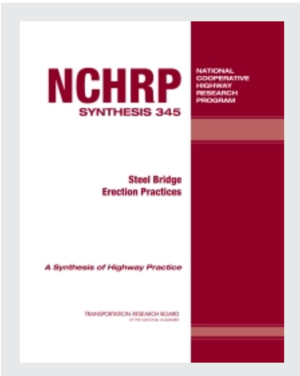

Steel Bridge Erection Practices

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 345

Steel Bridge Erection Practices

A Synthesis of Highway Practice

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SUBJECT AREAS

Bridges, Other Structures, Hydraulics, and Hydrology

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in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2005
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FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This report of the Transportation Research Board will be of interest to all individuals involved in steel bridge fabrication, assembly, and erection. It examines, discusses, and analyzes steel bridge erection practices for I-girder, tub-girder, and box-girder bridges; particularly curved, skewed, and staged structures. Key topics considered include the impact of design and analysis practices on erection; methods used to predict erection deflections as a function of bridge type and complexity; shop-assembly practices and alternate methods of ensuring properly assembled geometry; stability issues; field connection practices; examples of structures in which erection practices have caused problems; owner requirements for erection procedures, implementation of requirements, and the impact of procedures on the quality of erection; and current and proposed research.

This synthesis reports on the responses to three questionnaires sent to all U.S. state departments of transportation (DOTs) and Canadian provinces, 24 steel bridge fabricators, and 25 steel bridge erectors and contractors. Responses were received from 30 state DOTs, 2 provinces, 15 fabricators, and 4 erectors. Follow-up information was gathered by telephone interviews.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write the report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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STEEL BRIDGE ERECTION PRACTICES

SUMMARY

The erection of steel bridges, depending on the complexity of the structure, may pose critical issues for owners. Given such complexity, plus the great variety of practices being used today, there are often concerns with the integrity, speed, safety, quality, delays, and claims related to steel bridge erection. The number of curved structures and structures with complex geometry that are being constructed adds considerably to the type of steel erection issues that owners, designers, fabricators, erectors, and contractors are faced with at one time or another. A compilation of the methods employed by agencies or firms involved in all phases of a project, from design through construction, may be informative and may minimize these difficulties.

This synthesis reports the results of and analyzes questionnaires, telephone conversations, specification reviews, and research reports solicited from states, Canadian provinces, fabricators, and erector and contractors. A total of 111 questionnaires were distributed, with responses received from 30 states, 2 provinces, 15 fabricators, and 4 erector/contractors. The report concentrates on girder bridges—both I-girders and box girders.

The erection of steel girder bridges is both craft and science. Erection practices are based on experience, rules of thumb, and intuition. Successful erection demands both an effective implementation of these practices, the craft, and a design that has appropriately considered principles of stability, the science. This synthesis addresses the craft.

Most of the common problems that occur during erection can be prevented by taking the following measures:

- Verifying horizontal and vertical alignment before and during erection;
- Installing enough crossframes to maintain geometry and girder stability during erection;
- Properly using temporary falsework or additional cranes; and
- Rigorously following pinning, bolting, and tightening procedures.

It is important to recognize that many erection problems can be attributed to a lack of understanding of girder behavior during erection. Therefore, when dealing with the erection problems, it is important to ask the question, "Is corrective action needed?" Furthermore, establishing acceptable tolerances of deviation from the intended vertical or horizontal alignment of the superstructure would aid owners in knowing whether a true concern exists and save valuable construction time, while precluding frustration on the part of fabricators and erectors.

Although erection problems were reported by all parties, the findings do not suggest that the problems are endemic. Rigorous erection analyses, including the prediction and reporting of intermediate deflections (deflections before the final erected condition), which could anticipate the reported problems, are not made before erection. Before more rigorous incremental analysis is routinely instituted, the issue to be considered is whether the potential field costs to solve unanticipated problems exceed any proposed rigorous pre-erection analysis costs.

CHAPTER ONE

INTRODUCTION

BACKGROUND

The erection of steel bridges, depending on the complexity of the structure, may pose critical issues for owners. Because of this complexity, plus the great variety of practices currently being used, there are frequently concerns with the integrity, speed, safety, quality, delays, and claims related to steel bridge erection. The number of curved structures and structures with complex geometry that are being constructed adds considerably to the type of steel erection issues that owners, designers, fabricators, erectors, and contractors face. A compilation of the methods employed by those agencies or firms, involved in all phases of a project from design through construction, may minimize these difficulties.

SYNTHESIS OBJECTIVES

This synthesis examines and discusses issues relating to steel I-girder, tub-girder, and box-girder bridges; particularly curved, skewed, and staged structures. It addresses issues that influence steel bridge erection and the practices dealing with those issues. The key items to consider are:

- Impact of design and analysis practices on erection;
- Methods used to predict erection deflections as a function of bridge type and complexity;
- Shop-assembly practices and alternative methods of ensuring properly assembled geometry;
- Sequencing of erection to ensure proper fit-up and to achieve desired girder profile and geometry;
- Stability issues during all phases of bridge construction, such as deck overhang, concrete placement, lifting and handling, and temporary or permanent bracing or supports;
- Field connection practices and impact on final geometry;
- Examples of structures where erection practices have caused problems;
- Owner requirements for erection procedures, implementation of requirements, and impact of procedures on the quality of the erection; and
- Current and proposed future research.

SYNTHESIS APPROACH

This synthesis reports the responses of three different questionnaires that were sent to U.S. states and Canadian provinces, steel bridge fabricators, and steel bridge erectors and contractors. Questionnaires were sent to all state departments of transportation (DOTs) and Canadian provinces, 25 steel erectors/contractors, and 24 fabricators. Responses were received from 30 states, 2 provinces, 15 fabricators, and 4 erectors. See Appendix A for the questionnaires.

The questionnaires requested "Yes" or "No" answers, discussion type answers, additional contacts for follow-up information, and copies of construction specifications. The information provided in the completed questionnaires was then recorded. Follow-up telephone calls were made when appropriate contact information was provided. Information gathered by telephone interviews was also recorded (see Appendix B for the results grouped by each category of survey respondent).

TERMINOLOGY

Terms that pertain to procedures and materials are provided in this section.

Blocking dimensions: Offset dimensions that are measured in shop assembly from a reference line to the girder's bearing points, splice points, and camber points, to control the girder alignment when drilling or reaming the holes for the field splices (see Figure 1).

Deck cantilever brackets or deck support brackets: Cantilever brackets that attach to the outside girder to support the deck formwork and the concrete deck until it has cured (see Figure 2).

Drift pins or pins: Hardened steel round tapered pins that are used to align the holes in steel members during erection (see Figure 3).

Full girder assembly: The procedure consisting of shop assembling each continuous girder or rolled beam line to its full length (see Figure 4).

No-load condition, steel dead-load condition, and full dead-load condition: The possible load conditions under which the girder webs will be vertical or plumb. For the no-load condition, the girders and crossframes will be detailed, fabricated, and erected such that the webs will be vertical as

FIGURE 1 Measuring offset dimensions during shop assembly (Industrial Steel Construction, Inc.).

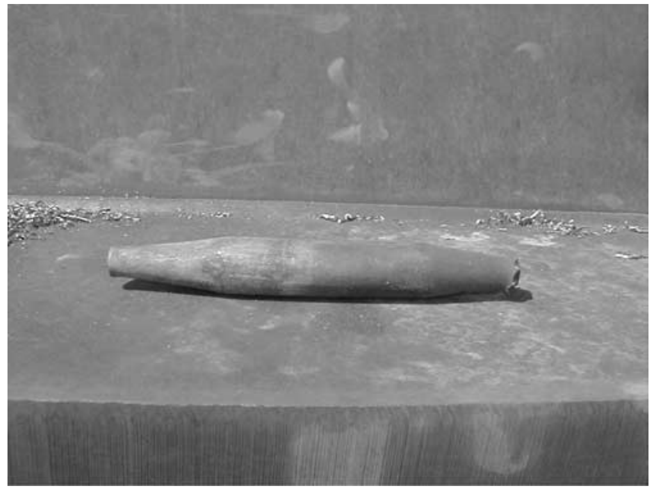

FIGURE 3 Drift pin.

though gravity is turned off. For the steel dead-load condition, the webs will be vertical after steel erection, and for the full dead-load condition, the webs will be vertical after all of the dead load has been applied. There is little uniformity of thought as to which load condition is appropriate for specifying plumb girder webs.

Pinning: The process of using drift pins when erecting steel members (see Figure 5).

Progressive girder assembly: The procedure in which a part of a continuous girder line is initially assembled and girders are progressively added and removed as the field splices are reamed and/or drilled. Normally, at least three members must be included in each assembly unless bearing-to-bearing requirements are specified (see Figure 6).

Shop assembly: The procedure of shop assembling individual girders in position to ream or drill holes for the field splices.

FIGURE 2 Deck cantilever brackets (DeLong's Inc.).

Special complete structure assembly: The procedure whereby the entire structure including crossframes, diaphragms, and floor beams are shop assembled (see Figure 7).

Stage construction: The construction condition where the deck on part of the bridge has been poured and cured and a transversely adjacent part, or second stage, has not been poured. This process is not to be confused with staged

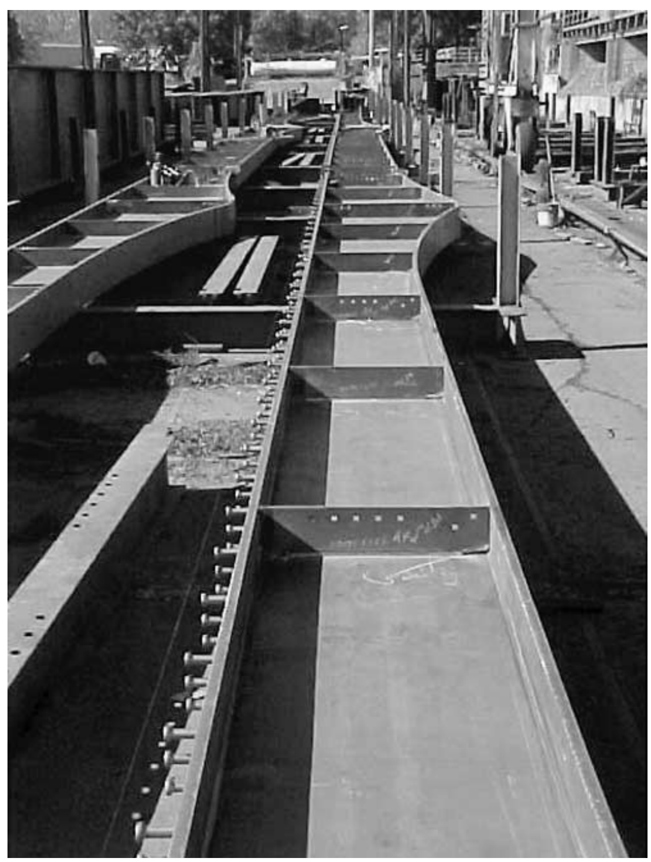

FIGURE 4 Full girder assembly (DeLong's Inc.).

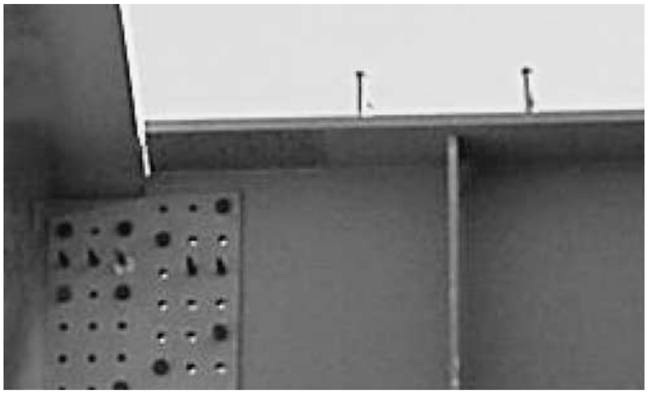

FIGURE 5 Drift pins used to erect a girder (Washington State DOT).

FIGURE 6 Progressive girder assembly.

deck placement, in which the erection of girders has not been staged.

REPORT ORGANIZATION

This report is organized into a summary, seven chapters, and two appendixes. This first chapter is the introduction. Chapter two discusses owner-specified or preferred practices, chapter three is a summary of fabricator practices and views, chapter

FIGURE 7 Special complete structure assembly (Washington State DOT).

four is a summary of erector practices and views, chapter five lists problems cited, chapter six discusses the solutions to the problems, and chapter seven presents the conclusions. The appendixes contain all of the questionnaires, responses, summaries of the responses, and results of specification reviews.

RESPONSES TO QUESTIONNAIRES

A total of 111 questionnaires were distributed, with 51 responses received. A slim majority of the owners (32 of 62) responded to the owners' questionnaire. A larger, yet not overwhelming, majority of fabricators (15 of 24) responded to their questionnaire. Only 4 of the 25 erectors/contractors that were solicited responded to their questionnaire.

The owners' response rate may be misleading. Many owners, because of tradition and other cultural reasons, and to a lesser degree technical considerations, do not construct many steel bridges. For example, the Sun Belt and Western states do not construct nearly as many steel bridges as do the states of the Rust Belt and the Northeast. States that construct fewer steel bridges were among those not responding, possibly indicating less interest in the topic. Thus, if the percentage of steel bridges being constructed in a particular state is entered into the analysis, it is found that the response rate is relatively high for those actively constructing steel bridges.

CHAPTER TWO

OWNER-SPECIFIED OR PREFERRED PRACTICES

Owner-specified or preferred practices related to steel bridge erection were reported in the questionnaires and follow-up telephone interviews. These practices are categorized by design, fabrication, or erection.

DESIGN

Flange Dimension Requirements

Owners restrict flange dimensions to limit unwieldy flexibility during handling and distortion after welding. Only one owner, Maine, restricts the width-to-thickness ratio (b/t) of flanges to between 12 and 20, with a preferred ratio of 16. Three owners limit the width of the flange to a minimum of 300 mm (12 in.). These owners also limit the thickness to a minimum of either 19 or 22 mm ($^{3}/_{4}$ to $^{7}/_{8}$ in.). Kansas has minimum flange dimensions that are a function of span length. Texas, although having no requirements, presents some preferences on the National Steel Bridge Alliance website (http://www.steelbridge.org-texas-Preferences-Nov-2000.doc). Although Washington State has no specific limits, officials there believe that some in-house guidelines and AASHTO specifications would be helpful. It should be noted that in Section 6 of the *AASHTO LRFD Bridge Design Specifications* (*1*), an upper bound of 12 is placed on b/t for tension and compression flanges.

Member Length-to-Flange Width Ratio (L/b)

Two owners require that L/b for compression members be less than 85. Minnesota requires an L/b ratio of between 80 and 85. Maine prefers that L/b for welded beams not exceed 90, but up to 110 may be used if economy dictates. Again, Texas presents some recommendations on its website.

In-House Steel Specialist or Advisory Group

Fifteen owners have a steel specialist or advisory group within their organization that reviews and provides assistance to designers developing steel bridge plans.

Analysis Methods for Complex Structures

A wide range of computer software and analysis methods were reported as being employed when there were concerns about actual deflections and rotations owing to structure complexity. These methods ranged from three-dimensional, finite-element analysis through simple one-dimensional, line-girder analysis. This range represents a tremendous variation in analytical sophistication and accuracy in capturing system behavior.

The state DOT respondents expressed varying opinions that the impact of the sophistication of the analysis method on erection procedures varied from minimal to total impact.

FABRICATION

Shop-Assembly Methods

The AASHTO/National Steel Bridge Alliance *Steel Bridge Fabrication Guide Specification* allows either full girder or progressive girder assembly (*2*). A review of specifications submitted in response to the questionnaire shows that seven owners require full girder assembly unless contract documents specify otherwise. Fourteen owners and the *AASHTO LRFD Bridge Construction Specifications* (*3*) either specify or allow progressive girder assembly as a first choice. Five of the owners apparently have no shop-assembly requirements, as no such provisions appear in their specifications.

There are various requirements for progressive girder assembly, whether first choice or an option to full assembly. They range from minimal numbers of girders (two or three) or spans (one or two) per assembly to no specified minimums at all.

Alternate Shop-Assembly Methods Allowed

Most owners allow alternate shop-assembly methods. Various additional requirements noted were:

- Must be approved,
- Should be equal or better than specified methods,
- Should be based on fabricators' performance,
- Must give credit based on cost differential,
- Used only if stresses and tolerances are within design limits,
- Must be in writing,
- Must meet minimum specifications,
- Only be considered if framing is simple,

- If requirements are generally upheld for complex geometries,
- If it makes sense,
- Provided that an unsatisfactory product will be corrected by the fabricator, and
- If the fabricator assumes full responsibility for the procedures.

Oversized Holes

Sixteen owners allow oversized or slotted holes under some circumstances to facilitate fit-up of diaphragms or crossframes. Another allows only vertical slots to permit differential movement between girders during deck pour (staged construction or bridge widening, not staged deck placement). Ten owners prohibit the use of oversized holes.

Load Condition for Detailing Crossframes

Three owners indicated a need to research the appropriate condition at which to detail crossframes: no-load, dead-load, or full-load condition. One owner is developing a set of special provisions dealing with this issue. Another owner volunteered that it requires crossframes to fit in the no-load condition (now a standard note on design drawing) for curved girder bridges, and in the steel-only dead-load condition for straight bridges.

ERECTION

Erection Procedures

The vast majority of responding owners (27 of 32) do not require the designers to provide an erection procedure for complex structures. The other five owners specifically require the designer to provide an erection procedure as a part of the contract drawings. On the basis of its experiences with severe problems with erection of curved girders, one owner noted the following among its standard procedures:

> When designing curved girder structures, designers must investigate all temporary and permanent loading conditions, including loading from wet concrete in the deck pour, for all stages of construction. Future decking must also be considered as a separate loading condition. Diaphragms must be designed as full load carrying members. A three-dimensional analysis representing the structure as a whole and as it will exist during all intermediate stages and under all construction loading is essential to accurately predict stresses and deflections in all girders and diaphragms and must be performed by the Designer.

The designer is responsible for ensuring that the structure is constructible and that it will be stable during all stages and under all loading conditions. To achieve this end, the designer must supply basic erection data on the contract plans. This information must include, but is not limited to, the following:

- Pick points and reactions at pick points for all girder sections;
- Temporary support points to be used during all stages and loading conditions, and reactions for which support towers should be designed at all of these points;
- Deflections to be expected in all girders under all conditions of temporary support and under all anticipated loading conditions; and
- Direction pertaining to the connection of diaphragms to ensure stability during all temporary conditions.

The opinions of the respondents on the value of erection procedures provided by the designer ranged from “a positive effect” to “a waste of time and money.”

A smaller majority of the owners (17 of 32) require the erector to submit an analysis and erection procedure whether or not the procedure was performed by the designer. The comments of individual respondents suggest that their requirements are not as rigorous, stating that the submitted erection procedures were for information only or record purposes, or both; required, but many times not actually submitted; and not necessarily based on analysis. A few of the remaining owners stated that the erector may be required to submit erection procedures if specified in the special provisions or contract plans.

Nineteen owners reported that they provide some sort of review (ranging from casual to thorough) of the erection procedures if submitted by the erector, but they apparently do not go so far as to approve the procedures. Among those owners that stated that they did not review the procedures, the following comments were added: “contractor’s responsibility,” “would if requested,” and “stay out of approval or checking.”

Preferred Field Connection Practices

Seven owners expressed a preference for field connection practices that lead to good final geometry. Shop assembly, good field inspection, verification of shop and field measurements, and use of experienced personnel are the most cited preferred practices. Texas uniquely indicated that bolting or welding of field connections work equally well when properly executed. Oklahoma indicated a preference for direct tension indicators to aid inspection of bolted connections.

Proven Methods for Erecting Complex Structures

Eighteen owners reported that temporary supports and/or bracing have proved valuable in erecting complex structures. Launching of girders, particularly box girders, was cited by three owners as a proven method. Four owners believed that full shop assembly is useful in ensuring more easily erected complex structures. Several owners cited novel methods for erecting unique complex structures. For curved box girders, one owner prefers only one bearing at a support for a single box.

Pinning and Bolting Procedures

Inadequate pinning and bolting practices, including field verification of horizontal and vertical alignment, were reported to be the cause of a number of problems. Conversely, many respondents listed good pinning and bolting practices as essential to achieving an effective erected structure.

The use of pins during the erection of the structure is an important concern because the pins are very nearly the same diameter as the drilled or reamed hole. This situation allows very little movement, and consequently it is critical in setting the final geometry of the structure. The AASHTO specifications and seven owners require an initial minimum requirement of 25% pins and 25% bolts in each connection. Nine owners cited an initial minimum requirement of 50% of the holes filled with pins or bolts. Individual owners specified various requirements: at least two pins in extreme hole locations; pins in extreme corners of splices; eight pins in each flange and web splice; 33% pins; a minimum of four pins; a preference for 25% pins, 15% pins, 50% pins, and 50% bolts in main splices; 50% pins and 50% bolts; adequate pins and bolts; a maximum of 15% pins and sufficient bolts to keep pieces together; and 25% bolts with the number of pins determined by the engineer.

