Long-Span Prestressed Girder Bridges Made High Performance for Extended Service Life

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ABSTRACT

The current use of high performance concrete (HPC) in the fabrication of prestressed concrete girders has resulted in economical bridge designs with longer spans Bridges. HPC improves durability, resistance to cracking, and decreases permeability and the effects of volume change due to shrinkage and creep. The use of HPC in the design of precast girder bridges has presented several new challenges, including difficulties in fabrication, shipping, and erection of long slender girders. This paper presents the effect of HPC on Washington State Department of Transportation (WSDOT) standard prestressed concrete girders. The results clearly indicate that the use of HPC, along with larger diameter strands, increase the span capability of prestressed concrete girders and, in some cases, can result in fewer girder lines or smaller, less expensive girders. A comprehensive review of WSDOT long-span prestressed girders, spliced-girders, and concrete deck slab is presented in this paper.

Keywords: Prestressed Girder, Long-Span, Spliced-Girders, HPC, LRFD, Shipping, Span Capability, Service Life

INTRODUCTION

The demand for durable concrete has always been the focus of the bridge engineering community. HPC mixes afford designers greater latitude in the use of prestressed concrete for longer spans. In addition to keeping piers out of waterways and crossing wider highways, HPC can also provide construction economy by reducing the size of superstructure elements or the number of required girder lines. Use of HPC for bridge deck slabs along with extended curing has successfully resulted in durable deck slabs for WSDOT bridges.

The recent development of long span prestressed girders has allowed WSDOT and other bridge owners to solve the problem of lengthening spans using construction material they prefer. Long span prestressed girders made with HPC eliminate the need for falsework, reduce on-site construction activities, reduce environmental impacts at water crossings, and minimize hazards, delays, and inconvenience to the traveling public. Use of HPC for spliced-girders provides structurally efficient bridges and greater economy, while improving durability, resistance to cracking, and the effects of volume changes due to shrinkage and creep.

HIGH PERFORMANCE CONCRETE

The primary environmental deterioration menacing the concrete structures is freeze-thaw damage, chloride attack, corrosion of reinforcing steel, alkali silica reactivity of aggregates, and sulfates attack. Concrete deterioration begins with the penetration of water or other harmful solutions into the concrete. HPC with low permeability has proven to resist the penetration of the aggressive compounds into the concrete and provide the necessary durability when exposed to the environment.

HPC is much less permeable than conventional concrete. It greatly reduces the ingress of chlorides and other contaminants that can cause accelerated corrosion of the reinforcing steel. HPC provides improved mechanical properties resulting in more resistance to traffic wear, less prone to cracking during construction and under service loads, and more manageable regarding long-term deformations such as creep and shrinkage.

HPC has recently become a standard material for the fabrication of prestressed girders, and cast-in-place (CIP) bridge deck slabs in Washington State. Although higher design strengths are also feasible, they are not normally necessary. While the high strength properties of HPC are the primary reason for its use in prestressed concrete girders, its improved durability is the reason for its use in the cast-in-place deck slab.

WSDOT conducted the HPC Showcase Project in cooperation with the University of Washington in 1996 through 1998. The HPC Showcase Bridge was a three-span continuous structure made of W74G standard prestressed girders composite with CIP deck slab. HPC was used in all prestressed girders and in the concrete deck slab. The bridge was designed for earthquake zone "C" with a seismic acceleration coefficient of 0.25 g. The design used the AASHTO Load and Resistance Factor Design (LRFD) bridge specifications[1], except as modified and supplemented by WSDOT Bridge Design Manual (BDM)[2]. The HPC Special Provisions for the contract were originally written so that the girder compressive strength requirements were 7.5 ksi (54 MPa) at release of prestress and 10.0 ksi (69 MPa) at 56 days. The prestress losses and camber calculations were based on the WSDOT modified rate of creep method (MRC) for prestress losses and girder deflection[3].

Five of the girders in the bridge were instrumented; three of the girders in the long span and two in the short span. The instrumentation allowed evaluation of internal concrete temperature during curing, end slip of the strands at detensioning, concrete strains, prestress losses, camber, and deflection. The durability and strength requirements varied according to the demands of the particular member. The contract originally specified the chloride permeability requirements for the deck slab and girders of less than 1000 coulombs at 56 days. The contract also specified the AASHTO T277 Rapid Chloride Permeability Test as the acceptance test procedure. However, the requirements for chloride permeability for deck slab and the freeze-thaw durability for the girders were changed to an information-only item. The following concrete properties were measured for the project: Chloride Permeability, Compressive Strength, Coefficient of Thermal Expansion, Creep, Shrinkage, Freeze-Thaw Durability, Modulus of Elasticity and Abrasion Resistance. The final report of WSDOT Showcase Bridge prepared by the University of Washington could be found in reference 4. The concrete mix designs for prestressed girders and deck slab are shown in Tables 1 and 2 respectively. The test results of HPC used for prestressed girders and deck slab are shown in Tables 3 and 4.

