Innovative Design and Erection Methods Solve Construction of Rock Cut Bridge

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Transportation difficulties, elimination of the center pier and environmental restraints presented a major design-construction challenge for this nearly 200 ft (61 m) long bridge in a mountainous region of Washington State. The solution was to divide the girder into three 63 ft (19.2 m) pretensioned bulb-tee girder segments and transport them 150 miles (240 km) to a staging area near the bridge site. There, the segments were spliced and post-tensioned to give a total girder length of 190 ft 6 in. (58.1 m). The girders were then hauled to the bridge site where they were guided into position with a launching truss and two cranes. Construction time took only 3½ months. This article discusses the project constraints, structural design, production, transportation, splicing and final erection. The highlights of the project are narrated from the perspective of the structural designer and precaster.

The new Rock Cut Bridge (see Fig. 1) is a spliced, single span 190 ft 6 in. (58.1 m) precast, prestressed concrete structure. The bridge is situated in a ruggedly beautiful mountainous region just 6 miles (10 km) south of the Canadian border over the Kettle River in Washington State. It provides a link between the area east of the river and the main state highway.

The existing bridge was a 152 ft (46.4 m) steel truss structure that was built in 1907. Over the years, the deck and timber stringer system had deteriorated so severely that in early 1995 the bridge was declared unsafe and closed, and was ordered to be replaced by year's end.

The owner of the bridge was Stevens and Ferry Counties, Washington. Partial funding for the new bridge would come from the federal government.

THE CHALLENGE

The restrictions imposed on constructing the new bridge were unusually severe:

- The bridge is located in an environmentally sensitive area. The surrounding wooded area and river, as well as the spawning and migration fishing windows were to be left undisturbed.

Fig. 1. Panoramic view of new Rock Cut Bridge.

- For environmental and structural reasons, no center pier (permanent or temporary) was allowed.
- Likewise, no scaffolding or other support system in the riverbed was permitted.
- The crossing would have to be about a 200 ft (61 m) clear span.
- Moving the bridge to some other location along the river was considered cost prohibitive.
- No part of the structure could be below the normal high water line. Doing so would have required environmental studies and hearings, which would have delayed construction of the bridge.
- The route leading to the project site was along a highway with steep slopes and sharp bends. This restricted the transportation of heavy, long span members.
- Since the bridge had to be complete and ready for service by the end of 1995, a fast track construction schedule was required.
- The project had to be built within a tight budget.
- Lastly, but most importantly, the preferred material was to be concrete. The major reason for this choice is that the counties wanted a bridge with minimal maintenance. A steel structure would in the future require paint removal and repainting.

THE SOLUTION

In early 1995, Stevens and Ferry Counties contacted Nicholls Engineering to find out whether a prestressed concrete solution would work in favor of the proposed bridge. Working together with Central Pre-Mix Prestress Company (CPPC), Nicholls Engineering came up with an elegant solution.

First, even though a 200 ft (61 m) long prestressed concrete girder was feasible and could be fabricated fairly easily, this approach was ruled out because such a long girder could not be transported along the winding highway in one piece. The girder would be too long, heavy, and unstable. Instead, it was decided to break up the girder into small segments that could be conveniently hauled and spliced.

Preliminary calculations showed that for two-lane traffic, the bridge could be built using four 190 ft 6 in. (58.1 m) long, prestressed bulb-tee girders. Each girder would be 7 ft 5 in. (2.26 m) deep and weigh about 120 tons (109 t). Fig. 2 shows a plan and elevation of the bridge. The girders are spaced at 6 ft $1^1/_8$ in. (1.86 m), making a total bridge width of 24 ft 6 in. (7.45 m). An elevation of one-half of the bulb-tee girder and a typical bridge section are shown in Figs. 3 and 4, respectively. Fig. 5 shows a cross section of the bulb-tee girder.

It should be mentioned that a bulb-tee girder was selected because it is a structurally efficient section and its wide top flange eliminates the need for deck panels.