Because the pins are important in setting the geometry, the stage at which the pins are removed (before or after bolts are tightened) may have an impact on the geometry. Three owners specify that all holes not containing pins be filled with tightened bolts before removing the pins. Two owners specify that all the holes be filled with snug-tight bolts, whereas one other owner specifies that all holes be filled with finger-tight bolts.

Twelve owners' specifications reflect several varying requirements as to when the bolts should be tightened. The major difference seems to be whether they should be tightened after full girder lines, at full structure, or as part of the structure has been erected, and if the horizontal and vertical alignments require verification.

Several owners reported problems with field inspections and verification procedures. Problems ranged from inexperience and failure to inspect to failure of inspectors or project engineers to require the contractor to follow the approved erection procedures.

CHAPTER THREE

FABRICATOR PRACTICES AND VIEWS

This chapter discusses fabricator practices and views related to steel bridge erection, as reported in the questionnaires and follow-up telephone interviews that were part of this synthesis.

GIRDER ASSEMBLY PRACTICES

Girder assembly refers to the shop practice of assembling girders to drill or ream the field splices and in some instances test-fit the crossframes. Questions pertain to whether the girders are assembled with the webs vertical or horizontal, the number of girders that are in an assembly, and whether the crossframes are assembled with the girders.

Straight I-Girder Assembly

Most of the fabricators, that is, 13 of 15, assemble the girders with their webs in the horizontal position without crossframes. The other two assemble them with the webs vertical, generally without crossframes. Several fabricators test-fit several crossframes if there is a large skew or complex geometry. Six fabricators assemble bearing to bearing (several with a minimum of three girders). Nine assemble a minimum of three girders. One fabricator pointed out that the issue of the minimum number of girders in an assembly depends primarily on span lengths, individual girder lengths, and the radius for curved structures.

Curved I-Girder Assembly

Ten of the fabricators assemble curved I-girders with their webs in the horizontal position. The remaining five assemble them mostly with their webs vertical, the exceptions being when the radii are short. (The responses included limits of less than 1,000 ft, 600 ft, and 500 ft, depending on the fabricator.) Eight fabricators assemble bearing to bearing, and the balance use a minimum of three members. Of those that assemble the girders with the webs vertical, a large number will assemble some, many, or all crossframes for test-fit, depending on the complexity of the structure.

Straight Box-Girder Assembly

Of the 15 fabricator respondents, 13 fabricate box girders. Nine of these fabricators assemble bearing to bearing and/or a minimum of three girders. Two assemble pier diaphragms and two others assemble with crossframes—one only if they attach to the web and flange. One also may drill crossframe connections from the solid in assembly.

Curved Box-Girder Assembly

All respondents that fabricate boxes do bearing-to-bearing and/or a minimum of three-girder assembly. Five assemble curved box girders with crossframes. Two others assemble them with crossframes if the geometry is complex and one assembles them with crossframes if the radius is less than 500 ft. Two others assemble them with pier diaphragms only. One also drills the crossframes in assembly.

FIELD CONNECTION PRACTICES

The fabricators' opinions on proper field connection practices of erectors are briefly summarized in this section.

Drift Pins

The proper use of drift pins during erection was the most common issue reported by the fabricators, who noted the following:

- Erectors do not use enough pins.
- Some erectors take the position that if they can install a bolt, they do not need to use pins.
- Erectors need to use full-size pins.

Crossframes

Sufficient crossframes need to be installed to stabilize the structure. Other comments provided by the fabricators relative to crossframes include that progressive assembly of crossframes and bolted crossframes for skewed bridges are difficult to do.

Bolt Tightening

Bolts should not be tightened until a horizontal and vertical alignment of the members has been made and accepted.

OTHER IMPORTANT ERECTION CONSIDERATIONS

Substructure Alignment

Horizontal and vertical alignment of the bearings and anchor bolts should be accomplished (by others) before erection begins. Adjustments for any errors in elevation or location should be made at this time.

Ground Assembly

When members are to be assembled on the ground, they should be properly blocked (in the no-load condition or the same condition as that used in the shop), pinned, and bolted. Also, the alignment should be checked before lifting the members in place. One fabricator suggested that the erector obtain records of the actual blocking dimensions recorded in the shop during the shop assembly.

Sequence of Erection

The sequence of erection has a great impact on the overall geometry. Owing to fabrication and erection tolerances and practices, member deflections, and bolting/pinning practices, both horizontal and vertical alignment and the stability of the structure are controlled by the sequence of the erection of the girders, as well as the attendant cross-frames.

Falsework

Proper placement of the required falsework is essential. Elevations should be set to account for tolerances and to match shop blocking dimensions. Additional cranes may be used as a substitute for falsework, if necessary or desirable.

KEY ISSUES FOR A PROPERLY ERECTED BRIDGE

In the collective opinion of the fabricators, a properly erected bridge should involve the following:

- The designer should address constructability issues (e.g., differential deflection) and keep the design simple.
- The owner should enforce submittal and approval of an erection procedure prepared by the erector.
- The fabricator should understand the geometric features and how they affect erection, properly match-mark the splice plates, maintain appropriate sweep and camber tolerances, consider complexity of the structure when determining shop-assembly method, accurately drill holes, and properly detail the structure.

The erector should provide an erection procedure that addresses measures that lead to the desired erected structure, keep the ends of the girders aligned and webs vertical, properly orient match-marked splice plates, and use qualified erectors and experienced crews.

In general, horizontal and vertical alignment verification of both the substructure and the superstructure at all stages of the process is critical to attaining a well-positioned and erected structure.

CHAPTER FOUR

ERECTOR PRACTICES AND VIEWS

This chapter discusses erector practices and views related to steel bridge erection, as reported in the questionnaires and follow-up telephone interviews that were a part of this synthesis. Information is based on responses from four erectors.

ERECTION PROCEDURE PROVIDED BY OWNER

Two of the erectors have not received erection procedures from the owner. The other two have, but they have diametrically opposite opinions on the procedure's worth. One believes that a required erection procedure from the designer has a positive effect because the designer must think through the scheme and the associated forces to erect the structure. The second believes that this practice does not improve the quality of the erected structure.

APPROACH TO ERECTION SEQUENCE AND LOCATION OF FALSEWORK

The responses to questions regarding approach suggest that a rigorous analysis is not employed. Rather, erectors depend on experience and intuition.

One erector indicated that the need to provide temporary support through falsework was based on bridge type, number of spans, and span lengths, indicating that long spans generally require multiple falseworks to control geometry. Another erector pointed to site limitations and the size and strength of the individual girder pieces as discriminators on the need for and location of falsework. Finally, one erector cited the rule of thumb of using falsework near splices and locating them under stiffeners, as well as the need to provide jacking reaction capabilities in falsework to adjust as necessary to maintain proper elevations.

An erector suggested that it is often possible to ground assemble two adjacent girders with the lateral bracing and crossframes, and then erect them as a single unit. In that way, temporary bracing is not required.

STABILITY WHEN LIFTING CURVED MEMBERS

Two of the erectors discussed maintaining individual girder stability through the choice of pick points (crane lifting points) for curved members. Their specific discussion of the calculation of pick points based on certain criteria suggests that this is the extent of their analysis of girder stability. One erector calculates the sum of moments in the transverse direction along the member length when picked to ensure that the girder remains level. The erector also reported that multiple cranes or shoring are used. The second erector discussing this topic reported that curved girders can be picked with a single crane using a correctly sized spreader beam or by using two cranes. The location of the pick points can be calculated so that the girder is picked straight without roll. That erector applies the rule of thumb that picking at two points usually eliminates any later stability problems, as long as a line between the pick points runs through the center of gravity of the girder.

FLANGE SIZING REQUIREMENTS FOR STABILITY

Two of the erectors reported that an L/b of 60 or less between unbraced points provides stability during transportation and erection. One of them went on to report that an L/b value of 60 to 80 may be adequate, but further stress calculations need to be verified, and values of more than 80 require temporary support (falsework or holding cranes) to provide stability. Another erector indicated that it is desirable that the flanges be sized so that each individual girder piece can laterally support itself when erected in a simple span or cantilever condition, depending on the erection sequence. With longer spans and smaller flanges, temporary lateral support trusses made of angles and wire rope are often required until adjacent girders are erected and permanent crossframes and lateral bracing are connected. The final erector simply stated that the stability of single girders needs to be addressed.

WHERE DOES RESPONSIBILITY FOR STABILITY LIE?

One erector raised the important issue of responsibility for bracing for stability, noting that certain states require the contractor to determine if lateral bracing is required for the bridge. The problem is that bracing for wind and steel erection issues may not suffice for deck forces or sequence of pour. The question remains: Who then is responsible at what stage?

FIELD CONNECTION PRACTICES

The erectors offered little opinion about field connection practices. One, however, opined that long-span straight bridges can have their splices tightened under the no-load condition. The same erector pointed out that erecting a structure and having to go over it again to tighten certain members adds to cost. That erector stated that the key is to survey the elevations during erection before tightening anything. Furthermore, it stated that geometry control is most important; preferring concentric, not oversized, holes in all members to ensure alignment, spacing, and cross-slope geometry with the exception of secondary members such as lateral bracing. Another erector stated that the use of drift pins before bolting ensures proper alignment.

GENERAL CONSIDERATIONS

One astute erector briefly summarized the key aspects for success in this way: Accurate shop fabrication, accurate location and elevation of supports, maintaining proper elevations at splices, and complete installation of connections before releasing falsework all contribute to a successful steel erection job.

CHAPTER FIVE

REPORTED PROBLEMS ENCOUNTERED IN THE FIELD

DISTORTION OWING TO DECK CANTILEVER BRACKETS

Deck cantilever brackets are used to support deck forms and the screed. If the bracket's diagonal strut does not intersect the flange, but instead the girder web at a point above the bottom flange, there is a potential for web deformation or fascia girder rotation, or both. The bracket rotation is in proportion to the actual deformation of the web as well as to any twist that may develop in the girder as a result of the cantilever load. The distortion will depend on the force in the diagonal, location of the diagonal/web intersection relative to the flanges, web thickness, how close the bracket is to a transverse web stiffener or crossframe, and any temporary support or stiffening provided.

Nine owners reported problems as a result of the displacement at deck cantilever brackets during the concrete pour. These problems included insufficient deck thickness and poor deck profile, resulting in poor riding characteristics and/or the potential for ponding.

One owner, Wyoming, cited a rule of thumb that web distortion becomes a problem when the overhang length exceeds the girder depth.

THERMAL DISTORTION OF SUN HEATING ERECTED MEMBERS

The expansion and contraction of parts of individual steel members owing to thermal effects from the sun can cause the horizontal and vertical alignment of the member to change continuously during the course of a day.

Although there were no questions asked directly about this problem, three owners reported horizontal and vertical girder movements on curved box-girder or I-girder bridges, or both, owing to thermal expansion caused by heating from the sun.

UNANTICIPATED RELATIVE DISTORTION BETWEEN CONSTRUCTION STAGES

As noted in chapter one, in the section on terminology, for purposes of this document, stage construction is defined as “The construction condition where the deck on part of the bridge has been poured and cured [Stage 1] prior to pouring a transversely adjacent part of the deck [Stage 2].” Problems develop owing to the transverse differences in elevation between the Stage 1 deflected position and the undeflected position of the Stage 2 members before pouring the Stage 2 concrete. Crossframe connections between Stage 1 and Stage 2 girders require special considerations. These problems may be magnified in curved or skewed structures.

Eight owners reported problems as a result of unanticipated lateral movement and rotation of girders during deck pour, including the installation of crossframes between stages. In addition, two fabricators cited problems arising from stage construction. One specifically reported problems with connecting crossframes between stages.

GIRDER STABILITY

The stability of girders during shipping, lifting, and erecting, and before completion of placement of the deck, is an important concern. As noted in the responses, there are a number of factors (e.g., b/t and L/b of flanges, crossframe design and erection practices, wind loading, temporary supports, and length of cantilevers) that need to be addressed to ensure stability of the individual members.

Five owners reported problems with, or at least concerns about, maintaining girder stability during the various stages of construction, up to the final condition. One owner reported that a girder fell because not enough crossframes were installed before releasing the crane. Two owners reported problems specifically with the ends of girders cantilevered from a pier to a field splice. Also, four owners reported specific stability problems as a result of winds during construction.

UNANTICIPATED DISTORTION

General

Two erectors agreed that there are generally few problems with the alignment of straight girders. Problems occur with deflection, web verticality, and elevation on certain highly skewed or curved and skewed bridges. The issue pertains to at what load condition the webs should be vertical and what tolerances are applied to “vertical.” Because skewed and curved girder bridges rotate under dead loads, the “desired plumb” condition must be established in advance or ignored.

External forces are needed to force a girder out of plumb during erection so that it will be plumb after the deck is cast. There will almost always be some distortion until all of the dead load is applied.

At Supports

Five owners reported problems resulting from unanticipated distortions at piers, abutments, or other supports. The unanticipated distortions cited at supports were either out-of-plane movement of girder webs or end rotations of girders or stringers.

Those distortions resulted in a moveable bridge unable to close owing to dead-load stringer end rotations, concrete deck cracking as a result of dead-load girder end rotations, difficulty in fitting box girders to bearings and loss of bearing pin keeper plates owing to differential lateral movement of the girder ends. Although some of these problems have occurred at skewed supports, that is not always the case.

In the Span

Twelve owners reported problems resulting from distortions that have occurred "in span" rather than at supports. The reported problems include webs not vertical, difficulty connecting crossframes, buckling of K-frame members, poor alignment, a dropped girder, and bolts popping. The problems often are a result of unanticipated differential deflections between adjacent girders in sharply skewed or curved bridges, improper or inadequate use of falsework, poor horizontal and vertical alignment control, use of oversized holes, or detailing inconsistencies.

Four fabricators reported problems as a result of unanticipated distortions in the span of bridges. Two specifically attributed problems to improper use of drift pins.

GENERAL COMMENTS ON PROBLEMS

One fabricator reported that most problems are the result of human error and are not technical problems. Such problems include designers providing incorrect information on the plans, fabricators exceeding tolerances, or erectors not controlling geometry. Such reports suggest that more care is needed, not a change in practices.

Another fabricator raised the issue of webs being cited as out of plumb and the question of what the effect on the bridge actually is.

CHAPTER SIX

SOLUTIONS TO REPORTED PROBLEMS

DISTORTION AT DECK CANTILEVER BRACKETS

In regard to owners, three reported that additional analysis of the fascia girder is required to solve the problem of distortion caused by the load of the cantilever brackets. One requires the designer to review the load condition on the fascia girder caused by the cantilever bracket forces and, where necessary, provide additional transverse stiffeners, require the bracket to be supported by the bottom flange of the fascia girder, or allow the contractor to propose an alternate solution. That owner also requires the designer to consider the effect of out-of-plane girder rotation.

Two owners have developed software to analyze the fascia girder under such conditions. In particular, the Kansas Bridge Office, in conjunction with Kansas State University, developed the program Torsional Analysis of Exterior Girders (TAEG 2.0), to predict the torsional resistance of the exterior girder eccentrically loaded with the screed machine and deck overhang concrete. Still another owner requires the contractor to submit his forming procedures for approval.

THERMAL DISTORTION OF SUN HEATING ERECTED MEMBERS

Although owners noted distortions of the steel-only superstructure as a result of thermal radiation, no solutions such as general requirements were cited. One owner indicated that the problem was mitigated with the completion of the deck formwork over the girders. Another employed temporary bracing when the problem was encountered on a specific bridge. To avoid reporting a problem that does not really exist, one erector suggested that the erector consider the position of the sun and temperature of the steel when checking the alignment of a structure. One line of girders may be longer than the other because of shading of one by the other.

STAGE CONSTRUCTION

Owners

Several owners have developed strategies for successful stage construction based on past successful practice. Five owners use a closure or construction pour between stages. One specifies at least three lines of girders in the first stage, with a strong preference for six lines where future redecking may be needed. Another owner requires at least three lines in any stage. Two owners use only a top and bottom strut between the girders of adjacent stages, and one of the owners adds cross bracing after the deck pour. Finally, one owner uses slotted holes to facilitate fit-up of adjacent stages.

Washington State cited a report by researchers from the University of Washington of particular interest. “Methods of Controlling Stresses and Distortions in Stage-Constructed Steel Bridges” (*4*) describes six design and construction methods, including a procedure for determining the forces in struts and/or crossframes for several of the methods, a design paradigm for the six methods, and typical strut and/or crossframe connection details.

Erectors

Only one erector offered a solution for the problems of stage construction. That solution is field-drilling the holes in one side of the crossframe after the deck is poured in Stage 2.

GIRDER STABILITY

There were several measures that owners reported in regard to solutions. Two owners address the problem of girder stability by placing more responsibility with the designer. One owner requires checks of the stability of a cantilever girder, adding lateral bracing if required; adequacy of the crossframes to avoid flange buckling owing to the dead load of the girder and/or concrete; adequacy of the flanges for lateral bending or buckling; erectability of the girders; and effects of the pouring sequence in the positive moment regions. The other owner requires the designer to show lateral bracing at middepth of the girders in either one or two bays (depending on bridge width) on spans more than 45 m (150 ft), to control instability owing to wind loads.

Two of the owners place more responsibility with the erector. One requires that the erector show lateral bracing in the erection procedure, if needed. Another recommends that the erector initially install enough crossframes to ensure the stability under wind loads of the erected girder, before erecting subsequent girders.

Other owners reported bridge-specific solutions used when problems arose with no change in their general requirements.

UNANTICIPATED DISTORTION

One erector believes that the use of undersized bolts will sometimes help in making the initial connections. However, slotted connections do not seem to be the answer when distortion results from loss of geometry control.

CHAPTER SEVEN

CONCLUSIONS

The findings of this synthesis study on the erection of steel bridges are based on survey questionnaires and interviews. They are summarized in these conclusions.

The overwhelming majority of respondents agree that most of the common problems that occur during the erection of steel bridges can be prevented by the following:

- Verifying horizontal and vertical alignment before and during erection;
- Installing enough crossframes to maintain geometry and girder stability during erection;
- Properly using temporary falsework or additional cranes; and
- Rigorously following pinning, bolting, and tightening procedures.

FINDINGS FOR OWNERS

In regard to the procedures used by the designer, states reported that consideration is merited as to whether the designer should include an erection procedure in the design.

Many states have reported problems with the deck profile resulting from the deflection, rotation, and translation of deck cantilever brackets. These deformations can be controlled through designer input on support locations to the contractor or contractor-developed forming plans.

Also, states reported that problems develop in stage construction as the result of differences in elevation between the Stage 1 deflected position and the undeflected position of the Stage 2 members before pouring the Stage 2 concrete. Deck alignment between Stage 1 and Stage 2 and crossframe connections between Stage 1 and Stage 2 girders require special considerations.

Successfully implemented strategies include the use of

- At least three girders in either or both stages to reduce transverse movement during deck pour,
- A closure or construction pour between the two stages, or
- Only a top and bottom strut between girders between stages. If deemed necessary, a strategy would be to add cross bracing after the deck pour.

Respondents reported problems relating to girder stability owing to wind, crossframe erection sequences, temporary supports, and deck pouring sequence. Considerations toward solving the problems could include:

- Verification of stability in using the pouring sequence in positive moment areas,
- Checking for stability of the cantilever end of girder field section from pier to field splice,
- Checking the member length-to-flange-width ratio (several states provide guidance with preferable values between 80 and 90), and
- Evaluating the need for lateral bracing.

Where there are differential deflections between girders at the ends of crossframe connections, the girders will rotate transversely as (1) the dead load of the steel is applied, and (2) the concrete dead load is applied. Curved bridges and skewed bridges represent the most common examples of where that condition will occur.

The designer should address the condition and should show on the design drawings whether the structure should be detailed so that the webs are vertical in no-load, steel dead-load, or full dead-load condition. Article 1.6.1 in the *Guidelines for Design for Constructability* (AASHTO and NSBA) discusses this issue in detail.

Also, it is not uncommon for girders to be out of plumb, and designers should evaluate the condition rather than speculating how much the out of plumb is problematic.

The twisting of box girders is another situation that needs to be considered if there is more than one bearing on either end of the box. Because of the rigidity of the boxes, provision must be made to allow for field adjustments in the bearing height to account for any twisting that will occur.

External crossframe connections can also be difficult because of the rigidity of the boxes to both transverse and twist movement. Article 3.9 of the *Guidelines for Design for Constructability* recommends that "If multiple straight boxes or tub girders are adequately braced internally, external intermediate crossframes are not required. For curved multiple box or tub girders that require crossframes between members, use permanent crossframes."

Bearing rotation was also mentioned by respondents. For tangent bridges on skewed supports, there is the potential for transverse rotation of the girder at the bearings, owing to differential deflections as well as to skewed pier diaphragms. Bearings for these types of structures should be designed to allow for this transverse rotation or, as a minimum, distortion-forgiving bearings such as elastomeric pads should be used.

Other survey responses pertained to certification of fabricators and erectors. The owner should mandate that the fabricator and erector be certified by the American Institute of Steel Construction or another suitable program. Furthermore, the owner should enforce submittal and review, accept, or approve, according to agency practice, the erection procedure prepared by the erector.

FINDINGS FOR FABRICATORS

The fabricator should strive to understand the geometric features and how they affect erection—particularly curvature, differential deflections, skew effects, tolerances, and member rigidity.

