultimate strength criteria nearly simultaneously in the positive and negative moment areas, while meeting the requirements of working stress design." [4]

The final analysis determined the critical features controlling the optimal girder shape were the overall cross sectional area, the area of the bottom flange and the width of the top flange. The study concluded that the girder which minimized overall cross sectional area, maximized the cross sectional area of the bottom flange and maximized the width of the top flange produced the most structural efficient and cost effective girder for post-tensioning. Structural efficiency was determined by using the same efficiency factors described in Section 2.3.1. The preliminary girder shape was then critiqued by design professionals and suggestions led to the final girder shape. The Nebraska University Proposed Girder Series (Appendix K) was the final design submitted.

The Nebraska University Proposed Girder Series was then evaluated against the most efficient girders on the market to date. It was found that the Nebraska girders were able to span greater lengths while maintaining shallower depths.
and less cost than any other girder in the range above 120 feet.

2.4 Summary

In summary, this chapter gave a brief history of current design practices for precast prestressed bridge girders as well as reviewed literature relevant to this study. Summaries of two reports pertaining to the optimization of highway bridge girders were reviewed. The first report was a nation wide survey done by Basile G. Rabbat and Henry G. Russell in 1982. The second report was a thesis written by Kathryn Lynn Geren at the University of Nebraska in 1992. The next chapter will include surveying the current use of precast pretensioned bridge girders from various departments of transportation, consultants, and precasters in the United States.
CHAPTER 3: EVALUATION OF BRIDGE GIRDER SECTIONS

3.1 Introduction

This task included surveying the current use of precast pretensioned bridge girders from various departments of transportation, consultants, and precasters in the United States. Surveys were conducted by mail as well as through telephone conversations and site visits. This survey provided information on many of the alternate bridge girder sections that are being utilized for spans between 30 and 130 feet. At the request of the Indiana Department of Transportation this study did not include box beams or post tensioning.

Two separate surveys were developed for mail distribution. One was sent to selected precasters in Indiana, Kentucky, Illinois, Wisconsin, Michigan, and Ohio. The other survey was sent to consultants in Indiana, and selected departments of transportation in the United States. These included Indiana, Florida, Illinois, Kentucky, Michigan, Washington, Texas, Wisconsin, Ohio, Pennsylvania, Virginia, and Colorado. Approximately 36 surveys were
mailed out and 22 were received. See Appendix A for a complete list of survey respondents.

The survey mailed to precasters included questions on design and construction details, fabrication details, transportation requirements and restrictions, and availability and costs. Surveys mailed to consultants and departments of transportation were similar except that fabrication details were excluded and structural durability questions were included. Survey forms and responses are included in Appendix A. In the following sections are the summaries of the major questions included in the survey and the most common responses are also presented.

3.2 Design and Construction Details

3.2.1 Girder Sections

A complete list of alternate prestressed concrete girder sections used by survey participants as well as their cross sectional dimensions is included in Appendix B. The majority of alternate sections received were utilized for spans between 70 and 130 feet. Some alternate sections were also received for spans between 30 and 70 feet.
Participants were asked the advantages of these alternate sections. Most participants replied that the alternate sections were more economical, providing longer span capabilities and wider beam spacing as well as being easier to transport.

3.2.2 Longest Spans

The longest spans built using single pretensioned girders were reported as 145' in Kentucky and Washington, 142' in Texas, 140' in Florida and Wisconsin, and 138' in Michigan.

3.2.3 End blocks

End blocks were not used in pretensioning applications except for the state of Colorado with the 5" and 6" webs and Minnesota and Wisconsin with the 6" webs.

3.2.4 Concrete Properties

Most survey respondents used normal weight concrete of 150 lb/cf for their bridge girders. The strength at release
ranged between a minimum of 3500 in Michigan and a maximum of 6400 in Texas with most using a release strength between 4000 and 5000 psi. The 28 day design strength for the bridge girders was reported between 5000 and 8500 psi with most states using a design strength between 5000 and 6000 psi. The maximum 28 day design strength that beam designers are allowed to use ranged up to 8500 psi in Colorado with most states only allowing between 6000 and 7000 psi. Lightweight concrete was not used by the majority of the survey participants.

3.2.5 Strand Properties

The most common strand used by respondents for pretensioned girders is Grade 270, 1/2" and 1/2" special low relaxation strands. Stress relieved strands are permitted in some states, but they are rarely used. A few states also used 7/16" and 9/16" strands on non-Federal Aid projects. Most strands were spaced at two inches.
3.2.6 Girder Spacing

Spacing between pretensioned girders varied between 4 and 10 feet. The most common maximum girder spacing was 9 or 10 feet with a few exceptions of 12 feet in Florida and 15 feet in Pennsylvania.

3.2.7 Decks

Most survey respondents used a cast in place concrete deck with a 28 day design strength between 4000 and 4500 psi. Some states are also using precast pretensioned concrete deck panels or permanent metal deck forms with their bridge girders.

3.2.8 Design Loads

The majority of designs were for an HS20 live load with the exception of a few states which also design for HS25.
3.2.9 Design Charts

Most states surveyed had some type of design aid either in the form of charts and tables or computer software. Most of the charts showed relations between girder span, spacing and number of required prestressing strands.

3.3 Fabrication Details

3.3.1 Draping or Debonding

Most precasters preferred debonding prestressing strands while some are using draping. Several precasters expressed concern in draping strands due to the possibility of uplift and breakage of strands.

3.3.2 Epoxy Coating

Epoxy coated mild reinforcement is being used by most participants where as epoxy coated strands are not being used. Precasters sighted the dangers of using epoxy coated strands since they often slip and may explode out of the beam.
3.3.3 Web Thickness

Minimum web thickness was limited to 6" although a minimum of 7" is often preferred. Precasters expressed concern in using thinner webs as it is difficult to achieve proper consolidation in the bottom flange.

3.4 Transportation Requirements and Restrictions

3.4.1 Girder Length

The maximum length girder transported without a permit ranged from approximately 50 to 60 feet while the length with a permit was usually not limited. Most respondents sighted an upper limit of between 150 and 200 feet depending on the project site.

3.4.2 Instability

Instability problems were noted when transporting beams with long spans. Lateral bracing is often used and strongbacks are attached to the top flange when necessary. These problems are evaluated for each job as they are specific to the construction site.
3.5 Structural Durability

3.5.1 Design Life

Bridge girders were most often designed for 75 - 100 years.

3.5.2 Inspection

Inspection of bridge beams was normally performed every 2 years unless problems were sighted. Most common problems consisted of deterioration of beam ends due to leakage of joints, and spalling concrete at bottom flanges due to clearance problems. Cracks were normally not encountered. If seen, they were usually at the junction between the web and the lower flange near the ends of the beam or in the prestressing yard after strand release.

3.6 Availability and Costs

Cost data obtained in the survey is summarized in Appendix A. Unit costs for materials, labor, and transportation varied from state to state as did the cost
per linear foot of each girder sections. Approximate unit costs were selected from the surveys and used to evaluate a relative cost effectiveness of alternate sections.

3.7 Additional Information

In response to the survey question concerning tension in the concrete during service load conditions, the most frequent response was, tension is allowed in the concrete as stated in the AASHTO code specifications.

The use of interior diaphragms varies from state to state. The average response however, was that diaphragms were used with girder lengths over 50 feet. The frequency and spacing varied due to bridge configurations and local site conditions.

One respondent expressed the desire to use higher strength concrete in their bridge girders. Also an alternate section with variable forms is preferred with depths from 40" - 85".

Concern was also expressed as to the validity that precast deck panels act compositely with the cast in place part of the concrete deck. The concern was noted due to the
different physical properties of the two materials and their interaction during posttensioning.

3.8 Summary

In summary, this task included surveying the current use of precast pretensioned bridge girders from various departments of transportation, consultants, and precasters in the United States. This survey provided information on many of the alternate bridge girder sections including design and construction details, fabrication details, transportation requirements and restrictions, structural durability, and availability and costs. The next chapter reviews the evaluation of these alternate sections. Comparisons were made using a structural efficiency factor, a computer program for structural evaluation, and graphs showing cost effectiveness.
CHAPTER 4: STRUCTURAL EFFICIENCY AND COST-EFFECTIVENESS

4.1 Introduction

This task included evaluating the structural efficiency and cost effectiveness of the alternate sections obtained through the survey conducted in the first task of the research project as presented in Chapter 3. These alternate sections were then compared to the standard sections which Indiana is currently using. Comparisons were made using a structural efficiency factor, a computer program for structural evaluation, and graphs showing cost effectiveness. Following is a detailed explanation of each of these tasks.

