CHALLENGES OF LONG-SPAN PRESTRESSED GIRDER BRIDGES IN WASHINGTON STATE

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ABSTRACT

The rising need to upgrade the aging highway bridge system requires the development of innovative solutions that will lead to durable bridges with low life cycle costs. The use of high strength concrete (HSC) and 0.6-in. diameter strand in the fabrication of precast, pretensioned concrete bridge girders has resulted in an improved economy through the use of longer spans, increased girder spacing or fewer girder lines, and shallower superstructures. The design, however, presents the engineer with several challenges regarding fabrication, handling, shipping, and erection of long, slender girders. Long-span precast girders are often used in environmentally sensitive terrains, water crossings, and in locations with traffic and geometrical restrictions. This paper provides an inside view of the challenges associated with long-span prestressed girder bridges in Washington State. It discusses the design, fabrication, shipping and handling associated with long-span precast pretensioned girders.

Keywords: Design, Prestressed Girder, Long-Span, Fabrication, Shipping

INTRODUCTION

The recent development of long span prestressed girders has allowed the Washington State Department of Transportation (WSDOT) and other bridge owners to solve the problem of lengthening spans using construction materials they prefer.

The use of high strength concrete (HSC) and 0.6-in. diameter strand in the fabrication of precast, pretensioned concrete bridge girders has resulted in an improved economy through the use of longer spans, increased girder spacing or fewer girder lines, and shallower superstructures. The design, however, presents the engineer with several challenges regarding fabrication, handling, shipping, and erection of long, slender girders. Precast pretensioned girders are beneficial for long span bridges due to their ease of construction, lower life-cycle cost and durability.

The AASHTO LRFD Bridge Design Specifications[1] (AASHTO LRFD) provide bridge engineers with the minimum design requirements for safe highway bridge structures. However, many bridge owners have adopted more stringent policies for the design of precast-prestressed girder bridges. These policies consist of some combination of design using gross or transformed section properties, reduced allowable tension stress under service loads, and the full envelope of simple span positive moments and continuous span negative moments for spans made continuous for superimposed dead and live loads.

PRECAST PRETENSIONED GIRDERS

The majority of bridges in Washington are prestressed girder bridges. The current WSDOT standard precast pretensioned wide flange girders span up to 240 ft, and standard precast pretensioned trapezoidal tub girders span up to 180 ft. The span capabilities take into account the girder cross section dimensions, shipping stability, and hauling weight limitations. Fig. 1 shows a typical precast prestressed girder bridge project in Washington.

Fig. 1: A Long Span Precast Girder Bridge Project in Washington State

HSC is used as a standard material for the fabrication and construction of long span prestressed concrete girder bridges in Washington. Concrete strengths of 7.5 ksi at prestress transfer and 10.0 ksi at final are the current upper limits. Higher concrete release strengths up to 8.5 ksi are possible if curing is extended to an every-other-day cycle.

The cross sections of WSDOT standard wide flange girders used in composite superstructures are shown in Fig. 2. The complete description of WSDOT standard pretensioned girders is presented in WSDOT Bridge Design Manual[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.

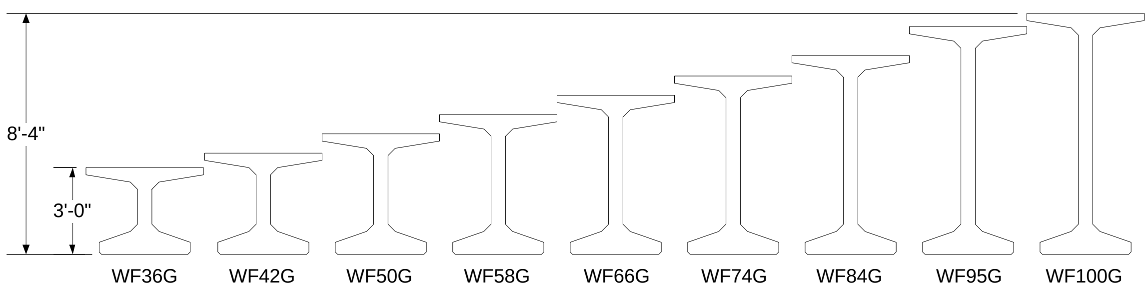

Fig. 2: WSDOT standard wide flange girders used in composite superstructures[2]