Table 1. Concrete Mix Constituents Used For HPC Prestressed Girders

Girder Mix Constituents	Quantities
Cement, type III, pcy	728
Fly Ash, Class C, pcy	222
Micro Silica, pcy	50
Fine Aggregate, pcy	890
Coarse Aggregate, pcy	1870
Water, pcy	265
Water Reducer, fl oz	29
High-Range Water Reducer, fl oz	215
Water Cementitious Ratio w/cm	0.26
Slump, in (mm)	6 +/- (152)
Ultimate Strength @ 56 days, ksi (MPa)	10.0 (70)

Pcy = 0.5933 kg/m^3

Table 2. WSDOT class 4000D (28D) Concrete Mix Design for Deck Slab

Girder Mix Constituents	Quantities
Cement, pcy	660
Fly Ash, pcy	75
Fine Aggregate, pcy	1100
Coarse Aggregate, pcy	1700
Water, pcy	290
Water Cementitious Material Ratio	0.39
Air Entrainment	6%
Water Reducer Type A	Required

Pcy = 0.5933 kg/m^3

Table 3. Test results of HPC Showcase Prestressed Girder

	Project Requirement	Test Result (Average)
Release Strength, ksi (MPa)	7.4 (51)	7.4 (51)
Final Strength (56 days), ksi (MPa)	10.0 (69)	10.8 (74)
Modulus of Elasticity, ksi (MPa)	Not Required	5.3 (37)
Tensile Strength, ksi (MPa)	Not Required	0.635 (4.3)
Maximum Creep Coefficient	Not Required	2.213
Maximum Shrinkage Strain	Not Required	-570 microstrains
Freeze-Thaw Durability, (300 Cycles)	Not Required	100%
Permeability, Coulombs	1000	1010
Water/Cementitious Ratio	0.26	0.26

Table 4. Test Results of Class 4000D Concrete from HPC Showcase Bridge

	Project Requirement	Test Result (Average)
Strength, psi (MPa)	4.0 (28)	5.3 (37)
Abrasion	4% to 8%	4.5%
Permeability, Coulombs	Optional	2645
Entrained-Air	6%	5.7%

The temperature was also measured at six locations along the midspan of the longer girders, measurements from casting through the release of prestress[4]. The concrete temperature varied considerably with time. It was coldest when the concrete was first cast but heated up during curing. The curing temperature in the concrete varied substantially over the height of the girder. It was lowest at the bottom flange and highest at the top flange. The peak temperature difference averaged nearly 45^{o}F (7^{o}C) between top and bottom. This variation is also a result of the steam heat rising to the top of the insulated tarp, which was draped over the forms. Differential cooling between flanges and web caused the web to crack, but the cracks closed during release of prestress.

The abrasion resistance tests have been conducted in accordance with ASTM C-944-95 on 6 inch diameter concrete test cylinders samples from the deck slab concrete[4]. The test results indicate a weight loss ranged from 0.11 to 0.13 oz. (3 to 4 gram) for the surfaces of the test cylinders, whereas the concrete test cylinders at midpoint cut surface had abrasion weight loss from 0.04 to 0.06 oz (1 to 2 gram). The test results of roadway deck concrete (Class 4000D) (28D) concrete indicate very good absorption resistance.

The rapid determination of chloride permeability of concrete, in accordance with AASHTO T277, was performed on the specimens cast with concrete from deck. The test results for the cylinders made from the concrete used to cast deck fall in moderate chloride ion permeability as defined by FHWA/HPC performance grades. In the permeability test, the concrete slab specimen is usually subjected to the infiltration of sodium chloride solution for 56 days.

Washington State has acquired several national awards since the adaptation of HPC in prestressed girder bridges as follows:

- HPC Showcase Bridge, three-span W74G pretensioned prestressed girder
- Padden Creek Bridge, three-span W83G pretensioned girder
- La Center Bridge, single span W83G pretensioned girder. This bridge was instrumented for the NCHRP project 18-07 (TRB Report 496)
- Twisp River Bridge, single span W95PTG post-tensioned spliced-girder
- River Side Bridge, five-span W83PTG post-tensioned spliced girder
- 38th Street Bridge, two-span post-tensioned trapezoidal tub girders
- Sunset Interchange over I-90, Three-span post-tensioned spliced tub girder

PRESTRESSED GIRDERS

In Washington State, the use of prestressed I-girders started in the 1950's. By the late-1950's, WSDOT had developed standard I-girder sections to facilitate economical design and construction. In 1990, revisions were made to the prestressed concrete girder standards incorporating the results of research done at Washington State University on girders without end blocks[5]. The revised standards used thicker webs in lieu of end blocks. In 1999, long span deep prestressed girders were added to the WSDOT inventory[6]. In 2001, a newly developed pretensioned trapezoidal tub girder, commonly called "bath-tubs", was adopted. In 2003, wide flange prestressed I-girders, and thin flange bulb-tee girders were added to the WSDOT inventory[7]. The cross sections of some of WSDOT standard girders, used in composite superstructures, are shown in Fig. 1 through 3. The complete description of WSDOT standard prestressed girders is presented in reference 2.