4.2 Structural Efficiency

Design of prestressed bridge girders is primarily based on flexure. It is therefore most optimal to maximize the section modulus and minimize the beam area. One method of quantifying this principle was developed by Guyon [7]. He derived an efficiency factor which is based on maximizing
the section moduli for top and bottom fibers for a given cross-sectional area. The efficiency factor is defined as:

$$\rho = \frac{r^2}{y_t y_b}$$  

(4-1)

$r = \text{radius of gyration of section}$

$y_t = \text{distance from center of gravity to top fiber}$

$y_b = \text{distance from center of gravity to bottom fiber}$

The efficiency factor for various sections is plotted with respect to depth of the sections in Appendix C. This is one way of comparing the proposed alternate sections with the standard AASHTO sections. The higher efficiency factors denote a beam with a more efficient cross sectional area with respect to section moduli for top and bottom fibers. These factors are plotted with respect to depth and therefore have no relation to girder span or spacing. A more detailed structural evaluation and cost analysis is needed for further comparison. This is done with a computer program for structural evaluation.
4.3 Structural Evaluation

A detailed structural evaluation was performed on each of the proposed alternate bridge girders. This was done using the computer program, "PCBM", developed by Professor Robert H. Lee at Purdue University. This program is currently in use by the Indiana Department of Transportation (INDOT). Bridge girders were analyzed at their respective spans in the range of 30 to 130 feet. Girder spacing was varied between 5 and 10 feet. In addition, the girder spacing was extended to 12 feet for some of the alternate sections. Other assumptions which reflect INDOT's design procedures as well as the majority of survey responses include:

- 8" concrete deck
- concrete deck acts compositely with the girder
- deck concrete design strength of 4000 psi
- beam concrete release strength of 4500 psi
- beam concrete design strength of 6000 psi
- grade 60 steel for slab reinforcement and stirrups
- grade 270 steel for prestressing
• 1/2" special low relaxation strands
• HS20 live load
• AASHTO 1993, Bridge Design Specifications
• future wearing surface load of 35 psf

Initial structural evaluations were performed on all the bridge girders at 5, 8, and 10 foot girder spacing. The initial computer runs were also done with girders simply supported and strands designed in a draped pattern. These assumptions were selected as a simplification which would still provide an accurate relative ranking of the alternate sections. Further analysis was performed on the most efficient beams including spans made continuous for live load, debonded strand patterns, and a beam concrete design strength of 7000 psi.

Computer input for "PCBM" is a function of the above assumptions and the cross-sectional dimensions of the girder. The computer program then designs a prestressed bridge girder first by working stress and second by checking ultimate moment. Output includes girder cross-sectional properties, required number and pattern of prestressing strands, required stirrup spacing, as well as moments, shears, stresses, and deflections at various sections of the
span. The beam cross sectional area, number of prestressing strands, and stirrup spacing are then used in the cost-effectiveness analysis. See Appendix L for typical PCBM input and output files.

4.4 Cost Effectiveness

Due to the variation of costs from state to state, it is not possible to perform an exact cost comparison on alternate sections received from different regions of the country. This was also not the intent of the study. Approximate unit costs were therefore obtained from INDOT as well as through survey responses to perform a relative cost comparison of the alternate sections. These costs reflect relative costs of material, labor, and construction. See Appendix A for costs obtained from surveys.

4.4.1 Concrete Deck

Costs for the 8" concrete deck were obtained from INDOT's continuous floor slab design chart. See Appendix D for a copy of this chart. Effective spans were calculated
as the clear span between top flanges for standard girders and the clear span plus one half of the top flange for bulb tees. This design chart includes concrete at $265/cy and both transverse and longitudinal epoxy-coated reinforcing steel at $0.64/lb.

4.4.2 Girder Concrete - $50/cy

This unit cost was selected from survey responses for the girder concrete. This figure reflects material only. Labor, transportation, and construction costs are included in the additional costs at the end of this section.

4.4.3 Prestressing Strands - $0.30/ft

The unit cost of prestressing strands was obtained from the surveys.

4.4.4 Stirrups - $0.45/lb

The stirrups were assumed to be #4 bars. The total number of stirrups required was calculated using the required stirrup spacing obtained from the computer output.
The length of each stirrup was computed as twice the girder height plus 2.3 times the top flange width. This length was found to be representative of the actual stirrup lengths used in the girder sections.

4.4.5 End Straps - $0.45/lb

End straps were assumed to be #3 bars placed at 12" spacing for twice the beam depth at each end. Their length was approximated by 2.3 times the bottom flange width.

4.4.6 Mild Reinforcement - $0.45/lb

Two #6 bars were used for the entire length of the beam.

4.4.7 Additional Cost - $250/cy of girder

This additional cost was chosen to reflect labor, transportation, and construction costs of the alternate sections. It was calculated per cubic yard of girder to reflect the higher costs associated with larger beams. This cost was also used to make the total cost of most alternate
sections representative of their actual cost given in the surveys.

4.4.8 Total Cost

The total cost of each beam is taken as the sum of the above costs. This cost is then plotted as $/lf versus span length at girder spacing of 5, 8, and 10 feet. See Appendix E for details. This comparison provides a detailed analysis of which alternate sections are more cost effective than the AASHTO sections. It should be noted that it is most efficient to place girders at the largest practical girder spacing as has been suggested by Scott and Jacques (5,8).

4.5 Summary

In summary, this section included evaluating the structural efficiency and cost effectiveness of the alternate sections obtained in the first task of the research project. These alternate sections were then compared to the standard sections which Indiana is currently using. Comparisons were made using a structural efficiency factor, a computer program for structural evaluation, and
graphs showing cost effectiveness. The next chapter involves selecting the best beams in each span range for additional evaluation and recommending the final girders to be used in each span range.
CHAPTER 5: FINAL BEAMS AND RECOMMENDATIONS

5.1 Introduction

This task included selecting the best beams in each span range for additional evaluation. Selection was based on least relative material costs as well as comparing criteria influencing the production of these girders. Cross sections and properties of the selected beams were sent to several precasters to obtain comments on their production. Recommendations were then made for the final girders to be used in each span range.

5.2 Selection of Beams

Before selecting beams from the cost versus span length charts developed in Section 4.4 and shown in Appendix E, several constraints were determined. These constraints were specified with the assistance from the Indiana Department of Transportation and the regional office of FHWA. This included minimum web size, end blocks, and depth to span ratios. The minimum web size was selected as 6 or 7 inches. This eliminated any girder with a 5 inch web such as the
Colorado G68. A preference toward 7 inch webs was also noted by INDOT. End blocks were not used in the majority of the girders. Nor were they preferred by most survey participants. Comments from precasters in Section 5.4 were evaluated before eliminating any girders with end blocks. Beams with small depth to span ratios were eliminated from the final selection as recommended by INDOT. This included the Texas 54 and Colorado G68.

Considering the above constraints, the best beams in each span range were then selected from the cost versus span length charts developed in Section 4.4 and shown in Appendix E. The top three girders were first selected based on least material cost. The next two least cost girders were then chosen with a minimum 7 inch web. An INDOT Bulb Tee was also selected for comparison with the best beams in each span range. Appendix F shows the final girders which were selected in each span range. Also shown is the girder's ranking, cross sectional properties, and average strands and stirrups. The rank is based on relative material cost. For example, a rank of 2/24 denotes that the beam is the second cheapest out of 24 beams in this span range. The average strands and stirrups are based on an 8 foot girder spacing at the middle span in each range. For example, the average
strands and stirrups for an 80 foot span were used for the 70 - 90 foot span range.

5.3 Additional Analysis and Comparisons

Once the best beams were selected in each span range, further analysis and comparisons were made before recommending any of these sections. This involved evaluating parameters related to girder production by obtaining comments from precasters in Indiana and Kentucky. Precasters were sent cross sectional properties of the girders as well as reinforcement details. They were asked to compare the cost of producing these alternate sections against the standard AASHTO girders that Indiana is currently using. This included the use of end blocks if they are currently being used with the girder and formwork which was to be assumed standard. In addition, they were asked to comment on any advantages or disadvantages regarding ease of handling and transportation.

Comments received from precasters included recommendations on web sizes, rebar configurations, end blocks, slopes of bottom flanges, handling, and forms. Precasters noted problems with 6" webs due to low slump concrete and reinforcement configurations. End blocks were
not recommended by precasters as they would require extra formwork and labor. One precaster stated that endblocks may double the cost of producing the girder. Precasters also noted problems with flat slope bottom flanges due to low slump concrete, and handling difficulties with thin top flanges. They also commented on the expense of creating new forms for each girder shape. Variable forms were preferred with the option of changing both web and depth dimensions.

5.4 Recommendations

Recommendations were made for the final girders to be used in each span range. This was based on the selection criteria stated in Sections 5.2 and 5.3 which consisted of least relative material costs as well as ease of production. Following are the recommendations in each span range. Detailed information on the final selection is listed in Appendix F.

5.4.1 30-50 Feet

The AASHTO I is ranked first out of 18 girders based on least relative material costs. The AASHTO II girder may
also be used in the upper portion of this span range. The alternate sections evaluated in this range were found to be less economical than the AASHTO sections. No alternate sections are therefore recommended in this span range.

5.4.2 50-70 Feet

The AASHTO III is ranked seventh out of 18 girders based on least relative material costs. The AASHTO II girder may also be used in the lower portion of this span range. Most of the alternate sections which were found to be more economical than the AASHTO sections had 6 inch webs. It is recommended that the AASHTO II and III continue to be used in this span range as no alternate sections provide sufficient savings.

5.4.3 70-90 Feet

The Illinois 54" is ranked second out of 24 girders based on least relative material costs. The AASHTO IV girder may also be used in this span range although it ranked 16 out of 24. Significant savings would not result with the Washington 58G which is ranked first. Therefore it is
recommended that INDOT's current alternate section, the Illinois 54", be used in this span range.

5.4.4 90-110 Feet

The AASHTO V is ranked sixteenth out of 30 girders based on least relative material costs. Significant savings would therefore result by using alternate sections. The table shows six final girders to be more cost effective than the AASHTO V girder. The top three girders were not selected as they had 6 inch webs. The fourth, fifth, and sixth girders had similar costs. The Kentucky 66" was chosen as it had variable forms and is being produced by local precasters. It is therefore recommended as an alternate section for 90-110 feet.