On complex structures, the fabricator should consult with the designer and the erector to determine the load condition for which the webs should be vertical. In this manner, all participants will understand the geometric assumptions.

Shop-assembly methods were also discussed. The complexity of the structure must be considered when determining the shop-assembly method. The most common method is the progressive girder assembly, with at least three members in an assembly, often including one span or bearing to bearing. Records of the actual shop-assembly blocking dimensions should be maintained and made available to the erector.

According to respondents, the use of standard size holes is encouraged. Oversized holes should generally be avoided, because the geometry of the structure can easily become imperiled.

In regard to fabrication details, particular emphasis should be considered on the following:

- Holes should be drilled accurately,
- Splice material and main members should be accurately match-marked, and
- Members should be fabricated to appropriate sweep and camber tolerances.

Attention should also be given to shipping stability. The fabricator should check the member length-to-flange-width ratio to ensure shipping stability. Where values exceed 60, computations should be made to determine if temporary bracing for shipping is required.

FINDINGS FOR ERECTORS

The erector should submit for review, acceptance, or approval (based on the agency's practice) an erection procedure that addresses all of the pertinent issues. This procedure should lead to a properly erected structure. The issues that follow should be included in the erection procedure, although they are listed separately here for emphasis.

To ensure erection stability, the erector might take the following several measures.

- Check the ratio of member length-to-flange width for erection stability,
- Install enough crossframes to avoid flange buckling owing to the dead load of steel and concrete,
- Verify the stability of the partially erected structure for wind loading, and
- Use falsework as appropriate.

Geometry control should be maintained at all stages of erection. This can be successfully accomplished by

- Determining, in conjunction with the fabricator and the designer, the condition at which the webs are detailed to be vertical and erecting them accordingly;
- Checking the vertical and horizontal alignment of bearings, falsework, and anchor bolt locations before erecting steel; and
- Using appropriate pinning and bolting procedures as detailed here.

The geometry of the erected structure may be significantly affected by the procedures and sequences used for pinning and bolting the members during the erection process. The procedures detailed in this report represent a reasonable balance of the various state requirements. They apply importantly to splices in continuous members and other connections where small movements or placement errors can have a substantial effect on geometry. The erector should review the shop-assembly blocking records to determine the effect of the camber fabrication tolerances on the final shape of the structure. A recommended summary procedure might contain the following:

- Initial pinning and bolting should consist of filling the holes in the connections with 25% pins and 25% bolts and the bolts at least snug tightened before releasing the crane and having the adjacent girders erected.
- The balance of the holes in the connections should be filled with snug-tight bolts.
- Final tightening of the bolts to installation tension should not start until a continuous line or at least adjacent spans have been erected and the vertical and horizontal alignment has been verified.
- Pins should not be removed from the connection until after the previous step has been accomplished.

Erectors should also be aware of potential thermal effects, such as heating from the sun. Also, only experienced road crews should be used.

An analysis of the questionnaire responses raised two general questions for the bridge community:

1. Do the reported problems caused by deviations from the vertical and horizontal alignment of the superstructure have a detrimental effect on the performance of the constructed bridges?
2. Are the problems described by the respondents endemic or more isolated?

There were also comments on the effects of deviation from planned alignment. During construction, when dealing with any of the erection problems as discussed herein, the important question to ask is this: Is corrective action needed when something does not go as expected? Many owners reported problems encountered during erection, such as out-of-plumb girders, which in the end were allowed to remain unaltered or that required additional manipulation to complete cross-frame connections. No detrimental effect of such misalignments was subsequently reported. Is this truly a problem, or must the ramifications of the misalignment, or lack thereof, merely be better understood? One astute fabricator noted that the term "plumb" has little meaning and that acceptable tolerances based on subsequent adequate performance need to be developed.

The erection of steel bridges, although based on science, is an art or craft. The practices and specification requirements are based on rules of thumb, experience, and intuition more so than on rigorous analysis. Rigorous erection analyses, including the prediction and reporting of intermediate deflections (deflection before the final erected condition) are not made, according to the survey responses. Without such analyses for certain types of structures, problems of fit can be expected and, as the responses suggested, they do occur. The problems are exacerbated by stage construction.

Determining acceptable tolerances of deviation from the planned vertical or horizontal alignment of the superstructure based on subsequent performance of the bridge could aid owners in determining whether a true problem exists and limiting or preventing much frustration on the part of fabricators and erectors. The current frequently cited use of the term plumb without associated tolerances given in specifications can be considered too restrictive and unenforceable.

Finally, many erection problems were reported by owners, fabricators, and erectors. For the most part, owners related specific bridges where problems were encountered during erection, whereas fabricators and erectors provided more general discussions of problems. Although most of the owners could cite a problem bridge, the problems seemed isolated. When asked to discuss the solution to the problem, the owners provided much information on how the problem was solved on the problem bridge. However, few offered a global solution to the problem, such as a change in their specifications or practices. This observation suggests that while the problems appear real to the owners, they are not endemic.

In many cases, when problems with alignment arose, the owners chose the do-nothing option with apparently no adverse impact on the performance of the bridge. It could be asked that when doing nothing is acceptable, does a problem exist?

For some specific field problems cited, other than those resulting from failure to follow appropriate specifications or acceptable practices, a rigorous incremental analysis of the erection process could solve problems. Today, such analysis is routine for more complex forms of bridge construction, such as segmental concrete bridges and cable-supported bridges. However, with such analysis, additional costs are incurred. In the majority of the reported cases, additional effort in the field solved the problem. Before more rigorous incremental analyses are instituted, the question to be answered is whether the potential field costs to solve problems exceed any proposed rigorous analysis costs before erection.

REFERENCES

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3. *AASHTO LRFD Bridge Construction Specifications*, 2nd ed., American Association of State Highway and Transportation Officials, Washington, D.C., 2004.
4. Swett, G.D., J.F. Stanton, and P.S. Dunston, "Methods for Controlling Stresses and Distortions in Stage-Constructed Steel Bridges," *Transportation Research Record 1712*, Transportation Research Board, National Research Council, Washington, D.C., 2003, pp. 164–173.

APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
PROJECT 20-5, SYNTHESIS TOPIC 33-10

STEEL BRIDGE ERECTION PRACTICES
OWNER QUESTIONNAIRE

There are many varied steel bridge erection practices, used on increasingly complex structural systems, which have a significant effect on the final profile, location, and position of the erected members. The primary concern is how do these different erection practices, as prescribed by owners and/or developed and implemented by erectors, affect the final position and function of the erected members. **This questionnaire is only for steel I-girder and box-girder bridges, with particular emphasis on curved, skewed, and staged or widened structures.**

Your help in developing a synthesis report of the issues, problems, and results of these erection practices is requested through the completion of this questionnaire. The information you provide will be used to develop a report that will provide an up-to-date compilation of current issues, problems, and practices.

Please return your completed questionnaire via e-mail, before August 9, 2002, to frbeckmann@att.net.

Please send the requested specifications and other documentation before August 9, 2002, to:

Fred Beckmann
Consultant
167 Hawthorne Lane
Chicago Heights, IL 60411

If you have any questions, please contact Mr. Beckmann by telephone at 708-754-1677 or by e-mail at frbeckmann@att.net.

Note: 1. The gray square boxes may be checked using the space bar on the keyboard or with a left mouse click.
2. The gray rectangular areas query a written entry that will allow multiple lines of text.
3. Save responses before closing a partially completed document and retrieve them when reopening the file.

Please provide the name of the person completing this questionnaire or someone who may be contacted to obtain any needed follow-up information:

Name: ______________________________
Title: ______________________________
Agency: ______________________________
Address: ______________________________
Town/State/Zip: ______________________________
Telephone: ______________________________
Fax: ______________________________
E-mail Address: ______________________________

Thank you very much for your help.

STATE QUESTIONNAIRE

This questionnaire has been developed as part of an NCHRP Synthesis Report addressing erection practices **for steel I-girder and box-girder bridges, with particular emphasis on skewed, curved, and staged or widened structures.** Please answer the questions from that perspective. Also note that this questionnaire is divided into five parts: General, Design, Fabrication and Detailing, Erection, and Other.

When returning any supporting documents with the report, please indicate the number of the applicable question. Also, in instances where a contact person is requested, please provide a name, telephone number, and e-mail address for follow-up considerations.

GENERAL

1. Please send a copy of your state's Standard Construction Specifications or those parts dealing with steel bridge fabrication and erection for comparison with the current AASHTO requirements.

2. Are there separate Standard Special Provisions or such documents, not part of your Standard Construction Specifications relating to steel erection, which are generally or often part of the bid documents for steel structures?

   ☐ Yes ☐ No

   If Yes, please return a copy of those documents with this questionnaire.

3. Have you experienced any problems in the alignment, deflection, or final position (both girder elevation and web verticality) of steel members after erection and/or deck pour that may be attributable to construction specification issues?

   ☐ Yes ☐ No

   If Yes, please furnish contact (if different from person named on Page 1)

   Name , Phone , E-mail address ,
   and any other available information

4. Have you experienced any stability issues as a result of wind loads, deck overhang, concrete placement, lifting and handling, and temporary and/or permanent bracing or supports?

   ☐ Yes ☐ No

   If Yes, please furnish contact (if different from person named on Page 1)

   Name , Phone , E-mail address ,
   and any other available information

5. Have you experienced any problems with staged construction that may be attributable to erection requirements or practices?

   ☐ Yes ☐ No

   If Yes, please furnish contact (if different from person named on Page 1)

   Name , Phone , E-mail address ,
   and any other available information

DESIGN

6. Do you require the design to show an erection procedure (similar to requirements for truss and cable-stayed bridges) for complex structures where there may be potential problems in alignment, deflection, or final position (girder elevation and web verticality) of the members due to skewed piers and abutments, curved structures, differential deflections, span lengths, etc.?

   ☐ Yes ☐ No

   If Yes, please furnish a typical sample of those requirements.

7. What impact does the sophistication of the design and analysis practices have on erection practices or procedures?

8. Have you experienced any problems in the alignment, deflection, or final position (girder elevation and web verticality) of steel members after erection and/or deck pour that may be attributable to design issues (differential deflection, curved members, skewed supports, etc.)?

   ☐ Yes ☐ No

   If Yes, please furnish contact (if different from person named on Page 1)

   Name , Phone , E-mail address ,
   and any other available information

9. If you are concerned with actual deflections and girder rotations due to geometry, what methods of analysis do you use to predict these deflections for straight or curved I-girders or box girders on normal or skewed supports?

10. Do you have requirements for flange width-to-thickness ratios or flange width-to-web-depth ratios that are different from those cited in AASHTO?

    ☐ Yes ☐ No

    If Yes, please furnish a copy of these requirements.

11. Do you have any requirements for flange width-to-member-length ratios for handling and erection concerns?

    ☐ Yes ☐ No

    If Yes, please furnish a copy of these requirements.

FABRICATION AND DETAILING

12. Have you experienced any problems in the alignment, deflection, or final position (girder elevation and web verticality) of steel members after erection and/or deck pour that may be attributable to fabrication and detailing issues?

    ☐ Yes ☐ No

    If Yes, please furnish contact (if different from person named on Page 1)

    Name , Phone , E-mail address ,
    and any other available information

13. Are your shop assembly requirements specified in the documents furnished in Questions 1 and 2?

    ☐ Yes ☐ No

    If No, please furnish a copy of these requirements.

14. Do you allow alternative shop assembly methods to those specified if so requested?

☐ Yes ☐ No

If Yes, under what conditions?

15. Do you allow the use of oversized holes in crossframes and connection stiffeners for skewed or curved structures?

☐ Yes ☐ No

If Yes, under what conditions?

ERECTION

16. Have you experienced any problems in the alignment, deflection, or final position (girder elevation and web verticality) of steel members after erection and/or deck pour that may be attributable to erection issues?

☐ Yes ☐ No

If Yes, please furnish contact (if different from person named on Page 1)

Name , Phone , E-mail address ,
and any other available information

17. Were the problems noted in Question 16 due to improper erection procedures?

☐ Yes ☐ No

If Yes, please comment.

18. Were the problems noted in Question 16 due to improper implementation of the erection procedures?

☐ Yes ☐ No

If Yes, please comment.

19. Have field inspection verification procedures been acceptable?

☐ Yes ☐ No

If No, please comment.

20. Do you require the erector to submit an analysis and erection procedure regardless of whether or not one was performed by the designer?

☐ Yes ☐ No

Please comment.

21. Do you check and approve erection procedures submitted by the erector?

☐ Yes ☐ No

If Yes, in what detail. If No, why not?

22. What impact do erection procedures written by the state DOT or transportation agency have on the quality of the erected structure (if required, see Question 6)?

23. What good field connection practices do you feel have the most impact on the final geometry of the erected structure?

24. What temporary methods have you successfully used in erecting complex structures (e.g., temporary bracing, construction sequences, etc.)?

OTHER

25. Do you have a "steel specialist" or "advisory group" within your organization that reviews and provides assistance to designers developing steel bridge plans?

    ☐ Yes ☐ No

    If Yes, please furnish contact (if different from person named on Page 1)

    Name , Phone , E-mail address

26. Can you supply the names of any contractors, fabricators, or erectors and a contact that have been involved with the type of problems addressed in this document and could provide another perspective on the issues?

27. Are you aware of any current research on the issues discussed?

28. Do you have any recommendations for future research specific issues?

29. In summary, what are the key issues associated with achieving a properly erected structure?

30. Additional comments are most welcome.

31. Please list documents sent to contractor.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
PROJECT 20-5, SYNTHESIS TOPIC 33-10

STEEL BRIDGE ERECTION PRACTICES
FABRICATOR QUESTIONNAIRE

There are many varied steel bridge erection practices, used on increasingly complex structural systems, which have a significant effect on the final profile, location, and position of the erected members. The primary concerns are how do these different erection practices, as prescribed by owners and/or developed and implemented by erectors, affect the final position and function of the erected members. **This questionnaire is only for steel I-girder and box-girder bridges, with particular emphasis on curved, skewed, and staged or widened structures.**

Your help in developing a synthesis report of the issues, problems, and results of these erection practices is requested through the completion of this questionnaire. The information you provide will be used to develop a report that will provide an up-to-date compilation of current issues, problems, and practices. If you prefer an electronic version that can be completed using MS Word, send an e-mail to frbeckmann@att.net requesting the "Fabricator Questionnaire Electronic Version."

Please return your completed questionnaire via e-mail, before August 9, 2002, to frbeckmann@att.net.

Please send any additional documentation or materials before August 9, 2002, to:

Fred Beckmann
Consultant
167 Hawthorne Lane
Chicago Heights, IL 60411

If you have any questions, please contact Mr. Beckmann by telephone at (708) 754-1677 or by e-mail at frbeckmann@att.net.

Note: 1. The gray square boxes may be checked using the space bar on the keyboard or with a left mouse click.
2. The gray rectangular areas query a written entry that will allow multiple lines of text.
3. Save responses before closing a partially completed document and retrieve them when reopening the file.

Please provide the name of the person completing this questionnaire or someone who may be contacted to obtain any needed follow-up information:

Name: ______________________________
Title: ______________________________
Company: ______________________________
Address: ______________________________
Town/State/Zip: ______________________________
Telephone: ______________________________
Fax: ______________________________
E-mail Address: ______________________________

Thank you very much for your help.

FABRICATOR QUESTIONNAIRE

This questionnaire has been developed as part of an NCHRP Synthesis Report addressing erection practices **for steel I-girder and box-girder bridges, with particular emphasis on skewed, curved, and staged or widened structures.** Please answer the questions from that perspective.

The primary focus of the synthesis report is based on a rather extensive set of questions that has been sent to the state bridge engineers; however, several of the issues require fabricator and erector input.

1. From a fabricator's perspective, what is the most effective shop assembly practice for straight I-girder bridges (webs horizontal or vertical, with or without crossframes, minimum three girders or bearing to bearing, etc.)?

2. From a fabricator's perspective, what is the most effective shop assembly practice for curved I-girder bridges (webs horizontal or vertical, with or without crossframes, minimum three girders or bearing to bearing, etc.)?

3. From a fabricator's perspective, what is the most effective shop assembly practice for straight box-girder bridges (minimum three girders or bearing to bearing, with or without external crossframes)?

4. From a fabricator's perspective, what is the most effective shop assembly practice for curved box-girder bridges (minimum three girders or bearing to bearing, with or without external crossframes)?

5. What impact do field connection practices have on final bridge geometry?

6. From a fabricator's perspective, what are the key important issues associated with achieving a properly erected structure?

7. Have you experienced any problems in the alignment, deflection, or final position (girder elevation and web verticality) of steel members after erection and/or deck pour that may be attributable to construction specification issues, design practices, or fabrication and erection practices?

   ☐ Yes ☐ No

   If Yes, please supply any information about the severity and frequency of the problems, their causes, appropriate fixes, and any recommendations that would prevent the problems on future work. Please furnish a contact name and phone number so that we may discuss the issues in more detail

8. Are you aware of any current research on these issues?

9. Any new research recommendations?

10. Additional thoughts.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
PROJECT 20-5, SYNTHESIS TOPIC 33-10

STEEL BRIDGE ERECTION PRACTICES
ERECTOR QUESTIONNAIRE

There are many varied steel bridge erection practices, used on increasingly complex structural systems, which have a significant effect on the final profile, location, and position of the erected members. The primary concerns are how do these different erection practices, as prescribed by owners and/or developed and implemented by erectors, affect the final position and function of the erected members. **This questionnaire is only for steel I-girder and box-girder bridges, with particular emphasis on curved, skewed, and staged or widened structures.**

Your help in developing a synthesis report of the issues, problems, and results of these erection practices is requested through the completion of this questionnaire. The information you provide will be used to develop a report that will provide an up-to-date compilation of current issues, problems, and practices. If you prefer an electronic version that can be completed using MS Word, send an e-mail to frbeckmann@att.net requesting the "Erector Questionnaire Electronic Version."

Please return your completed questionnaire via e-mail, before August 9, 2002, to frbeckmann@att.net.

Please send any additional documentation or materials before August 9, 2002, to:

Fred Beckmann
Consultant
167 Hawthorne Lane
Chicago Heights, IL 60411

If you have any questions, please contact Mr. Beckmann by telephone at (708) 754-1677 or by e-mail at frbeckmann@att.net.

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2. The gray rectangular areas query a written entry that will allow multiple lines of text.
3. Save responses before closing a partially completed document and retrieve them when reopening the file.

Please provide the name of the person completing this questionnaire or someone who may be contacted to obtain any needed follow-up information:

Name: ______________________________
Title: ______________________________
Company: ______________________________
Address: ______________________________
Town/State/Zip: ______________________________
Telephone: ______________________________
Fax: ______________________________
E-mail Address: ______________________________

Thank you very much for your help.

ERECTOR QUESTIONNAIRE

This questionnaire has been developed as part of an NCHRP Synthesis Report addressing erection practices **for steel I-girder and box-girder bridges with particular emphasis on skewed, curved, and staged or widened structures.** Please answer the questions from that perspective.

The primary focus of the synthesis report is based on a rather extensive set of questions that has been sent to the state bridge engineers; however, several of the issues require fabricator and erector input.

1. Have you erected any I-girder or box-girder bridges where the owner provided an erection procedure?

   ☐ Yes ☐ No

   If Yes, describe the bridge types and frequency.

2. If the answer to Question 1 was Yes, what impact did these owners' erection procedures have on the quality of the erected structure?

3. What approach or concept do you use to locate falsework and sequence erection to ensure proper fit-up, geometry, and girder profile?

4. Have you experienced any problems in the alignment, deflection, or final position (girder elevation and web verticality) of steel members after erection and/or deck pour that may be attributable to construction specification issues, design practices, or fabrication and erection practices?

   ☐ Yes ☐ No

   If Yes, please supply any information about the severity and frequency of the problems, their causes, appropriate fixes, and any recommendations that would prevent the problems on future work. Please furnish a contact name and phone number so that we may discuss the issues in more detail.

5. Do you have recommendations for flange-width-to-thickness ratios or flange-width-to-web-depth ratios that are different from those in AASHTO?

   ☐ Yes ☐ No

   If Yes, please furnish a copy of these requirements.

6. Do you have recommendations for flange-width-to-member-length ratios as they relate to handling and erection concerns?

   ☐ Yes ☐ No

   If Yes, please furnish a copy of these requirements.

7. Have you experienced any stability issues as a result of wind loads, deck overhang, concrete placement, lifting and handling, and temporary and/or permanent bracing or supports?

   ☐ Yes ☐ No

   If Yes, please supply any information about the severity and frequency of the problems, their causes, appropriate fixes, and any recommendations that would prevent the problems on future work. Please furnish a contact name and phone number so that we may discuss the issues in more detail.

8. Have you experienced any problems with staged construction that may be attributable to erection requirements or practices?

☐ Yes ☐ No

If Yes, please supply any information about the severity and frequency of the problems, their causes, appropriate fixes, and any recommendations that would prevent the problems on future work. Please furnish a contact name and phone number so to that we may discuss the issues in more detail.

9. How do you calculate or address stability issues when lifting individual curved members?

10. What impact do field connection practices have on final bridge geometry?

11. Are you aware of any current research on these issues?

12. Any new research recommendations?

13. From an erector's perspective, what are the key important issues associated with achieving a properly erected structure?