The key to solving the problem was to divide the "long" girder into three 63 ft (19.2 m) long girder segments with each segment weighing 40 tons (36 t). The segments were fabricated at CPPC's plant in Spokane and transported 150 miles (240 km) to a stag-

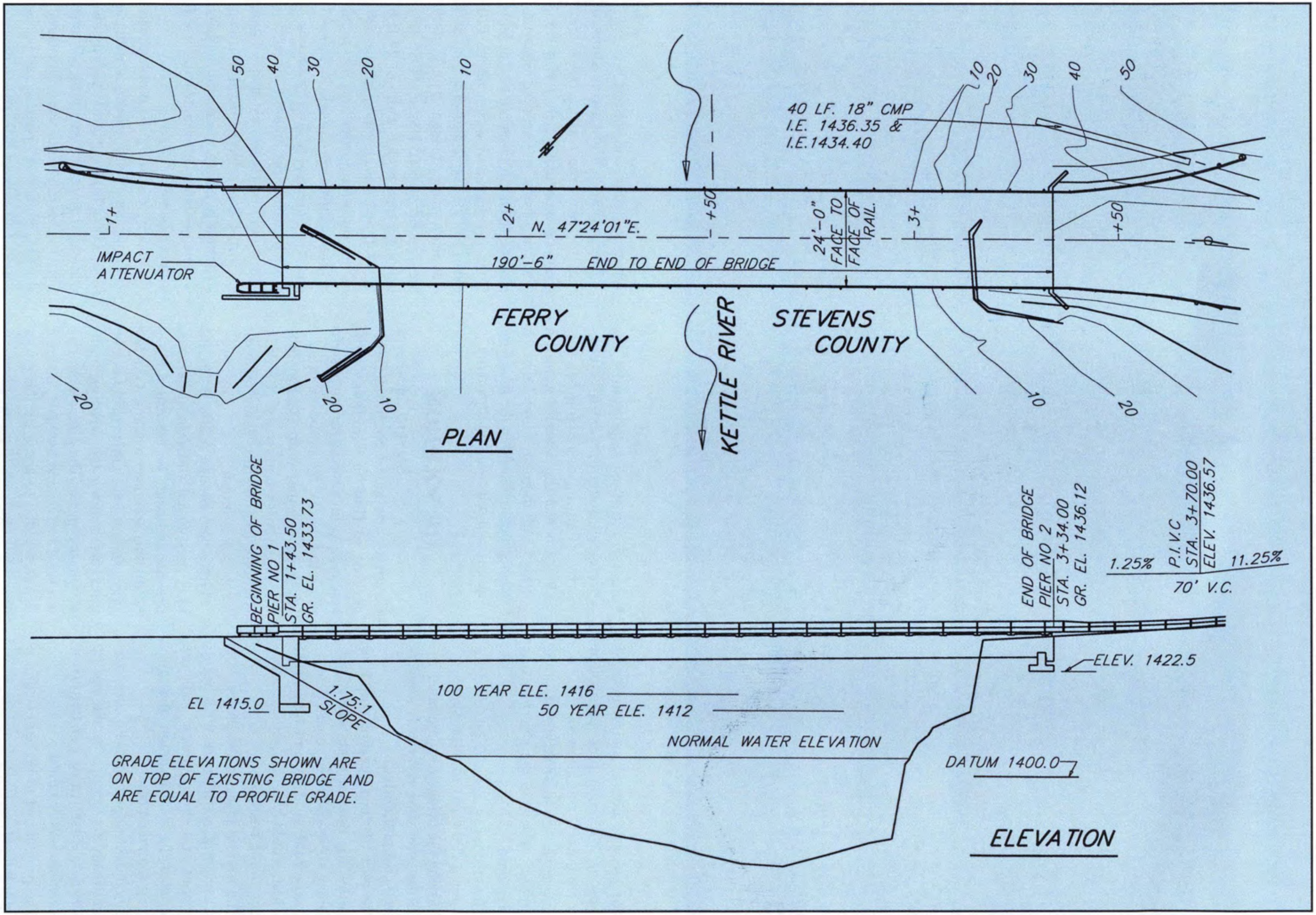

Fig. 2. Plan and elevation of bridge.