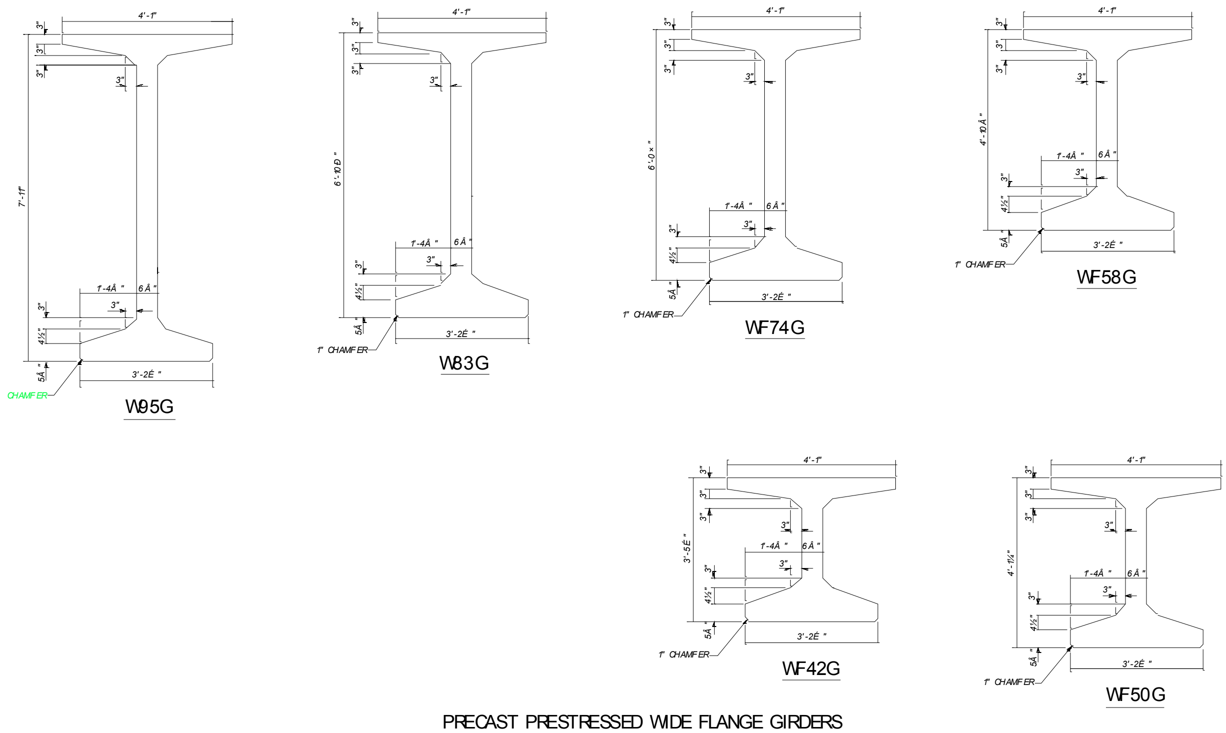

Fig. 1. WSDOT Wide Flange Prestressed Girders
ft = 0.3048 m, in = 25.4 mm

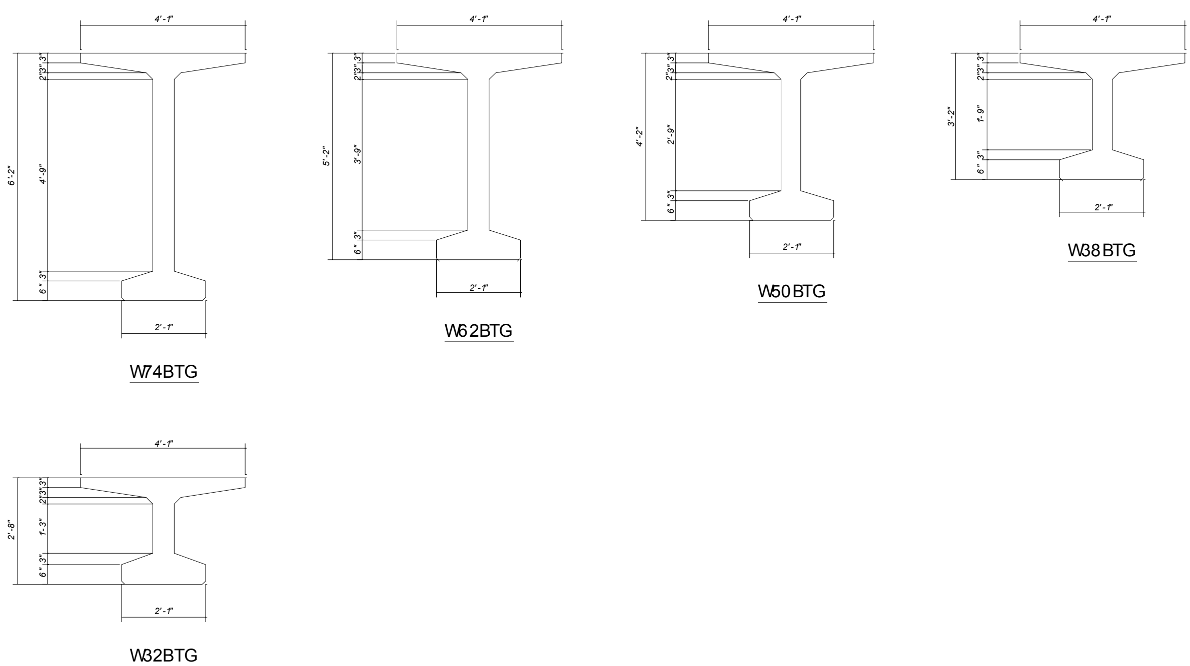

Fig. 2. WSDOT Thin Flange Bulb-Tee Prestressed Girders
ft = 0.3048 m, in = 25.4 mm

