ADVANTAGES OF POST-TENSIONED SPLICED GIRDERS FOR LONG SPAN BRIDGES AND COMPLEX INTERCHANGES

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ABSTRACT

Spliced-girders are the feasible design option with the greatest potential for extending span lengths in the range of CIP post-tensioned concrete or steel girder bridges. Bridges with spliced girders have the ability to accommodate horizontal curvature found in curved bridges and complex interchanges. The use of post-tensioned spliced-girders in bridge structures allows engineers to design bridges with longer span lengths. Long span precast girder bridges are an ideal design solution for crossing of waterways, major highways, or other obstacles where it is desirable to eliminate intermediate piers. Post-tensioned spliced-girders further the economies of long span pre-cast girders by allowing girders to be cast, shipped, and erected in smaller segments. The design of spliced girders involves greater complexity than for conventional prestressed concrete girder superstructures. The most relevant are time dependent effects, splicing locations, construction sequences, and combine pretensioning and post-tensioning. This paper focuses on the advantages of spliced-girder bridges in Washington State.

Keywords: Spliced-girders, Long Span, HSC, Design, Fabrication, Handling

INTRODUCTION

A spliced precast girder bridge is defined as a type of superstructure in which precast concrete beam-type elements are joined longitudinally, typically using post-tensioning, to form the complete girder. The resulting superstructure cross-section is a conventional beam-and-slab system with a composite cast-in-place deck. Among the reasons to use spliced girders are the reduction of substructure units due to increases span lengths, reduction of girder units due to increased girder spacing, and functionality and aesthetic improvements by reducing superstructure depth.

Spliced girder bridges have a proven track record in the Washington States. In spite of their past and continued use, the use of this technique is not widespread. A significant reason for their limited use is the ambiguity in their design and analysis, rooted in the consideration of various issues with which the designer of conventional precast prestressed concrete girders is typically not familiar. In addition, the information available in the literature regarding the design, analysis and construction of spliced girder bridges is limited, as the experience, information, and methods used on these projects have tended to be job-specific, and the knowledge gained has not been made widely available for use on similar projects.

The ability to achieve greater span lengths with the use of precast, prestressed spliced girders has introduced another structure type for long-span bridge design. This type of structure creates competition with traditional long span alternatives and has resulted in economy for bridge owners.

While the design requirements for spliced girder bridges are not significantly different from conventional prestressed concrete design, the analysis procedure must take additional considerations. Among the most relevant additional considerations are staged construction, multiple stressing stages, and combined prestressed and post-tensioning. Thus, the design of spliced girder bridges involves greater complexity than is required for conventional precast/prestressed concrete girder designs.

PRECAST PRESTRESSED SPLICED GIRDER BRIDGE PROJECTS

Table 1 lists several recently completed or in-progress projects in Washington State using the WSDOT STD precast spliced girder cross sections.

Table 1: List of Recent Spliced Girder Bridges in Washington State

Bridge	Location	Type	Length
Manette Bridge	Bremerton, Washington	WF I-Girder	250 ft.
Thurston Way	Vancouver, Washington	WF I-Girder	205 ft
Twisp River Bridge	Okanogan, Washington	WF I-Girder	195 ft.
Rock Cut Bridge	Kent, Washington	Bulb Tee	190 ft
SR 99 Riverside Bridge	Mount Vernon, Washington	WF I-Girder	181 ft
US 97 Satus Creek Bridge – Curved	SC Region, Washington	Tub-Girder	180 ft.
Yakima River Bridge	Yakima, Washington	WF I-Girder	175 ft

S 38th Street Bridge over I-5	Tacoma, Washington	Tub-Girder	164 ft
I-90 Sunset Interchange	Issaquah, Washington	Tub-Girder	155 ft
S 38th Street Bridge over I-5-PED	Tacoma, Washington	Tub-Girder	151 ft
317th Street Bridge of I-5- Curved	Federal Way, Washington	Tub-Girder	127 ft
S.R. 99/AWV – Little h – 3 Bridges	Seattle, Washington	Tub-Girder	117 ft.

Fig. 1 shows the construction of or the Manette Bridge in Bremerton, Washington to replace the old steel bridge. A large number of pre-cast hammerhead and drop-in girders were to be transported from the girder manufacturing site to the bridge construction site. The contractor owned flat deck cargo barge was used for the transport of these girders.