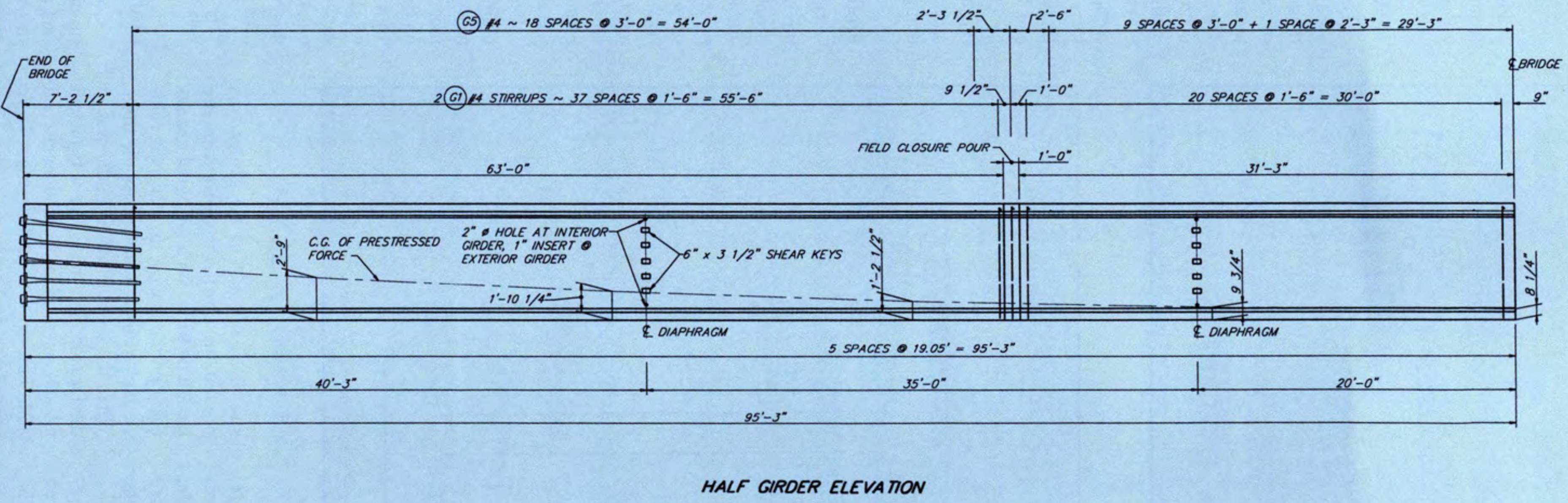

Fig. 3. Elevation of one-half of bulb-tee girder.

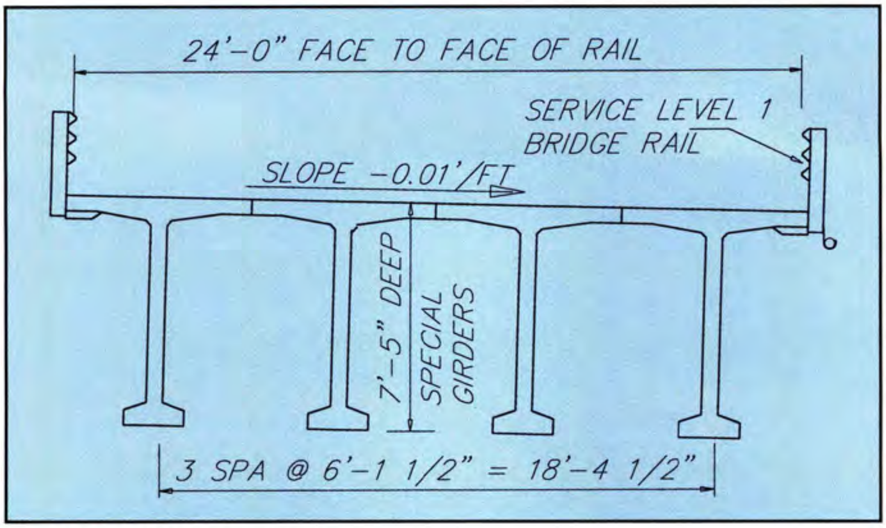

Fig. 4. Typical bridge section.

