AASHTO/NSBA G13.1, GUIDELINES FOR STEEL GIRDER BRIDGE ANALYSIS – A SYNOPSIS

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SUMMARY

In May 2007, the AASHTO/NSBA Steel Bridge Collaboration created its Task Group 13 (TG13), focused on analysis of steel bridges. For the next four years, the primary mission of TG13 was to create a guideline document addressing the analysis of steel girder bridges. The resulting document is a comprehensive 150-page compendium of guidance on a variety of steel girder bridge analysis topics. It was adopted by the AASHTO Subcommittee on Bridges and Structures (AASHTO SCOBS) in May 2011 and published by AASHTO in August 2011. This paper presents a brief synopsis of the development and contents of the guideline document, which is titled G13.1, *Guidelines for Steel Girder Bridge Analysis*.

AASHTO/NSBA G13.1, GUIDELINES FOR STEEL GIRDER BRIDGE ANALYSIS – A SYNOPSIS

Introduction

In May 2007, the AASHTO/NSBA Steel Bridge Collaboration created its Task Group 13, focused on analysis of steel bridges. For the next four years, the primary mission of Task Group 13 was the creation of a guideline document addressing the analysis of steel girder bridges. The resulting document – a comprehensive 150-page compendium of guidance on a variety of steel girder bridge analysis topics – was adopted by the AASHTO Subcommittee on Bridges and Structures (AASHTO SCOBS) in May 2011 and published by AASHTO in August 2011. This paper presents a brief synopsis of the development and contents of the document, which is titled Guideline G13.1, Analysis of Steel Girder Bridges.

The four-year effort involved in creating G13.1 represents a collaborative effort on the part of numerous professionals in the steel bridge industry from all across the nation. Participation covered all aspects of the industry, including owners, designers, fabricators, erectors, software providers and academic researchers, resulting in guidelines that truly represent consensus recommendations. The document is intended to supplement existing design codes and specifications and serve as one of many sources of guidance to bridge designers.

Development of G13.1

The AASHTO/NSBA Steel Bridge Collaboration (the Collaboration) is an affiliation of professionals in the steel bridge industry. As stated on the Collaboration's website, Reference (1):

"The mission of the Collaboration is to achieve quality and value in steel bridges by standardization of design, fabrication and erection and by the sharing of resources. Through the Collaboration, steel bridge professionals work together in a spirit of cooperation and mutual respect to develop details, specifications and practices and to exchange knowledge, technology and expertise. The [Collaboration] is a joint effort between AASHTO and the National Steel Bridge Alliance (NSBA) with representatives from state Departments of Transportation (DOTs), the Federal Highway Administration, academia, and the various industries related to steel bridge design, fabrication and inspection. The purpose of the Collaboration is to provide a forum where public and private professionals can work together to improve the quality and value of steel bridges."

The Collaboration meets regularly, generally twice a year, in various locations throughout the U.S., and further coordinates between meetings via e-mail, conference calls, etc.

In May 2007, the AASHTO/NSBA Steel Bridge Collaboration initiated its thirteenth subcommittee, called Task Group 13 – Analysis (TG 13), at the Collaboration's meeting in Atlantic City, NJ. The mission of TG 13 was to develop consensus recommendations regarding the analysis of steel bridges – to share and disseminate the collective knowledge of steel bridge professionals from across the nation for the betterment of the industry as a whole, with the ultimate goal of providing more value to the traveling public. Over time, participation in TG 13 increased and eventually the group included nearly 70 members. Today, membership covers the full gamut of the steel bridge industry, with representatives from owner-agencies, consulting design engineers, software providers, fabricators, erectors and academic researchers (Figure 1).

