CHALLENGES ENCOUNTERED IN DESIGN AND CONSTRUCTION OF A MULTI-SPAN POST-TENSIONED SPLICED-GIRDER CONCRETE BRIDGE

Khashayar Nikzad, PhD, PE, Harding ESE, A MACTEC Company, Bellevue, WA

Bijan Khaleghi, PhD, PE, WSDOT, Lacey, WA

Theo Trochalakis, PhD, SE, Harding ESE, A MACTEC Company, Bellevue, WA

Kunle Ogunrinde, EIT, Harding ESE, A MACTEC Company, Bellevue, WA

ABSTRACT

In this paper some of the important challenges encountered in design, staging and construction of the Riverside Bridge, which is a 5-span post-tensioned splice-girder bridge, are discussed. The Riverside Bridge girders were originally designed based on a 3-stage post-tensioning scheme but due to some delays in construction activities the design was changed to a 2-stage Post-tensioning scheme. A comparative study between the two mentioned Post-tensioning schemes is made and the advantages and disadvantages of each scheme are identified. Special attention is paid to topics like: time dependent girder deflections, concrete strength demands at cast-in-place closures, and lateral stability demands of assembled long girders during transportation and erection.

Keywords: Post-tension, Bridge, Spliced-girder, Multi-span, Deflections, Stability

INTRODUCTION

Riverside Replacement Bridge over Skagit River in Mount Vernon Washington is an 847-foot long, 72-foot wide, 5-span (150:180:180:180:150 ft.) post-tensioned spliced-girder bridge composed of W95PTG pre-tensioned segments (See Figure 1). Skagit River is a very environmentally sensitive river in the Pacific Northwest region requiring a very strict and relatively short construction window.

Its substructure is composed of cast-in-place reinforced concrete bents supported on circular 9'-8" in diameter drilled shafts extending below river mud-line by about 90 ft. Contractors were allowed to bid for two superstructure alternates, one in precast prestressed concrete W95PTG super-girders with spans of 150-180-180-180-150 ft., and the other in steel girders with spans of 270-300-270 ft. both made composite with a cast in place 8 inch reinforced concrete deck. The prestressed concrete alternate was cheaper by about 12 percent than the steel alternate and the contract was awarded to the lowest bidder Kiewit Pacific in March 2001.

The Riverside Bridge girders were originally designed based on a 3-stage post-tensioning scheme. In Stage 1, segments are assembled and post-tensioned for shipping and erection. Stage 2 post-tensioning is to compensate for the weight of the cast-in-place deck slab and intermediate diaphragms. Stage 3 post-tensioning (i.e. continuity PT) is to compensate for the effects of Vehicular Live Load and all the other Superimposed Additional Dead Loads that are applied to the composite girders.

Due to some unforeseen construction difficulties in drilling shafts, construction activities were delayed in the first construction window in the summer of 2001. In order to help the contractor to meet his new project timeline, and at his request, the owner and designers have agreed to reduce the original design's post-tensioning stages by one, by combining PT Stages 1 and 2. The new Stage 1 PT has higher post-tensioning demands.

DESIGN CONCEPT AND CONSTRIANTS

Washington State Department of Transportation, in collaboration with Concrete Technology Inc., recently developed the new 7'-10. 5" inch deep W95PTG super-girder with the intention of increasing the span capabilities of precast prestressed concrete girders in the State of Washington.

The goal of the designer of the bridge, Harding ESE, was to minimize the number of girders per span and the number of in-water piers. The result was utilizing 150-ft. and 180-ft. spans for end-spans and interior-spans of the bridge respectively with a typical 9-ft. spacing between girders. Environmental constraints did not allow the use of temporary supports in the river, and hence the designer had to design a 177.5-ft. long precast girder to be erected on top of the piers. Transportation constraints and weight limitations of trucks and trailers excluded the possibility of precasting the girders as a single piece, hence the girders were