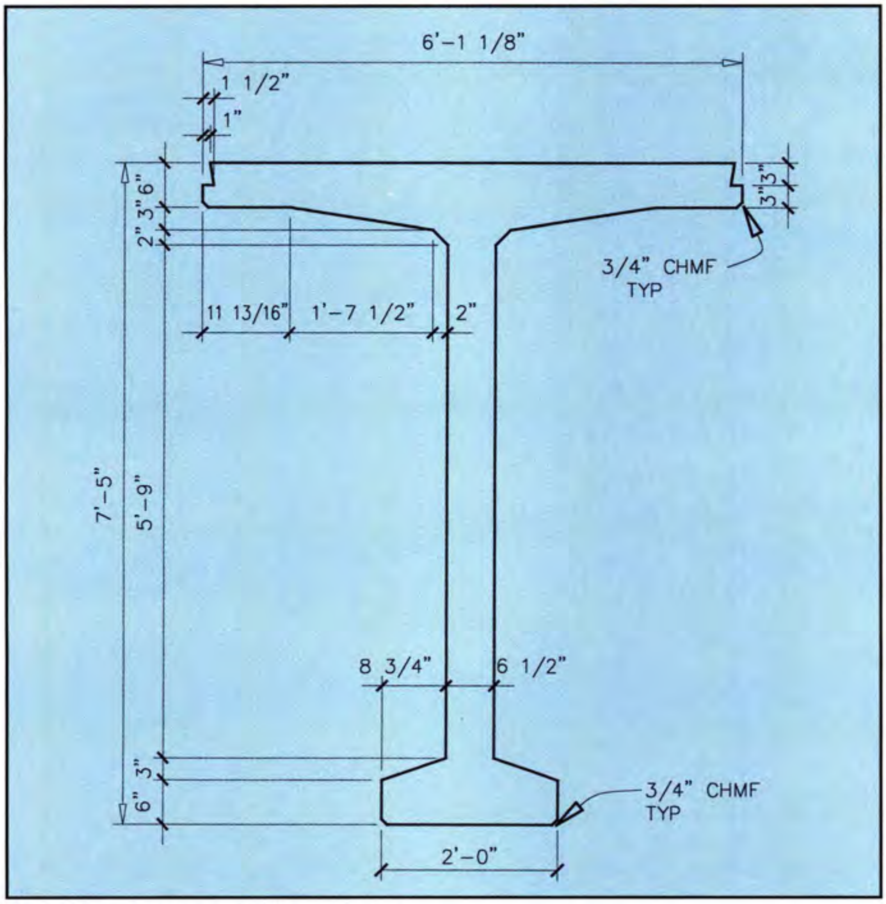

Fig. 5. Cross section of bulb-tee girder.

ing area near the bridge site. There, the segments for each girder were precisely aligned, closure pours made, and post-tensioning strand were threaded and jacked. Fig. 6 shows the splice detail.

The assembled girders were carefully loaded on specially configured carriers, and slowly transported the short distance to the bridge site. At the site, the near side of the girder was placed on a rolling trolley on the launching truss. With the girder end secured on the trolley, the transport vehicle backed the girders across the truss. When the far side of the girder was at the far side pier, the girder was picked up and set in place by cranes at each end. This way, all four girders were erected into final position.

BENEFITS FROM PRECAST CONCRETE

The following benefits resulted from using precast and prestressed concrete:

Time of Completion

The construction of this project was essentially completed in only 3 1/2 months. This was the time from start of removal of the existing bridge to having traffic on the new bridge. The project would have taken many months longer using any other method.

As it turned out, this project was completed at the same time other projects were starting winter shut down. In this northern climate, shut down can last as long as 5 months. Precast concrete had the advantage of allowing the superstructure to be fabricated at the same time the foundations were being cast-in-place at the project site.

Protection of River Environment

This project could be bid on schedule because the environmental permit process was reduced to a minimum amount of time. In the past, a similar project would have required a pier to be placed in the water, providing a source of concern from the permitting agencies. These concerns, in the past, are the source of negotiations and may result in plan changes during the project design.

Proposing a project that would eliminate piers in the water and keep new abutments above high water was met with enthusiasm and promptness on the part of the permitting agencies. Typical work windows allowing work in the water because of fish runs were not a problem. Because work is outside the water, work on the project could begin at almost any time. On this project, once the existing bridge was removed, the water was not touched.

Cost Savings

Constructing the bridge in one construction season proved to be a significant savings in cost. By using this construction method, money was saved in environmental permitting processes by