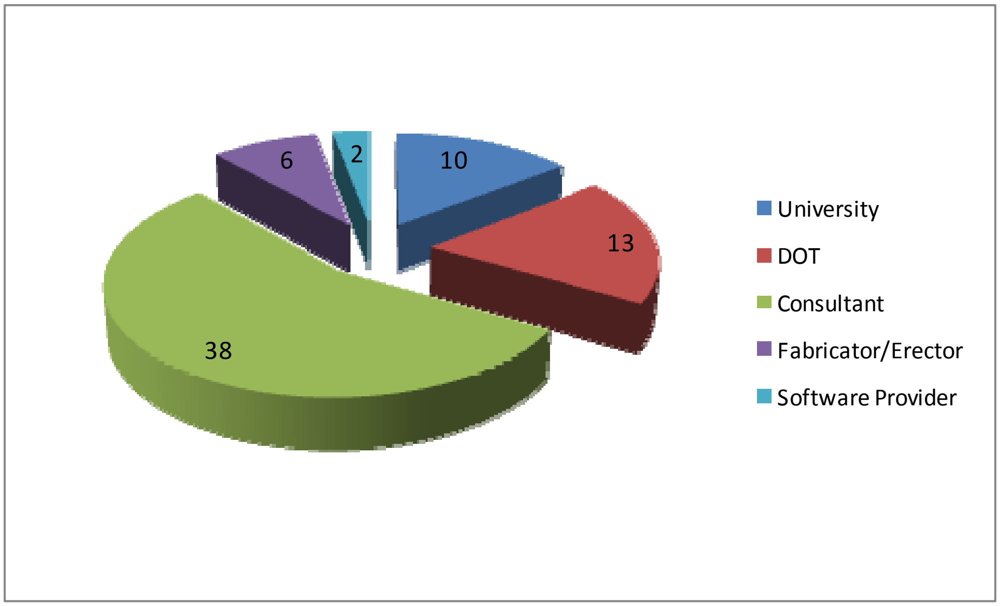


Figure 1: Membership in TG 13 represented a broad cross-section of the steel bridge industry.

TG 13 recognized that the nature of the steel bridge industry has changed over the years. In the past, professionals gained knowledge gradually over time through experience, mentoring and on-the-job training, drawing upon the experience and knowledge of a large cadre of senior professionals. However, for many years in the latter part of the 20th century the transportation industry experienced a lull in funding, and far fewer individuals entered the industry. As a result, there was a significant "gap" between the "Interstate Generation" of bridge engineering and construction professionals and the younger professionals who have entered the industry during the past decade. At this time, nearly all of the veterans of the Interstate Generation have retired, leaving few senior staff to take their place. With fewer opportunities to learn from mentors, the younger professionals in the industry needed additional sources of guidance. TG 13 recognized this need and identified the development of a comprehensive written guideline on the analysis of steel girder bridges as a way to help transfer knowledge to younger engineers.

TG 13 implemented a step-by-step plan to prepare such a guideline. The first step involved surveying the current practices in the industry. TG 13 collectively developed an 11-page Survey of Current Practice covering all types of steel girder bridges, including I-shaped and tub-shaped girders, tangent or curved, skewed or non-skewed. The survey was distributed to all state DOTs, as well as to numerous other professionals in the steel bridge industry, including consulting highway and railroad bridge engineers, other owner-agencies, fabricators and erectors. Response to the survey was strong, with responses from a total of 37 state DOTs, six railroad bridge engineers and 21 other professionals. The survey answers were evaluated, and an Executive Summary was prepared and distributed to all members of TG 13, as well as all participants in the survey. The results of the survey indicated what practices were commonly used for the analysis of steel girder bridges, and indicated in what areas the industry felt that more guidance was needed.

With the results of the survey in hand, TG 13 had an excellent picture of the current practices used across the U.S. for steel girder bridge analysis. TG 13 next developed an outline for a guideline document covering all aspects of steel girder bridge analysis. The outline was written collectively during one of TG 13's face-to-face meetings, and then routed to all members of TG 13 electronically for comment. Once TG 13 had achieved consensus on the content of the outline, it was distributed to all state DOTs for comment. These comments were addressed by TG 13, and the resulting final outline formed the framework for the development of the full guideline document.

Various members of TG 13 then volunteered to write individual sections of the guideline document. A common electronic document template was created to facilitate later compilation of the variously-authored sections into a single document. Over the next several months, various sections were written and incorporated into the master document. As the authors delved into the details of each section, the original outline was modified in some places to improve the organization and presentation of material; however, the final document remained largely true to the original intent. Once the majority of the document was completed, it was circulated to the members of TG 13 for comment. The document was reviewed, revised and redistributed several times until it was completely drafted and consensus achieved on its content.

At that point, the document, titled G13.1, Analysis of Steel Girder Bridges, was sent to Committee T-14 (Steel Bridges) of the AASHTO Subcommittee on Bridges and Structures (AASHTO SCOBS) for review and comment, and to the entire AASHTO/NSBA Steel Bridge Collaboration for ballot. Comments from AASHTO T-14 and from the Collaboration were received and addressed, and the revised version of G13.1 was sent back to AASHTO T-14 for final approval. AASHTO T-14 approved the document during its meeting in Norfolk, VA, in May 2011 and recommended approval by the larger AASHTO SCOBS, which occurred later the same week. The final document was formatted for publication and released by AASHTO as an AASHTO/NSBA Steel Bridge Collaboration Guideline in August 2011 under the title *G13.1, Guidelines for Steel Girder Bridge Analysis,* Reference (2).