5.4.5 110-130 Feet

The AASHTO VI is ranked nineteenth out of 21 girders based on least relative material costs. Significant savings would therefore result by using alternate sections. The table shows five final girders to be more cost effective than the AASHTO VI girder. The Kentucky 78" and 84" girders
with variable webs are ranked first, third, and fifth. They are therefore recommended as an alternate section for 110-130 feet. This would result in a savings of as much as 20 to 25 percent of the bridge superstructure as can be seen in Appendix J.

5.5 Summary

In summary, this section included selecting the best beams in each span range for additional evaluation. This selection was based on least relative material costs and criteria influencing the production of these girders. This included comments received from precasters in Indiana and Kentucky. No changes were recommended for the 30-90 span range. The Kentucky girders with variable webs and depths were recommended for the final girders to be used for the 90-130 foot span range. This would result in a savings of as much as 20 to 25 percent of the bridge superstructure. The next chapter explains the design aids created for the final girders and the standard AASHTO sections.
CHAPTER 6: DESIGN AIDS

6.1 Introduction

This task included preparing design aids for the final girders selected in Chapter 5 and the standard sections used by INDOT. The design aids were prepared for both simple and continuous spans as well as 6000 and 7000 psi girder concrete. They consist of three steps to select and design prestressed bridge girders. This includes choosing the appropriate girder for a given span range, and determining the required number and layout of prestressing strands.

6.2 Design Aid Analysis

Design aids were created in both SI and metric units to provide an initial prestressed bridge girder selection and design. They are not to be used as final designs, but are to be used as a starting point for the designers. Creation of the design aids was done by using the analysis section of the computer program, "PCBM," developed by Professor Robert H. Lee at Purdue University. This included provisions for simple and continuous spans, 6000 and 7000 psi girder
concrete, and number and layout of prestressing strands. Debonding of strands was also used to satisfy allowable stresses, but will not be shown in the design aids as it will have to be evaluated in the final design process. Also, the weight of intermediate diaphragms, the weight of permanent metal deck forms and the weight of composite loads, i.e. bridge railings, curbs or sidewalks, were not included in this study. These loads will have to be included in the final design process.

Computer runs at various continuous spans or with 7000 psi concrete showed an increase in span capabilities of between 5 and 10 feet when compared to simple spans or 6000 psi concrete. It was therefore decided to create the design aids with simple spans and 6000 psi concrete with a footnote stating that beam spans may increase 5 or 10 feet when using 7000 psi concrete or continuous spans. This was assumed adequate as the design aids are only an initial starting point for the designer and not a final design.

6.3 Step 1: Overall Girder Selection

The first step in the initial design process is to use the Prestressed Concrete I-Beam Selection Chart, found in Appendix G, to select the appropriate girder for a given
span and girder spacing. This chart shows the possible span ranges versus girder spacing for the AASHTO I-IV Series, Illinois 54" and the Kentucky BT Series.

For additional information with regards to economy refer to Appendix J. This chart was created by plotting cost per square foot of deck against girder spans between 30 and 130 feet. It can therefore be used to compare the cost of girders for any width of bridge deck.

Appendix J shows two charts plotted for 30-130 feet. The AASHTO beams, Illinois 54", and Kentucky sections are plotted at 5, 8, and 10 foot girder spacing. The legend is defined as the beam type followed by the girder spacing. For example, AAI-8 denotes the AASHTO I girder at 8' spacing, while KY66-5 denotes the Kentucky 66" girder at 5' spacing. These two charts were then broken down into 4 smaller span ranges to show a more detailed view of the chart. Appendix J shows each of these charts plotted for 30-65 feet, 65-90 feet, 90-110 feet, and 110-130 feet.

6.4 Step 2: Design Aid

The second step in the initial design process is to determine the approximate number of strands required for the girder selected in Step 1. Design aids were created to show
the number of strands plotted against the girder spacing and span. These design aids are shown in Appendix H in both metric (SI) and inch-pound units.

6.5 Step 3: Design Table

The third step in the initial design process is to determine the strand layout for the number of prestressing strands selected in Step 2. The table shows the layout of the bottom prestressing strands as well as the top prestressing strands. The top strands were used to help control tensile stresses near or at the top ends of the girders. For conformity this was done for every girder analyzed, but the actual need of the top strands will have to be evaluated during final design. It also shows the maximum allowable span for the given number of prestressing strands. In addition, the table shows a cross section of the girder as well as relevant properties to aid in the initial design process. These design tables are shown in Appendix I. See the end of Appendix L for reinforcement details.
6.6 Summary

In summary, this task included preparing design aids for the final girders selected in this study as well as the AASHTO standard sections and Illinois 54". The design aids were prepared for simple and continuous spans, and 6000 and 7000 psi concrete. They consist of 3 steps to select and design prestressed bridge girders. This includes choosing the most appropriate and economical girder as well as the required number and layout of prestressing strands. The next chapter summarizes the general conclusions from the work in this study.
CHAPTER 7: SUMMARY AND CONCLUSIONS

7.1 Summary

The objective of this investigation was to evaluate feasible alternatives to the current standard AASHTO bridge girder sections used in the State of Indiana. This included precast pretensioned bridge girders for spans from 30 to 130 feet with girder spacing between 5 and 10 feet and up to 12 feet for the longer spans. Other criteria included girder design concrete compressive strengths up to 7000 psi, 8” total concrete deck thickness with design strength of 4000 psi, grade 60 steel for slab reinforcement and stirrups, and 1/2” special grade 270 low-relaxation strand for prestressing steel. Post-tensioning and pretensioned box girders were outside the scope of the study.

Approximately 100 alternate sections were received from surveys sent to various departments of transportation, consultants, and precasters in the United States. The girder cross sections were then evaluated for their structural efficiency and cost effectiveness. This was done using the computer program, PCBM, developed by Professor Robert H. Lee at Purdue University and currently used by INDOT. Local
precasters were then contacted to obtain further comments on
the possible production of any of these girders.

7.2 Findings/Conclusions

The structural evaluation and cost effectiveness phase
of this study was performed to recommend the best beams in
each span range. Analysis showed the AASHTO I, II, & III
girders to be economical for spans from 30 - 70 feet. No
alternate sections were therefore recommended in this span
range. The Illinois 54” girder was found to be economical
for spans from 70 - 90 feet. Therefore its continued use was
recommended in this span range.

Alternate sections were found to be more economical for
spans over 90 feet. The Kentucky 66” Bulb Tee was
recommended for spans between 90 - 110 feet. The Kentucky
78” Bulb Tee was recommended for spans between 110 - 130
feet to provide considerable savings over the standard
AASHTO girders. This would result in a savings of as much as
20 to 25 percent of the bridge superstructure as can be seen
in Appendix J.

In general, structural evaluation of the alternate
sections showed that bulb tees were more efficient than
standard I-Shaped girders. Spacing beams at the largest possible girder spacing was also found to be the most cost effective.

7.3 Recommendations

The research described in this report supports more efficient alternate sections for use in the State of Indiana as replacements for the current standard AASHTO sections. Results of the study showed that the Kentucky Bulb Tees would provide considerable savings over the standard AASHTO girders in spans from 90 to 130 feet. Their use is therefore recommended to the State of Indiana.

Design Aids were created for these Kentucky Bulb Tees as well as for the AASHTO standards. This was done in metric (SI) and inch-pound units to simplify design of the existing sections and implement design of the proposed Kentucky sections.

The Kentucky sections are currently being produced by local precasters in Kentucky. They have variable forms with webs from 6 to 8 inches and depths from 60 to 78 inches. Adopting these alternate sections would result in savings of as much as 20 to 25 percent of the bridge superstructure.
7.4 Future Work

As prestressed technology advances, there is an increasing need to continue research in the area of bridge girder sections. This research should concentrate on both advances in materials as well as advances in design procedures.

This study supports further research in these areas. Future studies should include the implementation of LRFD design for precast prestressed bridge girders, the use of higher strength concrete in bridge girders, as well as other special topics. These include lateral stability, the use of precast prestressed bridge panels, and increased top flanges for enhanced structural performance. Other research studies are also encouraged and recommended for increased economy in bridge construction.
LIST OF REFERENCES

1. ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI-89)," American Concrete Institute, Detroit, Michigan, 1989.