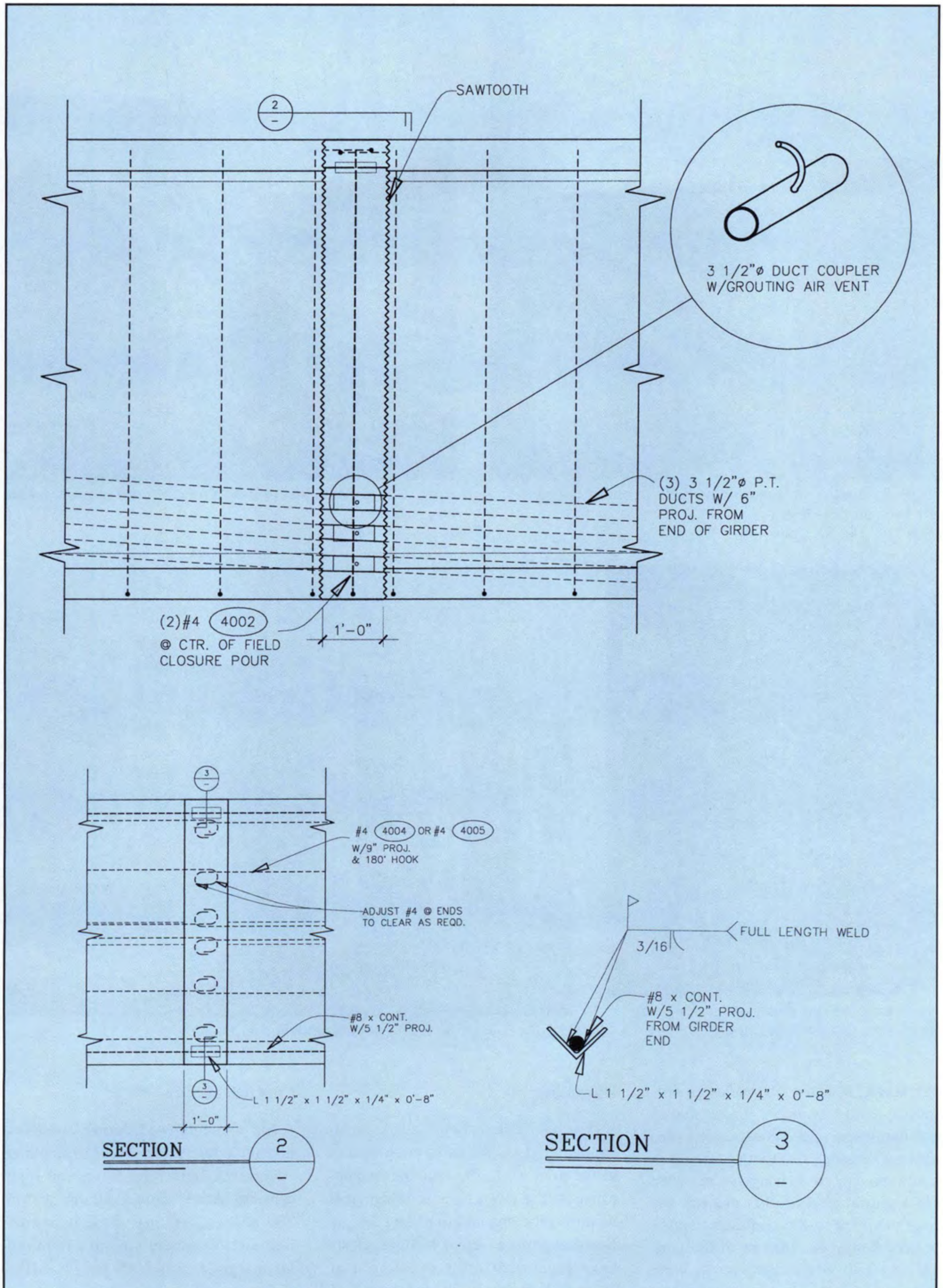

Fig. 6. Splice detail.

Fig. 7. Positioning post-tensioning ducts in one of the 63 ft (19.2 m) girder segments.

Fig. 8. Curing one 63 ft (19.2 m) girder segment after concrete was cast.

Fig. 9. Constructing girder and jacking cage after girder casting and curing.

Fig. 10. Four girder end segments ready for shipment.

eliminating hearings; in the design process by using available girder shapes and hardware; in the construction process by keeping construction time to a minimum. Because change orders were not a major item on this project, the final payment to the contractor was 2 percent below the amount of the contractor's bid. These cost savings were largely due to the use of a precast/prestressed concrete system.

Durability

Concrete bridges have shown excellent durability in the harsh environment of the northwest. The ongoing maintenance of the new concrete bridge will be minimal compared to a steel design. Besides painting steel bridges, costs have escalated in the protection of rivers and streams during the process of removing the existing paint.

Constructability

All elements used during construction including girder sections, hauling equipment, launching truss, and high capacity cranes were available within 200 miles (320 km) of the construction site. Concrete strength required for the girder was 6000 psi (41 MPa) and was achieved using standard design mixes. By working with the precaster during the design phase, girders were cast using existing available forms and equipment. Since construction is not dependent on the water elevation in the river, work on the project could begin without waiting for low water conditions.

How Concept Will Advance Industry

Based on the success of this project, several other agencies and consultants are using this method in the design of new bridges. This method has the distinct advantage of eliminating the center pier, its environmental scar during construction, its potential scour, the accumulation of debris, and maintenance to remove the debris that typically collects there. Construction is not dependent on water elevations or fishery windows.

This construction method offers a winning situation in all respects. It offers no piers in the water, no environmental questions by agencies or groups, no construction delays due to high water, no stoppage due to fishery windows, quick construction ($3^1/_2$ months in this case), no special equipment, and no non-standard concrete strengths. Aesthetically, it offers a sleek, attractive structure.

The total cost of the bridge was \$660,471. The cost of the precast concrete portion of the project, which included production, transportation, installation, and post-tensioning prior to launching, amounted to \$229,482. Details of the cost breakdown are listed in Table 1.

Table 1. Cost breakdown of project.