Organization and Content of G13.1

The G13.1 guideline document is organized into various sections. It begins with a Foreword with general background and introductory information. Next is a section of Modeling Descriptions intended to establish a consistent lexicon of terminology for the document, followed by a History of Steel Bridge Analysis, describing the development of the steel bridge industry and the design and analysis methods and criteria. Following this, the document launches into its main content with a large section on Issues, Objectives, and Guidelines Common to All Steel Girder Bridge Analyses. Next is a similarly large section of Analysis Guidelines for Specific Types of Steel Girder Bridges. G13.1 concludes with an extensive list of References, a full Glossary, and an Appendix containing the executive summary of the Survey of Current Practice.

As a consensus document, G13.1 does not present a single, narrow point of view on any topic. Instead, G13.1 was written specifically to provide broad and insightful guidance and information, rather than narrowly focused, prescriptive directives. Instead of providing the reader a collection of specific rules, it aims to educate the reader about the underlying issues, allowing the reader to make their own, better informed decisions about how to analyze their particular bridge. This approach offers the advantage of flexibility. As such, the guidelines are valuable to all bridge engineers in all parts of the country and are applicable to the analysis of any particular bridge, regardless of how unique.

G13.1 is also very comprehensive and broad ranging. The document is over 150 pages long and provides detailed guidance on a wide variety of steel girder bridge analysis issues and topics, as will be outlined in this paper.

Modeling Descriptions

To establish common definitions of the various methods used in steel girder bridge analysis, full descriptions of the most common modeling methods are provided. The methods are organized into two groups – Hand Analysis Methods and Finite Element Methods.

The Hand Analysis Methods include:

- *Beam Charts:* Simple graphs which provide rough guidance on span length, spacing and beam size for various types of loading.

- *Line Girder Analysis Method:* Simple analysis methods and computer programs which examine a single girder without refined consideration of system behavior.
- *V-Load Method:* The V-Load method is a statics-based method for analyzing curved steel I-girder bridges.
- *M/R Method:* The M/R method is a statics-based method for analyzing curved steel tub-girder bridges.

The Finite Element Methods include:

- *2-D Grid Analysis Method:* Steel framing modeled as two-dimensional array of nodes and line elements, with the deck effectively modeled in strips using line elements (see Figure 2, for example).

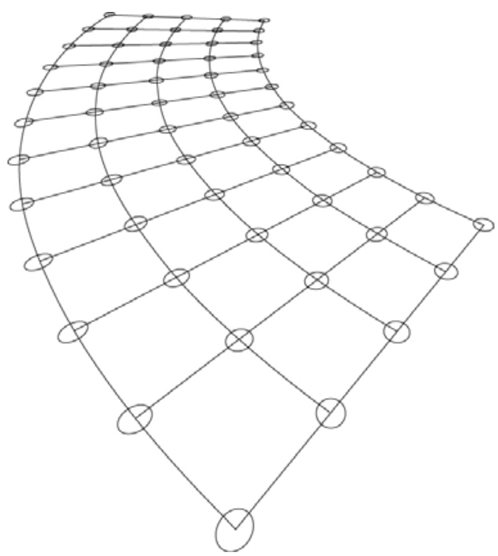


Figure 2: Traditional 2-D grid analysis model.

- *Plate and Eccentric Beam Analysis Method:* Steel framing modeled as two-dimensional array of nodes and line elements, offset from the deck which is modeled using plate or shell elements (see Figure 3, for example).

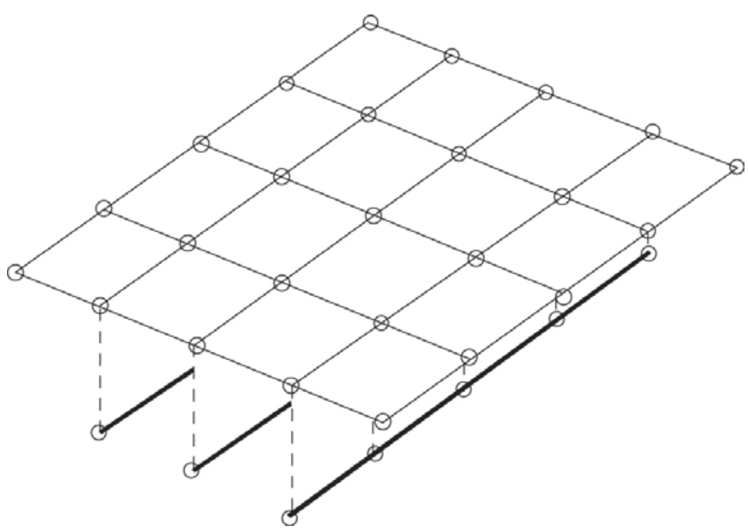


Figure 3: A variant on the 2-D grid analysis model – the plate-and-eccentric-beam model.