Appendix A
## Survey Summary for Precast Prestressed Highway Girders

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  - NA
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### DOT

- Indiana
- Washington
- Michigan
- Illinois
- Wisconsin
- Texas
- Ohio
- Kentucky
- Florida
- Pennsylvania
- Virginia
- Colorado

**Information not available**
# Survey Summary for Precast Prestressed Highway Girders

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*LL: Lo-Lax Strands
*SLL: Special Lo-Lax Strands
*SR: Stress Relieved Strands
N/A: Information not available

Note: The table includes information about the spans, beam properties, and concrete strengths for different projects across various states. The properties include the concrete strength (fcl), the maximum concrete strength (max fc), the load weight (lb/ft), and the type of strand (Strands*). The deck type is also noted alongside the concrete weight (lb/ft) and type (Type).
## Survey Summary for Precast Prestressed Highway Girders

### Consultants
- Butler, Faerman & Seufert
- ROAW & Associates
- Sioco
- American Consulting Engr. Bridge Dept.

### Precasters
- Hyland Conduit Corp., W.L.
- Henderson Hydro Cond., Dennis Buttram
- Pressman Services
- UCP Bill Law
- Egerton Concrete Co.
- Elk River Concrete

### DOT
- Indiana
- Washington
- Michigan
- Illinois
- Wisconsin
- Texas
- Ohio
- Kentucky
- Florida
- Pennsylvania
- Virginia
- Colorado

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<th>Load</th>
<th>Draping vs. Debonding</th>
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<th>Cost of Beam Type/$/ft*</th>
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**Notes:**
- *AAA - $50 AASHTO Type I Cost 50 $/ft* "36" Illinois 36" Beam
- "BT74" Bulb Toe 74" N/A Information not available
- "WL4G" Washington 24" Beam A= $39.60 Texas Type A
- "W1670" Wisconsin 76" Beam A= $39.60 Texas Type A
SURVEYS MAILED AND RECEIVED

PRECASTERS:
* Hydro Conduit (Lafayette, Indiana)
  Prestress Services (Decatur, Indiana)
* Hydro Conduit (Henderson, Kentucky)
* Prestress Services (Lexington, Kentucky)
* Essroc (Melbourne, Kentucky)
* Egyptian Concrete Company (Salem, IL)
  Illinois Concrete Company (Champaign, IL)
  Prestress Engineering Corporation (Algonquin, IL)
  Price Brothers-Midwest Inc. (Rochelle, IL)
  Spancrete of Illinois (Crystal Lake, IL)
  County Prestress Corp. (Eau Claire, WI)
  Spancrete Inc. (Green Bay, WI)
  Spancrete Inc. (Waukesha, WI)
  Premarc Corp. (Grand Rapids, MI)
  Superior Products (Taylor, MI)
  Marietta Structures Corp. (Marietta, OH)
* United Precast Inc. (Mt. Vernon, OH)
* Elk River Concrete (Maple Grove, Minnesota)

CONTRACTOR:
Rieth-Riley Construction (Goshen, Indiana).

CONSULTANTS:
* American Consulting Engineers (Indianapolis)
* Butler, Fairman & Sefert (Indianapolis)
  HNTB (Indianapolis)
* RQAW & Assoc. (Indianapolis)
  SECO Engineers (Indianapolis)
* SIECO (Columbus, IN)
  United Consulting Engineers (Indianapolis)

DEPARTMENTS OF TRANSPORTATION:
* Indiana
* Florida
* Illinois
* Kentucky
* Michigan
* Washington
* Texas
* Wisconsin
* Ohio
* Pennsylvania
* Virginia
* Colorado

* Denotes survey has been received
Survey of Current Use of Precast Prestressed AASHTO & Alternate Bridge Girder Sections
(Not including Box Beams)
for Precasters

Design and Construction Details

1. For pretensioning applications, which alternate prestressed concrete girder sections are being used in addition to or instead of the current standard AASHTO I-beam sections? (Also please enclose cross section details of these alternate sections.)

   What are their advantages?

2. Which AASHTO & Alternate prestressed concrete girders are being used for the following spans?
   - 30-45’
   - 40-60’
   - 55-80’
   - 70-100’
   - 90-120’

   Which bridge span range is the most common?

3. When were these alternate sections first used?

4. Which alternate sections would be preferred if made available?

5. What work is presently being done to modify or improve current I-beam sections?

6. What is the longest span built using single pretensioned girders? (not grouped or spliced)

7. Are end blocks required? If so, when are they used?

8. How is bursting (end splitting) reinforcement designed?

9. Is tension in concrete under service load permitted? If so, how much?
10. Which concrete strengths are being utilized? What is the strength at release (fci) and the 28 day strength (fc) for typical pretensioned beam designs? What is the maximum 28 day strength (fc) that a beam designer is allowed to use?

11. What is the weight per cubic foot of the concrete that is utilized?

12. Is lightweight or semi-lightweight concrete being used for bridge girders or decks? If so, what is the 28 day strength and weight per cubic foot?

13. What are the size and grade of prestressing strands being utilized? Are stress-relieved and low-relaxation strands both utilized?

14. What is the maximum girder spacing for pretensioning applications?

15. Are interior diaphragms used? If so, what is the criteria for their spacing?

16. What types of decks are being used with the prestressed girders? If concrete decks are used, what is the concrete design strength?

17. Are stay in place forms being used for concrete decks?

18. What standard highway live loads are the bridge girders designed for? (HS20 or HS25)

19. Are girder design aids for bridge designers available?

Fabrication Details

1. What is the minimum spacing between strands? Is draping or debonding of strands used?

2. Are epoxy coated strands and mild reinforcement being used?

3. What is the minimum concrete cover?

4. What is the limitation on web thickness?

5. What are the restrictions on draping locations?

6. How many precasting plants are in the State?
7. What out of State plants are utilized?
8. What is the normal turn around time for prestressing beds?
9. Are there any new developments in prestressing hardware systems?

Transportation Requirements and Restrictions

1. What is the maximum girder length allowed with and without a permit?
2. What is the maximum girder weight allowed with and without a permit?
3. What is the availability of moving equipment in the yard and on the road?
4. Are there instability problems during transportation and erection?

Availability and Costs

1. What is the cost in place per linear foot of each girder section?
2. What is the cost variation due to concrete strength?
3. How do girder fabrication costs vary for each type of bridge girder fabricated?
   - concrete ($/cy)
   - strands ($/ft)
   - reinforcement ($/lb)
4. What would new forms cost?
5. What are the average labor costs?
6. What could be done to cut down on costs?
7. What are the current hauling costs? ($/kip/mile)
8. What are the State unit prices for cost estimates?

9. What are the availability, capacity and costs for cranes at the plant?

Additional Information

Any additional information or comments would be appreciated. Also please enclose drawings of I-beam or girder sections and design aids if available.
Survey of Current Use of Precast Prestressed AASHTO & Alternate Bridge Girder Sections  
(Not including Box Beams)  
for Consultants

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4. Which alternate sections would be preferred if made available?

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6. What is the longest span built using single pretensioned girders? (not grouped or spliced)

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18. What standard highway live loads are the bridge girders designed for? (HS20 or HS25)

19. Are girder design aids for bridge designers available?

Transportation Requirements and Restrictions

1. What is the maximum girder length allowed with and without a permit?

2. What is the maximum girder weight allowed with and without a permit?

3. What is the availability of moving equipment?

4. Are there instability problems during transportation?
Structural Durability

1. What is the average design life span?
2. What is the frequency of inspection?
3. What problems are generally encountered?
4. Are cracks found in prestressed concrete girders?

Availability and Costs

1. What is the cost in place per linear foot of each girder section?
2. What is the cost in place per square foot of deck?
3. What is the cost per square foot of superstructure?

Additional Information

Any additional information or comments would be appreciated. Also please enclose drawings of I-beam or girder sections and design aids if available.
Survey of Current Use of Precast Prestressed AASHTO & Alternate Bridge Girder Sections
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for State

Design and Construction Details

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Appendix D
EFFECTIVE SPAN IN FEET

DESIGN DATA
1992 AASHTO Standard Specifications
For Highway Bridges (Load Factor Design)

F = 4,000 psi (Class C Concrete)
F = 6,000 psi

H20 Live Load + Impact
L.L. + Impact Moment Formula:

\[ S = \frac{(P + L \cdot B \cdot 0.8 \cdot 1.3)}{32} (\text{kips}) \]

Where S = Effective Span

Alloys For:

1 1/2 inches Veeing Surface
1 Inch Cover
35 psf Future Veeing Surface
15 psf Permanent Metal Forms

EFFECTIVE SPAN

C/C Girder/Beams
Effective Span (b) =
C/C Girder/Beams - 1/2 Flange Vich

STEEL STRUCTURES

EFFECTIVE SPAN

Effective Span (b) = Clear Span

CONCRETE STRUCTURES

CONTINUOUS FLOOR SLAB
DESIGN CHART

Attachment to Bridge Design
Memorandum #246, October 1, 1993

SLAB THICKNESS (IN.)
EST. COST PER SQ. FT.

* The estimated cost includes concrete at 8265/cu yd and both transverse and longitudinal epoxy-coated reinforcing steel at $0.64/lb.
Appendix E
Cost vs Span Length
Beam Spacing at 5 Feet

- 48 w/ 5 foot
- 48 w/ 4 foot
- Penn 24/48
- Penn 26/36
- Colorado BT 42
- Penn 24/45
- Penn 26/33
- Minnesota 45
- Penn 24/36
- Penn 24/42
- Ill. 48'
- AASHTO III
- W50G
- Penn 20/39
- Texas C
- Minnesota 40
- Texas 54
- Missouri 4
- Minnesota 36
Cost vs Span Length
Beam Spacing at 5 Feet

- Penn 26/83
- BT 72 5'-0" Top
- BT 72 4'-6" Top
- AASHTO-PCI V
- 72 w/ 5 foot
- Penn 26/60
- BT 63 4'-8" Top
- 66 w/ 5 foot
- 72 w/ 4 foot
- BT 63 4'-0" Top
- 60 w/ 5 foot
- 72' w/ 6" web
- 66 w/ 4 foot
- AASHTO V
- 66' w/ 8" web
- Penn 24/63
- MOD AASHTO V
- 72' w/ 7" web
- 60' w/ 8" web
- Texas 72
- Colorado BT 72
- 66' w/ 7" web
- Florida BT 63
- 72' w/ 6" web
- Minnesota 72
- 66' w/ 6" web
- Wisconsin 70"
Cost vs Span Length
Beam Spacing at 8 Feet