14. Additional thoughts.

APPENDIX B

Survey Responses

APPENDIX B1

Owners—Respondent Names and Yes or No Questionnaire Answers

State	Respondent	Phone Number	1 Spec. Rec'd.	1 Type, Paper, Elect, Internet	2 Spec. Provision	2 Received	2 Type	3 Constr. Spec. Problem	4 Stability Problem	5 Stage Constr. Problem	6 Design Erect. Proc. (E.P.)	8 Dif. Def. Problems	10 Flg. b/t	11 Flg. b/L	12 Det. or Fabr. Prob.	13 Assembly Req. in #1	14 Allow Alt. Assembly	15 Allow OS Holes	16 Prob. Due to E.P.	17 Poor Erect. Proc.	18 Poor Implement. E.P.	19 Field Inspection OK	20 E.P. Required by Erect.	21 State Check E.P.	25 Have Steel Expert
Alabama	Randall Mullins	334-242-6015	No		No			No	No	No	No	No	No	No	Yes	Yes	No	No	Yes	No	No		Yes	Yes	No
Arkansas	Jim Tribo & Emanuel Banks	501-569-2136 501-569-2251	Yes	P	No	No		No	Yes	No	No	No	No	No	No	Yes	No	Yes	No			Yes	Yes	No	No
California	Lian Duan	916-227-8220	Yes	P	Yes	Yes	P	Yes	No	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
Colorado	Mark Leonard	303-757-9309	Yes	I																					
Connecticut	Erika Smith	860-258-0701	No		No			No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No
Florida	Steve Platkin	850-414-4155	Yes	P	Yes	Yes	P	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes	No	No	No
Georgia	Reggie Fry	404-363-7619	Yes	P	No	No		Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Illinois	Jon Edwards	217-782-3586	No		Y/N	No		No	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No			No	Yes	No	Yes
Kansas	Richard Mesloh	785-368-7175	Yes	P	Yes	Yes	P	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Kentucky	Steve Goodpaster	502-564-4560	Yes	P	Yes	Yes	P	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No			Yes	Yes	Yes	No
Louisiana	Kian Yap	225-379-1330	Yes	E	No			Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes
Maine	Dennis Dubois	207-624-3406	Yes	E	No			No	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No		Yes
Manitoba	Sam Donachuk	204-945-3373	Yes	P	Yes	Yes	P	No	No	No	Yes	No	No	No	No	Yes	Yes	No	No			Yes	Yes	Yes	No
Minnesota	Paul Kivisto	651-747-2130	Yes	P	Yes	Yes	P	No	Yes	No	Yes		No	Yes		Yes		Yes	Yes	Yes		Yes	Yes	Yes	Yes
Mississippi	Harry Lee James	601-359-7200	Yes	P	No	No		No	No	No	No	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Missouri	Shelly Schaefer	573-751-3853	Yes	P	No	No		No	No	No	No	No	No	Yes	No	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes
Montana	William Fullerton	406-444-6261	Yes	P	No			Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	No	No	No	No	Yes	No	No	No
N. Dakota	Larry Schwartz	701-328-4446	Yes	P	No	No		No	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	No	No
Nebraska	Vince Koenig	402-479-3972	Yes	I	No	No		No	No	No	No	No	No	No	No	Yes	No	No	No	No		Yes	Yes	Yes	No
Nevada	Todd Stefonowicz	775-888-7550	Yes	P	No			No	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No
New York	Paul Rimmer	518-457-4526	No		No	No		Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes

APPENDIX B1 (Continued)

Owners—Respondent Names and Yes or No Questionnaire Answers

State	Respondent	Phone Number	1 Spec. Rec'd.	1 Type, Paper, Elect, Internet	2 Spec. Provision	2 Received	2 Type	3 Constr. Spec. Problem	4 Stability Problem	5 Stage Constr. Problem	6 Design Erect. Proc. (E.P.)	8 Dif. Def. Problems	10 Flg. b/t	11 Flg. b/L	12 Det. or Fabr. Prob.	13 Assembly Req. in #1	14 Allow Alt. Assembly	15 Allow OS Holes	16 Prob. Due to E.P.	17 Poor Erect. Proc.	18 Poor Implement. E.P.	19 Field Inspection OK	20 E.P. Required by Erect.	21 State Check E.P.	25 Have Steel Expert
Ohio	John Randall	614-387-6210	Yes	P	No	No		No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
Oklahoma	Walter Peters	405-521-2606	Yes	P	No			Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes
Oregon	Nowzar Ardalan	503-986-3345	No		No			No	No	No	No	No	No	No	Yes	Yes	No	No	No			Yes	Yes	Yes	Yes
Pennsylvania	Tom Macioce	717-787-7504	Yes	E	No			No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quebec	Jocelyn Labbe	418-644-0169	Yes	E	No	No		No	No	No	Yes	No	Yes	No	No	Yes	No	Yes	No	No	No	Yes	No	No	Yes
Rhode Island	Richard Snow	401-222-2053	Yes	I	Yes	No		No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	No
Tennessee	Edward Wasserman	615-741-3351	Yes	P	No			Yes	Yes	No	No	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Yes
Texas	Gilbert Sylva	512-416-2751	Yes	E	Yes	Yes	E	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Washington	Nathan Brown	360-705-7219	Yes	E	Yes	Yes	E	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Wisconsin	Craig Wehrle	608-266-8487	Yes	P	No	No		Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes			Yes	No	Yes	Yes
Wyoming	Greg Fredrick	307-777-4427	No		No			No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No			Yes	No	No	Yes

Notes: P = paper; I = Internet.

APPENDIX B2

Owners—Written Questionnaire Responses

State	Question	Comment
Connecticut	1	Will be mailed separately; see reply to Question 31.
Illinois	1	Note: For item 1 above, specifications are available online at http://www.dot.state.il.us/desenv/pdfspec2002/sec500.pdf. Section 500 covers structures and Section 505 is limited to steel structures. A copy of Section 505 is being mailed, but you may wish to refer to the website for Section 506 on painting steel structures and Section 1006 for metal materials.
Louisiana	1	(Please see attached file in the e-mail.) Section 807, pp. 600–643.
Nevada	1	Section 506 attached.
Florida	3	Charles Boyd (850) 414-4275
Kansas	3	Usually survey problems. Some overhang screed brackets.
Louisiana	3	Mr. Allen (225) 379-1565
Tennessee	3	But not attributable to construction specs.
Texas	3	Brian D. Merrill (512) 416-2232, e-mail: bmerrill@dot.state.tx.us
Connecticut	4	Tom Ryan (860) 563-9375, e-mail: cjm1137@aol.com
Florida	4	Charles Boyd (850) 414-4275
Illinois	4	None known.
Kansas	4	John Jones (785) 296-2066, e-mail: jjones@ksdot.org, and any other available information. The KDOT Bridge Office, in conjunction with Kansas University, has developed software, "Torsional Analysis of Exterior Girders (TAEG 2.0)" in an attempt to predict the torsional resistance of the exterior girder when it is eccentrically loaded with the screed machine and deck overhang concrete.
Kentucky	4	Steve Waddle (502) 564-4780, e-mail: steve.waddle@mail.state.ky.us
Minnesota	4	Bridge #27121 joints cracking in deck due to large deflection.
N. Dakota	4	Deck overhang forms deflected more than anticipated.
Nevada	4	Additional temporary bracing had to be added to box girders on a project due to temperature variations from one side to the other during erection.
Ohio	4	Integral abutments supported on bolts to achieve a rotation point. Bolts support beam ends supplied wood blocking on future jobs. Sketch supplied showing bolts projecting above concrete and double nutted supporting the beam.
Pennsylvania	4	See Lehigh University Fritz Engineering Laboratory Report 519.2 May 1995 and International Bridge Conference Paper IBC 88-52.
Tennessee	4	Ed Wasserman, Mitch Hiles (615) 741-3351, e-mail: Ed.Wasserman@state.tn.us, Mitch.Hiles@state.tn.us
Texas	4	Brian D. Merrill (512) 416-2232, e-mail: bmerrill@dot.state.tx.us
Wyoming	4	Web distortion of exterior girder when cantilever exceeds girder depth.
Connecticut	5	Tom Ryan (860) 563-9375, e-mail: cjm1137@aol.com
Florida	5	Charles Boyd (850) 414-4275

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Illinois	5	Years back, location and contact not known. During stage construction of a 4-girder bridge, 2 girders in Stage 1 moved laterally about 8 in. during deck pour. Could not move back with hardened deck in place after Stage 2 steel erected, so had to either make special diaphragms and forms or tear off Stage 1 deck (not sure which happened). Subsequently, ILDOT adopted policy of at least 3 girders in Stage 1 (Stage 2 can be braced against Stage 1), and strong preference for 6 lines where future stage redecking may be needed. Not economical, but reduces lateral motion.
Kansas	5	Difficulty installing frames due to differences in girder elevations between Phase I and Phase II.
Louisiana	5	Mr. Allen (225) 379-1565
Ohio	5	Hard to control delta deflection between phases. Use a construction closure pour or Phase III between Phases I and II.
Texas	5	Brian D. Merrill (512) 416-2232, e-mail: bmerrill@dot.state.tx.us
Florida	6	Charles Boyd (850) 414-4275
Alabama	7	The critical elements that the contractor must know are stated on the design plans. The contractor is responsible for the erection process. However, he is required to submit an erection plan with calculations stamped by a P.E.
Arkansas	7	No information.
California	7	To ensure that the design requirements are satisfied during construction stages.
Connecticut	7	Comment: Temporary shoring/bracing or the placement of larger diaphragms to accommodate erection stresses are common. Also, to address safety concerns of contractors.
Florida	7	The more sophisticated, the higher the level of review and submittal of procedures for review.
Georgia	7	Generally, we just make sure that there is a way to build the bridge; i.e., ensure there is enough room for false bents, access, etc.
Illinois	7	505.08 (e) of the ILDOT specifications requires submittal of an erection plan, but I do not think this is routinely enforced or evaluated on typical bridges. The Bureau of Bridges looks at them for major and unique structures. (Sorry, no “sample” available for Question 6.)
Kansas	7	May require more geometric control and contract plan notes. Constructibility issues may require a pre-bid conference.
Louisiana	7	Shop assembly is required for complex structures.
Maine	7	None
Manitoba	7	Could complicate erection and require a higher degree of engineering during construction phase.
Missouri	7	Not so much on erection, but in fabrication and preparation of shop drawings.
Montana	7	More refined designs are harder to construct.
Nevada	7	For typical projects—minimal impact. Bigger impact for atypical or major projects where a more thorough constructibility review is performed or where erection issues warrant a detailed analysis.
New York	7	Contractor may need to develop strategies out of the norm to accomplish the erection. Innovative techniques can be evaluated at construction.
Ohio	7	Currently contractor must develop erection procedure. CMS 501.06.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Oklahoma	7	Assumptions made in design must be consistent with erection procedures, especially on complex curved and skewed bridges.
Oregon	7	Some of the designs push the steel sections to such limits that the girders become too limber, hence making them problematic in the areas of stability and constructibility.
Pennsylvania	7	The sophistication of the analysis, such as a 3-D analysis, gives us results of the lateral deflection of the girder. For severely skewed bridges, we have shown this rotation of the girder and required the bridge to be fabricated and erected so that in the final position of the girders after all dead loads have been applied, the girder webs are plumb. This is primarily done on long-span, sharply skewed structures. See plan sheet submitted for Question 6.
Quebec	7	Nothing
Tennessee	7	Total impact. Where special design requirements can be impacted by erection, more detailed instructions to the contractor are required.
Texas	7	Sophistication of design could potentially have a bearing on the erection practices/procedures. In general, a more sophisticated design would require more sophisticated erection practices/procedures.
Washington	7	Not sure what the question means. A strict enforcement of methods and sequences during erection is needed to justify exotic design and contract requirements in this area. Contractors generally prefer latitude. Ensuring that a method is practical and safe is generally sufficient during the design stage (sometimes this requires sophisticated analysis). In other words, a general scheme, suitable for all contractors, is preferred. A specific contractor will need to adjust operations to get the required geometrics to work out. The converse may tend to favor one contractor over another or raise costs needlessly.
Wisconsin	7	No comment.
Colorado	8	(Note: Colorado did not fill out the form. They did send an e-mail with a site to get access to their specifications. They also make the following comments in their e-mail. The comments were not directly addressed to any particular question.) The answers to many of the questions in your survey are contained in these documents. Although I am not returning a completed survey, I wanted to make these documents, as requested in the first part of the survey, available to you. In the past several years there has not been a great deal of steel girder erection in Colorado. Two of the most significant problems we have had with steel girder erection in the past are poor external diaphragm and cross-bracing fit-up on curved, skewed, steel-box girders due to differential field rotation of the boxes, and occasional field fit-up problems in general on skewed steel girder for drilling bolt holes.
Connecticut	8	Tom Ryan (860) 563-9375, e-mail: cjm1137@aol.com
Florida	8	Tom Andres (850) 414-4269
Illinois	8	Randy DeBoer was the RE for the Edens/Kennedy (I-90/I-94) interchange in Chicago. A curved bridge over the Kennedy could not be supported between piers and ended up with significant lateral rotation that could not be corrected as subsequent girders were erected. A number of girders have webs out of plumb in the final structure.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Kansas	8	Ken Hurst (785) 296-3761, e-mail: kenh@ksdot.org, and any other available information. Deck placement sequence on long two-span structures. Large differential deflection between staged construction.
Nevada	8	Have experienced alignment problems during erection of curved girders from opposite supports—not attributed to design issues though.
Ohio	8	Occasional design errors; substructure elevation or alignment plan errors.
Pennsylvania	8	See International Bridge Conference Paper 02-43 and Pennsylvania DOT Research Report FHWA-PA-2002-003-97-04(74). A copy of this report was furnished to NSBA.
Tennessee	8	Ed Wasserman, Mitch Hiles (615) 741-3351, e-mail: Ed.Wasserman@state.tn.us, Mitch.Hiles@state.tn.us
Texas	8	John M. Holt (512) 416-2212, e-mail: jholt@dot.state.tx.us
Wyoming	8	Several long, skewed steel bridges have experienced differential lateral movement of the girder ends, resulting in loss of bearing pin keeper plates at the abutments.
Alabama	9	We are concerned and we reference AISC manual for the end cuts.
Arkansas	9	We do not treat curved or skewed bridges differently than straight square bridges.
Connecticut	9	DESCUS and STAAD analysis. Also, Bridge Software Development International, Ltd (BSDI) has been used.
Florida	9	The following computer programs are used during design: Simon, MDX, BSDI.
Georgia	9	No, not usually a concern.
Illinois	9	Have required finite-element grid analysis of girder–bracing system to design crossframes. Unfortunately, this has resulted in very heavy bracing connections when out-to-out with high skews and curve.
Kansas	9	STAAD Model, TAEG 2.0.
Louisiana	9	Pending on software.
Manitoba	9	Direct stiffness method through programs such as BRASS and STAAD.
Missouri	9	We only calculate tilts at expansion devices to enable proper placement of the device. If we need to look at deflections other than dead and live loads, we would need to use a finite-element program (SAP 2000) to check, which we normally do not do.
Nevada	9	Have not done this.
New York	9	Designer dependent.
Ohio	9	Merlin–Dash, Win–Descus; normally, very simple structures.
Oklahoma	9	Normal practice is NOT to use any finite elements except for curved girders.
Oregon	9	We typically use two-dimensional frame analysis using WinStrudl software. On highly skewed or curved girders we use three-dimensional analysis using the same software.
Pennsylvania	9	The most used program used is BSDI 3-D system.
Quebec	9	3-D

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Rhode Island	9	Blank
Tennessee	9	Line analysis for straight. Grid analysis/frame analysis for curved I-girder closed torsion for curved box girder.
Texas	9	Use a grid analysis.
Washington	9	gtstrudl or similar—space frame analysis.
Wisconsin	9	Computers
Maine	10	"Flanges for welded beams shall also be proportioned to give a b/t ratio (flange width/flange thickness) between 12 minimum and 20 maximum with a preferred ratio of 16. These limits are set so as to avoid either a very thin, wide flange that will distort when welded to the web, or a very thick, narrow flange that would be uneconomical to purchase and might be laterally unstable (see L/b ratio in number 11)."
Maine	11	"To facilitate handling in the shop and field and during shipping, the L/b ratio (unsupported length of member/compression flange width) for welded beam designs shall preferably not exceed 90. If using an L/b results in an uneconomical flange design, an L/b ratio up to 110 may be used." [Copied from page 800(1) received from Maine.]
Minnesota	11	Our current manual does not give requirements; however, our new LRFD manual, which is under development, will use a limit of 80 to 85.
Missouri	11	Copy of design information sent.
Montana	11	"Unsupported length in compression of the shipping piece divided by minimum flange width, L/b < 85. They also have design recommendations as follows: 1. Do not reduce flange thickness at a shop splice by more than 25%; 2. Minimim flange size 12 in. x 7/8 in.; 3. Initial trial design, flange width/web depth 20% to 25%; 4. Max. ship length 125 ft; and 5. Max. ship weight 180,000 lb."
Ohio	11	Define minimum flange as 7/8 in. x 12 in. to control fabrication and welding distortion.
Connecticut	12	Paul D'Attilio (860) 258-0305, e-mail: paul.dattilio@po.state.ct.us
Illinois	12	None known.
Kansas	12	Fill plate sizes.
Maine	12	Large skew yields out-of-plumb webs; this has been corrected by detailing accordingly and erecting per shop drawings.
Ohio	12	Occasional shop drawing error. More crossframe detail errors.
Oklahoma	12	We have had problems on skews with crossframes not fitting and on occasion we have had to use welding in the field instead of bolting as noted in the plans to make the connections.
Oregon	12	The problems have been minor and usually are in the area of camber.
Pennsylvania	12	Port Vue bridge near Pittsburgh Area and Ford City Bridge.
Tennessee	12	Ed Wasserman, Mitch Hiles (615) 741-3351, e-mail: Ed.Wasserman@state.tn.us, Mitch.Hiles@state.tn.us
Texas	12	Brian D. Merrill (512) 416-2232, e-mail: bmerrill@dot.state.tx.us
Wyoming	12	Misinterpretation of the design cross slope resulted in crossframe connection holes drilled in the incorrect location. The girders were subsequently misaligned upon erection and connection of the crossframes.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Florida	13	Very minimum requirements.
Mississippi	13	Contact Bridge Engineering for information.
California	14	Need RE's approval.
Connecticut	14	Alternative methods can be submitted by a contractor for almost any project, but they must be approved.
Georgia	14	The fabricator may submit alternate methods for approval by the engineer. Minor changes are often approved if deemed equal or better than specified methods.
Illinois	14	Depends on structure geometry. For most straight and curved structures, our specs already have latitude for web horizontal or vertical or Computer Numerical Control (CNC) with spot checks. For special cases, we consider contractor proposals.
Kansas	14	Strange support geometries may require a change in method. On occasion we allow a reduction in shop assembly complexity, but the fabricator must "donate" the difference in cost. Based on fabricator's performance.
Louisiana	14	Only if the final product stresses and tolerance are within the design limits.
Maine	14	Specifications allow alternatives with provisions.
Manitoba	14	Fabricator must assume full responsibility for his procedures.
Missouri	14	Alternative methods are considered, but must meet minimum of our specifications.
Nevada	14	As requested by the fabricator and approved by the department.
Ohio	14	See 863.20.
Oklahoma	14	The fabricator is required to put the alternative shop assembly in writing, which must be approved by the bridge engineer.
Pennsylvania	14	On some projects, High Steel Structures has requested a CNC and template drilling full size for field splices.
Texas	14	Alternative shop-assembly methods require approval of the engineer.
Washington	14	Simplification is only considered if framing is simple and requirements were overly restrictive. Requirements are generally upheld for complex geometrics.
Wisconsin	14	If it makes sense.
Wyoming	14	Certain specifications may be relaxed or alternative methods permitted, generally with the provision that an unsatisfactory product is the responsibility of the fabricator to correct or replace.
Alabama	15	Unless the design plans show them.
Connecticut	15	Contractors can submit a proposal to use oversized holes, which would be reviewed on a project-by-project basis and must be approved.
Florida	15	If these holes will ensure proper fit-up with a compromise of stress-carrying capacity.
Georgia	15	Typically, the crossframes or diaphragms have regular-sized round holes. One connection stiffener has regular-sized round holes and the opposing connection stiffener has slotted holes to facilitate installation. Crossframes and diaphragms are installed with ASTM A307 erection bolts and then field welded with E7018 low-hydrogen electrodes. Oversized holes would not be detailed when high-strength bolts (ASTM A325 or A490) are used to make the connection.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Illinois	15	Most cases, unless slight increase is allowable for standard size instead of oversize is needed, or ream assembled (RA) is stipulated in contract.
Kansas	15	In only one of the two members. Must be approved on shop drawings. See attached Standard Note.
Louisiana	15	High skew and phase construction when possible.
Maine	15	See specifications 503.34, next to last paragraph.
Missouri	15	On occasion, we have considered and used oversized holes in one ply of the connection (usually the crossframe) on structures where curvature effects are negligible.
Nevada	15	Only when erection difficulties are expected.
Ohio	15	Typical—Oversized with erection bolts in welded crossframes, delta deflection less than 1/2 in. Over 1/2 in. provide slots. Optional—Oversized with two HS bolts bolted crossframe, delta deflection less than 1/2 in. Over 1/2 in. provide slots. Curved with live load in crossframes (CVN)—Bolted connections with oversized holes. Reduce allowable bolt friction due to oversized. Standard holes require CVN and full shop assembly.
Oklahoma	15	Oversized holes are permitted in crossframe or connection stiffeners for skewed and curved structures. Shop drawings must specify washers for oversized holes.
Pennsylvania	15	On some skewed bridges we may elect to use vertically slotted holes to permit differential movement between girders during deck placement. This requires the bolts to be tightened after deck placement, which is an extra construction step.
Quebec	15	Only with slip-resistant connections.
Washington	15	This has only been allowed for one bolt in a group in case of a misdrilled hole. We always specify holes 1/16 in. larger for these connections.
Wisconsin	15	Designer must agree.
Wyoming	15	Oversized holes are not allowed in curved girders and in one ply of the crossframes.
Illinois	16	None known.
Kansas	16	Name: John Jones, and any other available information. Improper bolting procedures.
Louisiana	16	Mr. Allen (225) 379-1565
Maine	16	Insufficient alignment effort. Use of inexperienced crew.
Minnesota	16	27VC45—Wing girder fit up to straight girder.
Mississippi	16	Contact Bridge Engineering for information.
Missouri	16	Fred Caldwell—Senior Construction Inspector, MoDOT (816) 358-1861. Plate girder over Interstate that part of erection was conducted on the ground to minimize lane closures.
Ohio	16	Hamilton County over 75 in Cincinnati—plumbness of webs and alignment of pier on a curved structure due to lack of contractor experience and department oversight.
Pennsylvania	16	Port Vue Bridge near Pittsburgh and Ford City Bridge. On a project in State College, an erector walked off the job due to erection difficulties.
Tennessee	16	Ed Wasserman, Mitch Hiles (615) 741-3351, and e-mail: Ed.Wasserman@state.tn.us, Mitch.Hiles@state.tn.us