- *Generalized Grid Analysis Method:* A refined version of other grid analysis methods including consideration of shear deformation, warping stiffness and other parameters.
- *3-D FEM Analysis Methods:* Refined modeling where girders are modeled in detail; flanges modeled using beam or plate elements; webs modeled using plate or shell elements; cross frames modeled in detail; and decks modeled using plate, shell or solid elements.

History of Steel Bridge Analysis

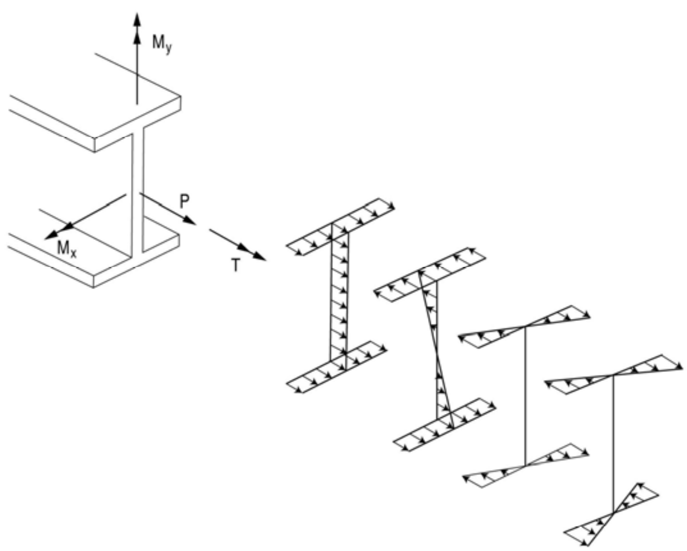
This section of G13.1 offers a brief history of the development of the steel bridge industry. It begins with a discussion of how steel girder bridges have changed in complexity – from the very simple structures of the early 20th century to the more complex structures of today. Following is a discussion of the development of bridge design codes, beginning with the Allowable Stress Design (ASD) approach, through the Load Factor Design (LFD) approach, and concluding with the Load and Resistance Factor Design (LRFD) approach currently used. The history section then looks at advancements in the analysis tools and methods available to designers, beginning with simple hand analysis methods such as moment-distribution analysis, through the development of more refined hand analysis methods such as the V-Load and M/R methods, and finally the development of computer modeling methods such as 2-D grid and 3-D FEM.

Issues, Objectives, and Guidelines Common to All Steel Girder Bridge Analyses

This is the first of the two main sections of guidelines provided in G13.1. The guidelines in this section are generally independent of specific girder types or bridge configurations and instead focus on more fundamental issues that affect the analysis of any steel girder bridge.

The topics covered in this section include:

- *Behavior Considerations:* A broad discussion of the behavior of tangent, curved and skewed bridges including consideration of torsional effects, flange lateral bending and system behavior (see Figure 4, for example).



$$\text{Total Normal Stress} = \sigma = \frac{P}{A} + \frac{M_x\, y}{I_x} + \frac{M_y\, x}{I_y} + \text{Warping Normal Stress}$$

Figure 4: Illustration of the general I-girder normal stresses that can occur in a curved or skewed I-girder bridge.

- *Section Property Modeling Considerations:* A discussion of the many complexities associated with composite steel girder behavior, including consideration of non-composite vs. composite stresses, phased construction and evaluation of existing bridges.
- *Loads on the Permanent Structure:* A compendium discussion of the various loads that occur on bridges, and special considerations that may be associated with them.
- *Strength Design:* A discussion of how to consider the ultimate capacity of the structure.
- *Inelastic Design:* A discussion of how to approach consideration of the capacity of steel girder bridges beyond the yield limit of the girder steel.
- *Fatigue Analysis and Evaluation:* A discussion of the unique behavior of steel structures with regard to repetitive loading, a key consideration in the design of steel girder bridges.
- *Superstructure Live Load Reactions for Substructure Design:* A discussion of the different approaches necessary for correctly calculating the loads applied to the substructure, which is often a separate exercise from the calculation of loads for design of the steel superstructure.
- *Constructability – Analysis Issues:* A discussion of constructability and how various construction considerations can affect the analysis of a steel girder bridge, including:
    - Evaluations of the erection sequence of the steel framing
    - Consideration of the deck placement sequence on stresses
    - Effects of overhang falsework loading on the girders (see Figure 5, for example)