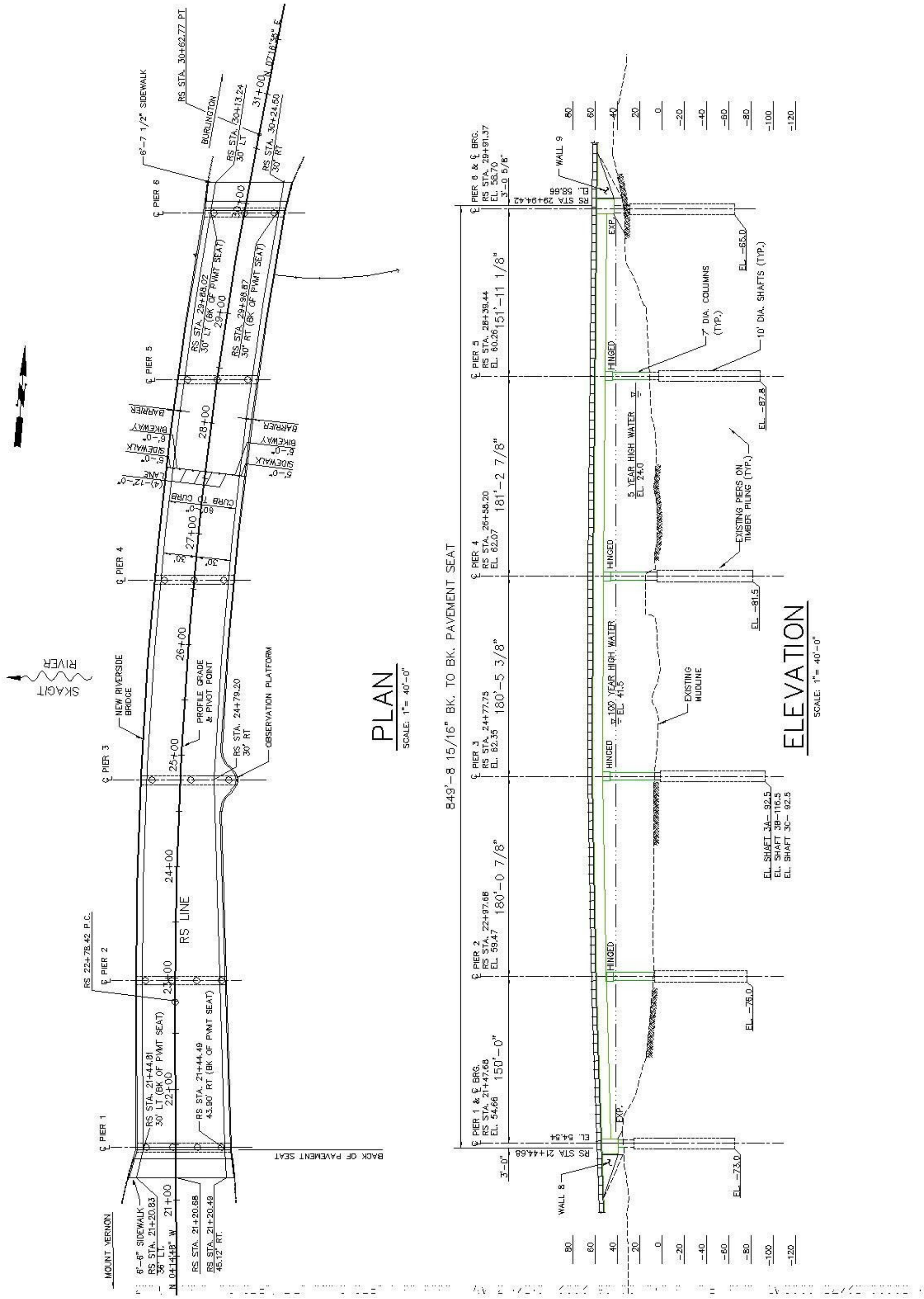

Fig.1 Riverside Bridge

produced and transported in segments, assembled and post-tensioned in their final length at a storage yard in the construction site. An additional constraint imposed by the aesthetics of the bridge is that the spans should not sag in the long term. Figure 2 shows an assembled 180-foot girder in the storage yard. Using the above constraints, as partial design criteria, an iterative design procedure was evolved. The design procedure used is best illustrated by the attached flow chart (See Figure 3).

