

## Precast I-Girder Bridge Widening by Using Different Girder Type and Span Length

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### ABSTRACT

*The existing bridge is a conventional precast I-girder bridge on a state highway. The bridge consists of multiple spans of 100 feet simply support I-girders. At the westbound, 6 end spans are widened to add a two-lane ramp for full HL-93 live load, reduced seismic load and dead load. Both the widening and the existing bridge will be removed in less than 5 years. Due to construction requirement and economic efficiency, the widening bridge will apply 3-continuous span frame to match every 100 feet simple span of the existing bridge. This causes three major structural changes for superstructure between widening and existing bridges. - First, change of span length -100 feet long span vs. 33'-4" feet long span; the second, change of support location-simple support vs. to 3-span continuous support ; and the third, change of girder type- 58" I-girder vs. 12" slab girder. These changes induce special issues for widening bridge design which include: determination of live load distribution factor for different girder types; girder displacement variance at the 1/3 span location for the existing bridge and zero displacement at the same location for widening bridge ; and rigid deck connection design for two different superstructure deck systems. Except for the superstructure, the substructure is also different for existing and widening bridges due to construction requirement and seismic criteria: 42" height concrete crossbeam vs. 22" height built-up steel crossbeam; 54" diameter prestressed concrete pipe pile vs. 24" driven steel pipe pile foundation.*

**Keywords:** Widening, Slab girder, Batter pipe pile, Seismic transfer, Live load distribution factor, Deck closure

## INTRODUCTION

Built in 1960s, the existing bridge on west approach was a 6,000-foot-long multi-span precast girder bridge connecting to the floating bridge crossing the lake on a Washington State Route. The existing bridge will be replaced by a new bridge at the adjacent parallel location and construction will start in 2014 fall. Prior to replacement bridge construction, the ramps will be demolished first to vacate for the construction and six west approach end spans of the existing bridge, lower bridge with traffic in picture below, Fig.1, will be widened to compensate for the traffic on the demolished ramps. During the replacement bridge construction, both the existing and widening bridges will maintain normal traffic operation until new bridge is completed. ..



Fig.1 Existing bridge to be widened, lower bridge

The existing superstructure consisted of 100 feet simply supported prestressed I-girders for 4-lane traffic. The substructure was made of concrete cap beam supported by precast prestressed concrete pile foundation. The lower part of the existing concrete cap beam is under the water level. 6 westbound approach spans are be widened to add a two-lane off-ramp bridge with a variable bridge deck width, framed part by red lines in Fig. 2. The widening off-ramp bridge is designed for full HL-93 live load; though for seismic design it is considered as a temporary structure of maximum 5 years life which induces a reduction factor of 2.5 according to AASHTO Guide Specifications for LRFD Seismic Bridge Design<sup>1</sup> (AASHTO LRFD Guide).

Except for the existing abutment, all other substructures are in the lake. The existing bridge deck elevation is 27.0 feet and above; the ordinary high water line is 18.72 feet. The mud ground lies about 6-9 feet under the lake water surface. Prior to temporary off-ramp widening construction, the over-cross ramps will be removed. It is required that the widening bridge is constructed in lake for both superstructure and substructure but without using cofferdam or working bridge or barge ship. The interruption or closure of traffic on the existing bridge is not expected since this bridge is on a major state route between two cities crossing the lake.