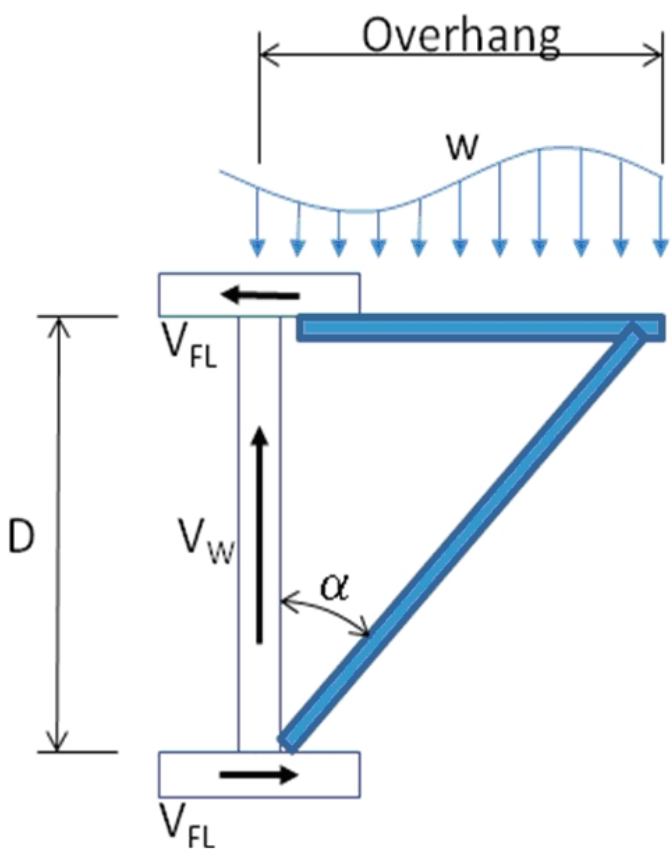
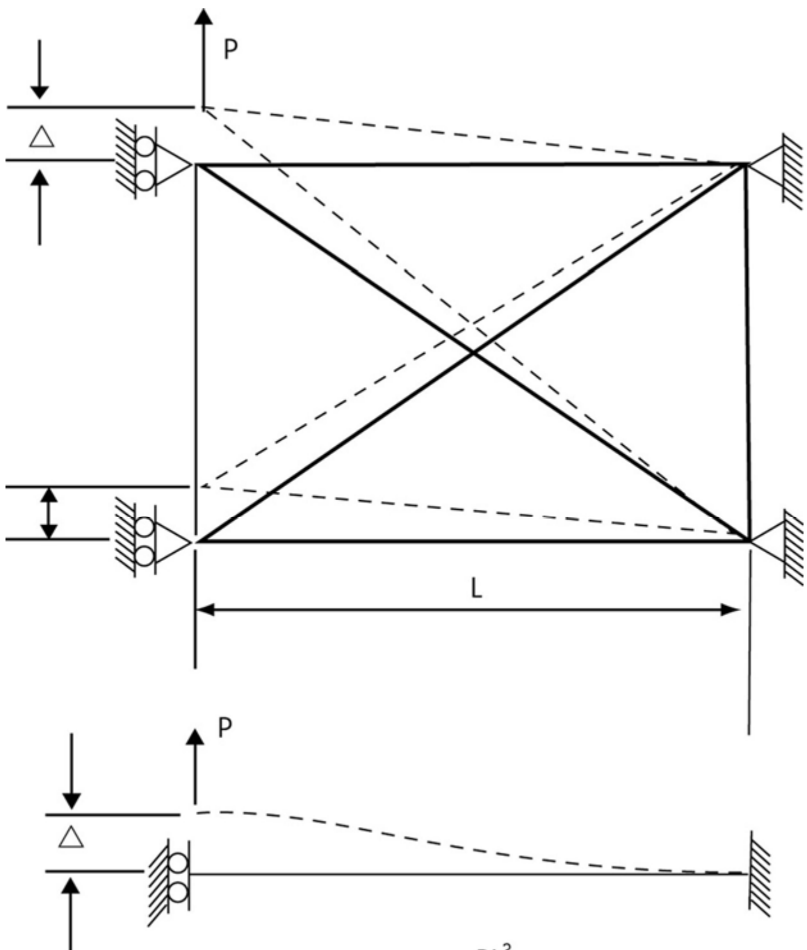


Figure 5: Freebody diagram of typical overhang bracket system.

- Wind loading during construction
- Live loads during construction
- Miscellaneous construction loads
- Stability analysis during various stages of construction (when the structure is only partially complete)

- *Prediction of Deflections:* A critical discussion of prediction of deflections, which affects fit-up and constructability of the bridge, and how there is no way to take a "conservative" approach to the calculation of deflections.
- *Detailing of Cross Frames and Girders for the Intended Erected Position:* A timely discussion of the various detailing methods used by steel detailers and erectors, and how the choice of detailing method and intended erected position can directly affect the stresses in the completed structure.
- *Cross Frame Modeling (2-D vs. 3-D):* A discussion of the simplifying assumptions that are inherent in the modeling of cross frames in simpler analysis methods, and what the implications of those simplifying assumptions may be on the accuracy of the analysis (see Figure 6, for example).



$$\triangle = \frac{PL^3}{12EI}$$

Figure 6: Cross frame model used to determine the equivalent stiffness of the line element used to model the shear stiffness of the actual cross frame.