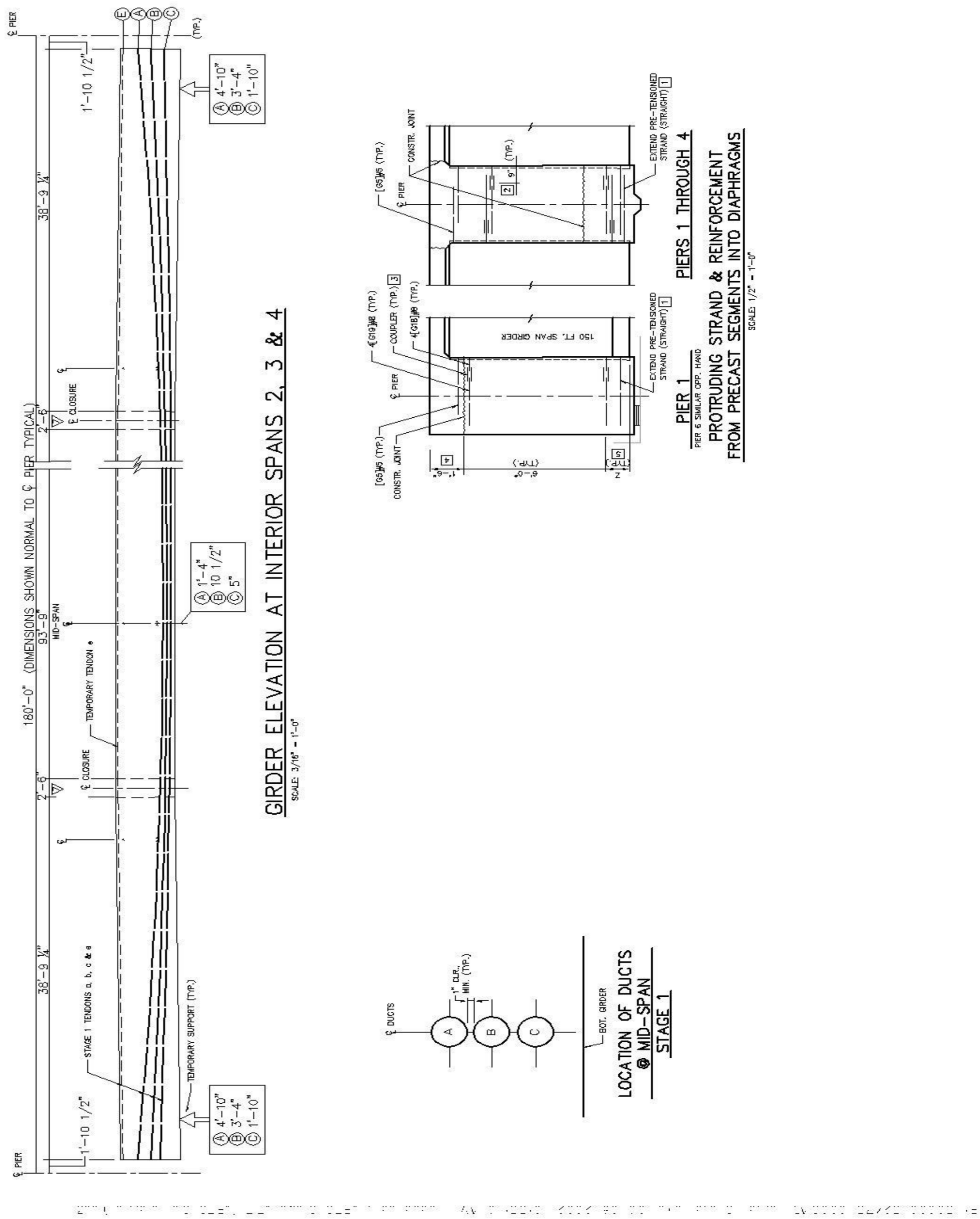

Fig. 2 Stage 1 Post Tensioning

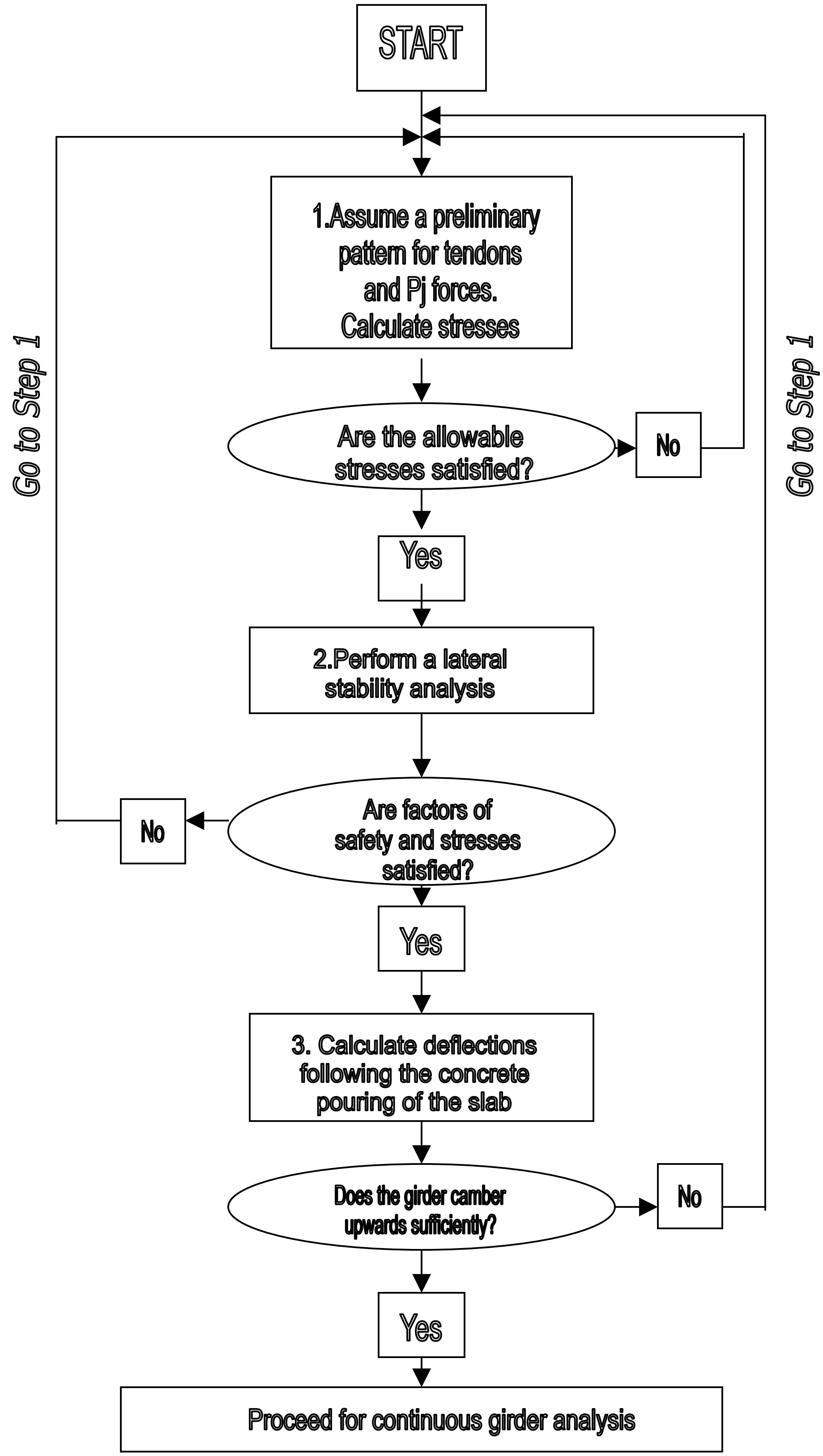

Fig. 3 Post-Tensioning Design Flow Chart

OPTIONS FOR THE LAYOUT OF TENDONS AND PT STAGES

PT Option 1

This option is the initial design, as detailed in the contract drawings. It involves three post-tensioning stages. Stage one consists of a simply supported girder; with sufficient post-tensioning force to balance the self-weight of the girder and give almost zero deflection. Stage two consists of a simply supported girder with additional post-tensioning to balance the dead load of the deck, and applied after the erection of the girders on the piers. Stage three consists of continuity post-tensioning, to be stressed from both abutments. This option has the advantage of going through a repetitive construction cycle of erecting girders and pouring the deck span-by-span and minimizing friction losses in the second stage tendons.

PT Option 2.

PT option 2 has three stages of post-tensioning, similar to option 1, except stage 2 post-tensioning is applied end-to-end as a continuity tendon following the erection of all girders, concreting of the closures over the piers and prior to the pouring of the deck. It has the advantage that the second and third stage post-tensioning is applied from the two abutments; moreover the dead load of the deck is carried by continuous girder lines thus reducing moments and deflections. Following the unforeseen delays in the construction of the shafts this option was suggested to the contractor in order to save time.

PT Option 3

This option was proposed by the contractor to compensate for some lost construction-window time and later was finalized by Harding ESE team. Presently the girders are being manufactured using this option. In this option the total post-tensioning force is split into two stages. Stage 1 is applied at the assembly of the segments as simply supported spans, and balances the self-weight of the precast girder and the dead load of the deck. Stage 2 is continuity post-tensioning applied from the two abutments, following the hardening of the deck. This method has the advantage of reducing the post-tensioning stages from three to two, but requires higher strength concrete, both in the precast segments and in the concrete closures, than in the other two options.

Figure 4 presents a schematic of the three PT options.