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Texas	16	Brian D. Merrill (512) 416-2232, e-mail: bmerrill@dot.state.tx.us
Georgia	17	We have had an incident in which the contractor dropped a girder as K-bracing was being attached to the adjacent girder. The dropped girder was improperly secured prior to being released from the crane. There was another incident on this same project in which the contractor erected a span of girders with web verticality problems. The contractor failed to ensure web verticality on the initial girder and transferred the error to each adjacent girder.
Illinois	17	None known.
Kansas	17	Girders bolted on ground and not blocked properly. Also, bolting splice without the proper use of drift pins and erection bolts.
Maine	17	Insufficient bolts to ensure proper alignment; did not verify vertical alignment during erection progress.
Mississippi	17	Contractor not following approved erection procedures.
Missouri	17	The project had no special erection procedures and process of erecting steel was responsibility of contractor.
Ohio	17	Probably needed a note to require plumbness of the web. Reviewers now look for this problem.
Oklahoma	17	Most of the problems we have experienced are from a failure to properly support the cantilevers. This results in a twisting of the outside beams and a thinning of the deck slab. It often requires that we add an overlay to correct the ride problems.
Oregon	17	I do not see a number 16.
Pennsylvania	17	Erector on the Port Vue Bridge did not maintain horizontal alignment as the structure was erected. The girders were a maximum 2.625 in. from straight alignment at the worst points along the girders. The erector had to go back and loosen the crossframes and push the girders into alignment.
Texas	17	Problems have been encountered when the contractor deviates from the approved erection plan.
Washington	17	Plots of bad flange profiles usually point to kinks at field splices. These have been realigned successfully in most cases if caught soon enough.
Georgia	18	There were no formal erection procedures; however, the contractor's actions resulted in unacceptable results which were linked to the implementation of poor erection practices.
Illinois	18	None known.
Kansas	18	Developed a Bridge Construction Manual to help educate.
Maine	18	Erection procedure did not address timely verification of vertical alignment.
Minnesota	18	We do not know for sure.
Missouri	18	See Question 17—Missouri.
Ohio	18	Combination of substructure layout and contractor experience.
Pennsylvania	18	In the State College project, the erector never completed a comprehensive erection procedure for the bridge. He started erecting the structure and ran into difficulties.
Texas	18	As noted in the previous question, improper implementation can occur when contractor seeks and gains a variance from the approved plan.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Washington	18	In rare instances, erectors have avoided the drift pin requirements. Most problems tend to be unanticipated; that is, everyone is following procedures. Stricter requirements for alignment would help.
Illinois	19	Bolt installation (all snug tight before final tightening) and verification of steel elevations before tightening often not properly accomplished.
Ohio	19	Hard to enforce connection to existing structure. Sometimes a problem with crossframe and stiffener alignment.
Texas	19	Inspectors or project engineer sometimes fail to require the contractor to follow the approved erection procedure.
Washington	19	Most problems can be traced to inexperience or lack of inspection. That is, no one is there to catch improper practices.
Wyoming	19	Occasionally, bolts have not been properly tensioned.
Alabama	20	The critical elements that the contractor must know are stated on the design plans. The contractor is responsible for the erection process. However, he is required to submit an erection plan with calculations stamped by a P.E. (Copied from Alabama Question 7.)
Arkansas	20	Standard specs require contractor to advise department of method or erection, type of equipment, and details of falsework. All items are for information and record purposes.
Connecticut	20	Contractor must provide erection procedure.
Georgia	20	The contractor is wholly responsible for the implementation of erection procedures based on sound engineering principles. Georgia DOT reserves the right to review said procedures whenever deemed necessary. Review of said procedures is purely informal and in no way relieves the contractor of its responsibility.
Illinois	20	Erection procedure required by 505.09(e), but many not submitted to engineer. Analysis by contractor not usually required or submitted.
Kansas	20	Only when specified by Contract Plan Note.
Manitoba	20	Erection procedures including temporary supports shall be designed and sealed by a registered professional engineer.
Mississippi	20	Contractor's erection procedure is reviewed; an analysis is not required.
Missouri	20	Only if specified in contract special provisions for large structures.
Nebraska	20	We provide a blocking and camber diagram on the design plans and require the fabricator to adapt that to the shop plans. We require the erector to base the field erection procedures on the blocking diagram.
Nevada	20	Analysis not typically required.
Ohio	20	Specifications require plan and calculations by professional engineer.
Pennsylvania	20	I believe this is an AASHTO requirement.
Alabama	21	Review only.
Arkansas	21	Specs. require that contractor be responsible for the safety of his methods and equipment, and for performing this work according to plans and specs.
California	21	Caltrans RE reviews detailed calculations and approves erection procedure.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Connecticut	21	Designer reviews procedures for constructibility and structural integrity. Pick locations, weights, and sequence are compared with crane charts and field conditions. The procedure submitted by the contractor is reviewed and returned with appropriate comments. The department does not approve the contractor's working drawings and procedures. Reviewed as a working drawing. Also, very detailed for constructibility, deflections, temporary supports, stage stress levels, etc.
Georgia	21	See Georgia Question 20 comments.
Illinois	21	This office would if requested, but does not routinely see these. Not sure about district construction and resident engineers.
Kansas	21	Contractor's responsibility. Only on critical traffic situations.
Kentucky	21	Thoroughly, and may require resubmittal.
Maine	21	Depends on complexity of structure; generally no review of simple span structures.
Manitoba	21	A thorough review.
Minnesota	21	The field personnel review and submit to the Bridge Office as needed.
Mississippi	21	General compliance with the specifications.
Missouri	21	Only if specified in contract special provisions and is usually checked by engineer of record.
N. Dakota	21	We have not had problems with erection procedures.
Nevada	21	Verify picking weights and points; verify crane capacity and placement.
Ohio	21	Currently check each procedure with staff professional engineer.
Oregon	21	We review and comment, but we do not "approve." The procedures are to be done by a P.E. and as such they must be responsible for the procedure.
Pennsylvania	21	We do not approve erection or contractor submissions; we accept the submissions. Sometimes we do an independent analysis that is very detailed and thorough, but this is typically not the routine.
Texas	21	Erection procedures are reviewed mainly for stability and safety.
Washington	21	We check for segment weight, length, and center of gravity, that cranes of sufficient size and reach can pick and place the segments; that stability in all stages has been addressed. But not final alignment issues.
Wisconsin	21	It has to make sense.
Connecticut	22	We customize each erection procedure in the design plans for curved, complex, or bridges over railroads, and they must be adhered to or an alternate plan can be submitted and stamped by a licensed Connecticut P.E.
Georgia	22	Georgia DOT does not provide written erection procedures for the contractor.
Illinois	22	Not known.
Kansas	22	Procedures guide the erector and clearly define what is expected of the erector by our inspectors.
Louisiana	22	They improve planning by contractor, but it is hard to quantify quality improvement on erected structure.
Maine	22	Usually good results are achieved.
Manitoba	22	Could have the advantage of gained experience if there is a process of communicating the "lessons learned" back to those responsible to maintain these procedures.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Mississippi	22	No comment.
Missouri	22	We are going away from method specs. to performance specs., making contractor responsible for what and how.
N. Dakota	22	N/A
Nevada	22	N/A
New York	22	Unknown
Ohio	22	Only used on specialized cable-stayed structures.
Oklahoma	22	This would be more critical on curved and severely skewed structures.
Oregon	22	A well-written erection procedure always has a positive effect on the quality of the erected structure.
Pennsylvania	22	Very little. I have yet to see an erection procedure in our plans that was even remotely close to the procedure used by the contractor. My personal opinion is that we waste time and money on these erection procedures in our design plans.
Quebec	22	These procedures are not used by us.
Tennessee	22	No erection procedures normally specified.
Texas	22	See "Additional Comments," Texas Question 30.
Washington	22	We have shown schematic details such as crane locations, temporary bents, and segment erection sequences in the plans. The contractor is allowed to change this, but in all cases is required to submit detailed erection plans and calculations.
Wisconsin	22	I do not know.
Arkansas	23	The use of erection pins and/or fitting-up bolts.
Connecticut	23	Recommended practices include: Ensure that the connection is in alignment before erection of next member in sequence, full bolt torque complete if adequate deflection is achieved, not completing appropriate connections until dead-load deflection has occurred is important, pre-assembly of all components, the erection firm must have a thorough knowledge of steel erection, and slotted bolt connections for diaphragms.
Georgia	23	Georgia DOT is one of few DOTs that routinely use a field-welded connection in continuous units versus the standard high-strength bolted connection more commonly used throughout the U.S. We feel that minor alignment corrections can be made easily with this type connection when followed by a qualified inspection and a certified welder.
Illinois	23	Having steel at correct elevation before pinning splices, so workers can install pins without deforming material.
Kansas	23	Drift pins (25%) while "holding in the fall." Using this percentage of pins, which are the same size as the bolt holes, is consistent with shop-assembly procedures.
Louisiana	23	The question is unclear to me. Please get with me at the number on page 1.
Maine	23	Ensure sufficient drift pins and minimum number of bolts to maintain vertical alignment. Verify vertical alignment as soon as practical—preferably before final tensioning of connections.
Manitoba	23	Lots of drift pins. Each span completely bolted and braced before moving on.
Mississippi	23	Competency and experience of field personnel; use of falsework where practical.
Missouri	23	Proper bolt tensioning and drifting. No field reaming at all.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
N. Dakota	23	N/A
Nevada	23	Review of field and shop measurements.
New York	23	?
Ohio	23	Shop assembly, required drift pins, lateral bracing where necessary, good field inspection, experienced erection crews and fabricator.
Oklahoma	23	Checking assembly in the shop, using DTIs, and proper weld inspection.
Oregon	23	Before we connect any steel sections, the position of the anchor bolts and the elevation of the bearings have a big impact on the final geometry. After beams are placed, the procedure of having bolts snug tight first and then tightened in a prescribed sequence ensures a good final geometry and structural integrity. On complex geometry structures, performing partial or full shop assembly makes a big difference in final geometry. In some cases, undersized holes with allowable field reaming makes a big difference in fit and geometry.
Pennsylvania	23	Use standard size holes; do not use oversize holes.
Quebec	23	Shop assembly.
Tennessee	23	N/A
Texas	23	Bolting or welding of connections should work equally well when properly executed.
Washington	23	Splice alignment can generally be reproduced if both fabricator and erector use similar drift pin techniques. Progressive rather than drop-in assembly tends to work better. Shoring near splices can have a number of benefits, including adjustment and stability control. Erectors have been asking for "gravity on" yard assembly with crossframes (curved girders), but stability and reproducibility of that scheme may be problematic in the field (it is also difficult to second guess the contractor/erector methods and means during design). Crossframes between curved girders can be difficult to fit, especially if not installed closely behind or with each girder segment.
Wisconsin	23	?
Arkansas	24	Temporary bracing has been successful.
Connecticut	24	Successful methods include chain falls; crane with straps; temporary support truss for erection on unstable foundations, i.e., barge, soft soil, etc.; dunnage/blocking; pre-assembly onsite or in the shop; full layout in the shop to check camber; erectability; and predrilled holes. Construction sequences, temporary bracing, flying splices and lateral launching of girders. Construction of temporary supports. The box girder must be picked at the correct location especially when you have a splice connection. Segmental launching of steel box girders over railroad, utilizing temporary towers. Also, stiffening diaphragms for construction stresses.
Florida	24	All methods.
Georgia	24	We often use temporary bracing to support cantilevered ends until field-welded splices can be effected. Proper elevations of bracing are very important to ensure fit-up of the connection. We typically provide a construction sequence for complicated structures as informational only. Contractor may submit their own sequence in lieu of using the sequence shown in the plans.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Illinois	24	Ramps for single-point diamond interchange (SPDI) framed into fascia girders on bridge, so ramps and fascias on falsework until slab poured for continuity and composite action. (Damen Ave. at I-55 in Chicago). Shop also supported all material with same jacking points and to same elevations to shop ream the splices.
Kansas	24	Construction sequences, temporary falsework support, temporary wind and stability bracing, and use of DTIs to verify bolting requirements.
Louisiana	24	Shop assembly, construction sequencing and temporary bracing.
Maine	24	Temporary supports (brackets) to hold pier girders.
Manitoba	24	Temporary supports and bracing; launching of box girders; pouring slabs in regions of positive moment first to reduce concrete cracking in negative moment areas.
Mississippi	24	Temporary shoring towers, members, etc. Full shop assembly is the best thing one can do for these.
Missouri	24	Contractor responsibility.
N. Dakota	24	N/A
Nevada	24	Use of “needle beam” for construction of an integral pier cap. Beam erected on column top. Girders threaded onto beam through holes in webs (of girders). Final assembly embedded in concrete.
New York	24	Stage diaphragms.
Ohio	24	Bracing towers, holding cranes, cable bracing to deadman, erection sequence to utilize crossframing for lateral bracing reducing unbraced length, temporary crossframing braces.
Oklahoma	24	We have used temporary bracing.
Oregon	24	I have not been involved in any really complex steel structures. Most of our steel structures are constant depth plate girders. Girder launching is the only procedure I have seen successfully performed.
Pennsylvania	24	Temporary towers are the most successful means in proper erection for accurate geometry. Additional cranes have also been successful.
Quebec	24	Temporary bracing.
Rhode Island	24	Temporary supports and braces.
Tennessee	24	Temporary supports at field splices in curved girders, integral caps to column.
Texas	24	Temporary bracing, construction sequence, shore towers, falsework.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Washington	24	Full trial assembly and splice drilling, with girders and crossframes in place, seems to be good insurance for highly curved and skewed framing. Some of our fabricators also take pictures at yard assembly in case of arguments with the contractors. They have also shared these pictures with contractors in a proactive manner. For curved box girders, we design and detail for one bearing per box. Two bearings per box with even loading is difficult to achieve. Also, bearings with some lateral and longitudinal movement, either temporary or permanent, allow for field fit-up (some bearings are more forgiving than others). Shoring is also beneficial. For widenings and staged construction, bracing to the existing bridges works better than independent construction (partial installation of crossframes without diagonals, one bolt each end). This also reduces the potential for lateral drift during slab placement and eliminates any need for bottom laterals.
Wisconsin	24	We did a 270 ft simple span in three 90 ft pieces.
Illinois	25	Jon Edwards (217) 782-3586
Kansas	25	Design manual.
Maine	25	Jeff Folsom (207) 624-3394; Bill Doukas (207) 624-3424; Dan Glenn (207) 624-3411
Minnesota	25	Tom Merritt (651) 747-2123, e-mail: tom.merritt@dot.state.mn.us or Todd Niemann (651) 747-2132, e-mail: todd.niemann@dot.state.mn.us
Missouri	25	Kent Nelson, P.E., Fabrication Operations Engineer (573) 751-3693
Ohio	25	Not formally usually as requested, same as design support request.
Oklahoma	25	Gerald Mooney (405) 521-6498, e-mail: gmooney@odot.org
Tennessee	25	Ed Wasserman, Mitch Hiles (615) 741-3351, e-mail: Ed.Wasserman@state.tn.us, Mitch.Hiles@state.tn.us
Texas	25	David Hohmann (512) 416-2210, e-mail: dhohmann@dot.state.tx.us
Wyoming	25	Jerry Ellerman (307) 777-4427, e-mail: jerry.ellerman@dot.state.wy.us
Connecticut	26	Hartland Building & Restoration, P.O. Box 614, 28 School St., E. Granby, CT 06626
Florida	26	No
Georgia	26	Please see attachment entitled "Qualified Products List 60 Bridge Fabricators."
Illinois	26	Halverson, Springfield; S&J, South Holland; could also try John Prendergast, City of Chicago (j_prendergast4cdot@yahoo.com) and Bob Rollings, ILDOT District 1 Construction Engineer (RollingsRR@nt.dot.state.il.us) for names of contractors with this expertise. Please do not ask them to complete full survey.
Kansas	26	Pick any one of them.
Kentucky	26	No
Louisiana	26	Boh Brothers Construction Company
Maine	26	Cianbro Corp., Brian Williams (207) 487-3311 and Reed & Reed, Ted Clark (207) 443-9747
Manitoba	26	Neil Harrington, Louisburg Construction, Winnipeg, Manitoba
Mississippi	26	Please contact to discuss.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
N. Dakota	26	No
Nevada	26	N/A without a significant effort to research contract specific issue discussed herein. We can try to obtain requested info.
New York	26	No
Ohio	26	Russ Duskey with Armstrong Steel (740) 345-4503, Mike King with Kokossing (614) 228-1029
Oklahoma	26	Fabricators: Capitol Steel—John Nesom (405) 632-7710, AFCO—Deane Wallace (501) 340-6214 Contractors: Jensen—Gene Spitza (918) 245-6691, Muskogee Bridge—Stuart Ronald (405) 524-3050
Oregon	26	Universal Structural, Inc., steel fabricators (360) 695-1261; Oregon Iron Works, Inc., steel fabricators (503) 653-6300
Pennsylvania	26	For State College project, contact High Steel Structures or the engineering firm of Gannet Fleming, Harrisburg PA. For Ford City Bridge, contact Trumbell Corp or the engineering firm of HDR both of Pittsburgh (HDR was the contractor's engineer).
Tennessee	26	No
Texas	26	N/A
Washington	26	Fabricators: Universal Structural, Inc. of Vancouver, Washington; Fought Inc. of Tigard Oregon; Oregon Iron Works of Clackamas, Oregon. Contractors: G.F. Atkinson; Peter Kiewit; Quigg Brothers. Smith, Monroe and Gray has been a good consultant providing erection plans to contractors.
Wisconsin	26	Call Finn Hubbard the state bridge engineer.
Florida	27	No
Georgia	27	No
Illinois	27	No
Kansas	27	Curved girder erection.
Kentucky	27	No
Louisiana	27	No
Maine	27	Vaguely
Manitoba	27	No
Minnesota	27	No
Mississippi	27	No
Missouri	27	Yes, upon request.
N. Dakota	27	No
Nevada	27	No
New York	27	Yes
Ohio	27	No
Oklahoma	27	Not at this time.
Oregon	27	No