Fig. 1 shows the construction of or the Manette Bridge in Bremerton, WA

Fig. 2a Shows the spliced girder hauling activities with pinned front dolly and torsionally stiff back double dolly. Fig 2b shows the spliced girder erection activities showing external lifting assembly, and Fig 2c, shows the girder splicing activities.

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 2. 2a: Shows the spliced girder hauling activities with pinned front dolly and torsionally stiff back double dolly. 2b: shows the spliced girder erection activities showing external lifting assembly, and 2c: shows the girder splicing activities.

Fig. 2: Spliced girder erection activities

The cross sections of WSDOT standard wide flange and trapezoidal tub spliced girders used in composite superstructures are shown in Fig. 3. The complete description of WSDOT standard pretensioned girders is presented in Reference[2]. Reference[3] introduces the newly developed WSDOT wide flange deep precast prestressed concrete girders. The benefits of high performance concrete for precast prestressed girders in Washington State are discussed in Reference[4]. Reference[5] discusses the minimum flexural reinforcement requirements and Reference[6]discusses the flexural strength of reinforced and prestressed concrete T- Beams, and Reference[7] discusses the prestressed girder design optimization.

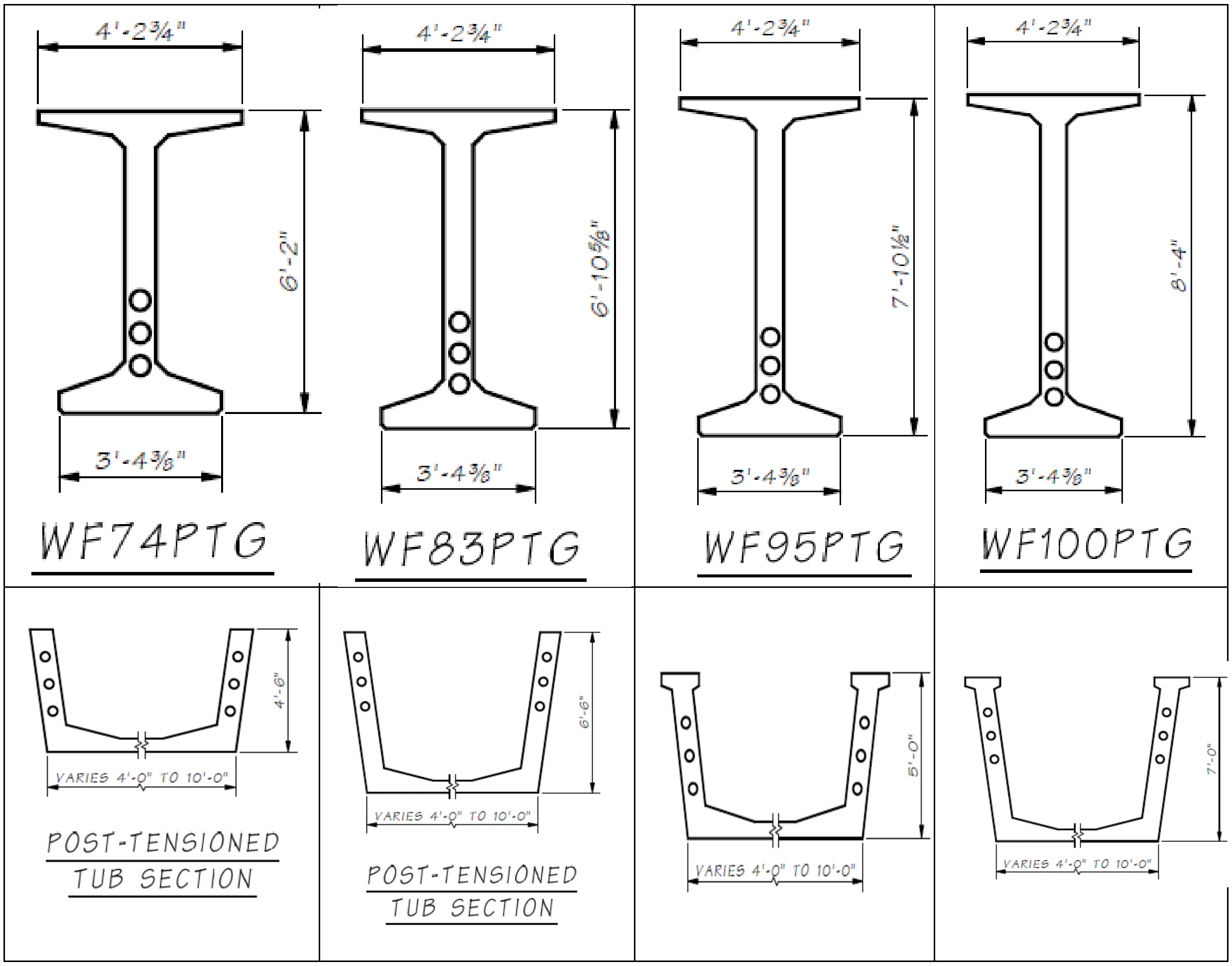

Fig. 3: The cross sections of WSDOT standard wide flange spliced girders

DESIGN CRITERIA

The design of spliced girder bridges depends on several parameters that significantly influence performance and cost. The most relevant are time dependent effects, splicing locations, construction sequences, girder segment geometries, number of beams, and number or profiles of prestress and post-tensioned reinforcement. The design criteria for spliced girders are:

- Design for Zero tension at Service III Limit state
- Simple span girder design for all permanent and transient loads
- Gross section properties for all designs
- Refined estimate of time dependent prestress losses
- Relative humidity of 75% under normal exposure
- Strength of concrete for girders 7.5 ksi at transfer and 10.0 ksi at final
- 0.6" diameter prestressing strand grade 270 for pretensioning strands.
- Includes 2" future HMA overlay with density of 140 pcf

The design of precast segments, as well as precast post-tensioned members, must satisfy the requirements for both allowable stress design and ultimate strength using the current AASHTO LRFD Specifications[1] and additional criteria detailed in the WSDOT Bridge Design Manual[1].