- *Deck Modeling:* A discussion of the simplifying assumptions that are inherent in modeling of the deck in simpler analysis methods, and what the implications of those simplifying assumptions may be on the accuracy of the analysis.
- *Bearings, Substructures, and Boundary Conditions for Models:* A critical discussion of the effects of the restraint of bearings and the stiffness of substructures on the behavior of the superstructure, and how to properly model those effects in the superstructure analysis (see Figure 7, for example).

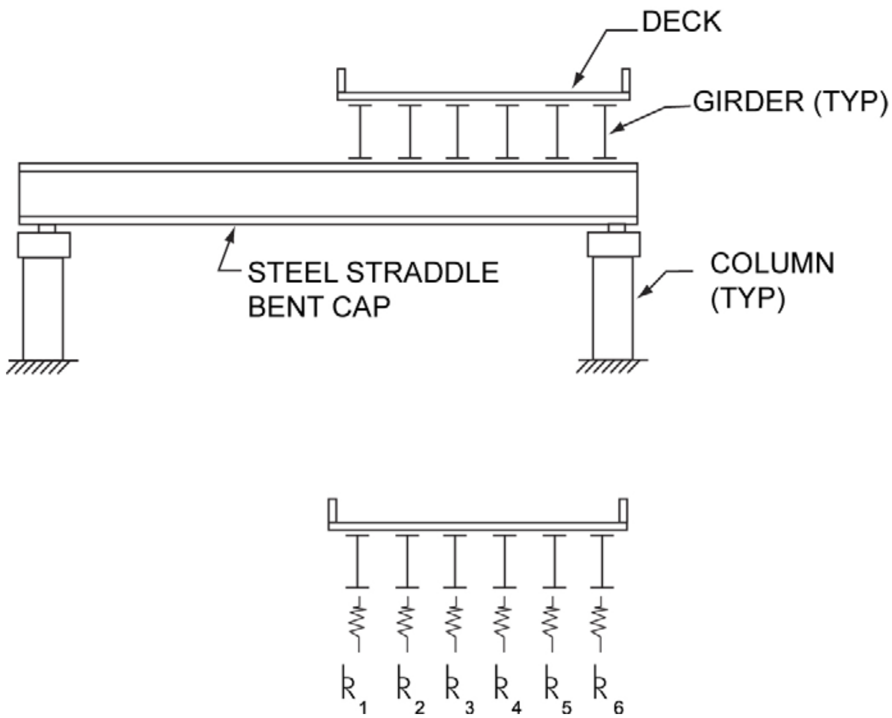


Figure 7: In some cases, individual girders at a given line of support may have different support stiffnesses, causing different load distribution among the girders than would be found if all girders had equally stiff supports. In this case k6 > k5 > k4 > k3 > k2 > k1.

- *Roadway/Structure Geometry Considerations:* A discussion of how geometry affects structure design, and suggestions for changes to geometry that will simplify analysis, detailing and construction of the structure (see Figures 8 and 9, for example).