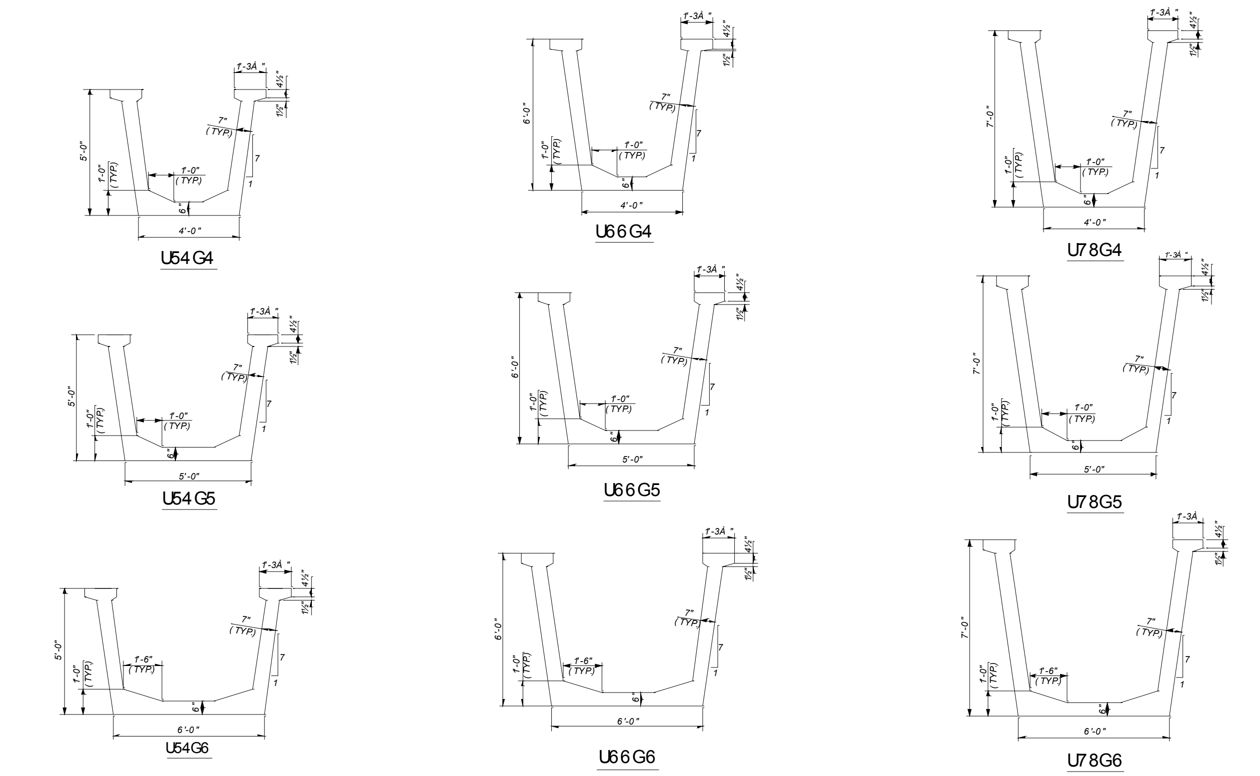

Fig. 3. WSDOT Trapezoidal Tub Girders with Subflange
ft = 0.3048 m, in = 25.4 mm

Today, over 80 percent of new highway bridges in Washington State are prestressed girder bridges. The current WSDOT standard pretensioned I-girders span up to 185 ft (56 m). The current WSDOT standard pretensioned trapezoidal tub girders span up to 140 ft (43 m) based on the cross section dimensions and shipping weight limitations.

HPC is used as a standard material for the fabrication and construction of long span prestressed concrete girder bridges in Washington State. Concrete strengths of 7.5 ksi (52 MPa) at prestress transfer and 9.0 ksi (62 MPa) at service are the current upper limits. Higher concrete release strengths up to 8.5 ksi (59 MPa) are possible if curing is extended to an every-other-day cycle. Although higher design strengths are also feasible, they are not normally necessary.

Stability of Long Span Precast Girders

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.

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. Pretensionned temporary strands are bonded along the end 10 ft (3.05 m) of the girder and unbonded elsewhere. Blockouts 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.

The introduction of temporary strands in the top flange of the prestressed girders also has beneficial effects on the girder design. The temporary top strands reduce the instantaneous deflection and long-term camber, which results in a reduction of the volume of concrete required for the cast-in-place deck haunches. This translates into less material, lower dead load moments, and lower required compressive concrete strength at transfer of prestress.

Structural Efficiency of WSDOT Wide Flange Prestressed Girders

The WSDOT prestressed I-girders are among the most efficient sections used in the industry[10]. Fig. 4 compares the structural efficiency of the WSDOT standard I-girders with girders from other states and organizations using Guyon's equation for structural efficiency. The Guyon equation is based on the cross sectional properties of the girder and expressed as:

$$\rho = \frac{r^2}{y_b y_t} \qquad (1)$$

Where □ is the efficiency factor, y_t and y_b are the centroid location measured from the top and bottom of the girder respectively, and r is the radius of gyration of the cross section, expressed as: $\sqrt{\frac{I}{A}}$.

An increase the in $\frac{I}{A}$ ratio will result in greater girder efficiency; which can be seen when comparing the W74G and WF74G girders as shown in Fig. 4.