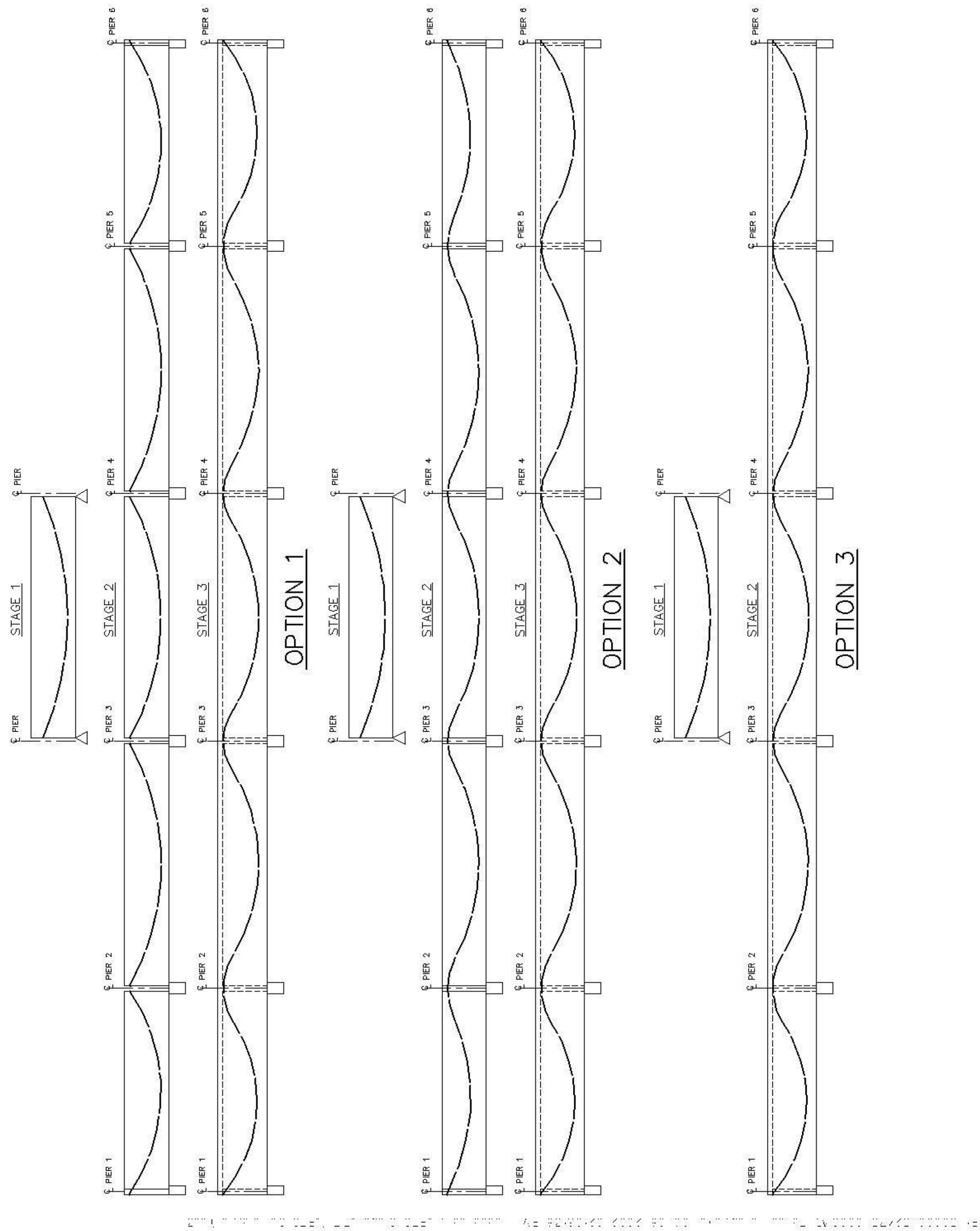

Fig. 4 Layout of tendons and Post-tensioning Stages

According to contract, the contractor is responsible for the safety and integrity of the girders during transportation and erection, and he decides the methods and equipment to be used for handling of the assembled girders. The contractor decided to erect the girders using a temporary work bridge in the river as an erection platform. Owing to the mentioned construction constraints the girders will be lifted to the piers using two cranes at 7 ft from the girder ends. The required concrete strength, governed by the contractor's handling procedures, is 10,000 psi at the mid span locations and 7200 psi at the closure locations of the spliced super-girders.

Moreover, it should be noted that in all of the three options, the final continuity post-tensioning stage consists of two tendons, one large and the other small. Due to the large number of duct splicing between segments (12 total), there is the likelihood of having higher friction losses than what are normally assumed in the design. During final stage post-tensioning if the friction losses are found to be as assumed in the design, then only the large tendon will be stressed. If friction losses are higher than assumed, then both tendons will be stressed, to compensate for the increased friction loss.