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Pennsylvania	27	Dan Linzell of Penn State University and Chris Earls of the University of Pittsburgh.
Quebec	27	No
Tennessee	27	No
Texas	27	No
Washington	27	NCHRP curved girder testing.
Wisconsin	27	No
Wyoming	27	Study of the Erection Issues and Composite System Behavior of the Full-Scale Curved Girder Bridge Research at Turner–Fairbank Highway Research Center. William Wright P.I.
Connecticut	28	Field welding—existing and new structures.
Florida	28	No
Georgia	28	Improved corrosion protection strategies.
Illinois	28	Stresses and distortions in bracing and main members of highly skewed structures with bracing continuous out-to-out. We are currently reviewing plans for a 69.5 degree skew three span with diaphragms perpendicular to girders and continuous across structure.
Kansas	28	Unique structures tend to have unique problems. Use the KISS method.
Kentucky	28	No
Louisiana	28	We need information on how to handle differential deflections in phased construction with crossframes.
Maine	28	None
Manitoba	28	No
Mississippi	28	None
Missouri	28	None presently.
N. Dakota	28	No
Nevada	28	No
New York	28	Yes
Oklahoma	28	Not at this time.
Pennsylvania	28	What load position should steel girders and crossframes be detailed: load, no load, full load?
Quebec	28	No
Tennessee	28	No
Texas	28	No
Washington	28	Check out the “gravity on” approach for connecting girders and crossframes (curved girders) during shop assembly and the corresponding requirements for camber and design.
Alabama	29	Good Q/A process.
California	29	Safely erect the structure in the designed final position.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Connecticut	29	Key issues include detailed erection procedure; large members must be fabricated within tight tolerances to eliminate cumulative "tolerance drift"; frequent meetings with design personnel to monitor deviations from erection procedure; approved erection procedures; proper erection; proper field inspection; erection crew must be experienced; and temporary forces induced by staged construction must be considered.
Florida	29	Accurate design deflection data, shop assembly of complex girder systems, proper erection procedures.
Georgia	29	1. A simplified design that minimizes the frequency of multiple flange thicknesses and provides for webs that are thick enough to inhibit buckling during fabrication and erection. 2. Qualified fabrication inspection including a three-girder laydown to verify field splice alignment. 3. Verified field elevations including a plan to correct minor deviations. 4. Qualified steel erector including approved procedures and erection sequence. 5. Qualified engineer support throughout the process.
Illinois	29	Anticipate probable behavior based on geometry and include provisions in fabrication and erection to it. Avoid problems and do not require unnecessary steps or actions by contractors that could be better addressed by good detailing.
Kansas	29	Qualified erectors, knowledgeable inspectors.
Louisiana	29	Experience
Maine	29	Experienced and trained personnel.
Manitoba	29	Good design, good implementation at all stages, good construction practice.
Minnesota	29	Think through the erection procedure.
Missouri	29	Good designs, good fabrication, good field personnel.
Nevada	29	Identification of special erection issues and design assessment. Adequate planning and experience of erection crew.
New York	29	Teamwork by all affected parties.
Ohio	29	Fabrication and assembly checks, proper lifting equipment and hardware and lifting beam spreaders, evaluation of lateral buckling bracing required, proper layout/elevation of substructure centerline bearings, job control alignment during erection, also plumbness. Proper hole drifting and bolting. Proper piece mark and match-marking techniques. Compliance to OSHA and general safety requirements.
Oklahoma	29	Using an experienced contractor with good design procedures.
Oregon	29	Design has to be reasonable and consider the challenges of fabrication, transportation, and erection. Fabrication has to be done with proper tolerances and quality control on fit and geometry. Erection has to be well thought out and done by people who are experienced at it.
Pennsylvania	29	Proper horizontal and vertical alignment. Proper deck thickness.
Quebec	29	Good plans, shop details, fabrication, and erection diagrams.
Tennessee	29	Good design, contract drawings, quality fabrication, and knowledgeable erector.
Texas	29	Must have a good design and a good erection plan. These plans must then be followed.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Washington	29	Appropriate trial assembly with matching field assembly, clearly stated in the contract, and strictly enforced. Knowledge of how complex steel framing will deform during various stages of erection. Safety and stability maintained through all phases of erection.
Wisconsin	29	Consider the weight and mass of the pieces, who is doing it, site limitations, and go about it carefully.
Connecticut	30	Conn DOT has a written policy for design engineers that details the information to be supplied in the contract plans and specifications. Major structures to be field top coated. Structures erected on moving surfaces require good survey control. Where vertical survey is required provide adequate control. To make the transition of steel from shop to field erection smoothly, fabricators must take QA/QC to the next level. Following AASHTO guidelines is just that, a guideline. To eliminate reaming of bolt holes for field splices, fabricators should recreate an erection sequence in the shop and then punch holes for splices. The use of templates can be continued only under these circumstances. If a shop chooses to select other means to mark field splices, then a template should be avoided to narrow the margin of error of bolt hole alignment. Issue of paint damage to steel box girders due to roller "failure" during launching operation.
Georgia	30	Interested in determining how other state DOTs correct alignment problems associated with bolted splices.
Illinois	30	Best I could do with limited knowledge of erection.
Kansas	30	The Collaboration Guidelines are helpful to designers. More stringent "owner" specifications are needed for a quality, maintainable product.
Manitoba	30	The beginning of your questionnaire indicates emphasis on curved structures. We do not have experience with curved steel girders, which is an important point that your survey does not question.
Oklahoma	30	None
Texas	30	Regarding Questions 10 and 11, even though we do not have any requirements, we do provide recommendations in our online TxDOT manuals. These can be accessed via the TxDOT website, www.dot.state.tx.us. Regarding Question 22, we do not require that a design have an erection procedure. However, we do have standard sheets that provide minimum erection and bracing requirements. This standard, MEBR(S), can be accessed via the TxDOT website, www.dot.state.tx.us.
Washington	30	Although WSDOT does not currently have specific limits based on Questions 10 and 11, sizing flanges wider than needed for ultimate composite conditions helps with stability during fabrication, shipping, and erecting. Generally, girders designed for wider spacing will already need heavier (and wider) flanges. Trimming down composite top flanges to the bare minimum seems to be false economy. We work with past bridges as examples and they all have wider flanges. It would help to codify some guidelines in-house and in AASHTO specifications.
California	31	Plans, Caltrans Standard Specifications, and Project-Specific Special Provisions.

APPENDIX B2 (Continued)

Owners—Written Questionnaire Responses

State	Question	Comment
Connecticut	31	Bridge Design Standard Practices (2 pp.). Request and approval letters to use Bridge Software Development International, Ltd, as a sole source vender of software for bridge analysis (2 pp.). Use of computer software on specific project description (16 pp.). Revision of design practice for curved girder erection, fabrication, and stability (2 pp.).
Illinois	31	Best I could do with limited knowledge of erection.
Kansas	31	1. Standard Specifications for State Road and Bridge Construction, Edition 1990, Kansas DOT, pp. 392–422; "Structural Steel Construction," pp. 896–899, "Steel Fasteners." 2. Special Provision 90M-0065-R14, Structural Steel Construction, 18 pp. 3. Heat Curving; 90M-0157-R1. 4. Contractor Construction Staking; 90M-0260-R1. 5. KDOT Design Manual, Vol. III, Bridge Section, pp. 3-39 to 3-42. 6. KDOT Bridge Construction Manual; Chapter 9, Structural Steel. 7. KDOT Bridge Office Standard Note 6410 "Bolted Connections," 17 pp.
Kentucky	31	Kentucky Standard Specifications for Road and Bridge Construction, Special Provision for Welding Steel Bridges.
Louisiana	31	Nothing special. Standard documents.
Manitoba	31	None
Mississippi	31	Standard specifications.
N. Dakota	31	Section 616—Structural Steel, North Dakota DOT, "Standard Specifications for Road & Bridge Construction."
Nebraska	31	Website for NDOR construction specs: http://www.dor.state.ne.us/ref-man/conmanual/700/704-02.pdf
Nevada	31	Section 506 of NVDOT specifications.
New York	31	None
Ohio	31	Three documents sent, all paper.
Oklahoma	31	ODOT Construction Specifications for Structural Steel.
Pennsylvania	31	408 especially, Design Manual Part 4, plan sheet from Standard Specs.
Quebec	31	Copy attached to e-mail.
Rhode Island	31	State standards are on our website, www.dot.state.ri.us
Texas	31	Standard Specifications 441. Special Provision 441-008.

APPENDIX B3

Owner—Phone Comments and Separate Report Comments

State	Question	Issue	Comment
Georgia	3	Const. Error	Incorrect cap elevations on continuous field-welded connections.
Washington	3	Shop Assembly	Have had problems where full shop assembly had not been specified in Special Provisions. Have had to loosen and retighten bolts in several cases.
Florida	4	Deck Overhang	Bridge with 9-ft-deep girders, where overhang brackets did not extend to bottom flange of girders. Webs deflected badly and the deck ride was bad. Had to grind deck for ride and bore holes in deck because of ponding. Ride still bad.
Kansas	4	Deck Overhang	Have problem with overhang brackets. Developed torsional loading and transverse movement of girders between crossframes due to bracket detail. Have developed a computer to calculate these effects.
Montana	4	Deck Overhang	Exterior girder rotation and out of plumb due to overhang bracket support. Also caused problems with deck profile.
N. Dakota	4	Deck Overhang	Had problem where overhang brackets were too long and bracket may have deflected excessively. Deck profile not good. After problem, developed new requirements about cantilever bracket length.
Oklahoma	4	Deck Overhang	Had curved roadway where girders were on chords. Girders did not deflect per drawings; cantilever brackets may have been a problem in that the strut did not go all of the way to the bottom flange. The deck was thin and the ride was bad. Had to top with a new surface. Very expensive fix.
Pennsylvania	4	Deck Overhang	Design specifications require the designer to review the load condition on the fascia girder due to the cantilever bracket forces and where necessary provide additional transverse stiffeners, require the bracket to be supported by the bottom flange of the fascia girder, or allow the contractor to propose an alternate solution. They also require the designer to consider the effect of out-of-plane girder rotation, stating that these rotations will cause the overhang formwork
Tennessee	4	Deck Overhang	Most contractors do not bring cantilever bracket to bottom flange. Have developed a computer program to predict deflections of bracket during concrete pour. If deflection excessive, they require supplemental bracing. They now try to put in contract based on an analysis of the girder.
Washington	4	Deck Overhang	Have special requirements for overhang brackets. Contractor must submit deck-forming procedures for approval.
Georgia	4	Deflection	K-bracing buckled after deck pour. Tried fix by cutting several loose, but there was such little movement that they did not fix the rest of the frames.
Ohio	4	Design Issue	For an integral abutment bridge, girder ends rested on anchor bolts that had 12 in. and 24 in. projections to allow for rotations. This was unstable. Had to put wood blocking to support.
Tennessee	4	Design Issue	Designer needs to check deck pouring sequence for the positive moment area.

APPENDIX B3 (Continued)

Owner—Phone Comments and Separate Report Comments

State	Question	Issue	Comment
Tennessee	4	Design Issue	Most designers do not check lateral flange bending.
Minnesota	4	End Rotation	Long simple span bridge, 8 ft deep, 12 in. deflection—expansion device was tacked at given gap before concrete poured. As concrete cured, the concrete cracked from the end rotations. Not necessarily an erection problem.
Tennessee	4	Erection Issue	Erector needs to have enough crossframes for wind.
Texas	4	Erection Issue	On a three-span S-curved bridge, one line fell because no falsework tower used. Falsework towers still officially required, but sometimes erector ignores requirement.
Pennsylvania	4	Fatigue Concerns	Potential fatigue concerns are discussed in a report by Yen, B.T., D. Bae, D.A. VanHorn, and T. Huang, "Lateral Deflection of Plate Girder Web Due to Diagonal Deck for Supports," *Proceedings of the International Bridge Conference*, 1988, pp. 275–281.
Florida	4	Lifting Girders	Have had problems with erection lifts where girders swayed badly and almost buckled.
Kentucky	4	Unstable Girder	Bridge was not stable from field splice to pier. Had to support with falsework on first pier. Stiffened girders at second pier. Blamed on thin web.
Alabama	4	Wind	Bridge with 360 ft span, 30 mph winds moved girders 12 in. up and down. Installed decking after winds died down.
Arkansas	4	Wind	Bridge with deep long girders, high over a ravine, where wind twisted the girders. Since then they have required lateral bracing on spans more than 150 ft. Bracing is placed at mid-depth of girders and will be in one or two bays depending on bridge width and is labeled as construction bracing.
Kentucky	4	Wind	Curved 4-line bridge. Bridge had been set, crossframes installed, and had been installing metal decking. 30 mph wind caused decking welds to break loose. Fixed after wind died down.
Kansas	5	Stage Const.	Require minimum 3 girders in any staged construction. AASHTO requires at least one frame per bay.
Louisiana	5	Stage Const.	Had to use slotted holes in diaphragms to make connections.
Minnesota	5	Stage Const.	Have built Stage 1 of a long bridge. Will soon do second stage; Stage 3 will be a construction pour between first two stages. Expect some problems when that happens.
Montana	5	Stage Const.	Have had problems where the deflection between stages became difficult to deal with. They now use a 600 mm closure pour.
Ohio	5	Stage Const.	Ohio uses an 800 mm closure pour between stages. Construction joints above flanges are not recommended.
Tennessee	5	Stage Const.	Keep one bay open and pour that stage last. Use top and bottom strut for bracing with one bolt in end of each member at the second stage, not the closure pour. Also, for staged construction, they require a closure pour.
Washington	5	Stage Const.	If connection between stages not made, have had problems with girder rotating and moving. Now use top and bottom struts with cross bracing added after concrete pour.

APPENDIX B3 (Continued)

Owner—Phone Comments and Separate Report Comments

State	Question	Issue	Comment
Texas	8	Deflection	Long-span bridge with sharp radius; erection bolts started popping after all of the steel was erected.
Arkansas	8	Diff. Deflection	Have some jobs under contract where there may be differential deflection issues.
Tennessee	8	Diff. Deflection	Have had problems; outside girder camber too high. They now cut the same camber on interior and exterior girders. Also, for skews greater than 30 degrees, they use crossframes normal to girder.
Nevada	8	Fab. Error	If curvature is not right when fitting crossframes, box girders will rotate and require jacking and pulling to achieve good fit on bearings.
Texas	8	K-Frame Design	On a long-span bridge, had to change the design of a bottom intersecting K-frame and add a top strut at the erectors request to stabilize the top flange of the girder.
Montana	8	Skewed Supports	Have had problems making field connections on skewed bridges due to deflection differentials.
Washington	8	Skewed Supports	Bridge skewed greater than 30 degrees; have trouble with screed elevations. Crossframes were normal to girders. Members were detailed to fit in no-load condition.
Louisiana	12	Detailing Error	Lift bridge, 100 ft span, full length 30 WF stringers framed into 8-ft-deep end-floor beams. Detail did not adjust for end rotation of stringer, when concrete deck was poured; the end-floor beam rotated out of plumb and the bridge would not close. Had to remove the back wall and repour to allow additional space for the out-of-plumb girder. Detailing error.
Pennsylvania	12	Detailing Issue	Ford City Bridge—The following information was taken from a report by B. Chavel and C.J. Earls, *Evaluation of Construction Issues and Inconsistent Detailing of Girders and Cross-Frame Members in Horizontally Curved Steel I-Girder Bridges,* International Bridge Conference Report IBC-02-43. The Ford City Bridge is a three-span continuous bridge, where two spans were straight and the third span was curved. There was a detailing inconsistency; the girders were detailed for the webs vertical in the no-load condition, and the crossframes to fit in the steel dead-load condition. Misfits of about 40 mm (1-1/2 in.) were reported in the crossframe-to-girder connection. This detailing inconsistency made field connections difficult, requiring additional forces to make the connections. Horizontal and vertical alignment were both in error due to this detailing inconsistency.
Kentucky	12	Diff. Deflection	Had problems with curved bridge. Tilt of web due to steel dead-load deflections had to be fixed. Was able to solve in field.
Maine	12	Diff. Deflection	After bridge bid, fabricator asked if state wanted webs plumb after or before concrete dead load applied. Owner decided after. Erector advised of decision and possible erection problems. Bridge went up just fine.

APPENDIX B3 (Continued)

Owner—Phone Comments and Separate Report Comments

State	Question	Issue	Comment
Tennessee	12	Diff. Deflection	Not worth worrying about girders being out of plumb for differential deflections issues.
Alabama	12	Fab. Error	One bridge with 360 ft center span, drop in girder was about 3 in. short. Fabrication and QA/QC error.
Florida	12	Fab. Error	Bridge detailed for a 24 in. camber, shop built it to a 12 in. camber. They fixed it by using a 12 in. haunch on the deck.
Oklahoma	12	Fab. Error	Continuous bridge, 60 degree skew. Crossframes did not fit. Had to weld the crossframes to the stiffeners. The holes in the stiffeners were improperly located.
Wisconsin	12	Fab. Error	Have had problems where sweep was at the boundaries of their tolerances on curved girders. Had to fight them to get acceptable fit.
Tennessee	12	Fabrication Issue	Have concern about gap between flange splice plates and girder flanges that may be a result of differences in flange plate thickness tolerances or differences in depth of adjacent girders.
Texas	12	Fabrication Issue	Have had problems where allowed two-girder laydowns were used when drilling field splices in shop. Should not have allowed it. Specifications require bearing-to-bearing laydown, but that is not always enforced.
California	12	Web Not Plumb	Had one bridge where the web at bearing was not vertical; was 4% out of plumb.
Colorado	15	Oversized Holes and Slots	Use oversized holes and short slots for crossframe connections for skews more than 20 degrees.
Connecticut	16	Box Girder Rotation	Had a problem on 225 ft simple span, curved box girder, 300–400 ft radius, sharply skewed bridge. Erector made improper assumptions as to what rotations would develop. Bridge had to be re-erected.
Georgia	16	Girder Fell	Released crane before all K-frames were connected. Girder hit building as it fell. Heat straightened and then erected it.
Mississippi	16	Erection Error	900-ft-long, curved, twin-tub girder bridge. Was shop assembled. Did use falsework but did not set elevations correctly. Tightened bolts as erection proceeded. Did not check alignment or elevations as they proceeded. When they got to the last pier, they were 6 in. short. They allowed erector to put a 6 in. piece of girder at one of the field splices rather than redo the job.
Mississippi	16	Erection Error	Had two other bridges where erector did not use falsework or follow erection procedure.
Missouri	16	Erection Error	Four-span bridge where girders missed bearing pads by 3 in. There was sweep in the girders that the erector did not correct for while erecting. Fixed by lifting girders and removing sweep condition.
Missouri	16	Erection Error	Erected first two girders on ground. Did not check elevation before tightening bolts.
Ohio	16	Const. Error	Much of the problem of web verticality on that job due to error in location of skewed piers.

APPENDIX B3 (Continued)

Owner—Phone Comments and Separate Report Comments

State	Question	Issue	Comment
Ohio	16	Erection Procedures	In process of developing new supplemental procedures for erection considerations relating to out-of-plumb girders on skewed, curved, and other similar type bridges.
Pennsylvania	16	Erection Procedures	Port Vue Bridge—Three-span continuous straight section with a curved two-span continuous curved section. Design requested job to be detailed with webs vertical in the steel dead-load condition. There was no lateral bracing, and oversized holes were used for the crossframe connections. The first erector erected the curved spans without falsework. Horizontal and vertical alignments were both bad. The straight section had horizontal alignment errors of 65 mm (2.6 in.) and the curved section had elevation errors of as much as 75 mm (3 in.). A second erector replaced the first erector. He employed falsework on the curved section, loosened the connections on both sections, and properly aligned the members and retightened the connections to complete the job properly.
Pennsylvania	16	Erection Procedures	State College Bridge—Curved girder bridge, relatively large radius. First erector did not submit a comprehensive erection procedure. Had trouble erecting and did not finish. Second erector submitted a complete erection procedure, loosened the connections, rebolted the connections, and successfully completed the job.
Tennessee	16	Design Issue	Need to have enough crossframes to avoid buckling due to dead load of girder and/or concrete.
Tennessee	16	Design Issue	Check if individual members are erectable.
Tennessee	16	Design Issue	For erection of cantilever girders, need to check if cantilever needs bracing. Designer does this.
Tennessee	16	Diff. Deflection	For curved girders require crossframes to fit in the no-load condition (standard note now on design drawings). For straight girders, require crossframes to fit in the steel dead-load condition.
Texas	16	Oversized Holes	Oversized holes used in diaphragms on a rolled beam bridge. Diaphragms slipped and girder twisted during concrete pour. Beams were 2 in. out of plumb. Do not use oversized holes if crossframes or diaphragms are to be bolted. For field-welded diaphragms, may allow oversized holes for fit-up bolts.
Texas	16	Erection Issue	Have had problems with field-welded splices where alignment was not checked prior to welding of splice.
Texas	16	Skewed Supports	If crossframes of diaphragms are to be field welded, those near skewed supports are field welded after the concrete deck has been poured.
Washington	16	Erection Issue	Have had problems where erector does not pin and align members in accordance with requirements.
Alabama	20	Lateral Bracing	No longer use lateral bracing in design. If needed for erection, erectors are required to show in erection procedure. Erectors usually use clamped bracing or use cables, they do not weld or bolt.
Tennessee	21	Erection Procedure	They try to stay out of erection procedure approval or checking.

APPENDIX B3 (Continued)

Owner—Phone Comments and Separate Report Comments

State	Question	Issue	Comment
Maine	23	Erection Practices	Try to have a pre-erection meeting to discuss pinning and bolting procedures plus elevation and alignment verification, particularly with inexperienced personnel.
Florida	32	Sun Effects	Curved girders move horizontal and vertical due to thermal effects of sun. Movement stops after forms are installed.
Tennessee	32	Sun Effects	Sun affects alignment and wracks girders during erection.