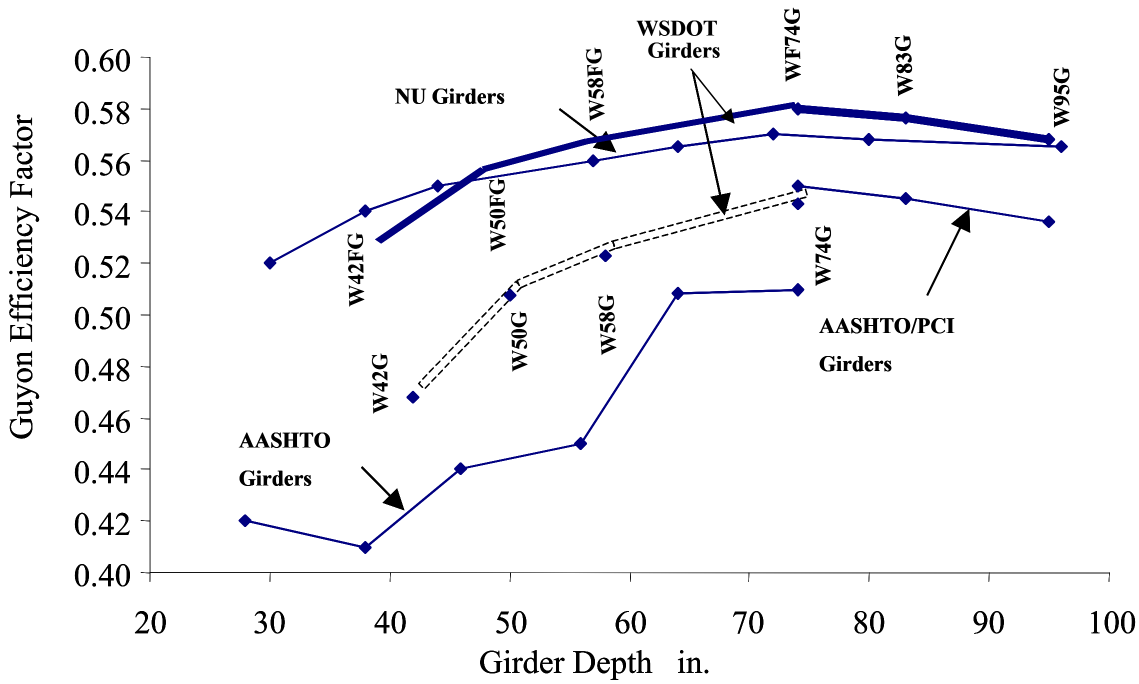

Fig. 4. Structural Efficiency of WSDOT Prestressed girders
ft = 0.3048 m, in = 25.4 mm

SPLICED GIRDERS

The post-tensioned precast spliced girder superstructure allows longer span lengths compared to that of conventional precast pretensioned girders. Post-tensioned spliced-girders have proven to be a cost-effective structural system for medium to long span bridges[8]. Use of HPC for spliced-girders yield in structurally efficient bridges and greater economy, while improving durability, resistance to cracking, and the effects of volume changes due to shrinkage and creep.

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. The current WSDOT standard post-tensioned spliced I-girders span up to 225 ft (68 m). The current WSDOT standard pretensioned trapezoidal tub girders span up to 190 ft (58 m) based on the cross section dimensions and shipping weight limitations. The cross sections of WSDOT spliced I-girders are shown in Fig. 5 with the complete description of WSDOT spliced-girders in reference 2.

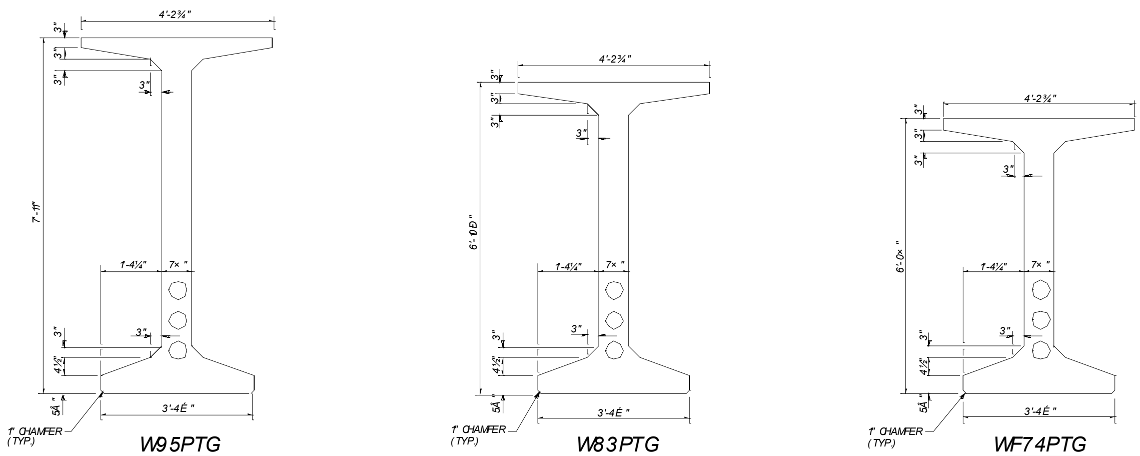

Fig. 5. WSDOT Post-Tensioned Spliced I-Girders
ft = 0.3048 m, in = 25.4 mm

CONCRETE DECK SLABS

The durability of concrete is one of the most important factors determining the service life of concrete deck slabs. Curing has a direct effect on the properties of hardened concrete such as durability and mechanical properties. Adequate and timely curing is a key factor in reducing cracking. High strength concrete should be avoided in bridge deck concrete. Increased strength, which is usually accompanied by increase in paste volume and higher hydration temperatures, causes more cracking in concrete deck slabs. The pour length, sequence, and rate of concrete placement may have some effects on deck cracking. It is recommended to specify appropriate construction sequence to avoid irregularities in the concrete deck slab construction.