COMPARATIVE STUDY

In the following we will revisit the 3 PT options described in the previous section in terms of lateral stability, factors of safety, stresses and deflection

LATERAL STABILITY

To our knowledge the Riverside Bridge precast girders are the longest and heaviest girders to be transported within a construction site and lifted to the piers in the state of Washington. To insure lateral stability during those operations is a major task. In addition to the required skillful and careful handling of the cranes, trucks and transportation dollies by the contractor, Harding ESE examined a number of parameters and their impact on lateral stability, as a check and supplement to the contractor's calculations. The analysis is based on References[1,2,3] in which the degree of safety is expressed in terms of various factors of safety and required concrete strengths.

Figure 5 shows the factors of safety during transportation as a function of the rotational stiffness of the transportation dollies. As the rotational stiffness of the dollies increases the stability of the girder improves.

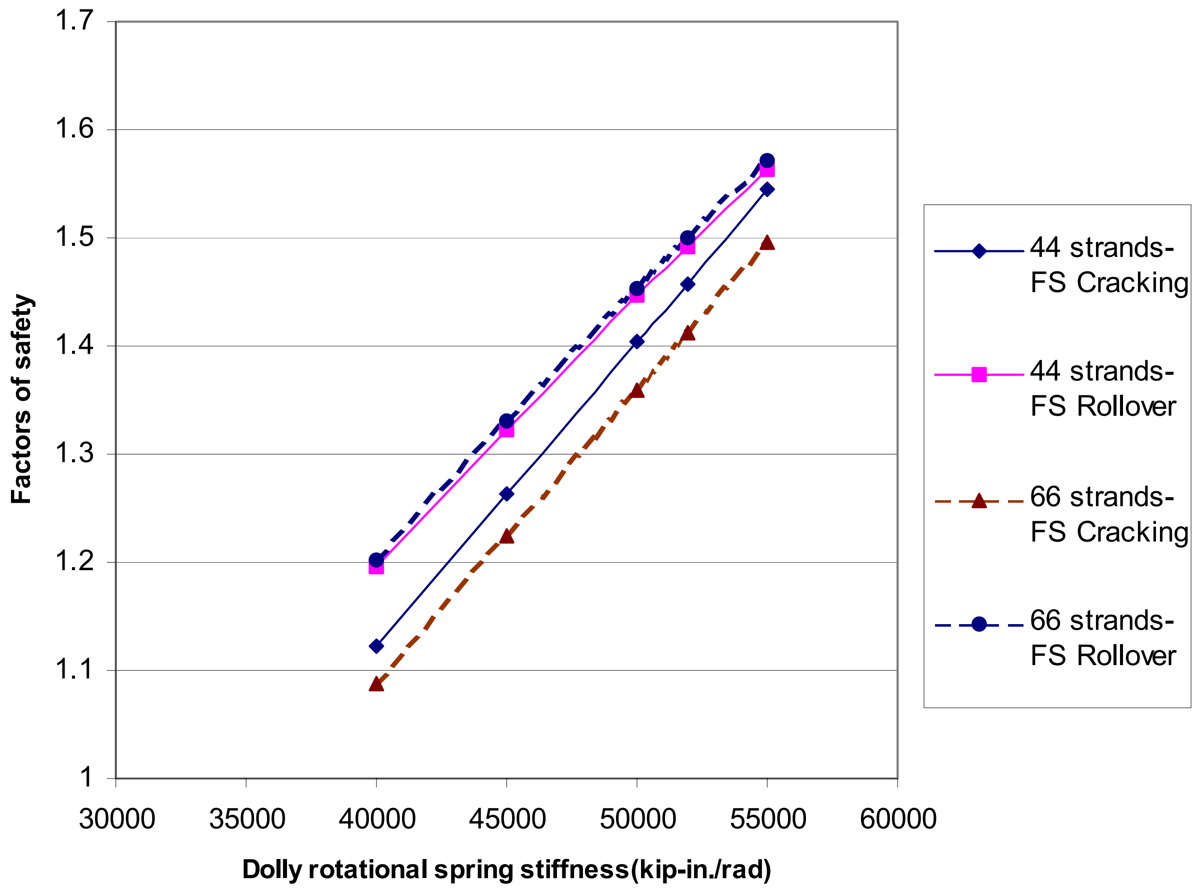

Fig. 5 Factors of safety during transportation vs. dolly rotational stiffness

Figure 6 shows the influence of the "a" distance on the factors of safety during transportation. Parameter "a" is defined as the distance from the end of the girder to the picking point. A relatively small increase in the "a" distance improves stability considerably. Initially the Harding ESE designers had specified a value of 15 feet for the "a" distance in the contract drawings. The contractor being responsible for the erection of the girders in order to accommodate the capacity of his cranes and work bridge decreased the “a” distance to 7 ft. As a result of the decrease in the “a” distance the factors of safety were reduced.