APPENDIX B4

Owners—Specification Review for Shop-Assembly Requirements

Organization	Shop-Assembly Requirements for Splice Drilling or Reaming
AASHTO	11.5.3.1—Progressive assembly with a minimum of three girders.
Arkansas	807.54—Assembly—full girder unless progressive or special complete structure is specified. Progressive is minimum of three girders and shall include two bearings.
California	55-3.16—Specifications are not clear whether full assembly or progressive assembly is required.
Collaboration	Reference (*7*) 7.1.1 and 7.1.2—Allows either full girder or progressive assembly and shall be bearing to bearing.
Colorado	509.21—May be full girder, progressive girder (three girders minimum), or special complete assembly at fabricator's option.
Florida	460-12—Specification does not address the degree of assembly for reaming or drilling.
Georgia	501.3.05E—Normal assembly—full-length girder; complete assembly (when contract requires)—entire structure plus floor system. Partial assembly (when authorized by engineer)—at least three abutting sections.
Illinois	505.04—Assembly may be horizontal, except curved members shall be web vertical unless otherwise approved. Progressive assembly with a minimum of three girders is allowed.
Kansas	702.051—Type B standard unless stated otherwise on plans. Type A (for curved, transitions, super elevation, and/or ramp tie-ins) minimum of two spans bearing to bearing, full-bridge width. Type B not less than two spans bearing to bearing. Type C—minimum of three girders.
Kentucky	607.03.04—Progressive assembly with a minimum of three girders.
Louisiana	807.17—Progressive assembly with a minimum of three girders, unless contract specifies full assembly or complete girder line.
Maine	504.31—Assembly requirements not clear.
Manitoba	Not specified in specifications.
Minnesota	2471.3J1—Progressive with a minimum of two spans bearing to bearing. Full assembly when in contract, length and width specified.
Mississippi	810.02.16—Assembly shall be full-girder assembly unless progressive or special complete structure is specified. Progressive assembly is three contiguous girders.
Missouri	712.3.3.5 and 712.3.3.16—Progressive assembly with a minimum of one span, bearing to bearing, unless the contract requires full shop assembly of all girders and crossframes.
Montana	556.03.13—Full-girder assembly unless insufficient shop space; then progressive assembly allowed (minimum of two girders).
N. Dakota	Not specified in specifications.
Nebraska	Not specified in specifications.
Nevada	506.03.06—Unless otherwise specified, assemble each girder full length.
New York	Full girder required unless progressive, with at least three girders listed as an alternate.
Oklahoma	506.04—Progressive with a least three girders.
Ohio	863.26—Progressive with at least three members. Girders to which diaphragms and floor beams frame shall be assembled to check fit.
Pennsylvania	Progressive with a least three girders.
Rhode Island	824.03.3—Specify AASHTO specifications ream assembled.
Quebec	Main beams (girders) that include field joints must be pre-assembled in the shop, marked lightly with an awl.
Tennessee	602.13—Unless contract states otherwise, assembly may be special complete, full girder, or progressive with at least three girders.

APPENDIX B4 (Continued)

Owners—Specification Review for Shop-Assembly Requirements	
Organization	**Shop-Assembly Requirements for Splice Drilling or Reaming**
Texas	441.7 (1)—Progressive with a least three girders or bearing to bearing.
Washington	6-03.3928—Unless contract states otherwise, contractor may choose between special complete, full girder, and progressive girder with at least three girders.
Wisconsin	506.3.7.1—Full-girder assembly is required unless otherwise approved.

APPENDIX B5

Owners—Specification Review for Pinning and Bolting Practices

Organization	Spec. No.	Field Pinning and Bolting Practices	Field Pinning and Bolting Sequencing
AASHTO	11.6.4.3 & 11.6.5	Min. 25% pins and 25% bolts.	During erection, the contractor will be responsible for supporting segments of the structure in a manner that will produce the proper alignment and camber in the completed structure.
Arkansas	807.69 & .71	Min. 50% holes filled with pins and bolts. At least 2 pins in extreme hole locations (e.g., 4 pins on each side of a flange splice).	All holes to be filled with snug-tight bolts before removing pins.
California		Information not found.	Information not found.
Colorado	509.21(I)	Min. 50% holes filled with pins and bolts with pins in extreme corners of splice connections.	For main member connections, the initial bolts tightened before support systems are removed and the connections completed.
Florida	460-34	Min. 50% holes with pins and bolts.	Information not found.
Georgia	501.3.05 B2	Information not found.	Before making connections, adjust splice joints to correct elevation and slopes and properly align beams.
Illinois	505.08(h)	Min. 25% pins and 25% bolts.	Bolt tightening not to commence until entire continuous line in place. Initial bolts and the balance of the bolts shall be finger tight before removing pins.
Kansas	702.07(i)(l)	Min. 25% pins and 25% bolts. All corners to be pinned.	Information not found.
Kentucky		Information not found.	Information not found.
Louisiana	807.48	Main splices, 50% pins and 50% bolts.	Information not found.
Maine	504.43	Eight pins in each flange and web splice and 50% snug bolts.	Crane not to be released until 50% bolts snug tight. Pins not removed until remaining bolts installed and snug tightened.
Manitoba	1061.73	50% pins and 50% bolts.	Information not found.
Minnesota	2402.3 F	Min. 25% pins and 25% bolts with balanced distribution.	Engineering approval required before tightening. For continuous bridges adjacent spans to be fully erected. Check of bearing and splice elevations required before final bolting.
Mississippi	810.03.28.10	Min. 25% pins and 25% bolts.	Information not found.
Missouri	712.5.1	Min. 33% pins and 17% bolts.	Information not found.
Montana	556.03.13B	Min. 50% holes filled with pins and bolts. At least 2 pins in extreme hole locations (e.g., 4 pins on each side of a flange splice).	Initial pins and bolts inserted before releasing load. Tightening not to begin until complete line is aligned and erected matching full camber line.

APPENDIX B5 (Continued)

Owners—Specification Review for Pinning and Bolting Practices

Organization	Spec. No.	Field Pinning and Bolting Practices	Field Pinning and Bolting Sequencing
N. Dakota	616.03 E3	Information not found.	Splice points in beams shall be brought to proper elevation and supported before bolts tightened.
Nebraska	704.03 E12	Adequate pins and bolts.	Structure to be adjusted to requirements of blocking diagram and verified by inspector before final phase of bolt tightening.
Nevada		Information not found.	Information not found.
Oklahoma	506.04 5	Min. 4 pins per connection and 50% bolts (maybe).	Fill remaining holes and tighten bolts; then remove pins.
Ohio	863.28	Min. 50% holes filled, prefer 25% pins and 25% bolts.	Structure adjusted to correct alignment and camber before permanent fastening is begun.
Pennsylvania	1050.3(C).3c & 6	Min. 25% pins and 25% bolts.	Support structure in a manner that will produce proper alignment and camber.
Quebec	116.9.10.1	Max. 15% pins and sufficient bolts to keep pieces together.	Information not found.
Tennessee	602.45	Min. 25% pins and 25% bolts.	Information not found.
Texas	447.5 (1)	Percent of pins determined by engineer and min. 25% bolts.	Fill remaining holes and tighten bolts; then remove pins.
Washington	6-03.3(31&32)	Min. 15% pins and 35% bolts.	Before bolting, contractor shall adjust structure to correct grade and alignment. Initial bolts to be tightened before member released from crane and next member added. Additional bolts may be added and tightened at that time. Drift pins to be replaced after all bolts tightened.
Wisconsin	506.3.29	Min. 25% pins and 25% bolts.	Before beginning the field bolting on a continuous span, the span and immediate adjacent continuous spans shall be adjusted to correct grade, including construction camber and alignment.

APPENDIX B6

Fabricators—Questionnaire Responses

Organization	Question	Comment
AFCO	1	Web horizontal, three piece minimum, for straight I-girders.
DeLong's	1	We use webs horizontal, no crossframes, bearing to bearing, if entire line will not fit on drill pad.
Egger	1	Webs horizontal. If it is a fully assembled bridge, we install the bracing and have webs vertical. Three girder laydowns is our norm, but will go four or five girders if space allows.
Fought	1	Webs horizontal, without crossframes, minimum three girders progressive assembly holding back one girder.
Grand Junction	1	Webs horizontal, no crossframes except diaphragms at bearings, minimum bearing to bearing or three members.
Harris	1	Webs horizontal without crossframes unless girders have a big skew or large camber; if so, then you may want to test fit a few frames in vertical position.
High	1	Our preference is to assemble girders with the web vertical. We know we are responsible to have proper fit in the field. Many times at the estimating stage, decisions are made to assemble difficult connections based on problematic configurations even if codes do not require assembly. Other times we see assembly requirements that would not be a problem if it were not done. Most of the time we do not see a need to assemble straight girder crossframes. Connection configurations are a determining factor. We do not like oversized holes as a fabricator and erector in frame connections. Lateral bracing oversized holes are fine provided that frames are pinned and bolted before lateral bracing is placed. As to how many pieces are required in assembly, assembly length, bearing-to-bearing requirements, and definition of carryover members in a continuous assembly, we offer the following comments. Bearing to bearing is better than number of members. It allows you to check distance from bearing to bearing and camber configuration between bearing points.
High	1A	Common sense applies, however, because spans are increasing in length, and we have seen several in the 400 to 500 ft range. My point is that space may dictate what you can do and, if hard and fast rules are in effect, what are the options. It is our responsibility to guarantee fit and meet schedule. Both items are critical to owners. As for the definition of carryover members, we need to consider that if we had a girder in Pennsylvania, we could set it up to the same configuration in California—guaranteed. Carryover should be defined as the last piece in the continuous assembly that is brought back to position one to continue with the line. Level lines can be shot on the girder to put it in the same position at the ends and camber quarter points.
Industrial	1	Minimum two bearings, webs horizontal, without crossframes. This is when we drill the field splices in the unloaded position. The unloaded position works because a bridge does not fully deflect from steel load until it is fully erected.
Lincoln	1	Webs horizontal without crossframes.
Stupp	1	We prefer to do straight I-girder assembly with the web horizontal and in an unloaded position. This position allows ease of adjustment for correct geometry prior to placement of the field connection holes. This position also gives you a clear picture of the camber pre-dead load. This is also the safest way to assemble. We prefer minimum of three members per assembly. Again this method gives you a very clear picture of one girder to another with regard to fit, length, and camber. We also understand that AASHTO/NSBA has looked at and recommended in some cases the need to only assemble two members at a time. In some cases, this may be very appropriate with regard to quicker assembly for quicker delivery or ease for those who CNC splices and do trial fit.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Tampa	1	Webs horizontal, without crossframes, prefer bearing to bearing with a three-girder minimum.
Trinity	1	Web horizontal; crossframes not usually assembled; either three-girders minimum or bearing to bearing.
Universal	1	We prefer to bunk the shop assembly by doing them vertical, bunking at least three girders at a time. We do not assemble any crossframes on straight bridges.
Vincennes	1	Webs horizontal, without crossframes, minimum three girders.
Unnamed	1	Web horizontal, no crossframes, minimum three girders.
AFCO	2	Web horizontal, three piece minimum (but no fewer than required to check center to center of bearings) for radii greater than 600 ft, barring other complex geometric features.
DeLong's	2	Webs horizontal, bearing to bearing as a minimum, no crossframes unless geometry is unusual.
Egger	2	Webs horizontal. If it is a fully assembled bridge, we install the bracing and have webs vertical. Three girder laydowns is our norm, but will go four or five girders if space allows.
Fought	2	If curved, and girder lengths are not excessive (radius 1,000 ft or larger, length 100 ft or less), webs horizontal in a two- or three-girder progressive assembly holding back one girder and a limited web vertical trial assembly of two lines and several girders with crossframes to verify fit. With a tighter curve, longer girders or both (radius less than 1,000 ft and longer than 100 ft or less), a webs vertical progressive assembly, holding back one girder, with a minimum of three girders, two or more lines wide, with a limited number of crossframes.
Grand Junction	2	Webs horizontal, no crossframes except diaphragms at bearings, minimum bearing to bearing or three members.
Harris	2	Depends on radius of curve and type of connections of frames. Large radius, horizontal, and no frames. Short radius (500') vertical no frames if simple connection and no skew. Use frames if complicated and skewed.
High	2	Webs vertical is our preference. We check the top and bottom flanges of each I-girder to ensure they are within tolerance with the girder standing vertical. The next consideration needs to be girder stiffness. In other words, how easily can a person flex the member laterally? We do not approve of any oversized holes or slotted holes in crossframe to stiffen connection because of geometry control (girder spacing, alignment, cross-slope configuration, etc.) when the bridge erects. As an erector, we have the same opinion. As for assembly length, our preference is the same as stated in High Question 1 this sheet.
Industrial	2	Curved I-girders are swept after laydown, the same assembly as straight girders for field-splice drilling. Curved bridges are assembled with webs vertical after heat curving, for sweep check, if required. AASHTO specifications for heat curving must not be violated.
Lincoln	2	Webs horizontal without crossframes.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Stupp	2	For all of the same reasons as above we prefer to do curved I-girders in the web horizontal position. With even more concern about geometry, in this type of bridge, this position allows you to safely and accurately check both camber and curvature. As for assembly with crossframes, there are some extreme curves and/or skews that should require some type of trial assembly of representative girder sections and their component parts, be it crossframes or lateral bracing, to ensure field fit. This type of assembly should be called for on the design drawings with guidelines establishing the requirements for assembly to meet the contract. We do not believe it necessary to assemble web vertical and crossframes for the majority of curved I-girders.
Tampa	2	Webs vertical "if" curve is tight, which would then require at least some crossframes. Prefer bearing to bearing with three-girder minimum.
Trinity	2	Web horizontal; I-girders moved during progressive assembly; therefore, "X" frames not usually shop assembled. Assembly depends on splice height and curvature for number of girders.
Universal	2	We prefer to bunk the shop assemblies of curved girder bridges in the vertical position. If the specifications require, we will install one or more girder lines parallel with each other and install crossframes and diaphragms to ensure the fit. We will also install any diagonal crossbracing at the same time.
Vincennes	2	Webs horizontal, without crossframes, minimum three girders.
Unnamed	2	Web horizontal, no crossframes, bearing to bearing, sometimes bearing to splice depending on length.
AFCO	3	Minimum three girders or bearing to bearing. If external transverse members frame to both web and flange, they also should be part of shop assembly.
DeLong's	3	We have not fabricated box girders.
Egger	3	We ream these in three-girder sets with no external bracing.
Fought	3	Minimum three girders, no crossframes.
Grand Junction	3	Minimum bearing to bearing or three members; no external crossframes: with diaphragm at bearings between girders.
Harris	3	Three girders without frames.
High	3	Our comments are the same as answered in Question 1, except for the need to assemble frames. Boxes do not flex; therefore, most of the time there is a need to assemble frames that tie boxes together. Sometimes they are drilled from solid in assembly. This is a fabricator's choice. As a fabricator and erector, we do not like oversized holes in frames.
Industrial	3	A true box girder is usually a pier cap without field splices, but occasionally one could have a field splice. Tub girders generally have field splices. Both tub and box are drilled in vertical assembly, minimum two bearings, supported against steel deflection.
Lincoln	3	Do not fabricate steel boxes.
Stupp	3	Our response would be the same as Stupp Question 1 this sheet. The only difference would be with respect to box girders used in truss type bridges and the need to assemble, be it trial or as part of the assembly, the vertical and lateral components to ensure field fit. In the case of simple straight box girder lines, no crossframes or other components should be required during assembly in the shop.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Tampa	3	Bearing to bearing with three-girder minimum, without external crossframes, but may need end or bearing diaphragms.
Trinity	3	Either three girders minimum or bearing to bearing without external crossframes.
Universal	3	USI prefers the minimum three-girder assembly procedure. We do not install external crossframes on a straight bridge.
Vincennes	3	Minimum three girders, without external crossframes.
Unnamed	3	Minimum three girders, no external crossframes.
AFCO	4	Minimum three girders or bearing to bearing. If external transverse members frame to both web and flange, they also should be part of shop assembly.
DeLong's	4	We have not fabricated box girders.
Egger	4	We ream these in three-girder sets, with no external bracing.
Fought	4	Minimum three girders. Depending on complexity, a trial assembly with crossframes may be needed to verify fit.
Grand Junction	4	Minimum bearing to bearing or three members; no external crossframes: with diaphragm at bearings between girders.
Harris	4	Depends on radius: large radius, no frames; small radius, 500 in., use frames.
High	4	Here again we check curvature of top and bottom flanges. Frames are put in assembly and reamed or drilled from solid. Boxes do not flex laterally. Assembly length preference is the same as stated in Question 1. Whether the box is curved or straight, we assemble them with the webs vertical.
Industrial	4	Curved box girders or tub girders are always assembled as curved. They will be drilled with webs vertical, minimum two bearings supported against steel deflection.
Lincoln	4	Do not fabricate boxes.
Stupp	4	Again, three-girder minimum is the preferred method with no crossframes. But each curved structure should be looked at closely for special requirements or needs based on geometry or radical changes in elevation or skew. That alone should determine the extent to which other components, crossframes or bracing, is added to the assembly process.
Tampa	4	Bearing to bearing with three-girder minimum, must have end-to-bearing diaphragms, possibly need crossframes.
Trinity	4	Either three-girder minimum or bearing to bearing with external crossframes. Crossframes should verify that girders are curved the same.
Universal	4	We prefer to assemble curved box girders similar to curved I-girders as identified in our answer for Question 3. We will set up lines parallel to each other and install crossframes to ensure fit.
Vincennes	4	Minimum three girders with external crossframes for tub girders.
Unnamed	4	Minimum three girders, no external crossframes.
AFCO	5	I assume the question refers to making connections during erection. As far as I am concerned, the use of drift pins is essential in achieving intended final profile, horizontal orientation, and girder attitude (plumbness). Additionally, the sequence of erection greatly impacts the overall geometry.
DeLong's	5	I think it is important to drill a line assembly to ensure fit in the field. I do not think it is necessary to include crossframes on most structures. The fabricators can do this at their option to improve their confidence level on a bridge with complex geometry.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Egger	5	This appears to be an engineering question. We are limited by the specifications for each bridge.
Fought	5	Failure to properly pin connection with drift pins prior to bolting can have an effect on geometry. When several girders are assembled on the ground and then raised as one unit, proper camber blocking must be used and connections properly pinned with drift pins to achieve the correct geometry before lifting into place. Proper installation (progressive) of crossframes on curved girders.
Grand Junction	5	Minimum full-sized pins installed before bolting should be 10% of each connection equally installed on either side of splice.
Harris	5	A lot. Most erectors do not use enough pins.
High	5	Geometry needs to be maintained during construction. Elevations can be adjusted with either falseworks or multiple cranes. Bolting solid should not be accomplished before elevations are verified.
Industrial	5	On long spans, enough crossframes or diaphragms must be installed to properly stabilize the structure and enough pins/bolts installed, in the field splices, to keep proper alignment.
Lincoln	5	Good field erection will have a large impact on the final product fit-up.
Stupp	5	Field connection practices have very minor impact on simple straight bridge types. These connections are simple and straightforward. Where we have seen an impact is in curved structures, where improper alignment due to the skew or elevation change has required the field to force connections, which can result in misalignment. In truss type components we have seen field problems as a result of the lengthening and shortening of members. In this case, the field is forced to align members out of plumb until the bridge is swung. This can result in a connection appearing to be totally out of alignment. This can be a major problem for those not aware of this condition prior to start of erection.
Tampa	5	If erector is bolting up on the ground, he must block to no-load position.
Trinity	5	Both bolted or welded field connections used with acceptable results. Bolted crossframes and diaphragms are difficult on skewed bridges.
Universal	5	When we assemble girders using the minimum three-girder assembly method, we match drill one end of the girder during assembly. We use pins to center the plates to the holes. If the field pins the connections as standard field practices require, we have no field fit-up problems.
Vincennes	5	Must torque bolts after all connections are made.
AFCO	6	1. The engineer must adequately address constructability issues in the design (e.g., differential deflection). 2. Fabricator's understanding of geometric features and how they impact erection. 3. Having an erection procedure that addresses issues that lead to the desired characteristics.
DeLong's	6	Bearings must be properly located in the field, including longitudinal and transverse dimensions, and elevations. Splice plates must be match-marked and properly oriented.
Egger	6	Accuracy of straightness (or sweep) and camber. Also, accurately drilled holes and clear match-marks at the spliced connections.
Fought	6	Simplicity of design—experienced erectors.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Grand Junction	6	Pins (full size); proper bearing seat and anchor bolt placement; correct falsework (if used) placement; enforce submittal and approval of an erection plan!
Harris	6	Common sense. You must consider what type of shop assembly to use, which is based on how complicated the structure is; i.e., straight, curved, radius, skew, connections, and camber.
High	6	Geometry control is a must.
Industrial	6	a. Substructure bearing seats adjusted for construction variations. b. Splice plates properly pinned. c. Enough stabilizing members in place. d. Main member webs kept as vertical as possible.
Lincoln	6	Good erection crews.
Stupp	6	One (if not the most important) issue is a properly detailed project. The detailing and the transfer of information through the shop and erection drawings is key. The next key issue for fabrication is the day-to-day control in the shop to ensure that the as-detailed bridge becomes a reality. Also staying within the tolerance ranges for camber and straightness as provided by AWS, AASHTO, and specific state specifications. Lastly, and very important, is the communication of as-built condition or any variation from the details to the erector.
Tampa	6	Field survey/concrete/bearing placement by others must be correct.
Trinity	6	Alignment of connections before final tightening of bolts.
Universal	6	We have found that if the erector does not properly pin the field connections with the proper amount of pins, the tolerance errors start to multiply throughout the remainder of the bridge, disallowing the proper camber and proper alignment of the webs (vertically).
Vincennes	6	All pieces must be clearly match-marked. Keep all camber and sweep within tolerance.
Unnamed	6	Keeping ends of girders aligned and webs vertical.
AFCO	7	Yes. Dennis Noernberg (501) 340-6314 The majority of the problems related to misalignment and poor final steel profiles are a result of the lack of use of drift pins. Many erectors are of the opinion that if a bolt will go in the hole I do not need pins. This is totally and grossly inaccurate. Pins in web splices ensure correct profiles and pins in flange splices make a straight bridge straight and not dog-legged. Furthermore, pins in crossframe connections on curved bridges will ensure that torsional rotation of erected-only steel is properly resisted; otherwise, “roll-over” can occur and cause numerous other problems.
DeLong’s	7	Yes, we occasionally have problems in jobs built in more than one stage. When the Stage 1 deck has been poured, and the erector is trying to install the crossframes that connect a Stage 1 girder to a Stage 2 girder, he will pull the Stage 2 girder out of plumb trying to make the crossframe fit. We suggest waiting until after the Stage 2 deck is poured before installing the crossframes that attach Stage 1 to Stage 2.
Egger	7	No
Fought	7	Improper pier elevations during erection—insufficient crossframe installation during curved girder erection. Insufficient shoring on tightly curved bridges during concrete pour. Improper pinning of splice joints during erection.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Grand Junction	7	Yes, have had problems on curved girder jobs where falsework could not be installed. Some of the girders had to be released from the crossframes and lifted with a crane and reconnected. Also had problems with curved box girders where the internal lateral bracing members were too light and had to be replaced.
Harris	7	Yes
High	7	Most issues were related to incorrect information on designs, fabrication tolerances exceeded, or erectors not controlling geometry. Let me briefly explain with examples. Rehab job designs sometimes do not reflect the as-built condition. The outcome is self-explanatory. We erected several jobs for other fabricators that mislocated the point of curvature on a girder (details correct). This obviously threw the girder spacing off and created crossframe connection fit-up problems. Several times we supplied steel to contractors where their erector misaligned boxes and had trouble making splices. One example of this is where the job was staged. It involved box cross girders. The first phase was to place a short box and erect the longitudinal girders to it. It involved two lines of girders. The next phase was to erect the longer pier box and tie multiple lines (8) of longitudinal girders to it. The call from the field was that the splice in the boxes could not be made.
High	7A	As the fabricator, we saw an opportunity to build the box as one complete member and affix the splice plates to it and drill from solid after which the boxes were parted. It was foolproof. When we got to the field the contractor's erector misaligned the two boxes and the elevation on the pier was off. Geometry control, geometry control, geometry control—I cannot say it enough times. Another time the contractor's erector decided not to use the erection procedure supplied by the owner. He eliminated falsework. Unfortunately, each pier had cross boxes and since it was a continuous structure, tie plates were used across the box tops to tie in longitudinal girders on either side. As the fabricator, we had all members in full no-load assembly. The call from the field was that they could only see half a hole in the splice plates over the box. We had the solution and the contractor had his erector temporarily report to us on site. I was personally on site with one of our fabrication supervisors.
High	7B	Since the longitudinal girders tied into the web of the boxes, everything needed to be exact. The first thing we checked with a surveyor was the face-to-face dimension at the bearing locations on the boxes within the span they were working. The one side measured 5/32 in. different than the other. Bolt holes are oversized by 2/32 in. The box was moved 3/32 in. The next move was to pick the girders spanning the face to face of boxes within the span with multiple cranes and spreader beams to get the girders in a no-load configuration. The erector did this. Not all girders were placed in this span before we erected girders in the adjacent span. All holes were made with 7/8 in. bolts without a problem. Eliminating falseworks without a procedure to maintain geometry does not work. Geometry control, geometry control, geometry control—I cannot say it enough times.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Industrial	7	Yes. On curved structures, which are subject to a steep grade and a tight curve, the problem of web verticality can become a heated issue. The top flange will resist coming to plumb. The contract design drawings will clearly define the amount of sweep and camber, but will ignore this problem of twisting or torque that the web is subject to. This problem is magnified when there is a restricted erection area. The state must recognize that not every point of the web plate will be absolute plumb after erection and steel-load deflection. The designer must be able to recognize this potential problem and perhaps design using tub girders in lieu of a single girder.
Lincoln	7	No
Stupp	7	The only problems recently have occurred on a couple of bridge-widening projects. In both cases there was no allowance made for the offset in elevation between the existing and new. I believe that in both cases there were assumptions made with regard to the dead-load deflection of the steel and decking to achieve proper alignment with the current deck elevation. In one case, the offset was minimal and the deck had been removed from the existing. The slight offset was made up in the deck pour. In the second case there was no deck removal and thus the new steel was significantly higher than expected after erection. This made it impossible to tie the structures together permanently until the deck was poured. Both cases resulted in acceptable bridge projects, although the second case took considerably more time and effort. Planning for these conditions on widening projects is extremely important.
Tampa	7	Yes. Had more than one project that deflected more than was anticipated by designers (tub girders). One of the problems is that fabricator has records for no-load camber position, but field has no check in the erected position so problem may not manifest itself until forms are in place. Then it is too late.
Trinity	7	No comment.
Universal	7	No
Vincennes	7	No
Unnamed	7	No
AFCO	8	No
DeLong's	8	No
Egger	8	There is some experimentation being conducted that calls for drilling splice connection holes in girders by means of a computer-aided manufacturing (CAM) setup. This eliminates the need to position continuous girders for reaming.
Grand Junction	8	No
High	8	FHWA's Turner–Fairbank Highway Research Center has full-scale research currently underway on curved I-girders. How they function and react could be tied into boxes. Understanding how curved and skewed bridges function and react is being addressed by the Associated Pennsylvania Constructors Subcommittee, Penn State University, and University of Pittsburgh for PennDOT.
Industrial	8	No
Lincoln	8	Yes. State of Kansas (John Jones).