Span capability of WSDOT wide flange precast pretensioned girders for various girder spacings is shown in Table 1. The design criteria used for developing table 2 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 deck slab 4.0 ksi
- 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
- Haunch built up is assumed to be 2.5 inches thick

Table 1: Span Capability of Wide Flange Girders for Different Girder Spacing[2]

Girder Type	Girder Spacing (ft)	Span Length (ft)	Shipping Weight (kips)	Span-to-depth Ratio-Girder	Span-to-depth Ratio-Composite

WF36G	6	105	79	35.0	27.1
	8	95	76	31.7	24.5
	10	85	68	28.3	21.9
	12	80	64	26.7	20.6
WF42G	6	120	96	34.3	27.4
	8	105	88	30.0	24.0
	10	95	80	27.1	21.7
	12	90	75	25.7	20.6
WF50G	6	135	119	32.4	26.8
	8	120	107	28.8	23.8
	10	110	98	26.4	21.8
	12	105	94	25.2	20.8
WF58G	6	150	141	31.0	26.3
	8	140	132	29.0	24.5
	10	130	122	26.9	22.8
	12	120	113	24.8	21.0
WF66G	6	165	159	30.0	25.9
	8	150	149	27.3	23.5
	10	140	139	25.5	22.0
	12	130	130	23.6	20.4
WF74G	6	175	178	28.4	24.9
	8	160	168	25.9	22.7
	10	150	157	24.3	21.3
	12	140	147	22.7	19.9
WF83G	6	190	204	27.5	24.4
	8	175	188	25.3	22.5
	10	160	177	23.1	20.5
	12	150	166	21.7	19.3
WF95G	6	215	220	27.2	24.5
	8	195	208	24.6	22.2
	10	190	196	24.0	21.6
	12	165	185	20.8	18.8
WF100G	6	240	240	28.8	26.1
	8	225	227	27.0	24.4
	10	215	215	25.8	23.3
	12	195	203	23.4	21.2

LONG SPAN PRETENSIONED GIRDER PROJECTS

Table 2 lists several recently completed or in-progress projects in North America using the generation of long span prestressed girders featured in the December 2011 issue of Concrete Products Magazine[9]. Note that 12 out of 17 longest bridges with one piece precast pretensioned girders are in Washington State.

Table 2: List of recently completed or in-progress projects in North America[9]

NO	Bridge	Location	Length	Year
1	37th Street	Calgary Canada	213 ft.	2002
2	S.R. 99/AWV	Seattle, Washington	205 ft.	2011
3	Highway 864 Taber	Alberta, Canada	203.5 ft.	2001
4	I-15 & Beck St.	Salt Lake City, Utah	195 ft.	2010
5	SR532 Mark Clark Bridge	Washington	186 ft	2009
6	Padden Parkway Bridge	Vancouver, Washington	185 ft	2002
7	I-405/NE 8th to SR 520	Washington	184 ft	2010
8	NE 12th over I-405	Attalia, Washington	181 ft.	2006
9	Tieton River Bridge	Yakima, Washington	180 ft	2009
10	SR9/Harvey Creek	Snohomish Washington	178 ft	2008
11	SR24 / Yakima River	Yakima, Washington	178 ft	2006
12	Methow River Bridge	Okanogan, Washington	177 ft	2001
13	I-5/SR 502 Interchange	Washington	176 ft	2007
14	Vancouver Rail Project	Vancouver, Washington	176 ft	2009
15	Highway 61 Mississippi River	Minnesota	175 ft	2011
16	Interstate 275 Pinellas County	Florida	175 ft	2011
17	SR 240, Yakima River Bridge	Yakima, Washington	175 ft	2005

WSDOT DESIGN CRITERIA FOR PRESTRESSED GIRDER

Precast prestressed girder bridges are designed as simple spans for all transient and permanent loads for both simple and continuous spans. Continuity reinforcement shall be provided at intermediate piers for transient and superimposed dead loads applied after completion of the bridge deck.

AASHTO LRFD 5.14.1.4 “Bridges Composed of Simple Span Precast Girders Made Continuous” allows for some degree of continuity for loads applied on the bridge after the continuity diaphragms have been cast and cured. This assumption is based on the age of the girder when continuity is established, and the degree of continuity at various limit states. Both degree of continuity and time of continuity diaphragm casting may result in contractual and design issues. Designing these types of bridges for the envelope of simple span and continuous spans for applicable permanent and transient loads is a conservative approach to addressing these issues.

Girder types and spacing shall be identical in adjacent spans. Girder types and spacing may be changed at expansion joints at intermediate piers. For continuous structures, the same type and number of prestressed girders shall be used.

For multi-span prestressed girder bridges, the sequence and timing of the superstructure construction has a significant impact on the performance and durability of the bridge. Particular attention should be paid to the timing of casting of the lower portion of the pier diaphragms/crossbeams (30 days minimum after girder fabrication) and the upper portion of the diaphragms/crossbeams (10 days minimum after placement of the deck slab). The requirements apply to multi-span prestressed girder bridges with monolithic and hinge diaphragms/crossbeams.

BENEFITS OF WSDOT PRESTRESSED GIRDER DESIGN POLICIES

The Washington State Department of Transportation (WSDOT) has a long history of satisfactory performance of prestressed girder bridges. Bridges constructed in the 1950's are still in service with no sign of design deficiency or deterioration of girders. The satisfactory performance and longevity is due in part to conservative and sound design policies used since the early days of prestressed girder bridges in Washington State.

The current AASHTO LRFD recommends a minimum service life of 75 years for bridge structures. Conservative bridge design policies leave a margin of safety for prestressed girder bridges for unforeseen demands over the life of the structure. Supporting reasons for the conservative design policies for prestressed girder bridges include:

1. Historical increase in bridge live load: AASHTO design live loads have been increasing over the past few decades from HS-15 to HS-20 to HS-25, and to HL-93 in 1994.
2. Increasing use of overload trucks: The majority of bridges in Washington State are precast-prestressed girder structures. Virtually every permitted overload vehicle crosses a precast-prestressed girder bridge. Overloads often exceed the AASHTO specified design live loads. The reserve capacity due to conservative design practices allows prestressed girder bridges to withstand the overload trucks. Commerce would be adversely affected if these overloads could not be safely and conveniently moved. It should be noted that trucks carrying long-span prestressed girders are among the heaviest loadings ever permitted in Washington State.
3. Increase in number of traveling lanes: Due to increasing traffic volumes, lane widths on some routes have been often reduced from 12 feet to 10 feet to accommodate more traffic lanes. The reserve design capacity allows prestressed girder bridges to accommodate increased traffic demand and conform to the minimum requirements specified by AASHTO without strengthening or other modifications.
4. Periodic change in Bridge Design specifications: AASHTO design specifications have been changed from allowable stress design (ASD) to load factor design (LFD) and to load and resistance factor design (LRFD). More stringent design requirements have been observed with each change in design specifications.
5. Reserve capacity for girders damaged by over height collisions: The over height load collisions on prestressed girder bridges often results in broken strands that need to be repaired. Prior to repairs being made, the reserve capacity of the undamaged girders helps to keep the bridge in service. The current practice for splicing and re-tensioning broken strands limit the stress level to values lower than the original design. The reserve capacity due to conservative design practices allows repaired prestressed girders to satisfy design requirements.

6. Uncracked concrete under service conditions: The zero tension policy ensures that prestressed girders remain uncracked under service load conditions and overloads, resulting in longer service life.
7. Increased shear capacity: The conservative policies results in designs that require additional prestressing strands. This increase in prestressing results in higher shear capacity due to the vertical component of the prestress force and reduced angle of the diagonal compression strut.
8. Reduced life cycle cost: The conservative design policies require more prestressing strands and possibly an additional line of girders, but results in longer service life and lesser life cycle cost.