Class 4000D (28D) concrete is typically used for CIP concrete decks in Washington State. Class 4000D (28D) concrete is a high performance air-entrained concrete specially designed for low permeability and high resistance to freeze-thaw in severe environmental exposures. This concrete mix along with the WSDOT extended wet curing for 14 days results in more durable concrete. After placement of concrete, two coats of liquid membrane-forming curing compounds are applied immediately after finishing or as soon as the visible bleed water has evaporated. The surface is then covered with presoaked heavy quilted blankets or burlap as soon as the concrete has set enough to allow covering without damaging the finish. Concrete temperature must be between 55^{o}F (12^{o}C) and 90^{o}F (32^{o}C) while it is being placed. The contractor is required to maintain the concrete temperature, during cure, below the 90^{o}F (32^{o}C) maximum.

The following recommendations based on the WSDOT concrete deck slab construction practice can be made as positive steps to improve the durability of bridge roadway decks and to reduce the potential of cracking:

- Reduce cement content to 660 lb/yd^3 (391 Kg/m^3). Consider using fly ash as substitution for cement up to 25% of cement content.
- Consider using lower strength concrete, usually 4 ksi (28 MPa), for bridge deck slab.
- Use Types I or II cement for bridge deck construction because of its reduced early thermal gradient and shrinkage.
- Limit the water cementitious ratio to 0.4. Make use of water reducers to reduce water content.
- Maximize the aggregate content and use the largest possible aggregate size.
- Use air-entrainment at a rate of 6% to improve the workability of fresh concrete and to increase the freeze-thaw resistance of hardened concrete.
- Specify extended wet curing with two coats of curing compounds and heavy quilted blankets or burlap for 14 days to achieve a superior concrete deck slab.

PRECAST DECKS

The CIP bridge deck is the preferred option for WSDOT bridge deck slabs; however, speed of construction in some cases requires the use of (Stay-In-Place) SIP deck panels for bridge deck construction. WSDOT requires a minimum thickness of 3.5 in (90 mm) for SIP deck panels and 5.5 in (140 mm) for CIP topping.

There have been some negative consequences in the form of deck cracking where SIP deck panels are used. Transverse cracking at the joint between adjacent panels and longitudinal cracks along the length of the girder at the edge of SIP deck panels have been observed. Longitudinal cracking is probably the most significant problem associated with the use of SIP deck panels because it can result in a reduction in deck stiffness over the girders that could compromise the deck's load-transfer mechanism. In many cases, bridge decks with SIP deck panels experienced significant longitudinal cracking along the panel edges over the girders. In most cases, these cracks can be attributed to insufficient bearing under the panels for live load. The causes of transverse cracking are shrinkage of the concrete, restraint provided by the panels, and the gap between adjacent panels[9]. These cracks do not affect the structural performance of the composite deck. To minimize the negative consequences of using SIP deck panels for WSDOT bridge decks, the following limitations are considered:

- Simple span precast prestressed I-shaped and trapezoidal Tub bridge girders.
- Positive moment region between the points of contraflecture of continuous spans.
- Continuous spans with longitudinal post-tensioning.
- In bridge widening and staged construction, the SIP deck panels are not allowed in the bay adjacent to the existing structure because of the requirement for CIP concrete closure. The SIP deck panels can be used on the other girders when the widening involves multiple girders.

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 and PGSplice programs are for design of simple span pretensioned girder, and post-tensioned spliced girder superstructures respectively. 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- or U-shaped beams; and allows customization of design criteria. Free download of this software is available at http://www.wsdot.wa.gov/eesc/bridge/software/.

DESIGN PARAMETERS

The span capability of WSDOT prestressed girders and post-tensioned spliced girders for composite superstructures are shown in Tables 5 through 8. The latest version of WSDOT PGSuper and PGSplice programs based on the AASHTO LRFD Specifications and modifications per WSDOT BDM are used in developing span capability charts. The design assumptions are:

- Design for straight interior girders without any vertical or horizontal curves.
- Design for service limit state and checked for strength limit state
- Lifting and hauling checks not necessarily satisfied
- Simple span girder design with span length of centerline to centerline bearings
- Relative humidity of 75% under normal exposure
- Strength of concrete for deck slab f'c = 4.0 ksi (28 MPa)
- Strength of concrete for girders f'_{ci} = 7.5 ksi (52 MPa) at transfer and design strength f'_c = 9.0 ksi (62 MPa)
- Strength of concrete for CIP closures at post-tensioning is limited to f'_c=5.0 ksi (34 MPa)
- CIP Closures located at ¼ points from the girder ends.
- 0.6" (15.24 mm) diameter prestressing strand grade 270 for pretensioning and post-tensioning strands.