- 54 w/ 5 foot
- BT 54 4'-0" Top
- 60 w/ 4 foot
- BT 54 3'-6" Top
- 54 w/ 4 foot
- Penn 24/54
- Penn 24/60
- 60" w/ 7" web
- Penn 24/51
- AASHTO IV
- Florida BT 54
- Minnesota 63
- Mod. IV 4' top
- 60" w/ 6" web
- Minnesota 54M
- MOD AASHTO IV
- Mod. IV 2'-2" top
- PCI 63' Bulb Tee
- PCI 54' Bulb Tee
- Missouri 6
- Colorado G 54
- Ill. 54"
- W58G
Cost vs Span Length
Beam Spacing at 10 Feet

- 48 w/ 5 foot
- 48 w/ 4 foot
- Penn 24/48
- Penn 25/36
- Penn 24/45
- Minnesota 45
- Penn 24/36
- Colorado BT 42
- Penn 26/33
- Ill. 48''
- AASHTO III
- Penn 20/39
- Penn 24/42
- Texas C
- Minnesota 40
- W50G
- Texas 54
- Missouri 4

Cost Per Linear Foot ($/lft)

Span Length (ft)
140.00
145.00
150.00
155.00
160.00
165.00
170.00
175.00
180.00
45 50 55 60 65 70 75
Cost vs Span Length
Beam Spacing at 10 Feet
Appendix F
# Properties of the Final Girder

## Span Range 30-50 Feet

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<th>AREA</th>
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## Span Range 50-70 Feet

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<td>7.0</td>
<td>495.5</td>
<td>18</td>
<td>54</td>
</tr>
<tr>
<td>AASHTO III</td>
<td>7/18</td>
<td>45.0</td>
<td>16.0</td>
<td>22.0</td>
<td>7.0</td>
<td>550.0</td>
<td>16</td>
<td>50</td>
</tr>
</tbody>
</table>
## Properties of the Final Girders

### Span Range 70-90 Feet

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>RANK</th>
<th>HEIGHT (in)</th>
<th>TOP FLANGE (in)</th>
<th>BOT FLANGE (in)</th>
<th>WEB (in)</th>
<th>AREA (in^2)</th>
<th>AVG. STRANDS</th>
<th>AVG. STIRRUPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wash. 58G</td>
<td>1/24</td>
<td>58.0</td>
<td>25.0</td>
<td>25.0</td>
<td>6.0</td>
<td>604.5</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>Illinois 54&quot;</td>
<td>2/24</td>
<td>54.0</td>
<td>20.0</td>
<td>22.0</td>
<td>6.0</td>
<td>599.0</td>
<td>24</td>
<td>62</td>
</tr>
<tr>
<td>Colo. G54</td>
<td>3/24</td>
<td>54.0</td>
<td>28.0</td>
<td>24.0</td>
<td>6.0</td>
<td>627.1</td>
<td>22</td>
<td>66</td>
</tr>
<tr>
<td>Missouri 6</td>
<td>4/24</td>
<td>54.0</td>
<td>24.0</td>
<td>24.0</td>
<td>6.5</td>
<td>644.1</td>
<td>22</td>
<td>62</td>
</tr>
<tr>
<td>PCI 54&quot; BT</td>
<td>5/24</td>
<td>54.0</td>
<td>42.0</td>
<td>26.0</td>
<td>6.0</td>
<td>655.5</td>
<td>22</td>
<td>66</td>
</tr>
<tr>
<td>AASHTO IV</td>
<td>16/24</td>
<td>54.0</td>
<td>20.0</td>
<td>26.0</td>
<td>6.0</td>
<td>789.0</td>
<td>24</td>
<td>60</td>
</tr>
<tr>
<td>Indiana BT 54</td>
<td>22/24</td>
<td>54.0</td>
<td>42.0</td>
<td>25.0</td>
<td>7.0</td>
<td>848.0</td>
<td>22</td>
<td>66</td>
</tr>
</tbody>
</table>

Denotes requirement of end blocks.

### Span Range 90-110 Feet

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>RANK</th>
<th>HEIGHT (in)</th>
<th>TOP FLANGE (in)</th>
<th>BOT FLANGE (in)</th>
<th>WEB (in)</th>
<th>AREA (in^2)</th>
<th>AVG. STRANDS</th>
<th>AVG. STIRRUPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wash. 74G</td>
<td>1/30</td>
<td>73.5</td>
<td>43.0</td>
<td>25.0</td>
<td>6.0</td>
<td>745.4</td>
<td>24</td>
<td>66</td>
</tr>
<tr>
<td>PCI 72&quot; BT</td>
<td>2/30</td>
<td>72.0</td>
<td>42.0</td>
<td>26.0</td>
<td>6.0</td>
<td>763.5</td>
<td>24</td>
<td>66</td>
</tr>
<tr>
<td>Wisconsin 70</td>
<td>3/30</td>
<td>70.0</td>
<td>30.0</td>
<td>26.0</td>
<td>6.0</td>
<td>770.0</td>
<td>26</td>
<td>70</td>
</tr>
<tr>
<td>Colo. BT 72</td>
<td>4/30</td>
<td>72.0</td>
<td>43.0</td>
<td>27.0</td>
<td>7.0</td>
<td>860.5</td>
<td>26</td>
<td>70</td>
</tr>
<tr>
<td>Texas 72</td>
<td>5/30</td>
<td>72.0</td>
<td>22.0</td>
<td>22.0</td>
<td>7.0</td>
<td>884.0</td>
<td>26</td>
<td>66</td>
</tr>
<tr>
<td>Ky. 66 w/ 7&quot;</td>
<td>6/30</td>
<td>66.0</td>
<td>35.0</td>
<td>25.0</td>
<td>7.0</td>
<td>834.0</td>
<td>28</td>
<td>74</td>
</tr>
<tr>
<td>* AASHTO V</td>
<td>16/30</td>
<td>72.0</td>
<td>20.0</td>
<td>26.0</td>
<td>8.0</td>
<td>933.0</td>
<td>26</td>
<td>66</td>
</tr>
<tr>
<td>Indiana BT 63</td>
<td>22/30</td>
<td>63.0</td>
<td>48.0</td>
<td>25.0</td>
<td>7.0</td>
<td>942.8</td>
<td>30</td>
<td>78</td>
</tr>
</tbody>
</table>

* INDOT version of AASHTO Type V girder
# Properties of the Final Girders

**Span Range**: 110-130 Feet

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>RANK</th>
<th>HEIGHT (in.)</th>
<th>TOP FLANGE (in.)</th>
<th>BOT FLANGE (in.)</th>
<th>WEB (in.)</th>
<th>AREA (in.²)</th>
<th>AVG. STRANDS</th>
<th>AVG. STIRRUPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ky. 78 w/ 6&quot;</td>
<td>1/21</td>
<td>78.0</td>
<td>34.0</td>
<td>24.0</td>
<td>6.0</td>
<td>840.0</td>
<td>36</td>
<td>84</td>
</tr>
<tr>
<td>Minn. 81</td>
<td>2/21</td>
<td>81.0</td>
<td>30.0</td>
<td>26.0</td>
<td>6.0</td>
<td>838.8</td>
<td>32</td>
<td>82</td>
</tr>
<tr>
<td>Ky. 84 w/ 6&quot;</td>
<td>3/21</td>
<td>84.0</td>
<td>34.0</td>
<td>24.0</td>
<td>6.0</td>
<td>875.0</td>
<td>32</td>
<td>76</td>
</tr>
<tr>
<td>Colo. BT 84</td>
<td>4/21</td>
<td>84.0</td>
<td>43.0</td>
<td>27.0</td>
<td>7.0</td>
<td>944.5</td>
<td>32</td>
<td>80</td>
</tr>
<tr>
<td>Ky. 78 w/ 7&quot;</td>
<td>5/21</td>
<td>78.0</td>
<td>35.0</td>
<td>25.0</td>
<td>7.0</td>
<td>918.0</td>
<td>36</td>
<td>82</td>
</tr>
<tr>
<td>Indiana BT 78</td>
<td>12/21</td>
<td>78.0</td>
<td>42.0</td>
<td>25.0</td>
<td>7.0</td>
<td>1016.0</td>
<td>36</td>
<td>84</td>
</tr>
<tr>
<td>AASHTO VI</td>
<td>18/21</td>
<td>72.0</td>
<td>42.0</td>
<td>28.0</td>
<td>8.0</td>
<td>1072.8</td>
<td>40</td>
<td>90</td>
</tr>
</tbody>
</table>

*Denotes requirement of end blocks.*
Appendix G
PRESTRESSED CONCRETE I-BEAM SELECTION CHART

KENTUCKY BT's w/ 7" Web

60"  66"  72"  78"

DATA:
1) 6 1/2" Comp. Slab f'c 4000
2) AASHTO HS20 L.L.
3) 35 PSF Future Surface
4) Girder f'c = 6000 psi
5) Girder f'ci = 4500 psi

GIRDER SPACING (feet)

AASHTO I  AASHTO II  AASHTO III  Illinois 54  AASHTO IV

SIMPLE SPAN (feet)

25  35  45  55  65  75  85  95  105  115  125  135  145

Beam spans may increase 5 to 10 feet when using 7000 psi concrete or continuous spans.
PRESTRESSED CONCRETE I-BEAM
SELECTION CHART (METRIC)

DATA:
1) 16.5 cm Comp.
   Slab f'c 27.6 MPa
2) AASHTO HS20 L.L.
3) 1675 Pa Future Surface
4) Girder f'c = 41.4 MPa
5) Girder f'ci = 31.0 MPa

KENTUCKY BT's w/ 7" Web
60°  66°  72°  78°

AASHTO I  AASHTO II  AASHTO III  Illinois 54  AASHTO IV

GIRDER SPACING (meters)

SIMPLE SPAN (meters)

Beam spans may increase 1.5 to 3 meters when using 48.3 MPa concrete or continuous spans.
DESIGN AID
AASHTO I
HS20  f'c = 6000 psi
f'ci = 4500 psi

N = Number of bottom prestressing strands.