The WSDOT conservative design policies are an inexpensive insurance policy against future events including increasing legal loads, changing specifications, and unforeseen physical distress to the structure. The premium for this insurance policy is a one-time expense for as little as a half a dozen strands to one additional line of girders. This is typically a negligible percentage of overall project costs.

DESIGN TOOLS

WSDOT Bridge and Structures Office has created computer aided design software and has made it available through a mechanism labeled "open source." The PGSuper program is for design of simple span pretensioned girder superstructures. The program features the use of LRFD Bridge Design Specifications and WSDOT BDM. It designs and analyzes precast, prestressed concrete girders for flexure and shear; provides camber and deflection analysis as well as girder stability analysis for lifting and shipping; provides detailed reports to support every calculation; has a fully customizable library for any I-shape beams; and allows customization of design criteria. Free download of this software is available at http://www.wsdot.wa.gov/eesc/bridge/software/.

INTERMEDIATE DIAPHRAGMS FOR PRECAST GIRDER BRIDGES

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

4. 1/4 points of span for span lengths 120′-0″ to 160′-0″
5. 1/5 points of span for span lengths over 160′-0″

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.

DEFLECTION CALCULATION FOR PRESTRESSED GIRDERS

Flexural members are designed to have adequate stiffness to limit deflections or any deformations which may adversely affect the strength or serviceability of the structure at service load plus impact. The minimum superstructure depths are specified in AASHTO LRFD Table 2.5.2.6.3-1 and deflections shall be computed in accordance with AASHTO LRFD 5.7.3.6.2.

WSDOT requires two levels of girder camber at the time the deck concrete is placed, denoted as D_{40} and D_{120}. The "D" dimension is the computed girder deflection at midspan (positive upward) immediately prior to deck slab placement. The concept is to provide the contractor with lower and upper bounds of camber that can be anticipated in the field. They shall be shown in the Contract Plans to accommodate early girder placement and slab casting for ABC projects.

The upper bound of camber D_{120} is estimated as the upper bound of expected camber range at a girder age of 120 days after the release of prestress, and is primarily intended to mitigate interference between the top of the cambered girder and the placement of concrete deck reinforcement at midspan.

The lower bound of camber D_{40} is estimated as the lower bound of expected camber range at a girder age of 40 days (30 days after the earliest allowable girder shipping age of 10 days). To match the profile grade, girders with too little camber require an increased volume of haunch concrete along the girder length. For girders with large flange widths, such as the wide flange series, this can add up to significant quantities of additional concrete for a large deck placement. Thus, the lower bound of camber allows the contractor to assess the risk of increased concrete quantities and mitigates claims for additional material.

FABRICATION OF LONG SPAN PRECAST GIRDERS

The method selected for strand tensioning may affect the design of the girders. The strand arrangements shown in the plans are satisfactory for tensioning methods used by the fabricators. Harped strands are normally tensioned by pulling them as straight strands to a partial tension. The strands are then deflected vertically as necessary to give the required harping angle and strand stress. In order to avoid over-tensioning of the harped strands by this procedure, the slope of the strands is limited to a maximum of 8:1 for 0.6″ φ strands for long span prestressed girders. The straight strands are tensioned by straight jacking.

For long span precast pretensioned concrete girders, the total number of permanent prestressing strands (straight and harped) is limited to 100 - 0.6″φ strands. Harping points are set at 0.4 times the girder length from either end. The forces on the hold-down units are developed as the harped strands are raised. Forces on the hold-down units are developed as the harped strands are raised. The hold-down device provided by the fabricator must be able to hold the vertical component of the harping forces. WSDOT does not allow debonding for wide flange pretensioned girders.