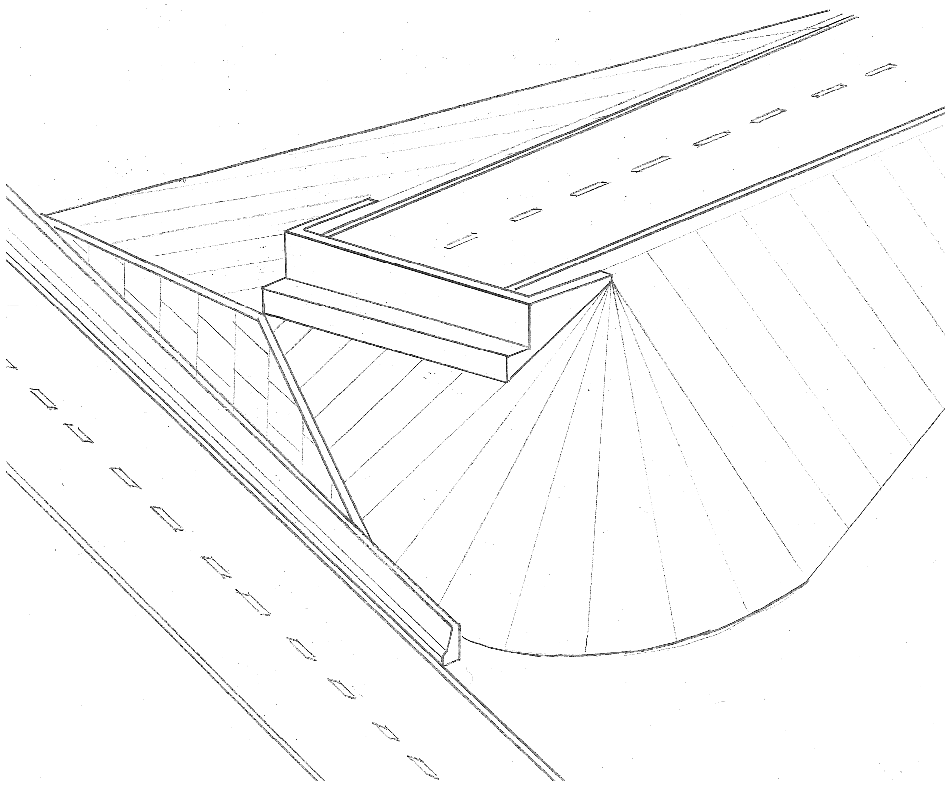


Figure 8: Isometric sketch of the use of a small retaining wall to reduce skew without lengthening the *span.*

Figure 9: A steel girder bridge where a small mechanically stabilized earth (MSE) retaining wall was used to reduce the severity of skew without significant increase in span length.

- *Second-Order Effects:* A discussion of second-order nonlinear behavior in steel girders, and when it is important to consider second-order amplification of loading effects, with individual discussion of straight steel girders, curved girders and narrow steel girder systems.
- *Phased Construction, Redecking, and Widenings:* A discussion of the unique complicating effects of building (or rebuilding) bridges in phases, including discussions of locked-in stress effects and consideration of differential deflections during construction.
- *Temperature Effects:* A discussion of the effects of uniform temperature changes in the structure, temperature gradients in the structure, temperature effects during construction, and special considerations for wide and/or highly skewed bridges.
- *Analyzing Older Bridges:* A discussion of how to approach load rating and fatigue evaluation of older bridges that may be subject to deterioration or out-of-date construction methods that affect the behavior and capacity of the structure.
- *Discontinuities in Structures:* A discussion of the need for detailed stress analysis of stress concentrations and evaluation of access openings required in some types of steel structures.
- *References to Benchmark Analysis Problems:* A listing of several current published example design calculations and analysis benchmarks.

Analyses Guidelines for Specific Types of Steel Girder Bridges

This is the second of the two main sections of guidelines provided in G13.1. The guidelines in this section are specific to individual types of steel girder bridges.

The topics covered in this section include:

- *Plate Girders – General Issues:* A discussion of topics such as cross frame modeling, 2-D and 3-D analysis techniques, lateral bracing, stability and redundancy analysis of narrow steel girder systems, variable depth girders, and width-to-span ratios and their influence on secondary effects.
- *Tangent Steel Plate Girders or Rolled Beams:* Considerations for bridges with various degrees of skew, including multiple different skews, as well as a discussion of through girder bridges.
- *Curved Steel Plate Girders or Rolled Beams:* A discussion of analysis methods such as V-Load analysis, grid analysis and 3-D analysis, and special considerations for skewed and curved I-girder bridges.
- *Tub Girders – General Issues:* Discussion of the analysis of internal framing such as internal intermediate diaphragms and top flange lateral bracing, the analysis of external framing, stability and redundancy analysis of narrow steel girder systems, and variable depth girders.
- *Tangent Steel Tub Girders:* Considerations for bridges with various degrees of skew, including multiple different skews.
- *Curved Steel Tub Girders:* Considerations for curved tub girder bridges and curved and skewed tub girder bridges.
- *Bridges with Significantly Complex Framing:* A varied discussion of considerations for bridges with variable girder spacing, discontinuous girders, transfer girders, girder-substringer systems, elevated T-intersections, and single point urban interchanges (SPUIs) (see Figures 10 and 11, for example).

Figure 10: View of curved infill framing area between two orthogonal regions of conventional parallel stringer framing in one of the ramp flare areas of a SPUI bridge structure.