Table 5. Span Capability of WSDOT wide flange prestressed girders

f'ci = 7.5 ksi, f'c = 8.5 ksi Strand diameter = 0.6" Grade 270 ksi low relaxation									
Girder Type	Girder Spacing (ft)	Span Length (ft)	Straight Strands	Harped Strands	Harped Strand Offset*	Top Temp. Strands	Excess Camber (in)	"A" Dim (in)	Deck Thickness (in)
WF42G	5	115	24	24	0	6	2.162	11.00	7.5
	6	110	26	24	2	6	2.227	11.00	7.5
	7	105	24	24	1	6	2.197	11.00	7.5
	8	100	24	24	2	6	2.076	11.00	7.5
	9	95	26	19	0	6	2.316	11.25	7.5
	10	90	22	22	0	6	2.073	11.00	7.5
	11	85	20	23	0	4	2.043	11.50	8.0
	12	80	20	20	0	0	2.120	12.00	8.5
WF50G	5	130	32	20	0	6	2.508	11.50	7.5
	6	125	32	22	3	6	2.336	11.25	7.5
	7	120	30	21	0	6	2.543	11.50	7.5
	8	115	28	23	1	6	2.352	11.25	7.5
	9	110	26	24	0	6	2.386	11.25	7.5
	10	105	26	23	0	6	2.337	11.25	7.5
	11	100	24	24	1	6	1.963	11.25	8.0
	12	95	22	24	0	6	1.787	11.75	8.5
WF58G	5	145	34	21	0	6	2.343	11.25	7.5
	6	135	30	22	0	6	2.225	11.00	7.5
	7	130	32	20	0	6	2.463	11.25	7.5
	8	125	30	22	0	6	2.404	11.25	7.5
	9	120	30	20	0	6	2.333	11.25	7.5
	10	115	28	22	0	6	2.281	11.25	7.5
	11	110	26	23	0	6	2.042	11.50	8.0
	12	105	26	22	0	6	1.925	11.75	8.5
WF74G	5	175	40	23	0	6	2.389	11.25	7.5
	6	170	40	24	0	6	2.666	11.50	7.5
	7	160	38	24	3	6	2.431	11.25	7.5
	8	155	38	24	2	6	2.675	11.50	7.5
	9	145	34	23	0	6	2.500	11.50	7.5
	10	140	34	22	0	6	2.497	11.25	7.5
	11	135	36	23	6	6	2.264	11.75	8.0
	12	130	34	23	2	6	2.312	12.25	8.5
W83G	7	165	42	17	0	6	2.637	11.50	7.5
	8	160	42	17	0	6	2.755	11.75	7.5
	9	155	40	19	0	6	2.709	11.50	7.5
	10	150	40	20	1	6	2.766	11.75	7.5
	11	145	38	22	0	6	2.674	12.00	8.0
	12	135	36	19	0	6	2.254	12.25	8.5
W95G	9	160	34	24	6	6	2.838	11.75	7.5
	10	155	34	24	5	6	2.953	11.75	7.5
	11	150	34	22	0	6	3.066	12.50	8.0
	12	150	38	24	5	6	3.163	13.00	8.5

* Offset at harping point

ksi = 6.894 MPa, ft = 0.3048 m, in = 25.4 mm

Table 6. Span Capability of WSDOT Thin Flange Bulb-Tee Girders

f'ci = 7.5 ksi, f'c = 8.5 ksi Strand diameter = 0.6" Grade 270 ksi low relaxation									
Girder Type	Girder Spacing (ft)	Span Length (ft)	Straight Strands	Harped Strands	Harped Strand Offset*	Top Temp. Strands	Excess Camber (in)	"A" Dim (in)	Deck Thickness (in)
W32BTG	5	75	20	5	0	6	2.895	11.75	7.5
	6	75	18	10	3	6	2.924	11.75	7.5
	7	70	18	8	0	6	2.839	11.75	7.5
	8	65	18	6	0	6	2.380	11.25	7.5
	9	65	18	8	2	6	2.427	11.25	7.5
	10	60	16	8	0	6	2.123	11.00	7.5
	11	60	18	7	0	6	2.218	11.25	7.75
	12	55	16	7	0	6	1.763	11.25	8.0
W38BTG	5	90	22	8	2	6	3.308	12.25	7.5
	6	85	22	7	0	6	3.245	12.00	7.5
	7	80	22	6	0	6	2.956	11.75	7.5
	8	75	20	7	2	6	2.537	11.50	7.5
	9	75	20	8	0	6	2.742	11.50	7.5
	10	70	18	9	1	6	2.372	11.25	7.5
	11	65	20	5	1	6	2.009	11.25	7.75
	12	65	20	6	0	6	2.087	11.50	8.0
W62BTG	5	130	26	12	0	6	3.415	12.25	7.5
	6	125	26	13	0	6	3.536	12.50	7.5
	7	120	26	12	0	6	3.364	12.25	7.5
	8	115	26	12	0	6	3.354	12.25	7.5
	9	110	26	11	0	6	3.161	12.00	7.5
	10	105	26	10	0	6	2.967	11.75	7.5
	11	100	26	9	0	6	2.742	11.75	7.75
	12	95	26	8	0	6	2.513	12.00	8.0

ksi = 6.894 MPa, ft = 0.3048 m, in = 25.4 mm

Table 7. Span Capability of WSDOT Trapezoidal Tub girders

f'ci = 7.5 ksi, f'c = 8.5 ksi Strand diameter = 0.6" Grade 270 ksi low relaxation									
Girder Type	Girder Spacing (ft)	Span Length (ft)	Straight Strands	Harped Strands	Harped Strand Offset*	Top Temp. Strands	Excess Camber (in)	"A" Dim. (in)	Deck Thickness (in)
U78G4	8	170#	32	42	8	0	0.000	9.00	7.5
	10	165#	32	46	8	0	0.000	9.00	7.5
	12	160#	32	48	8	0	0.150	9.00	7.5
	14	150#	32	44	4	0	0.354	9.00	7.5
	16	145#	32	46	4	0	0.730	9.25	7.5
U78G5	9	170#	46	34	8	0	0.000	9.00	7.5
	11	165#	46	36	4	0	0.000	9.00	7.5
	13	160#	46	38	4	0	0.037	9.00	7.5
	15	155#	46	40	4	0	0.439	9.00	7.5
	17	150#	46	40	4	0	0.655	9.25	7.5
U78G6	10	165#	52	32	8	0	0.000	9.00	7.5
	12	160#	52	34	8	0	0.000	9.00	7.5
	14	155#	52	34	4	0	0.000	9.00	7.5
	16	150#	52	34	4	0	0.000	9.00	7.5
	18	145#	52	34	4	0	0.000	9.00	7.5
UF84G4	10	190#	32	66	12	0	0.000	9.00	7.5
	12	185#	32	70	16	0	0.938	9.50	7.5
	14	180#	32	72	16	0	1.310	10.00	7.5
	16	170#	32	68	8	0	1.074	9.50	7.5
UF84G5	11	185#	46	52	8	0	0.000	9.00	7.5
	13	180#	46	54	8	0	0.269	9.00	7.5
	15	175#	46	56	8	0	0.657	9.25	7.5
	17	170#	46	58	8	0	1.038	9.50	7.5
UF84G6	16	170#	52	50	8	0	0.000	9.00	7.5
	18	165#	52	50	8	0	0.000	9.00	7.5