Precast girders shall also be checked during lifting, transportation, and erection stages by the designer to assure that girder delivery is feasible. Impact during the lifting stage shall be 0% and during transportation shall be 20% of the dead load of the girder. Impact shall be applied either upward or downward to produce maximum stresses.

Temporary top strands are used to improve the girder stability during handling and shipping. Temporary top strands are pre-tensioned or post-tensioned shortly after the forms are stripped from the girder. Pretensioned temporary strands are bonded along the end 10 ft (3.05 m) of the girder and unbonded elsewhere. Block-outs are provided at the middle of the girder to allow access to the strands. Temporary strands are released after final placement just prior to placing the diaphragm concrete by cutting or burning the strands. Failure to release the prestress force may have an adverse effect on the structural behavior of the girder. WSDOT requires that all temporary strands be flagged when girders are shipped to the job site and the bridge plans provide instructions for releasing the temporary strands.

Welded wire reinforcement can be used to replace mild steel reinforcement in precast prestressed girders. The design yield strength up to 75 ksi is used. Welded wire reinforcement shall be deformed and shall have the same area and spacing as the mild steel reinforcement that it replaces. Shear stirrup longitudinal wires (tack welds) shall be excluded from the web of the girder and are limited to the flange areas as described in AASHTO LRFD 5.8.2.8. Longitudinal wires for anchorage of welded wire reinforcement shall have an area of 40% or more of the area of the wire being anchored.

The splitting resistance of pretensioned anchorage zones shall be as described in AASHTO LRFD 5.10.10.1. For long span pretensioned wide flange girders, the end vertical reinforcement shall not be larger than #5 bars and spacing shall not be less than 2¼″. The remaining splitting reinforcement not fitting within the h/4 zone may be placed beyond the h/4 zone at a spacing of 2¼″.

STABILITY OF LONG SPAN PRECAST GIRDERS

The ability to ship deep girder sections can be influenced by a large number of variables, including mode of transportation, weight, length, height, and lateral stability. Some variables have more influence than others. As such, the feasibility of shipping deep girders is strongly site dependent. It is recommended that routes to the site be investigated during the preliminary design phase.

The WSDOT prestressed girder sections are relatively wide and stiff about their weak axes and, as a result, exhibit good stability even at their longer pretensioned lengths. The simplest method of improving stability is to move the lifting devices away from the ends. This invariably increases the required concrete release strength, because decreasing the distance between lifting devices increases the concrete stresses at the harp point. Stresses at the support may also govern, depending on the exit location of the harped strands. Temporary prestressing in the top flange can also be used to provide a larger factor of safety against cracking.

Long prestressed girders can become laterally unstable when handled and shipped. Lift points never perfectly coincide with the center of gravity of the girder. As such, the girders tend to roll about the lift axis and deflect laterally until equilibrium is achieved. Camber amplifies this condition. During shipping, the girders are subjected to lateral deflections due to super-elevation along the route. Girders with large top flanges have a tendency to adversely affect the stability of the truck. Shipping support locations on the truck shall be carefully studied to improve the girder stability. Shipping support locations shall be no closer than the girder depth to the ends of the girder at the girder centerline.

A variety of methods are used to erect precast concrete girders, depending on the weight, length, available crane capacity, and site access. Lifting long girders during erection is not as critical as when they are stripped from the forms, particularly when the same lifting devices are used for both. If a separate set of erection devices are used, however, the girder shall be checked for stresses and lateral stability. In addition, once the girder is set in place, the free span between supports is usually increased. Wind can also pose a problem. Consequently, when long girders are erected, they shall immediately be braced at the ends. Generally, the temporary support of the girders is the contractor's responsibility.

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.

CONCLUSIONS

The new WSDOT girders enable engineers to design bridges with longer span lengths, fewer girder lines, and shallower girder sections. Longer spans permit the use of fewer supports, which reduces environmental impacts at water crossings and improves traffic safety, especially at locations with high traffic congestion. Fewer girders resulting from increased girder spacing reduce fabrication, transportation, and erection costs. Shallower girders create economies in the construction of approach embankments, abutments and improve vertical clearance.

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