GIRDER SPACING (feet)

SIMPLE SPAN (feet)

N = 12
N = 10
N = 8
N = 6
DESIGN AID
AASHTO II
HS20 f_c = 6000 psi
f_{ci} = 4500 psi

N = Number of bottom prestressing strands.
DESIGN AID
AASHTO III
HS20  f'_c = 6000 psi
f'_ci = 4500 psi

GIRDER SPACING (feet)

N = 16
N = 20
N = 22

N = 14
N = 12
N = 10

N = 8

SIMPLE SPAN (feet)

N = Number of bottom prestressing strands.
DESIGN AID
Illinois 54"
HS20  $f_c = 6000$ psi
$f_{ci} = 4500$ psi

$N = 22$  $N = 26$

$N = 20$

$N = 16$

$N = 14$

$N = 12$

$N = $ Number of bottom prestressing strands.
DESIGN AID
AASHTO IV
HS20  f_c = 6000 psi
f_ci = 4500 psi

N = Number of bottom prestressing strands.
DESIGN AID
Kentucky BT 60" w/ 7" Web
HS20 \( f_c = 6000 \text{ psi} \)
\( f_{cl} = 4500 \text{ psi} \)

\( N = 24 \quad N = 27 \quad N = 32 \)
\( N = 22 \)
\( N = 20 \)
\( N = 18 \)
\( N = 16 \)
\( N = 14 \)
\( N = 12 \)

ORDER SPACING (feet)

SPAN LENGTH (feet)

\( N \) = Number of prestressing strands.
DESIGN AID
Kentucky BT 66" w/ 7" Web
HS20  fc = 6000 psi
fci = 4500 psi

N = Number of prestressing strands.
DESIGN AID
Kentucky 72" w/ 7" Web
HS20  f_c = 6000 psi
f_cl = 4500 psi

N = Number of prestressing strands.
DESIGN AID
Kentucky BT 78" w/ 7" Web
HS20  fc = 6000 psi
fci = 4500 psi

N = 27  N = 30  N = 34  N = 38
N = 24
N = 22
N = 20
N = 18
N = 17
N = 15
N = 14

5  6  7  8  9  10  11  12  13
85 90 95 100 105 110 115 120 125 130

GRIDER SPACING (feet)
SPAN LENGTH (feet)
N = Number of prestressing strands.
N = Number of bottom prestressing strands.
METRIC DESIGN AID
AASHTO II
HS20  f_c = 41.4 MPa
f_{ci} = 31.0 MPa

GIRDER SPACING (meters)

N = 14  N = 16
N = 12
N = 10
N = 8
N = 6

SIMPLE SPAN (meters)

N = Number of bottom prestressing strands.
METRIC DESIGN AID
AASHTO III
HS20 $f_c = 41.4$ MPa
$f_{ci} = 31.0$ MPa

$N = 16$  $N = 20$  $N = 22$

$N = 14$

$N = 12$

$N = 10$

$N = 8$

SIMPLE SPAN (meters)

GIRDERS SPACING (meters)

$N =$ Number of bottom prestressing strands.
METRIC DESIGN AID
Illinois 54"
HS20 f_c = 41.4 MPa
f_{ci} = 31.0 MPa

GIRDER SPACING (meters)

N = 22
N = 20
N = 16
N = 14
N = 12

SIMPLE SPAN (meters)

N = Number of bottom prestressing strands.
METRIC DESIGN AID
AASHTO IV
HS20  $f_c = 41.4$ MPa
  $f_{ci} = 31.0$ MPa

GIRDER SPACING (meters)

SIMPLE SPAN (meters)

$N =$ Number of bottom prestressing stands.
METRIC DESIGN AID
Kentucky BT 60" w/ 7" Web
HS20  \(f_c = 41.4 \text{ MPa}\)
\(f_{ci} = 31.0 \text{ MPa}\)

\[\begin{align*}
N &= 24 & N &= 27 & N &= 32 \\
N &= 22 & N &= 30 & N &= 32 \\
N &= 20 & N &= 28 & N &= 32 \\
N &= 18 & N &= 26 & N &= 32 \\
N &= 16 & N &= 24 & N &= 32 \\
N &= 14 & N &= 22 & N &= 36 \\
N &= 12 & N &= 20 & N &= 36
\end{align*}\]

GIRDER SPACING (meters)

SIMPLE SPAN (meters)

\(N\) = Number of bottom prestressing strands.
METRIC DESIGN AID
Kentucky BT 66" w/ 7" Web
HS20  $f_c = 41.4$ MPa
$f_{cl} = 31.0$ MPa

$N = 36$
$N = 32$
$N = 27$
$N = 24$
$N = 22$
$N = 20$
$N = 18$
$N = 16$

$N = 38$

$N = \text{Number of bottom prestressing strands.}$
METRIC DESIGN AID
Kentucky BT 72" w/ 7" Web
HS20  $f_c = 41.4 \text{ MPa}$
$f_{ci} = 31.0 \text{ MPa}$

N = 30  N = 34  N = 38
N = 27
N = 24
N = 22
N = 20
N = 18
N = 16
N = 14

GIRDER SPACING (meters)

SIMPLE SPAN (meters)

$N =$ Number of bottom prestressing strands.
METRIC DESIGN AID
Kentucky BT 78" w/ 7" Web
HS20 $f_c = 41.4$ MPa
$f_{cl} = 31.0$ MPa

$N = 27$  $N = 30$  $N = 34$  $N = 38$

$N = 24$

$N = 22$

$N = 20$

$N = 18$

$N = 17$

$N = 15$

$N = 14$

GIRDERS SPACING (meters)

SIMPLE SPAN (meters)

$N =$ Number of bottom prestressing strands.
Appendix I
AASHTO TYPE I

Girder Section Properties
- A = 276.00 in^2
- I = 22,744.00 in^4
- Sb = 1,807.00 in^3
- St = 1,476.00 in^3
- Yb = 12.59 in
- Yt = 15.41 in
- f'c = 6,000 psi
- f'ci = 4,500 psi

Strand Properties
- Seven-Wire Special Low-Lax Strands
  - A = 0.167 in^2
  - fpu = 270,000 psi

Deck Properties
- Slab = 6.50 in
- Top = 1.50 in
- f'c = 4,000 psi
- fy = 60,000 psi

Design Table
All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 6</td>
<td>6</td>
<td>2</td>
<td>35</td>
<td>10.7</td>
</tr>
<tr>
<td>N = 8</td>
<td>6</td>
<td>2</td>
<td>40</td>
<td>12.2</td>
</tr>
<tr>
<td>N = 10</td>
<td>6</td>
<td>4</td>
<td>45</td>
<td>13.7</td>
</tr>
<tr>
<td>N = 12</td>
<td>6</td>
<td>6</td>
<td>40</td>
<td>12.2</td>
</tr>
</tbody>
</table>
AASHTO TYPE II

Girder Section Properties

\[
\begin{align*}
A &= 369.00 \text{ in}^2 \\
I &= 50,979.00 \text{ in}^4 \\
S_b &= 3,221.00 \text{ in}^3 \\
S_t &= 2,527.00 \text{ in}^3 \\
Y_b &= 15.83 \text{ in} \\
Y_t &= 20.17 \text{ in} \\
f_c &= 6,000 \text{ psi} \\
f_{ci} &= 4,500 \text{ psi}
\end{align*}
\]

Strand Properties

Seven-Wire Special Low-Lax Strands

\[
\begin{align*}
A &= 0.167 \text{ in}^2 \\
f_{pu} &= 270,000 \text{ psi}
\end{align*}
\]

Deck Properties

\[
\begin{align*}
\text{Slab} &= 6.50 \text{ in} \\
\text{Top} &= 1.50 \text{ in} \\
f_c &= 4,000 \text{ psi} \\
f_y &= 60,000 \text{ psi}
\end{align*}
\]

Design Table

All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 6</td>
<td>6 6</td>
<td>2</td>
<td>40</td>
<td>12.2</td>
</tr>
<tr>
<td>N = 8</td>
<td>8</td>
<td>2 2</td>
<td>45</td>
<td>13.7</td>
</tr>
<tr>
<td>N = 10</td>
<td>8 8 2</td>
<td>2</td>
<td>50</td>
<td>15.2</td>
</tr>
<tr>
<td>N = 12</td>
<td>8 4</td>
<td>2</td>
<td>55</td>
<td>16.8</td>
</tr>
<tr>
<td>N = 14</td>
<td>8 6</td>
<td>2</td>
<td>60</td>
<td>18.3</td>
</tr>
<tr>
<td>N = 16</td>
<td>8 8</td>
<td>3</td>
<td>65</td>
<td>19.8</td>
</tr>
</tbody>
</table>
**AASHTO TYPE III**