Substructure	\$ 84,576
Superstructure	\$ 575,895
Total bridge cost	\$ 660,471
Precast cost included in superstructure	\$ 229,482

Note: The precast costs include fabricating girder elements, transporting them to the assembly area near the bridge site, closure pours, post-tensioning, and pumping the tendons with grout.

The design contract was signed with the consultant on March 15, 1995. The job was bid on July 25. Production of the precast girders began on September 22. Construction of the bridge took less than $3^1/_2$ months to complete. The bridge was opened to traffic on December 8, 1995.

Thus, in a time span of less than 9 months, this Federal Aid Project was

Fig. 11. Girder segment [63 ft (19.2 m) long and weighing 40 tons (36 t)] leaving precasting plant.

Fig. 12. Girder segments aligned at staging area near construction site.

Fig. 13. Welding the outside #8 reinforcing bars at the closure segment.

Fig. 14. Jacking the 190 ft 6 in. (58.1 m) girders after curing of closure pour.

designed, bid, and constructed successfully and on schedule. The bulb-tee girders are among the longest such members constructed.

The successful completion of the Rock Cut Bridge is a triumph for the owner, design engineer, contractor, and precaster. More than that, however, it shows the versatility of precast and prestressed concrete, and opens the way for bridge spans greater than 200 ft (61 m) using this material and construction method.

PRECASTER'S ROLE

Although 98 percent of county, state, and federally funded off-system bridges, with spans up to 200 ft (61 m) in the northwest are built using prestressed concrete, the challenges facing the construction of the Rock Cut Bridge were formidable. Fabricating a 190 ft 6 in. (58.1 m) long prestressed concrete girder was not the real problem. [Central Pre-Mix Prestress Company (CPPC) and other precast producers have built prestressed girders with spans greater than 200 ft (61 m).] The major problem was getting the girders to the bridge site, and once there, placing them across the river.

The mountainous highway, with its steep slopes and sharp turns, precluded transporting 190 ft 6 in. (58.1 m) long girders to the project site. In addition, the exclusion of a central pier and disallowance of falsework in the riverbed would make installation of such girders extremely difficult.

Often, prestressed bulb-tee girders are used today for long span bridges because the sections are structurally more efficient than standard I-girders. In addition, because the top flange of the bulb tee touches the edge of the adjacent bulb tee flange, no deck panels are needed. Therefore, during the early stages of this project, CPPC together with the structural engineer, began thinking about a longer, deeper bulb-tee girder than sections ordinarily used.

CPPC's bulb-tee bed had the capability to make bulb tees from 3 ft 5 in. to 5 ft 5 in. (1.04 to 1.65 m) in depth simply by adding fillers to the stem portion of the form. Top and bottom bulbs remain unchanged. Preliminary calculations showed that a 7 ft 5 in. (2.26 m) depth bulb tee had adequate

Fig. 15. Picking spliced girder in staging yard.

Fig. 16. Positioning spliced girder on seven-axle, 26-tire carrier.

Fig. 17. Spliced girder [190 ft 6 in. (58.1 m) long and weighing 120 tons (110 t)] on the road and ready for the haul.

Fig. 18. Girder heading for bent opening specially modified for these girders.

Fig. 19. At bridge site, end of girder placed on launcher trolley and pushed across by truck unit.

Fig. 20. Girder, weighing 120 tons (110 t), being lifted by a 200 ton (180 t) crane at one end and a 140 ton (127 t) crane at the other end.

Fig. 21. Girder gently lowered into position on abutments.

depth for a span-to-depth ratio of 25. Looking at the total lineal feet of 1 ft (0.305 m) filler, which was enough to raise the 180 ft (54.9 m) long form 2 ft (0.61 m), suggested that if the 190 ft 6 in. (58.1 m) girders were built in three segments, there would be enough filler pieces without buying additional material. That length also worked well for hauling length and weight.

Complicating the project was that the river channel was too deep and rocky for two temporary intermediate piers to be used. The girder would have to be constructed at one end of the existing bridge and launched across the river. Both approaches were difficult and had steep grades and sharp curves leading to where the bridge was to be placed.

A possible staging area near the turnoff from the highway, several hundred feet from the bridge, was identified. Between the staging area and the bridge were several curves, a grade, and a railroad overpass with narrowly spaced timber bents and a height restriction. However, the county and the engineer had confidence in the abilities of the precaster to overcome these obstacles and decided to change from the originally conceived steel structure to a concrete bulb-tee girder bridge.

To assist the contractor, CPPC would reassemble the bulb-tee segments near the jobsite, splice post-tensioning ducts, form and pour closures, thread and stress strands, and pump tendon ducts with grout. Thus, a "ready to go" 190 ft 6 in. (58.1 m) long bulb-tee girder would be turned over to the contractor.