Allowable stresses for prestressing strands used in precast segments are $0.75f_{pu}$ at transfer and $0.8f_{py}$ at service limit state. The allowable stresses for post-tensioning strands are $0.8f_{pu}$ at jacking, and $0.75f_{pu}$ at the end of the zone affected by seating loss. The anchor set for post-tensioning tendons is 3/8" and stress in post-tensioning strands after seating loss is limited to $0.7f_{pu}$. Designers are encouraged to limit this stress to $0.68f_{pu}$ or $0.69f_{pu}$ to allow for some unforeseen adjustments during construction.

DESIGN TOOLS

The spliced-girder analysis and design may be done using any program with time-dependent analysis capabilities. The program shall be capable of analyzing a structure that is constructed in many stages. In addition to the section properties, and applied loads, program should allow time dependent material properties, prestressing tendons, and multiple erection phases at different times. To facilitate the design of spliced-girders the WSDOT Bridge and Structures Office is in process of developing the PGSplice™ program in accordance with the AASHTO LRFD[1] and WSDOT Bridge Design Manual (BDM[2]) requirements. WSDOT Uses Consplice program for continuous spliced girder bridges.

ALTERNATIVE DESIGN FOR LONG SPAN PRECAST GIRDERS

Long span prestressed concrete girder bridges may bear increased costs due to difficulties encountered during the fabrication, shipping, and erection of such one-piece girders. Providing an alternate spliced-girder design to long span one-piece pretensioned girders may eliminate the excessive cost through competitive bidding. The following procedure for alternative design of prestressed concrete girders in the Plans shall be followed:

- All prestressed concrete girders with shipping weight less than 190 kips shall be shown in the Contract Plans as pretensioned only.
- All prestressed concrete girders with shipping weight between 190 and 240 kips shall include both pre-tensioned and post-tensioned spliced prestressed concrete girder.
- All prestressed concrete girders with shipping weight exceeding 240 kips shall be spliced prestressed concrete girders, with post-tensioning applied after the casting of the girder closures and deck slab.

The designer shall provide shipping support locations in the plans to ensure adequate girder stability. For normal designs, shipping support locations should not be closer than the girder depth to the ends of the girder. The overhangs at the leading and trailing ends of the girders should be minimized and equal, if possible. However, the leading end overhang should not exceed 15′ to avoid interference with trucking equipment. Shipping support locations shall maintain the concrete stresses within allowable limits.