**Girder Section Properties**

- $A = 560.00 \text{ in}^2$
- $l = 125,390.00 \text{ in}^4$
- $S_b = 6,185.00 \text{ in}^3$
- $S_t = 5,071.00 \text{ in}^3$
- $Y_b = 20.27 \text{ in}$
- $Y_t = 24.73 \text{ in}$
- $f'_c = 6,000 \text{ psi}$
- $f_{ci} = 4,500 \text{ psi}$

**Strand Properties**

- Seven-Wire Special Low-Lax Strands
  - $A = 0.167 \text{ in}^2$
  - $f_{pu} = 270,000 \text{ psi}$

**Deck Properties**

- Slab $= 6.50 \text{ in}$
- Top $= 1.50 \text{ in}$
- $f'_c = 4,000 \text{ psi}$
- $f_y = 60,000 \text{ psi}$

**Design Table**

*All straight strands, no draping.*

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strands Required</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>N = 8</td>
<td>8</td>
<td>2</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>N = 10</td>
<td>10</td>
<td>2</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>N = 12</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>65</td>
</tr>
<tr>
<td>N = 14</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>N = 16</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>75</td>
</tr>
<tr>
<td>N = 20</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>N = 22</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>85</td>
</tr>
</tbody>
</table>
ILLINOIS 54"

Girder Section Properties

\[ A = 599.00 \text{ in}^2 \]
\[ I = 213,721.00 \text{ in}^4 \]
\[ S_b = 8,559.00 \text{ in}^3 \]
\[ S_t = 7,362.00 \text{ in}^3 \]
\[ Y_b = 24.97 \text{ in} \]
\[ Y_t = 29.03 \text{ in} \]
\[ f_c = 6,000 \text{ psi} \]
\[ f_{ci} = 4,500 \text{ psi} \]

Strand Properties

Seven-Wire Special Low-Lax Strands
\[ A = 0.167 \text{ in}^2 \]
\[ f_{pu} = 270,000 \text{ psi} \]

Deck Properties

\[ \text{Slab} = 6.50 \text{ in} \]
\[ \text{Top} = 1.50 \text{ in} \]
\[ f_c = 4,000 \text{ psi} \]
\[ f_y = 60,000 \text{ psi} \]

Design Table

All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 12</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>N = 14</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>N = 16</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>65</td>
</tr>
<tr>
<td>N = 20</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>N = 22</td>
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<td>10</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>N = 26</td>
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<td>10</td>
<td>6</td>
<td>100</td>
</tr>
</tbody>
</table>
AASHTO TYPE IV

Girder Section Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>789.00 in²</td>
</tr>
<tr>
<td>I</td>
<td>260,741.00 in⁴</td>
</tr>
<tr>
<td>Sb</td>
<td>10,542.00 in³</td>
</tr>
<tr>
<td>St</td>
<td>8,909.00 in³</td>
</tr>
<tr>
<td>Yb</td>
<td>24.73 in</td>
</tr>
<tr>
<td>Yt</td>
<td>29.27 in</td>
</tr>
<tr>
<td>f_c</td>
<td>6,000 psi</td>
</tr>
<tr>
<td>f_ci</td>
<td>4,500 psi</td>
</tr>
</tbody>
</table>

Strand Properties

- Seven-Wire Special Low-Lax Strands
  - A
  - fp
  - A = 0.167 in²
  - fp = 270,000 psi

Deck Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab</td>
<td>6.50 in</td>
</tr>
<tr>
<td>Top</td>
<td>1.50 in</td>
</tr>
<tr>
<td>f_c</td>
<td>4,000 psi</td>
</tr>
<tr>
<td>f_y</td>
<td>60,000 psi</td>
</tr>
</tbody>
</table>

Design Table

- All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 13</td>
<td>11</td>
<td>2</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>N = 14</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>75</td>
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<tr>
<td>N = 16</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>N = 17</td>
<td>11</td>
<td>6</td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td>N = 21</td>
<td>11</td>
<td>10</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>N = 24</td>
<td>11</td>
<td>11</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>N = 26</td>
<td>11</td>
<td>11</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>N = 30</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>105</td>
</tr>
<tr>
<td>N = 35</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>110</td>
</tr>
</tbody>
</table>
KENTUCKY BT 60" w/ 7" WEB

Girder Section Properties

- \( A = 792.00 \text{ in}^2 \)
- \( I = 361,830.00 \text{ in}^4 \)
- \( Sb = 12,740.00 \text{ in}^3 \)
- \( St = 11,451.00 \text{ in}^3 \)
- \( Yb = 28.40 \text{ in} \)
- \( Yt = 31.60 \text{ in} \)
- \( fc = 6,000 \text{ psi} \)
- \( fcd = 4,500 \text{ psi} \)

Strand Properties

Seven-Wire Special Low-Lax Strands

- \( A = 0.167 \text{ in}^2 \)
- \( fpu = 270,000 \text{ psi} \)

Deck Properties

- Slab = 6.50 in
- Top = 1.50 in
- \( fc = 4,000 \text{ psi} \)
- \( fy = 60,000 \text{ psi} \)

Design Table

All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N = 12 )</td>
<td>10 10 2</td>
<td>2 2</td>
<td>75</td>
<td>22.9</td>
</tr>
<tr>
<td>( N = 14 )</td>
<td>10 10 4</td>
<td>2 2</td>
<td>80</td>
<td>24.4</td>
</tr>
<tr>
<td>( N = 16 )</td>
<td>10 10 6</td>
<td>2 2</td>
<td>85</td>
<td>25.9</td>
</tr>
<tr>
<td>( N = 18 )</td>
<td>10 10 8</td>
<td>2 2</td>
<td>90</td>
<td>27.4</td>
</tr>
<tr>
<td>( N = 20 )</td>
<td>10 10 10</td>
<td>2 2</td>
<td>95</td>
<td>29.0</td>
</tr>
<tr>
<td>( N = 22 )</td>
<td>10 10 10 2</td>
<td>2 2</td>
<td>100</td>
<td>30.5</td>
</tr>
<tr>
<td>( N = 24 )</td>
<td>10 10 10 4</td>
<td>2 2</td>
<td>105</td>
<td>32.0</td>
</tr>
<tr>
<td>( N = 27 )</td>
<td>10 10 10 7</td>
<td>2 2</td>
<td>110</td>
<td>33.5</td>
</tr>
<tr>
<td>( N = 32 )</td>
<td>10 10 10 10 2</td>
<td>2 2</td>
<td>110</td>
<td>33.5</td>
</tr>
<tr>
<td>( N = 36 )</td>
<td>10 10 10 10 6</td>
<td>3 3</td>
<td>110</td>
<td>33.5</td>
</tr>
</tbody>
</table>
KENTUCKY BT 66" w/ 7" WEB

Girder Section Properties
\[ A = 834.00 \text{ in}^2 \]
\[ I = 462,009.00 \text{ in}^4 \]
\[ S_b = 14,807.00 \text{ in}^3 \]
\[ S_l = 13,276.00 \text{ in}^3 \]
\[ Y_b = 31.20 \text{ in} \]
\[ Y_l = 34.80 \text{ in} \]
\[ f_c = 6,000 \text{ psi} \]
\[ f_{ci} = 4,500 \text{ psi} \]

Strand Properties

Seven-Wire Special Low-Lax Strands
\[ A = 0.167 \text{ in}^2 \]
\[ f_{pu} = 270,000 \text{ psi} \]

Deck Properties

\[ \text{Slab} = 6.50 \text{ in} \]
\[ \text{Top} = 1.50 \text{ in} \]
\[ f_c = 4,000 \text{ psi} \]
\[ f_y = 60,000 \text{ psi} \]

Design Table

All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>N = 16</td>
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<td></td>
</tr>
<tr>
<td>N = 18</td>
<td>10</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N = 20</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N = 22</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>N = 24</td>
<td>10</td>
<td>10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>N = 27</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>N = 32</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>N = 36</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>N = 38</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>
KENTUCKY BT 72" W/ 7" WEB

Girder Section Properties

- $A = 876.00 \text{ in}^2$
- $I = 577,140.00 \text{ in}^4$
- $S_b = 15,196.00 \text{ in}^3$
- $S_t = 34.02 \text{ in}$
- $Y_b = 37.98 \text{ in}$
- $f_c = 6,000 \text{ psi}$
- $f_{ci} = 4,500 \text{ psi}$

Strand Properties

- Seven-Wire Special Low-Lax Strands
- $A = 0.167 \text{ in}^2$
- $f_{pu} = 270,000 \text{ psi}$

Deck Properties

- Slab = 6.50 in
- Top = 1.50 in
- $f_c = 4,000 \text{ psi}$
- $f_y = 60,000 \text{ psi}$

Design Table

All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 14</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>N = 16</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>N = 18</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>N = 20</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>105</td>
</tr>
<tr>
<td>N = 22</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>110</td>
</tr>
<tr>
<td>N = 24</td>
<td>10</td>
<td>10</td>
<td>4</td>
<td>115</td>
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<td>10</td>
<td>7</td>
<td>120</td>
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<td>N = 30</td>
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<td>10</td>
<td>10</td>
<td>125</td>
</tr>
<tr>
<td>N = 34</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>130</td>
</tr>
<tr>
<td>N = 38</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>130</td>
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<td>8</td>
<td>39.6</td>
</tr>
</tbody>
</table>
KENTUCKY BT 78" w/ 7" WEB

Girder Section Properties

\[
\begin{align*}
A &= 918.00 \text{ in}^2 \\
I &= 707,986.00 \text{ in}^4 \\
S_b &= 19,210.00 \text{ in}^3 \\
S_l &= 17,208.00 \text{ in}^3 \\
Y_b &= 36.86 \text{ in} \\
Y_l &= 41.14 \text{ in} \\
f'c &= 6,000 \text{ psi} \\
f'c_l &= 4,500 \text{ psi}
\end{align*}
\]

Strand Properties

Seven-Wire Special Low-Lax Strands

\[
\begin{align*}
A &= 0.187 \text{ in}^2 \\
f_{pu} &= 270,000 \text{ psi}
\end{align*}
\]

Deck Properties

\[
\begin{align*}
\text{Slab} &= 6.50 \text{ in} \\
\text{Top} &= 1.50 \text{ in} \\
f'c &= 4,000 \text{ psi} \\
f_y &= 60,000 \text{ psi}
\end{align*}
\]

Design Table

All straight strands, no draping.