Just before bidding, several of CPPC's key personnel visited the jobsite and came back questioning the wisdom of the company taking on this much risk. However, after due consideration, their concerns were overridden, and the job was bid on July 25. The contract was awarded on July 28, so now it was time to make preparations for the work ahead.

Design

Engineering/shop drawings began to be developed in early August. The design required a 1,665,000 lb (7406 kN) post-tensioning force, to be supplied by three tendon ducts each having fifteen 0.6 in. (15 mm) diameter

Fig. 22. Girder clear of launching truss being set in place.

Fig. 23. Finished bridge as seen this past summer.

strands. Each strand was initially stressed to 43.94 kips (195 kN) or $0.75F_y$. The strands would be encased in a $3^1/_2$ in. (89 mm) outside diameter galvanized duct. The $6^1/_2$ in. (165 mm) wide stem would provide 1 in. (25.4 mm) of cover and a #4 stirrup on each side of the duct.

The four girders, 6 ft $1^1/_8$ in. (1.86 m) wide, would give the required 24 ft 6 in. (7.47 m) width bridge. To provide end anchorages for the post-tensioning, a separate end block was cast. The end block had spiral and end cage reinforcement to carry the large post-tensioning force into the girder. Since it was vital that the tendon forces be applied uniformly over the end block, steel forms were used for precision.

It was extremely important to analyze the girder for lateral stability. If there was a tendency for the girder to buckle, a method for increasing the stability of the girder would need to be developed. Fortunately, because of the wide top flange, the bulb tee was very stable laterally, so handling the girder was not a concern.

To lift the heavy assembled girder, standard lift loops would be inadequate. A pair of extra strong $3^1/_2$ in. (89 mm) diameter pipes were cast-in 5 ft 4 in. (1.63 m) apart. Special yoke handling devices with a high strength 3 in. (76 mm) diameter pin were designed and fabricated by CPPC and furnished to the contractor. Shop drawings were prepared, approved by the engineer, rechecked, and sent to the production department.

Production

At the same time the shop drawings were being prepared, CPPC production crews were modifying the form to cast a 7 ft 5 in. (2.26 m) deep girder with a $6^1/_2$ in. (165 mm) wide web. Top and bottom flange widths were 6 ft $1^1/_8$ in. and 2 ft (1.86 and 0.61 m), respectively.

The specified compressive strength of the concrete was 6000 psi (41.5 MPa). Actual concrete strengths were higher. The strand release strength of concrete was set at 4000 psi (27.6 MPa).

Production of the girder segments began at the CPPC plant in Spokane on September 22. The segments were

Fig. 24. Bridge will not disturb river and natural habitat.

finished on October 12. While this was going on, the contractor was casting the footings, walls, and preparing the site for the girders to be placed. Girders were cast one per day and secondary end pours sequentially made as the girders were cast.

By casting the end pours, which contained the post-tensioning anchorages, as a secondary pour, the bulb tee form itself did not need modification to add an end block. Using custom made steel forms for the end pours worked well, and could be cast on a daily cycle. Shear lugs and inserts were provided in the edges of the end pours to facilitate the contractor casting an end diaphragm between the ends of the girders after they were erected.

Figs. 7 through 10 show various stages of the fabrication of the girder segments at the plant.

Transportation

The segments had six straight strands in the bottom bulb that were prestressed at the plant for girder handling and hauling stresses.

The segments were hauled one per load on a standard tractor with fifth wheel bunk and steering trailer arrangement, as most of the bridges made by CPPC are. There was some concern initially because of the very high center of gravity of the load — nearly 13 ft (4 m) in the air! Because the haul route had so many superelevated curves, the concern was that the load may break loose from the tie-down chains, with a load that "top heavy" working on them. Double sets of chains were used, and no problems were encountered.

The girder segments were hauled (see Fig. 11) by truck trailer 150 miles (240 km) north to the staging area which was close to the bridge site. After unloading, the segments were set on temporary concrete bunks prepared by One Way Construction.

An interesting sidelight on the field work was the fuss created by the property owner on the Ferry County side who was adamantly opposed to building the bridge. After several threats and vandalism to One Way's equipment, a judge's restraining order was obtained to allow the work to proceed.

Erection

With the girders on site, the race to finish the job began! There was much to do, and winter comes early this far north. A key element in successfully finishing the project was the help provided by Duncan Crane Service and especially owner Bill Fairbanks. With their girder launcher, capable of carrying half the weight of the girder across the river, Duncan supplied the key ingredient to making all this happen. Bill Fairbanks approached the job with his usual professionalism. Zillah Hauling, one of his subcontractors, very carefully assembled a special tractor/fifth wheel and steering trailer to handle the girder weight. That takes many axles!