Length between shipping support locations may be governed by turning radii on the route to the jobsite. Potential problems can be circumvented by moving the support points closer together (away from the ends of the girder), or by selecting alternate routes. A distance of up to 130′ between supports is typically acceptable for most projects.

The height of a deep girder section sitting on a jeep and steerable trailer is of concern when considering overhead obstructions on the route to the jobsite. The height of the support is approximately 6′ above the roadway surface. When adding the depth of the girder, including camber, the overall height from the roadway surface to the top of concrete can rapidly approach 14′. Overhead obstructions along the route should be investigated for adequate clearance in the preliminary design phase. Obstructions without adequate clearance must be bypassed by selecting alternate routes.

Expectations are that, in some cases, overhead clearance will not accommodate the vertical stirrup projection on deeper WSDOT standard girder sections. Alternate stirrup configurations can be used to attain adequate clearance, depending on the route from the plant to the jobsite.

INTERMEDIATE DIAPHRAGMS FOR PRECAST SPLICED GIRDER BRIDGES

Prestressed concrete girder bridges are often damaged by over-height loads. The damage may range from spalling and minor cracking of the bottom flange or web of the prestressed concrete girder to a loss of a major portion of a girder section.

Based on research done by WSU[8] the use of intermediate diaphragms for wide flange I-shape and deck bulb tee prestressed concrete girder bridges shall be as follows:

a. Full depth intermediate diaphragms shall be used for Interstate bridges, and other bridges crossing over roads of ADT > 50000
b. Either full depth or partial depth intermediate diaphragms may be used for all other precast girder bridges

The use of full or partial depth intermediate diaphragms in bridge widenings shall be considered on a case-by-case basis depending on the width of the widening and number of added girders.

WSDOT requires intermediate diaphragms for all prestressed girder bridges. The location and number of diaphragms are shown below:

1. 1/5 points of span for span lengths over 160′-0″
2. ¼ points of span for span lengths 120′-0″ to 160′-0″
3. ⅓ points of span for span lengths 80′-0″ to 120′-0″
4. Midpoint of span for span lengths 40′-0″ to 80′-0″
5. No diaphragm requirement for span lengths less than 40′-0″

CONSTRUCTION OF SPLICED GIRDER BRIDGES

To improve the design and construction of post-tensioned spliced girders the following revisions shall be made:

The web stirrups concrete cover at the cast-in-place (CIP) closures of pier diaphragms shall not be less than 2 ½ in. If intermediate diaphragm locations coincide with CIP closures between precast segments, then the concrete cover at the CIP closures shall not be less than 2 ½ in. Increase in concrete cover thickness is not necessary if intermediate diaphragm locations are away from the CIP closures.

The effects of in-plane and out-of-plane forces of curved tendons as prescribed in LRFD article 5.10.4.3 shall be investigated during the design. When tendons curve in two planes, the effects of in-plane and out-of-plane forces shall be added. Adequate reinforcement shall be provided to confine tendons at CIP closures and at intermediate pier diaphragms. The reinforcement shall be proportioned to ensure that steel stress during jacking operation does not exceed $0.6f_y$.

The clear spacing between ducts at CIP closures of pier diaphragms shall be 2.0 in. min. The duct diameter for WSDOT Standard spliced girders shall not exceed 4.0 in. for spliced I-girders and $4^{1/2}$ in. for spliced Tub Girders.

On the construction sequence sheet indicate that the side forms at the CIP closures and intermediate pier diaphragms shall be removed to inspect for concrete consolidation prior to post-tensioning and grouting.

WSDOT BDM requires a minimum of 2 ½ in. concrete cover for cast-in-place post-tensioned superstructures. This requirement is now extended to CIP closures of spliced girders to ensure the proper flow and vibration of concrete through reinforcement and ducts. Removing the side forms at the CIP closures allows inspectors to ensure the soundness of concrete prior to post-tensioning and grouting.

The in-plane and out-of-plane force effects of curved tendons if not considered in design could result in concrete spalling and duct failure during post-tensioning. The minimum reinforcement requirement is to provide adequate resistance to in-plane and out-of-plane force effects of curved tendons during post-tensioning.

The cast-In-Place (CIP) closures for spliced-girders are recommended to be located away from the point of the maximum moment to minimize flexural stress across the joint. The quality of concrete for the cast-in-place joint closure is the primary concern in this case. WSDOT requires a minimum of 2 ft (610 mm) CIP closure opening between segments. The closure opening dimensions must be large enough to allow post-tensioning tendon duct splicing, but should be short enough to minimize the effect of lower strength and younger concrete used for the closure compared to the rest of the girder. Fig. 4 shows the cast-in-place closures for spliced girders.

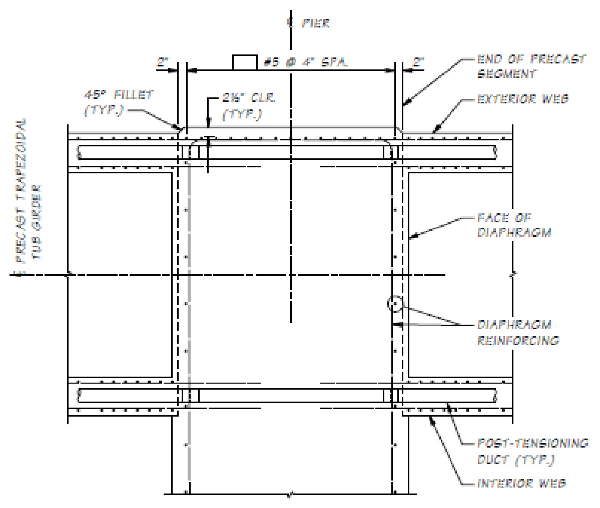

Fig. a.

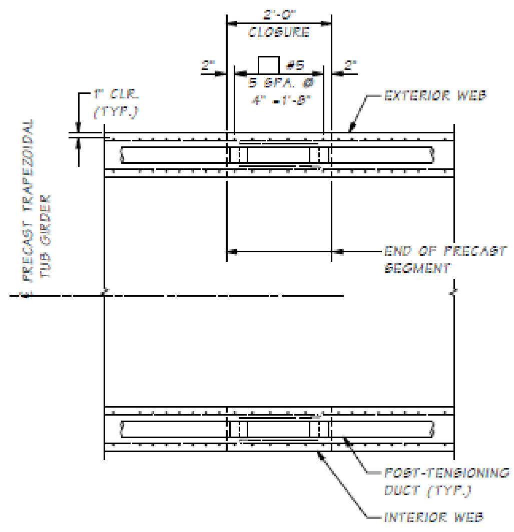

Fig. b.

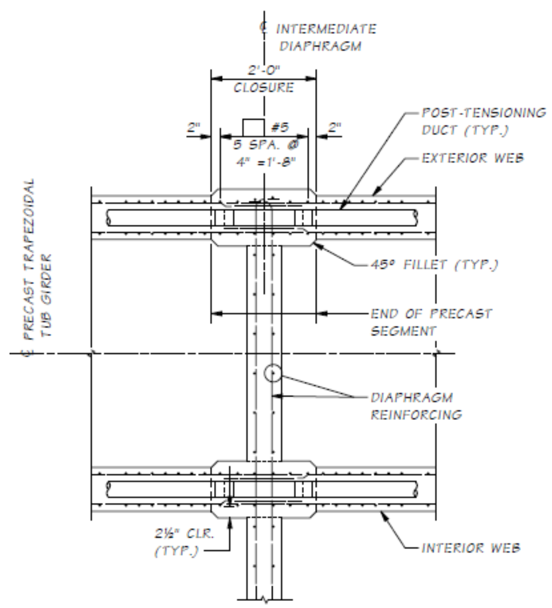

Fig. c.

a. CIP Closure at Pier Diaphragm
b. CIP Closure Away from Intermediate Diaphragm
c. CIP Closure at Intermediate Diaphragm

Fig. 4 Cast-In-Place Closures For Spliced Girders

CONCLUSIONS

Spliced girder technology yields in structurally efficient bridges with greater economy. Special attention must be given to location, detailing, and the quality of concrete for CIP closures. The WSDOT BDM method for spliced girder applications is simple and accurate for simple span spliced girders made of normal strength or high-strength concrete post-tensioned before or after slab casting. Successful completion of recent projects demonstrates that spliced-girder technology can be applied to girder lengths that are beyond the customary spans and transverse spacing of standard precast, prestressed concrete girders. Assembling the girders near the site and erecting them in one piece eliminates falsework problems. This particular method of bridge construction requires no precast pier segments or temporary, intermediate supports.

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