Figure 7 shows the increase in the factor of safety against cracking as the number of temporary tendons at the top flange increase.

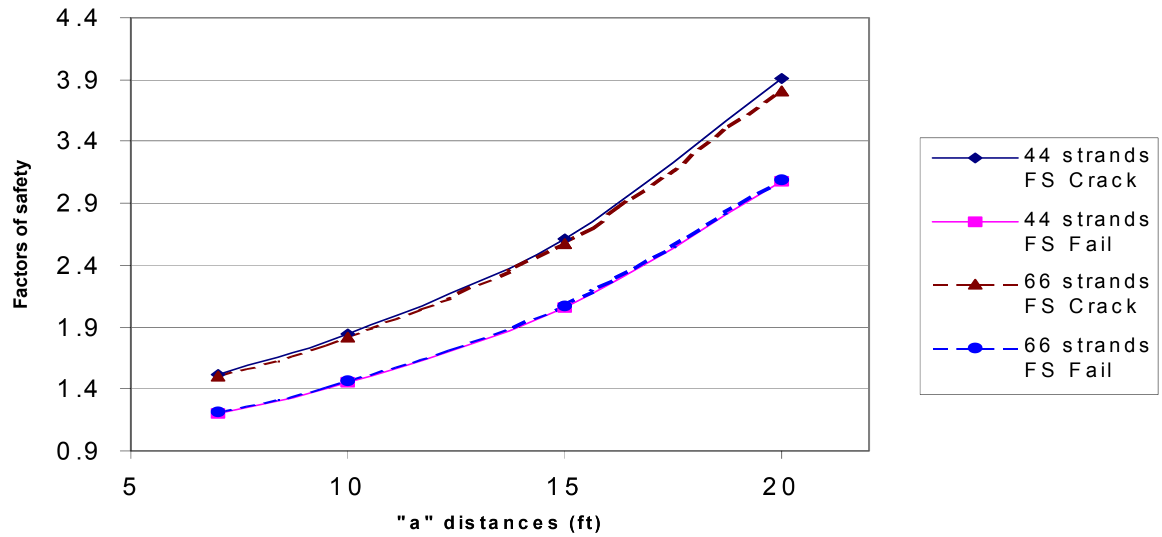

Fig.6 Factors of safety at lifting vs. picking points

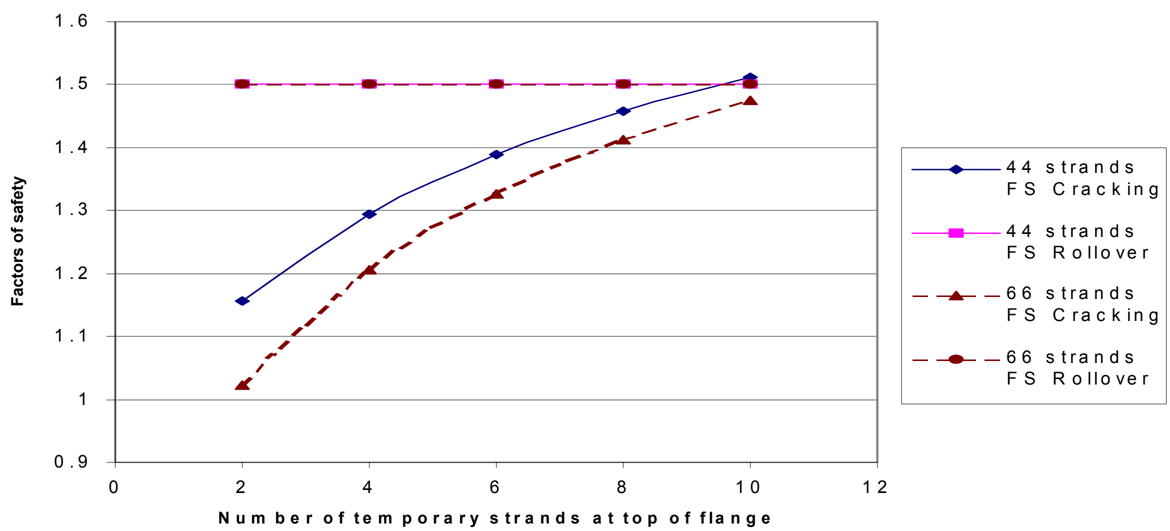

Fig.7 Factors of safety at transportation vs. number of temporary strands (Torsional stiffness of dollies=52000K-in/rad)

Figure 8 shows the increase in the required concrete strength, at mid-span and closures during transportation, as the number of tendons increases from two to three.