Field work began on October 18. As CPPC crews were splicing the post-tensioning ducts, forming and pouring closure pours, threading strand and post-tensioning, One Way Construction and Duncan were readying the site. To complicate matters, a cold snap hit the region just when closure pours and tendon grouting were ready to begin, so CPPC had to tent and heat the girders. Girder camber after post-tensioning very closely matched the predicted camber, which in this case was about 3 in. (76 mm). Magnesium phosphate grout together with pea gravel was used in the closure pours to accelerate concrete strength gain so that post-tensioning could proceed on schedule.

Figs. 12 through 14 show how the girder segments were spliced and post-

Fig. 25. Rock Cut Bridge fits aesthetically into northwest wilderness.

tensioned. Figs. 15 through 18 show the care in which the assembled girders were hauled to the bridge site.

Launching

Finally, on November 8, the big day arrived. The time to launch the girder was at hand. Dewey Hyatt, the owner of One Way Construction, gathered everyone together for a short safety meeting and to say a prayer. Everyone held their breath as the cranes at each end lifted the girder to set the girder ends on their respective conveyances. Even though all the calculations checked out, there was still some anxiety picking up these nearly 250,000 lb (1112 kN) girders!

Ted Massender, the owner of Zillah Hauling, took the responsibility to personally back the tractor with its loadster around the corner, down the hill, and between the bents of the railroad bridge with the rear end of the girder. With all those axles, Massender had to back carefully because it would not be possible to pull ahead for another chance to correct his path. Fill was placed, retained by gabions, to straighten the road in order to give the girders a straight shot to the launcher.

Figs. 19 through 22 show the launching of the girders.

Our second worst nightmare was that the portion of the road that was straightened with fill would fail when the girder went through the railroad bridge and take the railroad bridge out when it fell. This fill did not shift in the end, so everything worked out as planned with all parties in radio contact with each other for coordination. The girder was lifted from the steering car and placed on the trolley on top of the launching truss.

The tractor continued backing the girder across until the fifth wheel assembly came to the end of the truss. Then the near side crane lifted that end of the girder and a backhoe pushed it the remainder of the way across. Of course, our first biggest nightmare was that this top heavy girder would tip off the trolley, take the launcher out when it fell, break, and fall into the river, but that did not happen.

The trolley moved across smoothly until the far side 200 ton (181 t) crane could reach the girder. Then it and the near side 140 ton (127 t) crane, working together, swung the girder into place. It was really a sight to behold! Despite the frigid air and long wait, a large crowd of people gathered to watch this dramatic moment. It took most of one day to set the first girder. Now that the launching crew knew the procedures, the next three girders were set in place routinely the following day.

Various photographs of the completed bridge are shown in Figs. 23 through 25.

CONCLUDING REMARKS

In retrospect, this project "pushed the envelope," so to speak. Not in an unsafe manner, but in the sense of using a larger span prestressed girder than would have conventionally been possible. The project was a success because it required a cooperative effort and all parties are happy with the outcome. The counties now have a low maintenance long clear span bridge in place, the contractor has completed a difficult job on time and on budget, the engineer has seen his design successfully implemented, and the prestressed concrete manufacturer knows that he has the ability to do it again! The engineer is now working on a 200 ft (61 m) span bridge to be built the same way!

It is expected that with the experience gained on this project and as engineers and contractors become familiar with the construction method, bridge spans beyond 200 ft (61 m) will become possible.

In June of this year, the Rock Cut Bridge won two prestigious awards in two categories of the 1997 PCI Design Awards Program:

- Harry H. Edwards Industry Advancement
- Bridges with Spans Greater than 135 ft (41.2 m)

The following were the jury's comments:

"An innovative solution to a difficult construction and environmental problem. The notion of hauling precast segments to a staging area, splicing them into a nearly 200 ft (61 m) long girder, and using a launching truss to span the assembled units across a river proved to be an effective and economical project for the owner. This concept can be extended to other long span bridges."

CREDITS

Owner: Stevens/Ferry Counties, Washington (Administered by Stevens County, Colville, Washington)

Engineer: Nicholls Engineering, Spokane, Washington

Contractor: One Way Construction, Sedro Woolley, Washington

Erection Subcontractor: Duncan Crane Service, Moses Lake, Washington

Precast Prestressed Concrete Manufacturer: Central Pre-Mix Prestress Company, Spokane, Washington