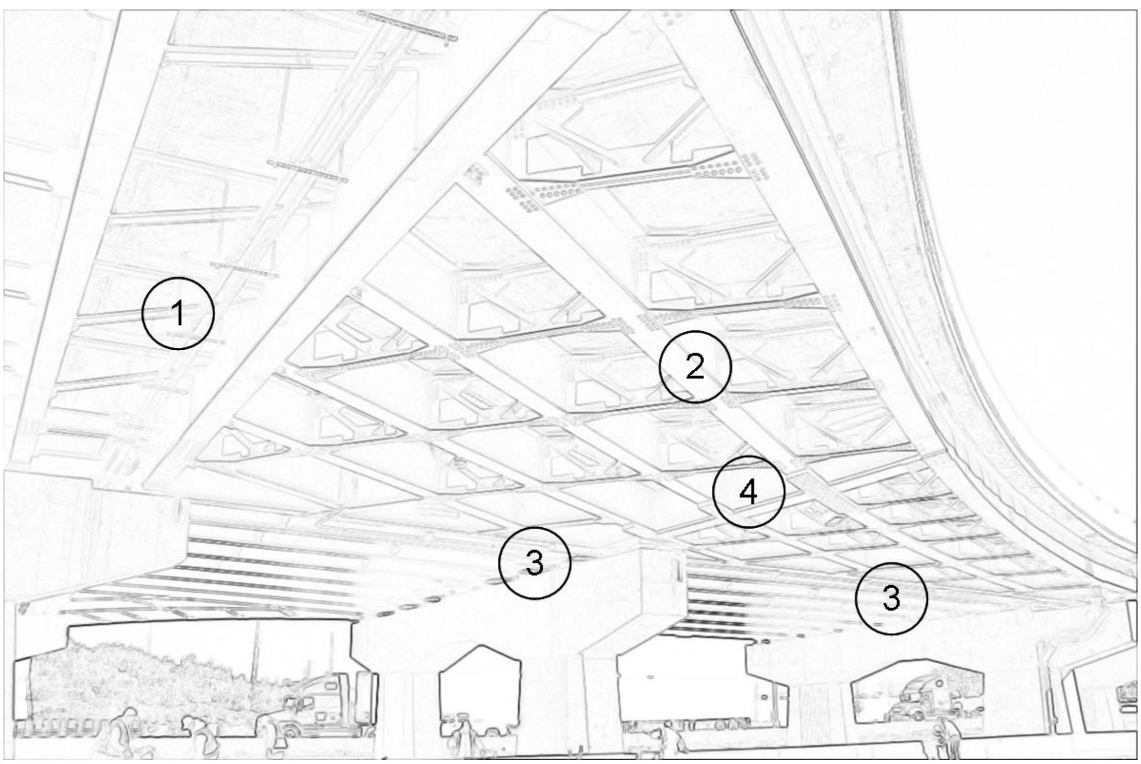


Figure 11: Figure 63 Legend view; refer to enumerated discussion points in the text.

References, Glossary, and Appendices

G13.1 concludes with an extensive list of references, a comprehensive glossary, and an appendix. The References list represents nearly 100 books, papers and other references available to the reader for further information. The Glossary provides a handy listing of common terms and their definitions. The Appendix features a copy of the Executive Summary of the Survey of Current Practice conducted by TG 13 as part of the development of the G13.1 document.

Conclusion

The AASHTO/NSBA Steel Bridge Collaboration guideline document *G13.1, Guidelines for Steel Girder Bridge Analysis* is a valuable resource for bridge engineers. It provides comprehensive guidance on a wide range of steel girder bridge analysis topics. G13.1 is a consensus document, carefully crafted to provide background information and broad guidance to educate the reader on the underlying issues associated with various analysis topics, rather than providing narrowly focused, prescriptive directives. As such, G13.1 offers the advantage of flexibility. The guidelines are valuable to all bridge engineers in all parts of the country and are applicable to the analysis of any particular bridge, regardless of how unique.

As part of the preparation of this synopsis, the author conducted a brief, informal survey of state DOTs regarding whether and how they have implemented the recommendations presented in the G13.1 guideline document. Based on responses received, it appears that at this time most state DOTs are aware of the G13.1 guideline document, and many have begun using it informally. Formal implementation of policy changes has been limited to date; most DOTs explaining that they want to study the recommendations further before implementing policy changes. However, the general feedback from all users of the document has been very positive. Select comments from several DOT representatives are presented below:

> *"We have reviewed the guidelines, but have not been using them specifically on our projects. However, during some recent revisions to design policies, the guidelines helped confirm some of the changes we had been considering. The guidelines are very helpful in explaining the full process of designing and erecting a steel bridge, especially for newer engineers who may not have had previous involvement in the steel bridge design process."*

> *"[We have] made this document available to in-house engineers via [our] website. [We have not yet changed any policies] specifically, but we do use the guidelines as a resource for bridges that require non-routine analysis. Excellent publication. Good resource for seasoned engineers. Should be required reading for new engineers."*

> *"We recommend the Guidelines be used in the design offices. [We have not yet] changed any of our policies or practices based on these guidelines, [but the] guidelines shall also be distributed to Software developers to encourage them to update the software based on the state-of-practice recommended in the Guidelines."*

References

1) *http://www.aisc.org/contentNSBA.aspx?id=20096&linkidentifier=id&itemid=20096*, The National Steel Bridge Alliance, Chicago, IL (accessed Nov. 11, 2011).

2) *G13.1, Guidelines for Steel Girder Bridge Analysis*, 1st Edition, American Association of State Highway Transportation Officials, Washington, DC, 2011.