Note: Adding bottom flange width does not necessarily increase the span capabilities
* Offset at girder end

ksi = 6.894 MPa, ft = 0.3048 m, in = 25.4 mm

Table 8. Span Capability of WSDOT Post-Tensioned Spliced I-girders

Girder Type	Girder Spacing (ft)	Span Length (ft)	Cast-in-Place Closures f'ci = 6.0 ksi f'c = 9.0 ksi	Spliced Post Tensioned Girder									
				Strands per Duct (#4 @ bottom)				Total Jacking Force (kips)	Total Prestress Force after Seating (kips)	Total Prestress Loss (kips)	E1 (in)	E2 (in)	E3 (in)
			Length (ft)	1	2	3	4						
WF74PTG Post-tensioned Before Slab Casting	6	**170**	2		22	22	22	2970	2660	747	43.9	19.2	11.0
	8	**145**	2		22	22	22	2970	2631	776	43.9	19.2	11.0
	10	**135**	2		22	22	22	2850	2507	780	43.9	19.2	11.0
	12	**115**	2		22	22	22	2755	2387	805	43.9	19.2	11.0
	14	**100**	2		22	22	22	2590	2242	785	32.9	16.5	11.0
WF74PTG Post-tensioned After Slab Casting	6	**195**	2		22	22	22	2940	2674	703	48.9	20.5	11.0
	8	**185**	2		22	22	22	2965	2691	711	48.9	20.5	11.0
	10	**175**	2		22	22	22	2990	2709	718	48.9	20.5	11.0
	12	**165**	2		22	22	22	2990	2703	725	48.9	20.5	11.0
	14	**155**	2		22	22	22	3020	2722	735	48.9	20.5	11.0
W83PTG Post-tensioned Before Slab Casting	6	**175**	2		22	22	22	3000	2690	747	52.6	23.7	14.0
	8	**160**	2		22	22	22	2940	2617	760	52.6	21.4	11.0
	10	**150**	2		22	22	22	3000	2666	771	43.6	19.2	11.0
	12	**130**	2		22	22	22	2850	2479	809	52.6	21.2	10.7
	14	**110**	2		22	22	22	3020	2606	850	47.6	19.9	10.7
W83PTG Post-tensioned After Slab Casting	6	**200***	2	19	19	20	20	3400	3209	694	43.6	23.7	17.0
	8	**200**	2	22	22	22	22	3896	3667	812	43.6	23.7	17.0
	10	**190**	2	22	22	22	22	3880	3651	812	43.6	23.7	17.0
	12	**180**	2	22	22	22	22	3880	3652	812	43.6	23.7	17.0
	14	**170**	2	22	22	22	22	3880	3658	812	43.6	23.7	17.0
W95PTG Post-tensioned Before Slab Casting	6	**195**	2		22	22	22	3015	2710	742	57.0	22.3	10.7
	8	**180**	2		22	22	22	3030	2708	760	57.0	22.3	10.7
	10	**165**	2		22	22	22	3030	2690	778	57.0	22.3	10.7
	12	**150**	2		22	22	22	3030	2669	798	57.0	22.3	10.7
	14	**130**	2		22	22	22	3015	2622	830	57.0	22.3	10.7
W95PTG Post-tensioned After Slab Casting	6												
	8	**215**	2	21	22	22	22	3850	3635	771	54.0	26.3	17.0
	10	**205**	2	22	22	22	22	3979	3755	807	54.0	26.3	17.0
	12	**195**	2	22	22	22	22	3979	3748	814	54.0	26.3	17.0
	14	**185**	2	22	22	22	22	3979	3742	820	54.0	26.3	17.0

ksi = 6.894 MPa, ft = 0.3048 m, in = 25.4 mm

CONCLUDING REMARKS

1. The availability of HPC enables WSDOT 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 at locations with high traffic congestion. Fewer girders resulting from increased girder spacing reduce fabrication, transportation, and erection costs. Shallower girders, made possible by higher strength concrete, create economies in the construction of approach embankments and abutments as well as improving vertical clearance.
2. Use of HPC in post-tensioned spliced girders yield structurally efficient girders with greater economy. Special attention must be given to location, detailing, and the quality of concrete for CIP closures.
3. The WSDOT class 4000D (28D) concrete, along with extended curing, improves the durability of concrete and extends the service life of bridge decks.
4. Precast slabs may be advantageously used in rapid bridge deck construction, but limitations shall be imposed to minimize the negative effects of precast deck construction.

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