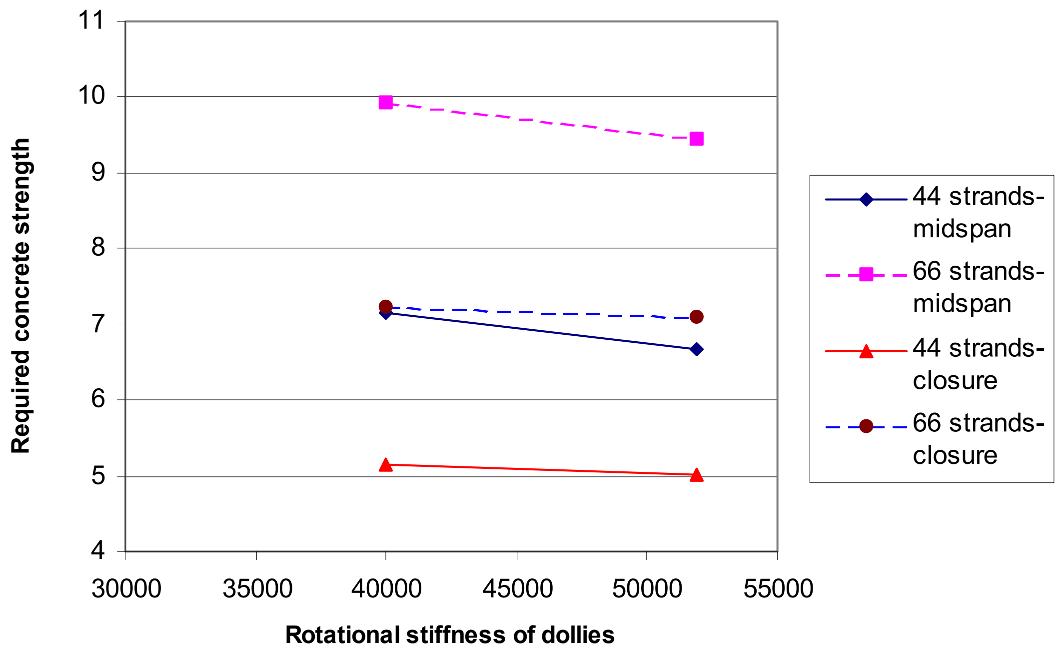

Fig. 8 Required concrete strength at midspan vs. rotational stiffness of dollies during transportation

GIRDER STRESSES

To evaluate the time dependent long term deflection and stress response of the bridge the Leap Consplice[4] PT software was utilized. All stresses at intermediate and final stages were found to comply with the AASHTO allowable limits.

GIRDER DEFLECTIONS

All deflections were calculated chronologically, whenever a change in loading or post tensioning takes place, including time dependent effects.

Since a large number of variables affect deflections, the actual girder deflections will be measured prior to pouring the deck and adjustments will be made to the depth of the haunch above the girder if needed to obtain a smooth riding surface.

CONCLUDING REMARKS

Three different post-tensioning schemes are compared in conjunction with the Riverside Bridge, which utilizes W95PTG spliced super girders. The capability of the new W95PTG super-girder to span 180 ft. at a relatively wide spacing of 9 ft. has been established. Moreover, if the assumptions used in the analysis are fulfilled at the site, the long and slender super-girders will not buckle during transportation and erection.

The successful completion of this bridge will establish the fact that the use of the new super-girder can lower the price of bridges with a span range of 180 ft., where traditionally steel and concrete box girders have been used in the past. The design would have been simpler and easier to construct if few temporary supports were environmentally acceptable.

REFERENCES

1. Seguirant, S J, "New Deep WSDOT Standard Sections Extend Spans of Prestressed Concrete Girders", PCI Journal, V. 43, No. 4, July-August 1998, pp. 92-119
2. Mast, R. F., “Lateral Stability of Long Prestressed Concrete Beams, Part 1.” PCI JOURNAL, V. 34, No 1, January- February 1989, pp. 34-53.
3. Mast, R. F., “Lateral Stability of Long Prestressed Concrete Beams, Part 2.”PCI JOURNAL, V. 38, No. 1, January-February 1993, pp. 70-88.
4. Zokaii T, "LEAP CONSPLICE PT", November 2001