<table>
<thead>
<tr>
<th>Strands Required</th>
<th>Bottom Rows</th>
<th>Top Rows</th>
<th>Maximum Span (feet)</th>
<th>Maximum Span (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 14</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>N = 15</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>N = 17</td>
<td>10</td>
<td>7</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>N = 18</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>105</td>
</tr>
<tr>
<td>N = 20</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>110</td>
</tr>
<tr>
<td>N = 22</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>115</td>
</tr>
<tr>
<td>N = 24</td>
<td>10</td>
<td>10</td>
<td>4</td>
<td>120</td>
</tr>
<tr>
<td>N = 27</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>125</td>
</tr>
<tr>
<td>N = 30</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>130</td>
</tr>
<tr>
<td>N = 34</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>130</td>
</tr>
<tr>
<td>N = 38</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>130</td>
</tr>
</tbody>
</table>
Appendix J
### BEAM AND DECK COSTS FOR 12' SPACING

<table>
<thead>
<tr>
<th>Unit Costs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Concrete (6000 psi)</td>
<td>50</td>
<td>$/yard</td>
</tr>
<tr>
<td>Strands</td>
<td>0.30</td>
<td>cft</td>
</tr>
<tr>
<td>Stirrups</td>
<td>0.45</td>
<td>cft</td>
</tr>
<tr>
<td>End Straps</td>
<td>0.45</td>
<td>cft</td>
</tr>
<tr>
<td>Beam Mild Rein.</td>
<td>0.45</td>
<td>cft</td>
</tr>
<tr>
<td>Additional Costs</td>
<td>250</td>
<td>$/yard</td>
</tr>
</tbody>
</table>

#4 bars. Estimated length is 2’ height + 2.3’ top flange width.
#3 bars at 12 in. for below the beam depth at each end. Estimated length is 2.3’ bottom flange

### BEAM SPACING

<table>
<thead>
<tr>
<th>BEAM SPACING</th>
<th>12 FEET</th>
</tr>
</thead>
</table>

### STRANDS & STIRRUPS (SLF)

<table>
<thead>
<tr>
<th>BEAM TYPES</th>
<th>SPAN (ft)</th>
<th>LR. SPAN</th>
<th>DECK COSTS</th>
<th>BEAM CONCRETE</th>
<th>ADD'ED COST</th>
<th>END STRAPS</th>
<th>MILD REIN</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KY 80&quot; w/ 7&quot; web</td>
<td>75-50</td>
<td>10.84</td>
<td>11.27</td>
<td>135.24</td>
<td>10.19</td>
<td>50.89</td>
<td>18.22</td>
<td>1.36</td>
<td>13.90</td>
<td>14.60</td>
</tr>
<tr>
<td>KY 66&quot; w/ 7&quot; web</td>
<td>90-95</td>
<td>10.84</td>
<td>11.27</td>
<td>135.24</td>
<td>10.73</td>
<td>53.89</td>
<td>17.54</td>
<td>1.35</td>
<td>18.02</td>
<td>16.80</td>
</tr>
<tr>
<td>KY 72&quot; w/ 7&quot; web</td>
<td>90-100</td>
<td>10.84</td>
<td>11.27</td>
<td>135.24</td>
<td>11.27</td>
<td>58.33</td>
<td>18.48</td>
<td>1.36</td>
<td>18.90</td>
<td>17.42</td>
</tr>
<tr>
<td>KY 76&quot; w/ 7&quot; web</td>
<td>90-105</td>
<td>10.84</td>
<td>11.27</td>
<td>135.24</td>
<td>11.81</td>
<td>59.63</td>
<td>21.09</td>
<td>1.35</td>
<td>14.85</td>
<td>18.11</td>
</tr>
</tbody>
</table>

### BEAM & DECK COSTS (SALF)

<table>
<thead>
<tr>
<th>BEAM &amp; DECK COSTS (SALF)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SPAN 1</td>
<td>211.74</td>
<td>212.72</td>
<td>214.41</td>
</tr>
<tr>
<td>SPAN 2</td>
<td>219.16</td>
<td>219.93</td>
<td></td>
</tr>
<tr>
<td>SPAN 3</td>
<td>220.40</td>
<td>221.81</td>
<td>223.09</td>
</tr>
<tr>
<td>SPAN 4</td>
<td>222.81</td>
<td>223.78</td>
<td>225.08</td>
</tr>
</tbody>
</table>
## Beam and Deck Costs for 10' Spacing

| Beam Concrete (6000 psi) | $50 per yard
| Strands | 0.30 cft.
| Stirrups | 0.45 cft.
| End Straps | 0.45 cft.
| Ties TID 90 | 0.45 cft.
| Additional Costs | $250 per yard

### Beam Spacing: 10 Feet

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Span (ft)</th>
<th>Width (ft)</th>
<th>Deck Costs</th>
<th>Steel</th>
<th>Concrete</th>
<th>Steel</th>
<th>Concrete</th>
<th>Mild Steel</th>
<th>Steel</th>
<th>Concrete</th>
<th>Steel</th>
<th>Concrete</th>
<th>Steel</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO I</td>
<td>30</td>
<td>10.47</td>
<td>104.70</td>
<td>5.83</td>
<td>17.25</td>
<td>4.84</td>
<td>1.35</td>
<td>6.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO III</td>
<td>50</td>
<td>10.47</td>
<td>104.70</td>
<td>7.20</td>
<td>38.01</td>
<td>10.70</td>
<td>1.55</td>
<td>9.81</td>
<td>10.04</td>
<td>50.73</td>
<td>10.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO IV</td>
<td>70</td>
<td>10.47</td>
<td>104.70</td>
<td>9.24</td>
<td>36.82</td>
<td>12.84</td>
<td>1.35</td>
<td>9.30</td>
<td>10.51</td>
<td>51.28</td>
<td>12.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois 54</td>
<td>50-75</td>
<td>10.47</td>
<td>104.70</td>
<td>10.19</td>
<td>50.82</td>
<td>14.22</td>
<td>1.15</td>
<td>11.06</td>
<td>12.38</td>
<td>51.73</td>
<td>15.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KY 90&quot; w/ 1&quot; web</td>
<td>70-90</td>
<td>10.47</td>
<td>104.70</td>
<td>10.19</td>
<td>50.82</td>
<td>14.22</td>
<td>1.15</td>
<td>11.06</td>
<td>12.38</td>
<td>51.73</td>
<td>15.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KY 90&quot; w/ 1.5&quot; web</td>
<td>90-100</td>
<td>10.47</td>
<td>104.70</td>
<td>10.71</td>
<td>53.83</td>
<td>17.84</td>
<td>1.35</td>
<td>14.26</td>
<td>15.88</td>
<td>57.39</td>
<td>17.90</td>
<td></td>
<td></td>
<td></td>
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### BEAM AND DECK COSTS FOR 5' SPACING

#### Unit Costs

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#### BEAM SPACING

5' PER FT

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<th>SFL</th>
<th>RAW CONCRETE (Ft)</th>
<th>ADED CONCRETE (Ft)</th>
<th>END STRIPS (Ft)</th>
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<th>COSTS (Ft)</th>
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### BEAM & DECK COSTS (Ft)

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COST SAVINGS EXAMPLES
3 SPAN 48' WIDE TYPICAL BRIDGE

EXAMPLE 1

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<th>SPACING (feet)</th>
<th>SPAN (feet)</th>
<th>WIDTH (feet)</th>
<th>COST ($/sf)</th>
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SAVINGS

EXAMPLE 2

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<th>SPAN (feet)</th>
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SAVINGS

EXAMPLE 3

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<th>WIDTH (feet)</th>
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SAVINGS

Note: Costs are for superstructure only (beam and deck)
AASHTO GIRDER SELECTION
30-130 Feet  f'c = 6000 psi
f'ci = 4500 psi

Beam spans may increase 5 to 10 feet when using 7000 psi concrete or continuous spans.
Beam spans may increase 5 to 10 feet when using 7000 psi concrete or continuous spans.
GIRDER SELECTION
30-65 Feet $f_c = 6000$ psi
$f_{cl} = 4500$ psi

COST PER SQUARE FOOT ($/ft^2$)

SIMPLE SPAN (feet)
GIRDER SELECTION
65-90 Feet  f_c = 6000 psi
f'ci = 4500 psi

COST PER SQUARE FOOT ($/sf)

AASHTO III - 5ft
AASHTO IV - 8ft
Illinois 54 - 8ft
AASHTO IV - 10ft
Kentucky 60" - 8ft
Kentucky 60" - 10ft
Illinois 54 - 10ft

SIMPLE SPAN (feet)
Appendix K
Nebraska University Proposed Girder Series.