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
Stupp	8	There is an effort by the AASHTO/NSBA Collaboration Task Group on Erection in considering standards covering some of these areas in which our company is participating. Also, there are task groups within the organization reviewing and updating standards for shop fabrication and quality control.
Tampa	8	No, except differential deflection discussions at NSBA.
Trinity	8	No comment.
Universal	8	No
Vincennes	8	No
Unnamed	8	HDR has or is doing a study, I think.
AFCO	9	Research should be done by AASHTO so as to enable engineers to properly address problems of differential deflection at the design stage and not ignore the problem. Even an experienced erector can experience makeup problems and end up with a structure that is not consistent with the intent of the designers unless this sort of problem is dealt with early in the process.
DeLong's	9	No
Grand Junction	9	None
High	9	We need to consolidate current efforts and control the outcome with a better understanding. Pockets of activity usually do not lead to accepted standards.
Industrial	9	Research the use of low-price stainless steel in bridge construction.
Lincoln	9	Blank
Stupp	9	We have no research recommendations at the moment.
Trinity	9	No comment.
Universal	9	No
DeLong's	10	The alignment, deflection, and final position issues are discussed regularly at the NSBA/AASHTO collaboration meetings. Even with all of the educated, intelligent people participating in these discussions, we still have not reached a consensus. I believe these issues need to be looked at on a case-by-case basis. There is not a single, correct answer that will work for every structure.
Grand Junction	10	For complicated structures (other than straight and square), contractors and designers should require results (records) of QC/QA final shop-assembly results. This ensures that the fabricator has assembled to match shop-assembly drawing requirements (within specified or agreed upon tolerances).
Harris	10	Erectors tend to avoid using enough falsework or pins in connections. They think a bridge will hold its geometry and camber if they put a bolt in the hole.

APPENDIX B6 (Continued)

Fabricators—Questionnaire Responses

Organization	Question	Comment
High	10	Contractors, fabricators, erectors, designers, and owners need to be on the same page. Standards need to be established relative to determining if a girder does or does not need to be out of plumb at the time they are erected. This is based on girder stiffness and allowable stresses in girders and diaphragms. Crossframes will be detailed according to this determination. This is another standard to consider—detailing frames. Tolerances at time of erection and after decking need to be established also. We just cannot use the word "plumb," although it is the theoretical target.
Industrial	10	The steel manufacturing industry and the steel fabrication/construction industry must start working together, like we have in the past.
Lincoln	10	Blank
Stupp	10	What we have seen over the years is a better environment for communication between designers, engineers, fabricators, and erectors. We all must continue in this effort to share ideas and experiences. We applaud this and other efforts within our industry to provide growth and understanding.
Trinity	10	Have used two-girder assemblies with customer approval and had acceptable results.
Vincennes	10	Oversized holes in crossframes. For box girders used as pier caps, keep the connection from the girder to the pier cap girder simple. We have seen these connections to be very difficult to ream while in assembly.

APPENDIX B7

Erectors—Questionnaire Responses

Erector	Question	Comment
High	1	We answered "No." However, we have bid jobs where the owner provided a suggested erection scheme. We have seen this in both Pennsylvania and New Hampshire recently. The erectors that were awarded these jobs did alter the provided schemes shown on the plans to erect the job.
Neal	1	I cannot recall working on any bridges where the owner provided an erection procedure. The contract documents often provide criteria that govern the sequence of some steps of the erection procedure. For example, one part of the erection must be done before another part is started to accommodate traffic during erection. These requirements have had little effect on the quality of the erected structure.
Peterson	1	No
Rollins	1	No
High	2	We believe it has a positive effect because the designer needs to think through the scheme and associated forces to erect the project. We did see a project recently where the owner's designer stated on the bid package that the structure, after a pair of girders is erected and certain crossframes are bolted, can withstand a certain wind velocity and be stable. I am stating this because we, as the erector, had to prove the stability. Having found the statement to be true, we question the need for the verification. It seems like a waste of time and money for the owner to want things to be double calculated.
Neal	2	I cannot recall working on any bridges where the owner provides an erection procedure. The contract documents often provide criteria that govern the sequence of some steps of the erection procedure. For example, one part of the erection must be done before another part is started to accommodate traffic during erection. These requirements have had little effect on the quality of the erected structure.
High	3	The first thing we look at is do we need to support girders based on type of bridge, number of spans, and span length. The second item we check is to see if anything prohibits us from setting a falsework or positioning a crane. Holding cranes and rigging can function similar to falseworks many times. Span lengths control the need for either a falsework or multiple crane approach. Long spans usually require multiple falseworks to control geometry, especially in a multiple, continuous scenario.
Neal	3	The location of falsework and sequence of erection are generally governed by (1) the overall site limitations and (2) the size and strength of the individual girder pieces. Examples of each are as follows: 1A. The clear channel requirements imposed by the Coast Guard may limit the placement of falsework. 1B. The location of streets and highways and railroads passing under the bridge will limit the location of falsework. 1C. The height of the bridge above the terrain will often limit the amount of falsework that can be economically used. 2A. The spacing of the falsework is a function of the strength of the girders and their ability to cantilever from one falsework to the next. 2B. It is often desirable to start erection with a "haunch" girder balanced on a pier using a bracket attached to the pier and then land on a falsework with the next girder. 2C. For curved girders, additional falsework is often required to prevent the girder from rolling. The falsework is usually set to the cambered geometry with vertical adjustments provided by jacking devices. Deflections are calculated and the jacking range allows for landing on the adjacent pier or abutment.

APPENDIX B7 (Continued)

Erectors—Questionnaire Responses

Erector	Question	Comment
Peterson	3	Locate falsework near splices and under stiffeners (add stiffeners as necessary if none are available), provide jacking capabilities in falsework, and adjust as necessary to maintain proper elevations at the splices until all permanent connections are completed.
Rollins	3	Engineering
High	4	Yes. We have experienced problems with deflection, web vertically, and elevation—not alignment. We have had issues with certain highly skewed and a combination of curved/skewed bridges. A combination of high skew angle and a small curvature radius will be the most difficult. Owners want the girders plumb after the deck is poured and cured. One issue is plumb has no tolerance associated with it. For bridges with a high skew we detail the crossframes for final position. This means that the girder webs need to be forced out of plumb at the time of erection. The girder's rigidity or flex contributes to how easily this can be accomplished. For bridges with less skew or "right" bridges we detail the crossframes so that the webs are vertical under the steel dead load at the time of erection. We determine which way to proceed based on a calculation. No matter what the outcome, if the webs are leaning 1/16 in. from top to bottom after the deck is poured, the webs are not plumb.
High	4A	A tolerance needs to be defined, and the designer should verify that the tolerance is acceptable and frames, diaphragms, connections, and girders are not overstressed. We suggest 1/8 in. per foot of girder depth.
Neal	4	There are generally few problems with alignment of straight girders during or after erection. With curved girders, where the girders are detailed to cambered geometry and the crossframes are detailed to final geometry, there will always be some distortion until all dead loads are finally applied. This leads to the curved girders being erected out of plumb in order to connect the crossframes. The use of undersized bolts will sometimes help in making the initial connections. Slotted connections do not seem to be the answer to this problem due to the loss of control of geometry.
Peterson	4	No
Rollins	4	No
High	5	Yes. The answer again is dependent on span length. Our fabrication group does not want to see a flange size less than 12 x 3/4. "Flange cupping," when welding bearing stiffeners or other connection stiffeners, creates a flatness problem when smaller flanges are used.
Neal	5	It is desirable that the flanges be sized so that each individual girder piece can laterally support itself when erected in a simple span or cantilever condition depending on the erection sequence. With long spans and small flanges, temporary lateral support trusses made of angles and wire rope are often required until adjacent girders are erected and permanent crossframes and lateral bracing are connected.
Peterson	5	No
Rollins	5	No

APPENDIX B7 (Continued)

Erectors—Questionnaire Responses

Erector	Question	Comment
High	6	Yes. Not only handling and erection concerns, but transportation concerns also come into play. Girder stability is essential when driving down the highway. First let me make a statement for the erectors if using beam clamps to erect the bridge. Lighter girder sections imply smaller beam clamps can be used. However, a 15-ton beam clamp can only grip the flange edge, if the flange is 12 in. wide. A 25-ton beam clamp requires a minimum flange size 15 x 1 to function. Therefore, we need to rig girders differently if flange sizes are in the 12 in. category to put them in place, and we do. Optimizing girder flanges requires a look at fabrication, transportation, and erection as a total picture. If asked independently, these three groups will supply different answers. LRFD design specifications take material designs to their theoretical strength limit states, thus saving on material costs. If the fabrication group can tolerate flange sizes 12 x 3/4 and design allows it, we need to verify if special handling is required during transit and erection. This means that special consideration should be given to how girders are picked and wheel spacings on how they get transported. Optimized materials in fabrication can be verified by designers if designers consider the unbraced length of the compression flanges, the width, and girder length. A good indicator (rule of thumb) is girder length (inches) divided by compression flange width (inches).
High	6A	Experience shows a value of 60 or less has stability during transport and erection. A value of 60 to 80 may be OK, but needs further stress calculations to verify, and values of more than 80 require temporary support (falsework or holding cranes) to offer stability.
Neal	6	It is desirable that the flanges be sized so that each individual girder piece can laterally support itself when erected in a simple span or cantilever condition depending on the erection sequence. With long spans and small flanges, temporary lateral support trusses made of angles and wire rope are often required until adjacent girders are erected and permanent crossframes and lateral bracing are connected.
Peterson	6	The length-to-width ratio between braced points should not exceed 60 to ensure stability while handling and erecting the members.
Rollins	6	Yes. Stability of single girders.
High	7	Yes. We encounter an issue when bidding certain states. The designs simply state that the general contractor is required to determine if lateral bracing is required for the bridge. The problem is that the bracing required for dead load and wind forces during erection may determine bracing sizes that do not suffice dead load of deck forces or sequence of pour. It is not a problem to make the bridge stable at any point, but the process is confusing during and after bid time. This is a real "stability issue." Bob Cisneros (717) 293-4086, Senior Project Engineer, serves on the APC Subcommittee on the Stability of Structural Steel and would be our contact for discussion.
Neal	7	Each girder needs to be analyzed to determine the pick point(s) and whether temporary lateral support bracing is necessary. It is often possible to ground assemble two adjacent girders with the lateral bracing and crossframes and erect them as a unit so that temporary bracing is not required.
Peterson	7	No
Rollins	7	Yes. Stability of girders in handling and erection.

APPENDIX B7 (Continued)

Erectors—Questionnaire Responses

Erector	Question	Comment
High	8	Yes. If you are erecting two halves of a bridge with one half complete and open to traffic and later are required to connect the other half to it with diaphragms or crossframes, connect the one side with full-sized holes and field drill the other after the deck is in place. If you are rehabbing a job with deck removed from one half and live traffic on the other, leave the connections of the two halves in place.
Peterson	8	No
Rollins	8	No
High	9	Girders need to be plumb when picking or after erected. Multiple cranes or shoring is an answer. We simply calculate the sum of moments in the transverse direction along the member length when we pick them to ensure they are level.
Neal	9	Curved girders can be picked with a single crane using a correctly sized spreader beam or by using two cranes. The location of the pick points can be calculated so that the girder is picked straight without roll. Picking at two points usually eliminates any lateral stability problems as long as a line between the pick points runs through the center of gravity of the girder.
Peterson	9	My experience with curved girders is limited.
Rollins	9	Engineering
High	10	Owners vary in their concept as to when to tighten bolts. Erecting a structure and having to go over it again to tighten certain members adds to cost. Girder stiffness and crossframe design come into play. We believe that long-span, straight bridges can have their splices tightened under no-load conditions. The key is to survey the elevations during erection before tightening anything.
Neal	10	Most states require a minimum of 50% of the splice holes filled with pins and bolts at erection. The use of oversized drift pins ensures that the splice is properly aligned before final bolting.
Peterson	10	None, so long as the final connections are correct.
Rollins	10	Engineering
High	11	Yes. Currently the Associated Pennsylvania Constructors Subcommittee on Stability of Structural Steel is addressing different related concepts. Penn State University and the University of Pittsburgh have also taken field data related to these subjects. Also, the FHWA Turner–Fairbanks Highway Research Center has a full-scale research project currently investigating curved girder functions.
Neal	11	Much research has already been done on curved girders. More needs to be done. As mentioned above, when the girders are detailed and fabricated to their cambered shapes and the crossframes and lateral bracing are detailed and fabricated to their geometric shapes, they will not fit when erected. Only after all dead load is applied will the bridge be properly aligned and plumb, which after all is the goal we all strive for.
Peterson	11	No
Rollins	11	No
High	12	We need to consolidate current efforts and control the outcome with a better understanding. Pockets of activity usually do not lead to standardization.

APPENDIX B7 (Continued)

Erectors—Questionnaire Responses

Erector	Question	Comment
Neal	12	The key important issues associated with achieving a properly erected structure are accurate detailing and fabrication with adequate shop assembly to ensure the correct fit of the individual girders in the field.
Peterson	12	No
Rollins	12	No
High	13	Geometric control. We like concentric, not oversized holes on all members to ensure alignment, spacing, and cross-slope geometry. Secondary members such as lateral bracing are an exception to this rule.
Peterson	13	Accurate shop fabrication, accurate location and elevation of supports, maintaining proper elevations at splices, and complete installation of connections before releasing falsework.
High	14	Contractors, fabricators, transporters, erectors, designers, and owners need to be on the same page.
Peterson	14	Take into consideration the position of the sun and temperature of the steel when checking the alignment of a structure. One line of girders may be longer than the other because of shading of one by the other.

APPENDIX B8

Fabricators—Respondents

Fabricator	City	State	Respondent	Phone Number
AFCO Steel	Little Rock	AR	Dennis Noernberg	501-340-6314
DeLongs's Inc.	Jefferson City	MO	Gary Wisch	573-635-6121
Egger Steel Company	Sioux Falls	SD	Fred Lebichuk	605-357-2249
Fought & Company, Inc.	Tigard	OR	Terry Weir	503-639-3141
Grand Junction Steel	Grand Junction	CO	Jeff Bishop	970-242-4015
Harris Structural Steel Co.	Piscataway	NJ	Richard McCallum	732-752-6070
High Steel Structures, Inc.	Lancaster	PA	Robert Kase	717-390-4240
Industrial Steel Construction	Hodgkins	IL	Robert Emerson	708-482-7500
Lincoln Steel Co.	Lincoln	NE	Calvin Schrage	402-474-3030
Stupp Bridge Company	St. Louis	MO	Dennis Nash	314-638-5000
Tampa Steel Erecting Company	Tampa	FL	Cathy Klobuchar	813-677-7184
Trinity Industries, Inc.	Houston	TX	Thomas Guzek	713-861-8181
Universal Structural, Inc.	Vancouver	WA	Dave Williams	360-695-1261
Vincennes Steel Corp.	Vincennes	IN	Kevin Day	812-882-4550
Unnamed				

Erectors and Contractors—Respondents

Erector/Contractor	City	State	Respondent	Phone Number
High Steel Structurers, Inc.	Lancaster	PA	Robert Kase	717-390-4240
JS Rollins, Inc.	Barlow	KY	Jay Rollins	270-334-3725
James Neal	Trophy Club	TX	James Neal	817-430-3197
Peterson Beckner Industries	McKinney	TX	Gilbert Bailey	972-562-6294

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation