USE OF NON-CONCENTRIC CURVED GIRDER FRAMING FOR VARIABLE WIDTH BRIDGES

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BIOGRAPHY

Michael Quirin is a Senior Structural Engineer with the Chicago office of Parsons. He has over 8 years of experience in bridge engineering and construction. He has BSCE and MSCE degrees from the University of Illinois (Urbana campus).

SUMMARY

The alignment of the proposed U.S. 20 Mississippi River crossing between Dubuque, Iowa and East Dubuque, Illinois imposed several constraints, which resulted in the use of non-concentric curved girder framing on three bridges to achieve the complex roadway geometry. The U.S. 20 project will be presented as a case study of the application of non-concentric curved girder framing to achieve complex bridge roadway geometries.

The technical focus of this paper includes the layout, analysis and advantages of a non-concentric girder solution. It presents several examples of non-concentric framing and discusses the evolution of the framing plans, geometric layout of non-concentric curved girders, the software used for analysis and advantages over other framing methods such as flared, straight girders and dropped girders.

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INTRODUCTION

As populations in urban areas steadily grow, roadway capacity improvement projects are essential to ensuring that local economies keep pace. Many of these projects involve building roadways parallel to existing alignments to increase their capacities. Instances in which separate parallel alignments must converge into single point interchanges sometimes require the placement of curved or tapered geometries on bridges. The need to locate complex geometries on a bridge can also be attributed to other physical site constraints such as avoiding topographical features, proximity of existing roadways or staging requirements. Additionally, other factors, such as environmental protection, hazardous waste avoidance and community concerns can also contribute to geometric challenges.

CASE STUDY

Background

The existing Julien Dubuque Bridge over the Mississippi river opened to traffic in 1943. The two lane bridge carries U.S. 20 traffic between Dubuque, IA and East Dubuque, IL. The Dubuque area has experienced rapid growth in recent years and development on the riverfront has increased traffic. Current AADT is about 20,000 vehicles and design year 2025 AADT is predicted to be about 35,000 vehicles. Capacity analysis indicated that a four lane crossing would be needed. Consequently, the Iowa and Illinois Department's of Transportation, in conjunction with various public and private concerns, decided that a parallel alignment which utilized the existing bridge for two lanes of westbound traffic and added a new bridge for two lanes of eastbound traffic would be the most efficient means of capacity improvement. **Figure 1** shows a rendering of the new bridge with a picture of the existing bridge.

Figure 1: New and Existing U.S. 20 Main Span Bridges

The Proposed Structure

The new crossing will consist of 13 bridges totaling over 8,600 feet in length. An 845 foot span tied arch will serve as the main span for the new eastbound bridges. The adjacent or flanking span bridges are three span continuous, variable depth steel plate girder structures with 300 to 360 foot spans. The Iowa approach bridges are three span continuous steel plate girders with 100 to 230 foot spans. Illinois approach bridges are comprised of a multiple span prestressed concrete beam bridge and steel plate girder bridges. Of the 8,600 feet of total bridge length, 7,400 feet is comprised of steel structure utilizing over 31 million pounds of structural steel.

Figure 2: SPUI Rendering

The Iowa approach will consist of new westbound bridges which meet the existing bridge and new eastbound bridges. The all-new parallel approach structures will converge at a single point urban interchange or SPUI at the intersection of U.S. 20 and Locust Street, located about a third of a mile from the river. **Figure 2** shows a rendering of the SPUI and **Figure 4** shows an aerial photograph of the Iowa approach.

Site Constraints

The alignment to the west of the SPUI follows a natural valley cut through rock bluffs as shown in **Figure 3.** The topography of the bluffs dictates the alignment of U.S. 20 and Locust Street, causing the rotated orientation of the intersection as seen in **Figure 4**. Additionally, the location of the intersection was constrained by hazardous waste to the north, rock outcroppings to the south and industry to the east.

Figure 3: View of Bluffs, Looking West along U.S. 20

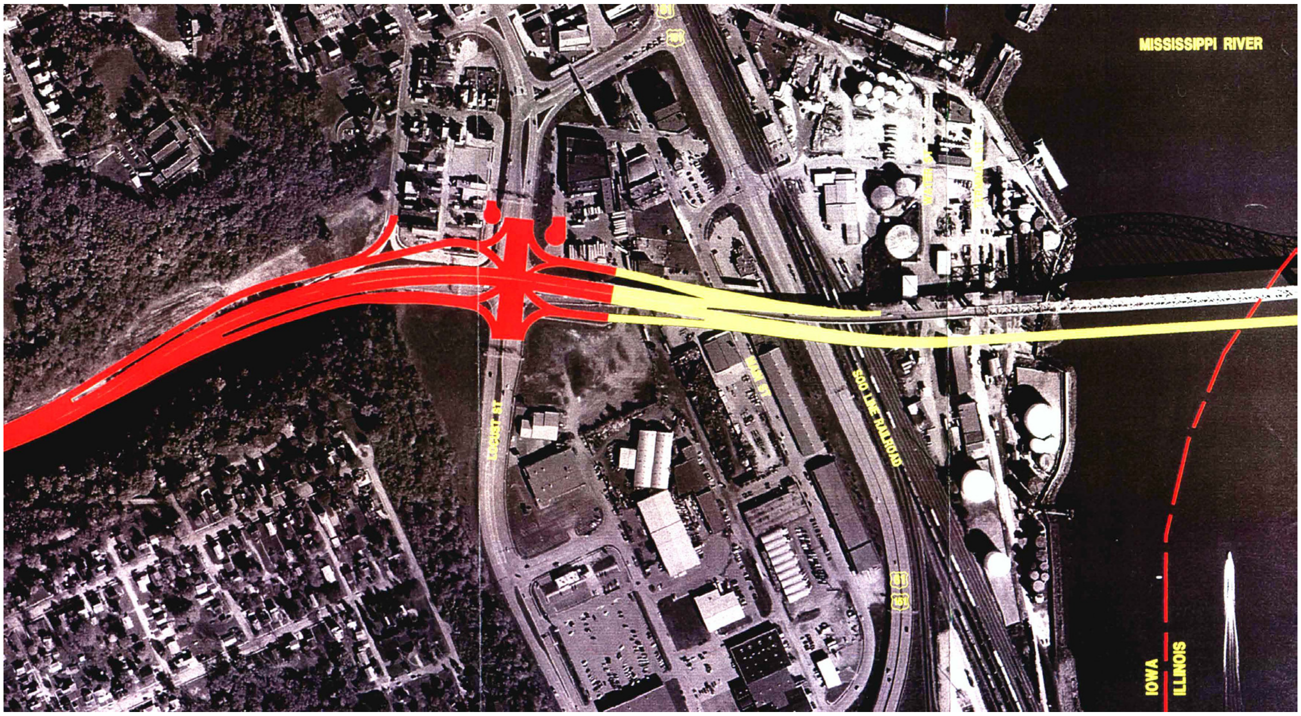

Figure 4: Iowa Approach Aerial View (Note: North is up)

The shaded areas in **Figure 4** represent the proposed alignment. The lighter shade represents the new elevated approach structures.

Roadway Geometric Challenges

The main source of geometric complexity was the need to place the curved, tapered off/on ramps and the thru lanes on the same bridge. One such bridge is the U.S. 20 westbound Iowa approach bridge, shown in **Figure 5**. The upper edge of this bridge follows the radial alignment of the ramp and the lower edge follows the radial alignment of the mainline. Additionally, the west end of the bridge is more than twice as wide as the east end. Placing the ramp on the bridge contributed to vertical profile design challenges. As shown in **Figure 5**, span 4 contains a barrier enclosed gore area to separate ramp C traffic from thru traffic. In this area, the ramp begins its descent to grade at the SPUI, while the mainline maintains its "flat" grade. The vertical grade of the ramp had to satisfy road geometric requirements while maintaining a practical transverse girder-to-girder elevation drop to avoid the need to evaluate the structure for a large, abrupt transverse elevation change over a single bay.

The U.S. 20 eastbound Iowa approach bridge, shown in **Figure 6**, also has a curved tapered ramp in addition to a different curved mainline alignment. This bridge does not have the change in width that the westbound bridge has, but is much wider due to the addition of a ten-foot wide sidewalk. The main geometric challenge involved setting up the horizontal geometries of the ramp baseline and the mainline profile grade line. The ramp baseline in the vicinity of span 6 is not concentric with the adjacent gutter line. This is attributed to the need for the ramp D gutter line to eventually become the mainline gutter line in span 7 of the Iowa flanking span bridge, shown in **Figure 7**. A location map of the three bridges discussed in this section is found in **Figure 8.**

Bridge Design Challenges

The task of designing 13 bridges under normal budget and time constraints would in itself be challenging. Adding geometric complexities such as variable widths, non-concentric curves, skewed piers and complex vertical/horizontal roadway geometry to the task creates an even greater challenge. Particularly for large jobs such as U.S. 20, automation tools are essential to getting the job done. For this project, computer programs to calculate screeds for non-concentric girder lines and bridge cross sections with varied widths and cross slopes were employed to quickly and accurately determine the elevations. Similar automation strategies were employed for all aspects of the design.

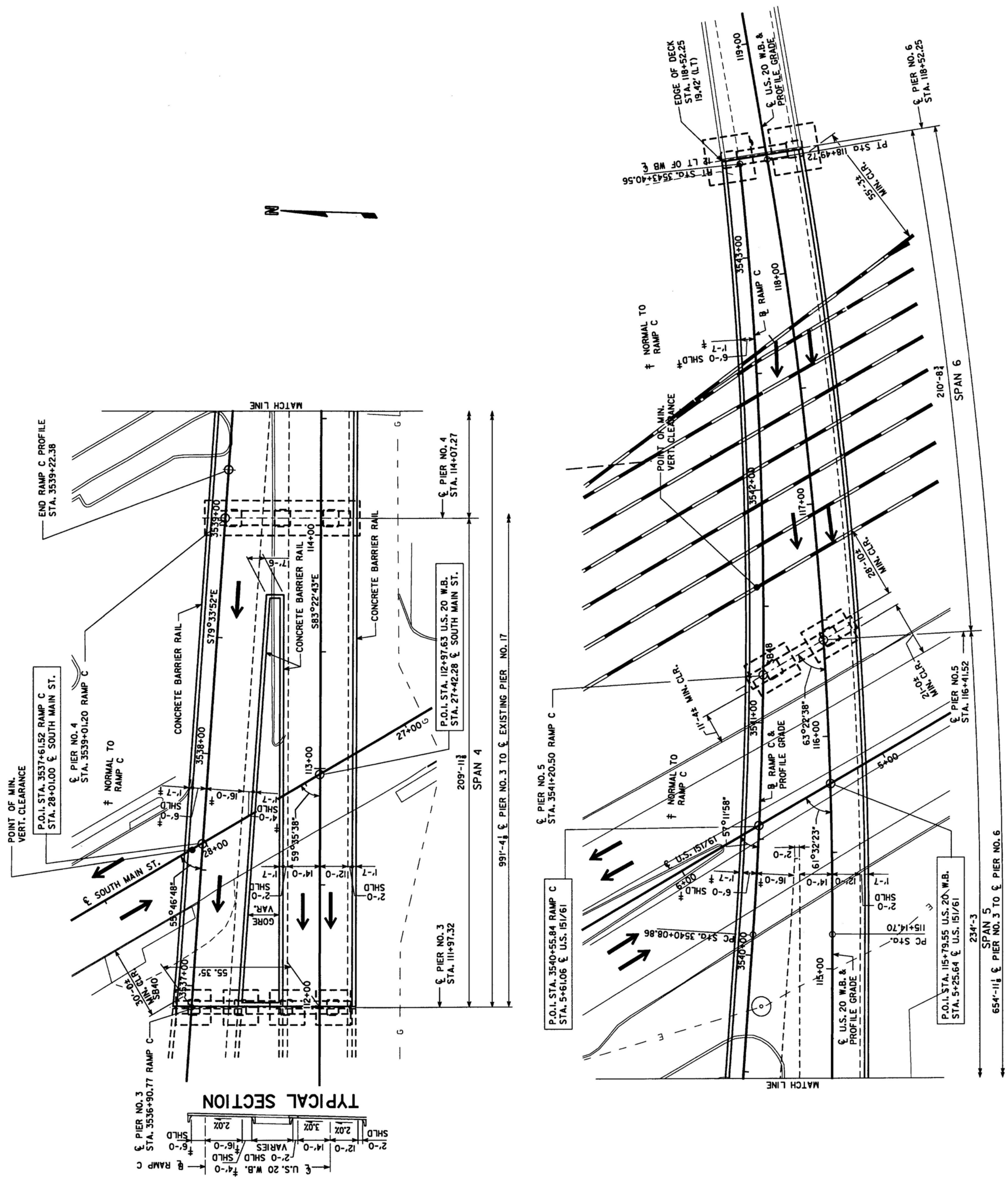

Figure 5: U.S. 20 Westbound Iowa Approach Bridge

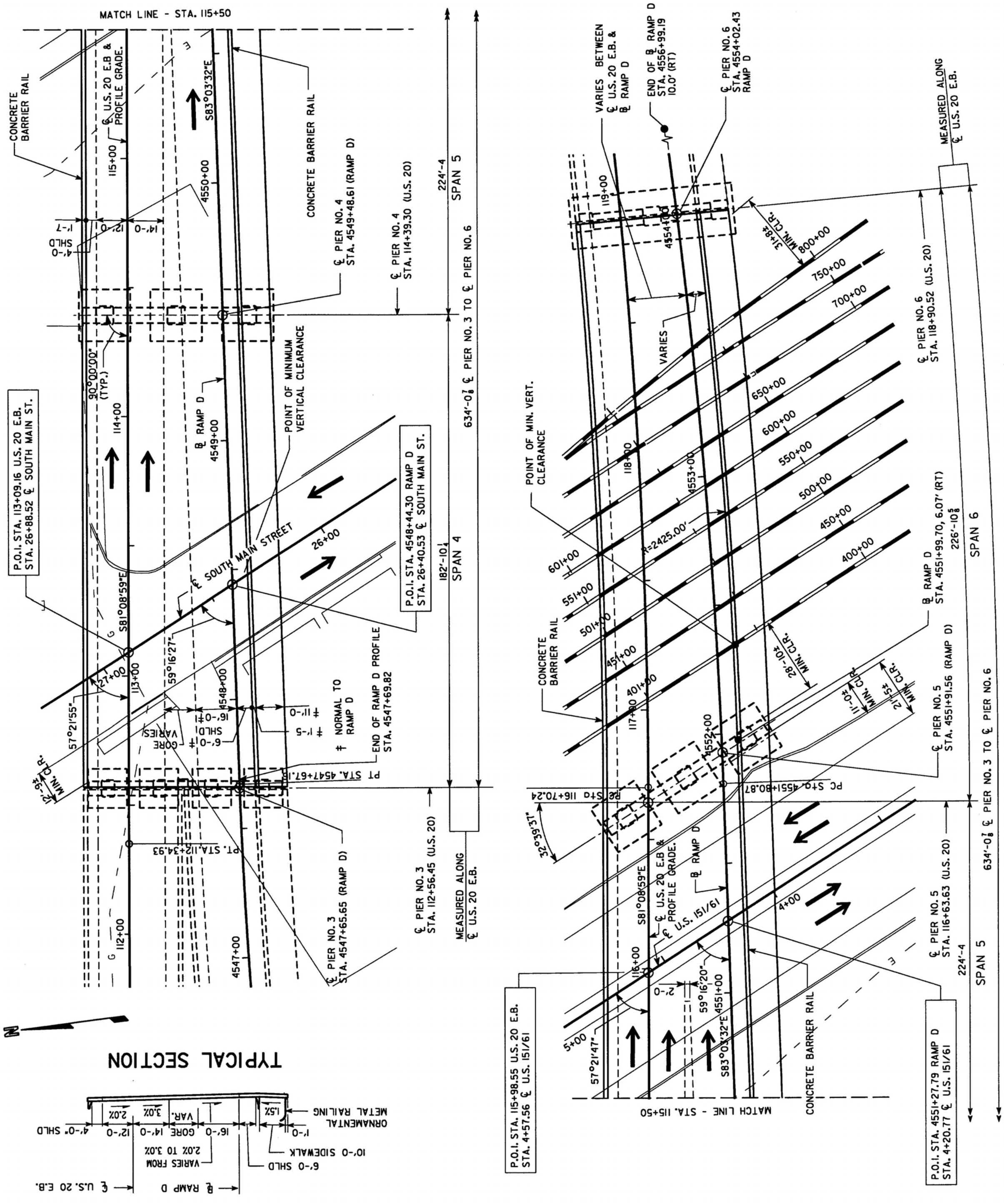

Figure 6: U.S. 20 Eastbound Iowa Approach Bridge

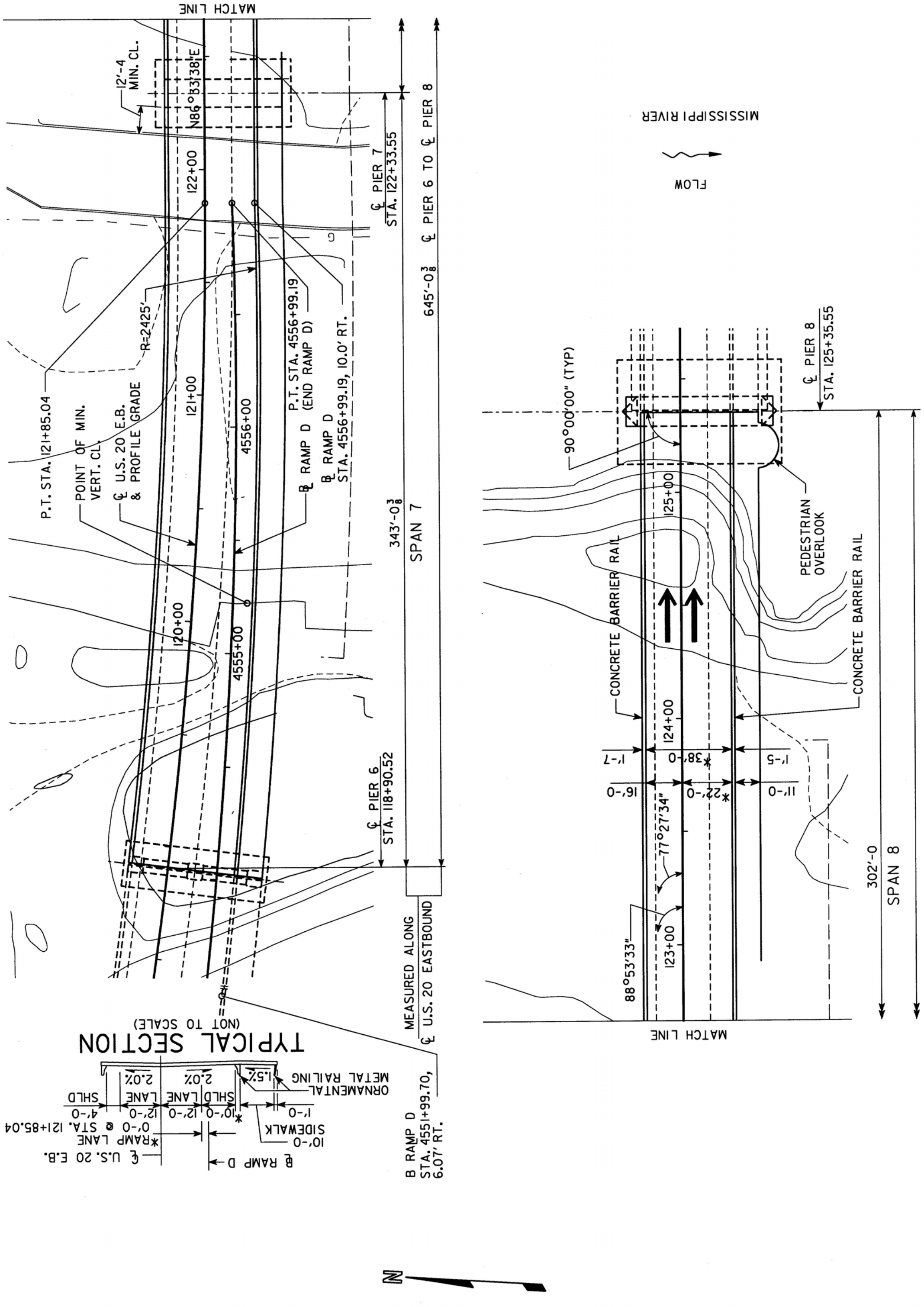

Figure 7: U.S. 20 Eastbound Iowa Flanking Bridge

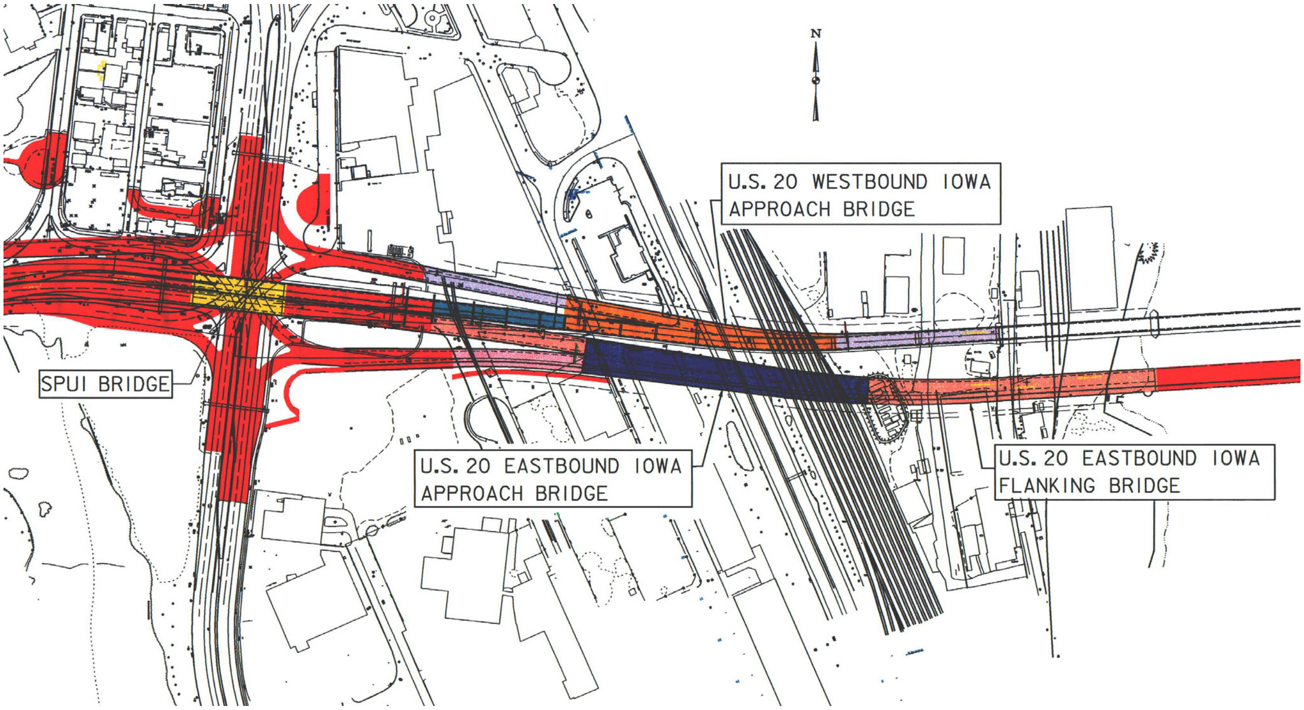

Figure 8: Bridge Locations

Non-Concentric Girder Framing

The framing plans for the three bridges mentioned above are shown in **Figures 9, 10 and 11**, respectively. The common feature among these bridges is the use of non-concentric curved girder framing. The U.S. 20 westbound Iowa approach bridge was the most complicated bridge to frame. Referring to **Figure 9**, span 4 is comprised of straight flaring girders, span 5 straight and non-concentric curved girders with the PC (point of curvature) of the curved girders located near mid-span and span 6 non-concentric curved girders. Note that 8 girder lines in span 4 drop to 7 girder lines in span 5 and 6 girder lines in span 6. Header beams, placed near an inflection point, were used to frame the dropped girder lines. As a general rule for the framing plan development, headers were to be avoided to the extent possible. As the framing plan evolved, alternatives were judged by their efficiency and ability to provide an easily understood and well defined load path. The preliminary framing schemes sought to maintain a full-length girder configuration for the lower, non-tapered portion of the framing (e.g. girders E thru H) and a tapered geometry, dropping multiple girders at the same location, for the upper, tapered portion. These schemes were generally inefficient in that the bay widths varied considerably along the girders. Many dropped girders and headers were required to maintain economical bay widths along the bridge. The use of non-concentric girders reduced the number of headers required and resulted in an efficient framing plan with clean lines and direct, uninterrupted load paths. **Figure 13**, presented at the end of this paper, shows the shop fit-up of a framing system similar to the U.S. 20 bridges. Note the amount of flare achieved by the non-concentric girders.

As mentioned above, headers were avoided as much as possible. They are generally discouraged in that they complicate the framing and require additional plan detailing. If headers must be used in conjunction with curved girders, the designer should verify that the analysis program to be used accurately models the dropped girders.

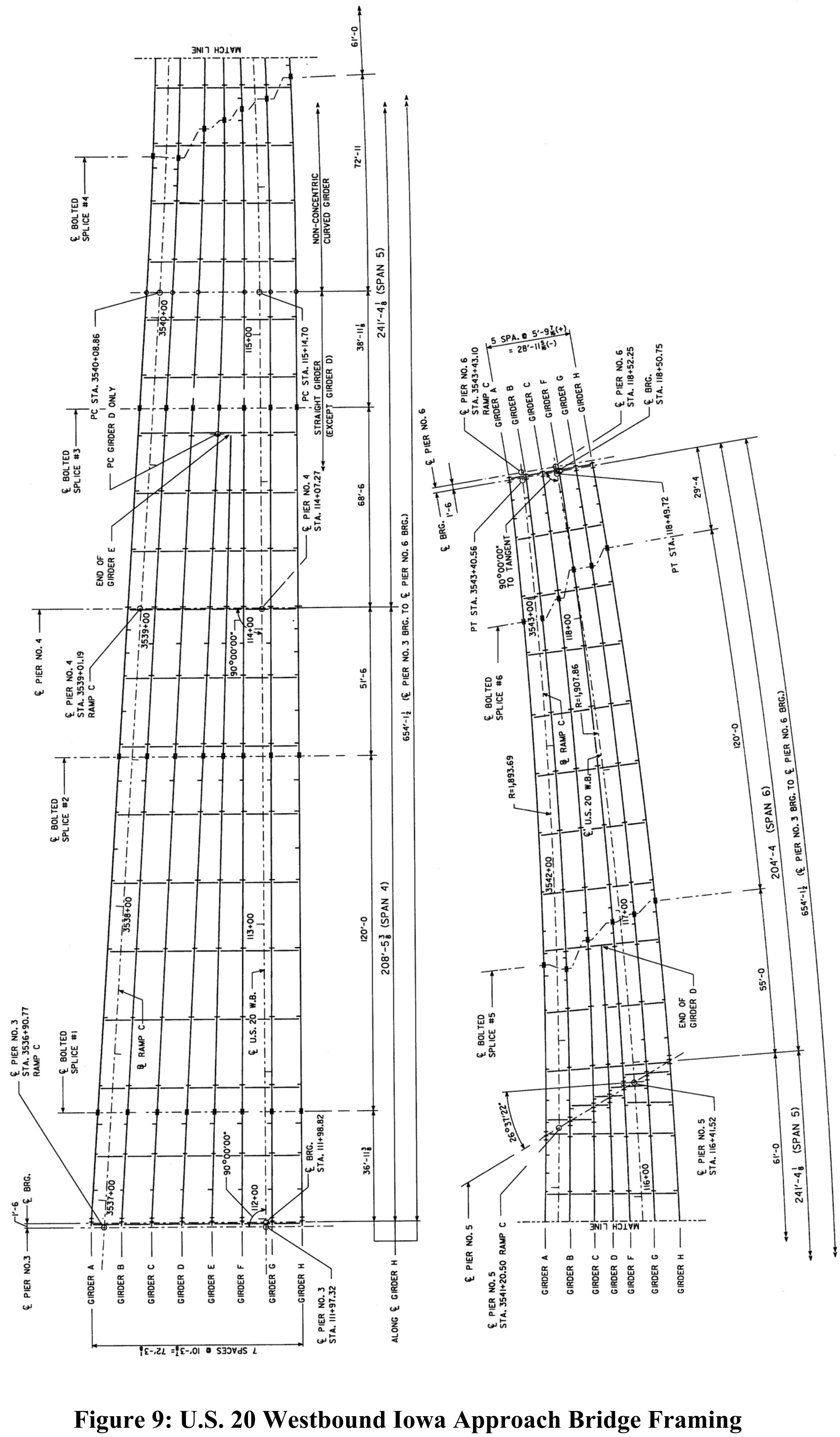

Figure 9: U.S. 20 Westbound Iowa Approach Bridge Framing

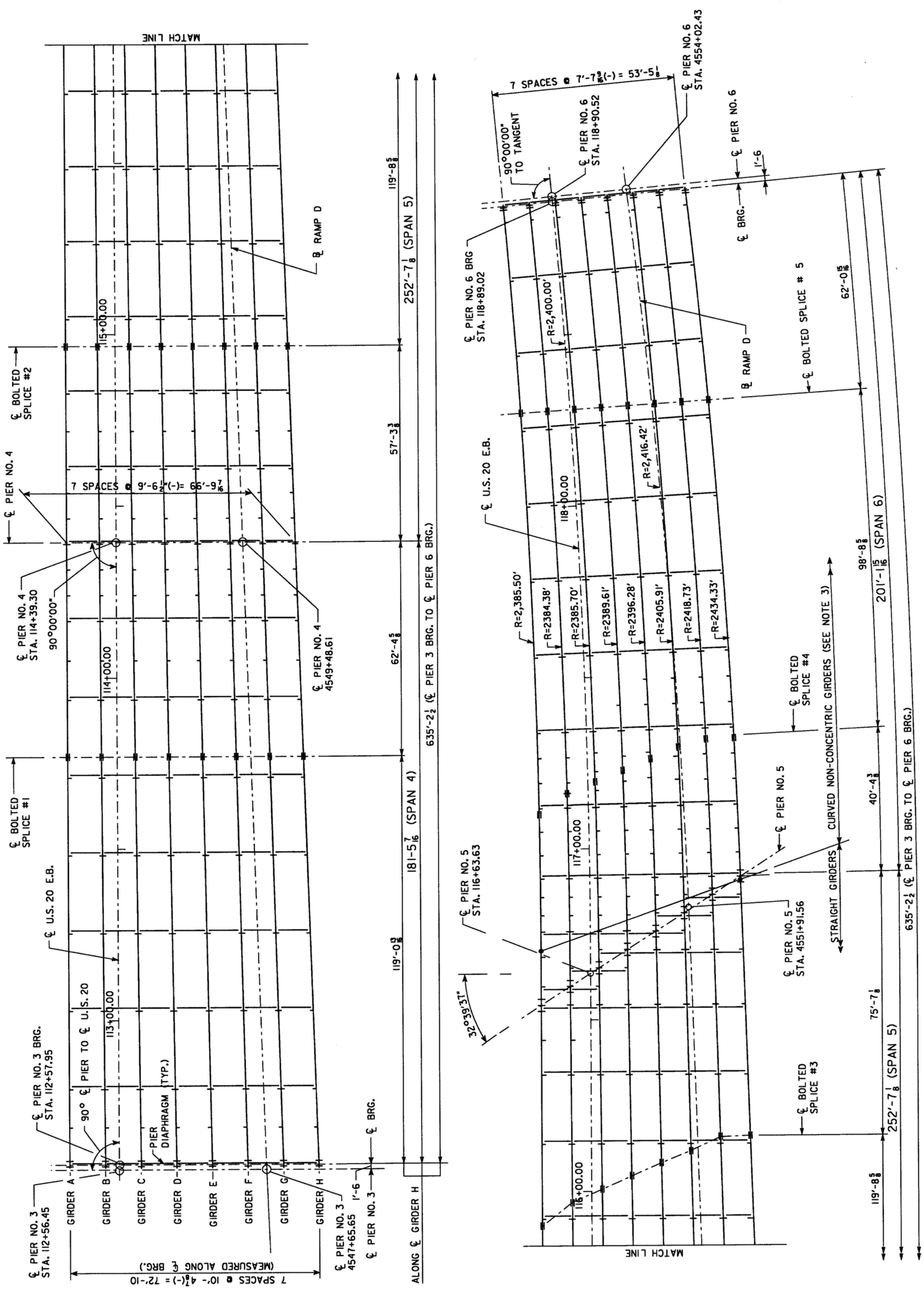

Figure 10: U.S. 20 Eastbound Iowa Approach Bridge Framing

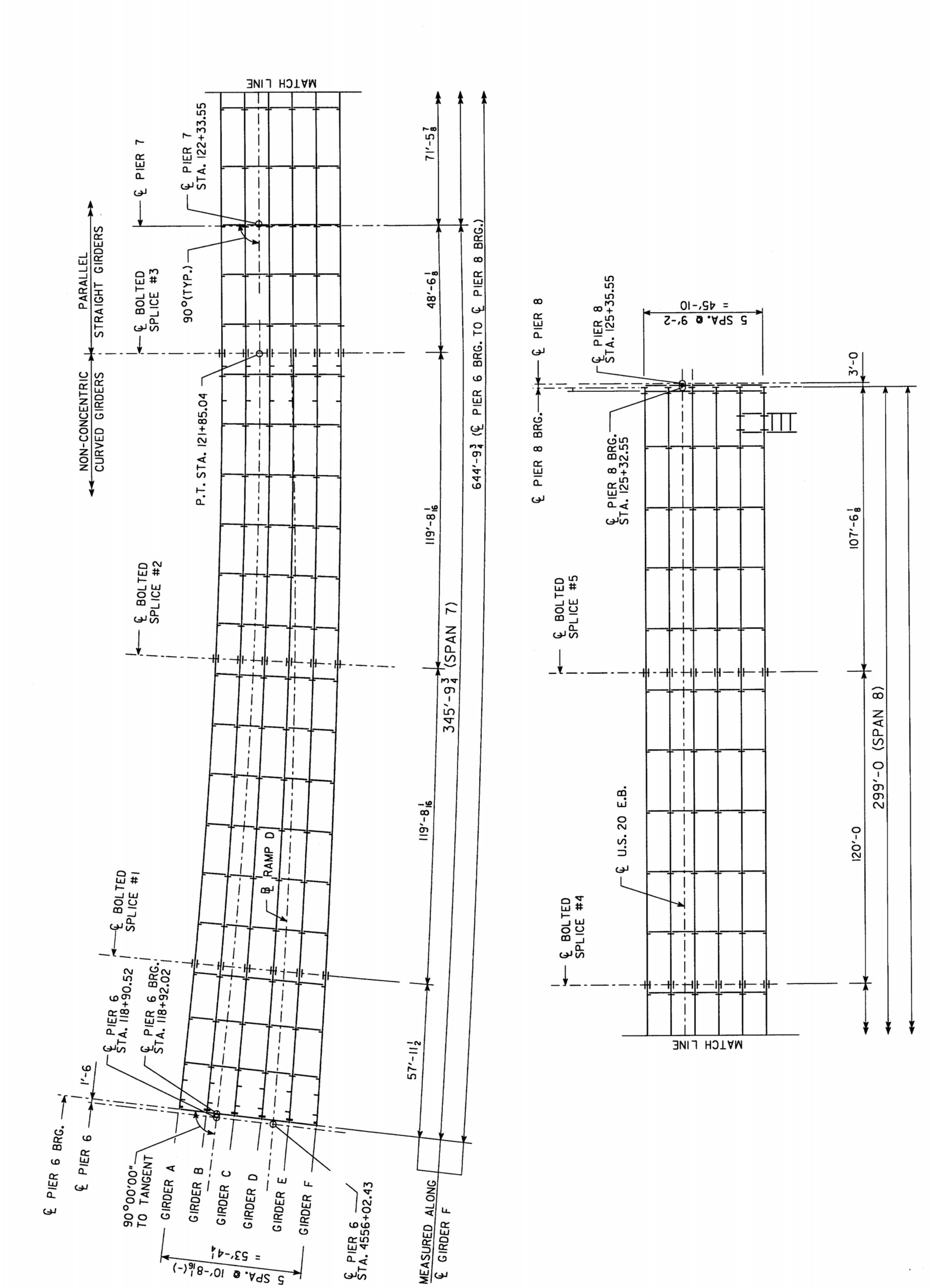

Figure 11: U.S. 20 Eastbound Iowa Flanking Bridge Framing

LAYOUT OF NON-CONCENTRIC GIRDERS

Procedure

The layout of non-concentric curved girders is fairly straightforward. Referring to **Figure 12**, Step 1 is to set the point of curvature (PC) of the girders or the point of tangency (PT) of the girders, as the case may be. The most logical location for the PC of the girders is the corresponding PC of the bridge. The framing plans shown in **Figure's 9 and 11** have PC's set in this fashion. Note that the PT in **Figure 11** coincides with a splice line. Such an arrangement is convenient, but is not required for fabrication ease. In other words, a girder piece can be comprised of both radial and tangent sections. In some instances, the PC of the girders is shifted slightly from the PC of the bridge (Girder D in **Figure 9**). The framing shown in **Figure 10** shifts the PC clear of pier number 5 in order to eliminate radial effects at the pier section (see **Figure 6** for the bridge PC location). Step 2 is to construct the chord line of the non-concentric curved girder. Step's 3 and 4 involve bisecting the chord line and constructing the arc.

Layout Tools

The easiest way to layout and devise complex framing is to draw the framing full scale using CAD software. The main advantage of this approach is the ability to quickly and accurately lay out framing alternatives and track how the framing evolves to its final configuration. The idea is to systematically improve the framing plan using deduction. After the framing plan is finalized in CAD, the next step is to lay out the framing using a coordinate geometry program. There are two reasons for doing this: firstly, the coordinate geometry can be used to check the CAD geometry and secondly, it can be manipulated and dumped directly into the analysis software to define the structural model geometry. There are also analysis pre-processing programs that import the CAD drawing straight into the analysis program.

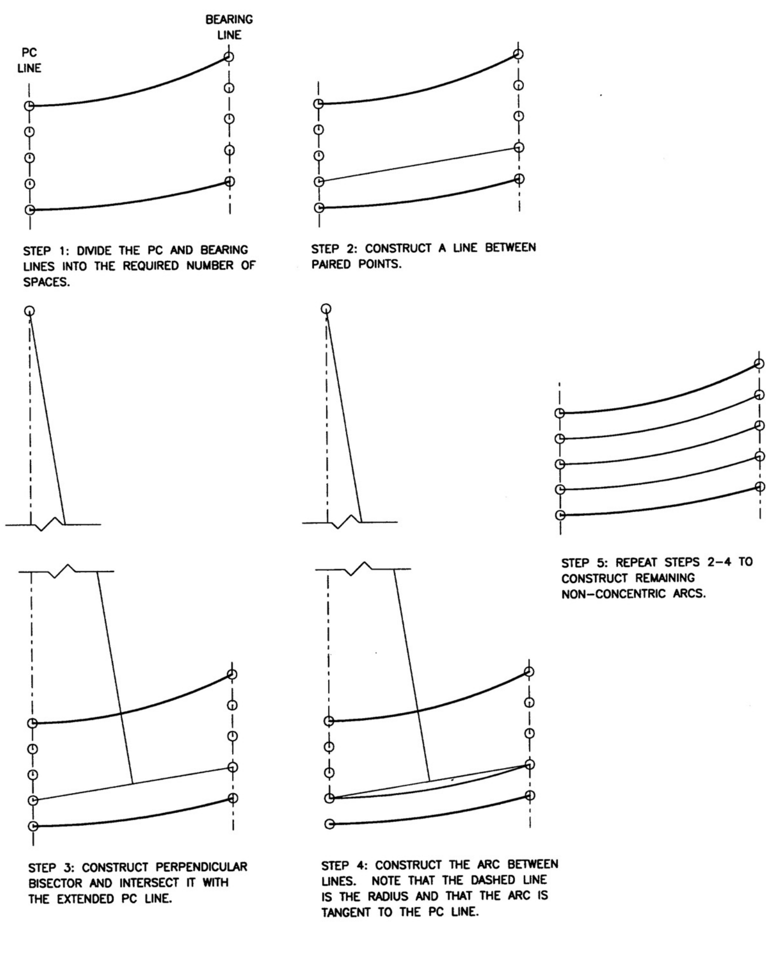

Figure 12: Layout of Non-Concentric Curved Girders

ANALYSIS SOFTWARE

The selection of analysis software to be used for bridges with complex framing requires foresight and knowledge of the software's capabilities. The engineer should select software based on its ability to model anticipated geometries such as curved girders and dropped girder lines and their experience with the software. Regardless of the software chosen to carry out the analysis, it is always a good idea to run a confirmation program. As an example, the complex framing on U.S. 20 was analyzed using the program MDX. To confirm MDX's results, the program DESCUS was used. When MDX and DESCUS result differed, the program CURVBRG was used to further confirm the results. Web site information for CURVBRG, DESCUS and MDX are listed in References.

CONCLUSION

As more and more capacity improvement projects are undertaken on sites posing significant constraints, greater geometric challenges are imposed on bridge designers. Creative framing solutions are the key to effectively meeting these geometric challenges.

The use of non-concentric curved girder framing proved to be an efficient framing solution for the complex bridge geometries on the U.S. 20 project and afforded the designer greater flexibility in devising economical framing solutions.

Figure 13: Shop Fit-Up of Non-Concentric Framing

REFERENCES

1. Whitlock et al, "Efficiencies of Non-concentric Curved Girders", 2003 World Steel Bridge Symposium (2003).
2. CURVBRG: http://nisee.berkeley.edu/software/curvbrg/ (2005).
3. DESCUS: http://www.best.umd.edu/software/descus-i/ (2005).
4. MDX: http://www.mdxsoftware.com/ (2005).