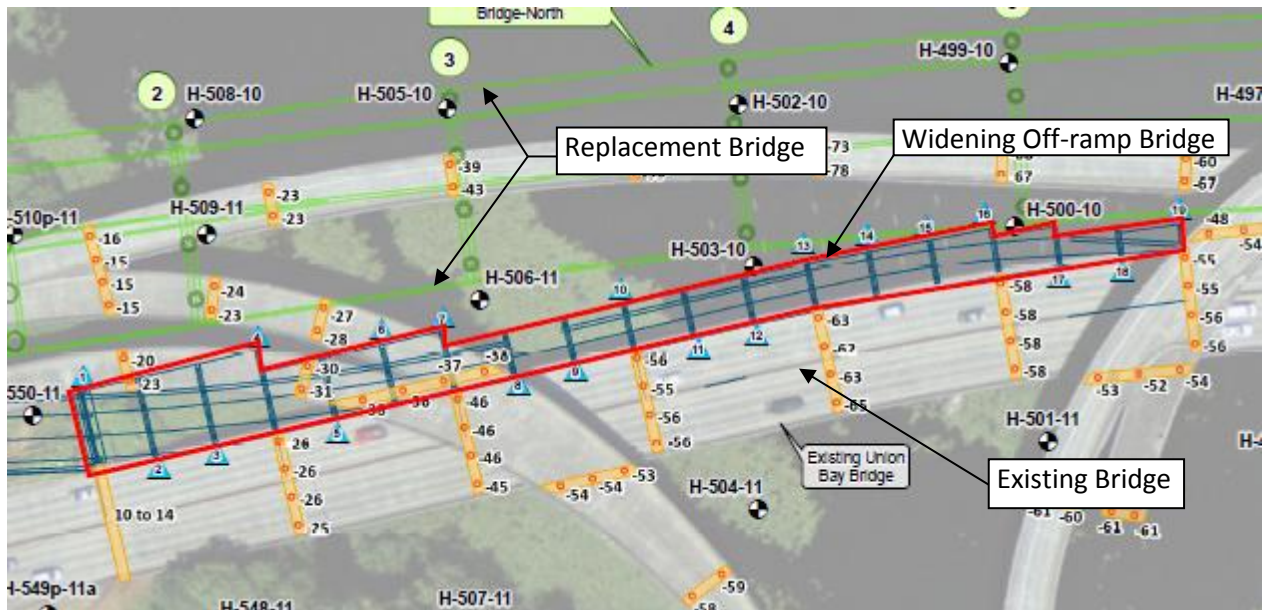


Fig. 2 Widening off-ramp layout

The new replacement bridge spans more than 6000 feet long in its westbound approach and the construction is expected to start in 2014 fall. The widening off-ramp bridge is required to be built prior to that time. Currently, both the replacement bridge and widening bridges are under final design phase so the accelerated construction for widening bridge is anticipated to meet a tight schedule. The elevated superstructure and crossbeam is required for either no underwater construction or no need of cofferdam in the lake. After widening bridge is completed, the entire deck surface shall be integrated smoothly so no deck joint is allowed between the widening off-ramp and existing bridge due to driving safety. The bridge locates at seismic zone 4 area, however, the existing bridge was designed prior to the adoption of the seismic specifications. In another word, the existing bridge was not designed to resist seismic forces. It is required that the seismic demand on the seismic demand on the existing bridge shall not to be increased after it is widened.

The above requirements are to be accommodated in designing the widening off-ramp bridge. For consideration of no underwater and accelerated construction, cast-in-place concrete foundation is excluded and driven steel pipe pile is used in this design. The shallow girder and crossbeam shall be used to reduce the structural height and make it possible the construction above water. Shallow girder leads to short span length. For each 100 feet span length of the existing bridge, 3-continuous spans with length of 33'-4" are made of a 100 feet frame, accordingly. The purpose using a shorter span length is to use as shallow girder as possible. Comparing to the 4'-10" existing precast

prestressed I-girder, the 1 foot prestressed slab girder is adopted to dramatically reduce the superstructure height for widening bridge. Comparing to the existing 3'-6" concrete crossbeam, the built-up steel crossbeam with total height of 1'-10" is used to further reduce height of structure components above water. The reduced structure height saves enough space which avoids welding work under water or building cofferdam. Comparing to the existing 4'-6" diameter prestressed concrete pipe pile, the widening bridge foundation uses 24"-Diameter driving steel pipe pile to satisfy the accelerated construction and above water construction. Pile layout configuration of both plumb and battered piles at each pier is proposed to adjust widening bridge stiffness to limit the seismic force transfer between the widening and existing bridges.

**SELECTION OF SPAN LENGTH AND GIRDER TYPE**

The existing bridge span was made of 100 feet long simply support I-girders. The superstructure height was 64" in total, including 58" girder and 6" deck. The existing girder bottom is about 2 feet above the water surface. The lower part, one-third of crossbeam height, was under water. Widening bridge crossbeam has to be built under water if the similar span length and girder type are applied. To avoid the in-water concrete placement for crossbeam, a shallow girder has to be selected to reduce the superstructure height.

12-inch precast prestressed slab girder is the shallowest girder in Washington state practice for bridge span. The maximum span capacity for this slab girder is 33 feet which is around one-third of the existing 100 feet span length. It dramatically reduces girder height to 12" comparing to the existing 58" girder. The individual girder weight with 4'-0" slab girder width is 22 kips which makes the construction lifting equipment as light as possible to reduce construction live load.

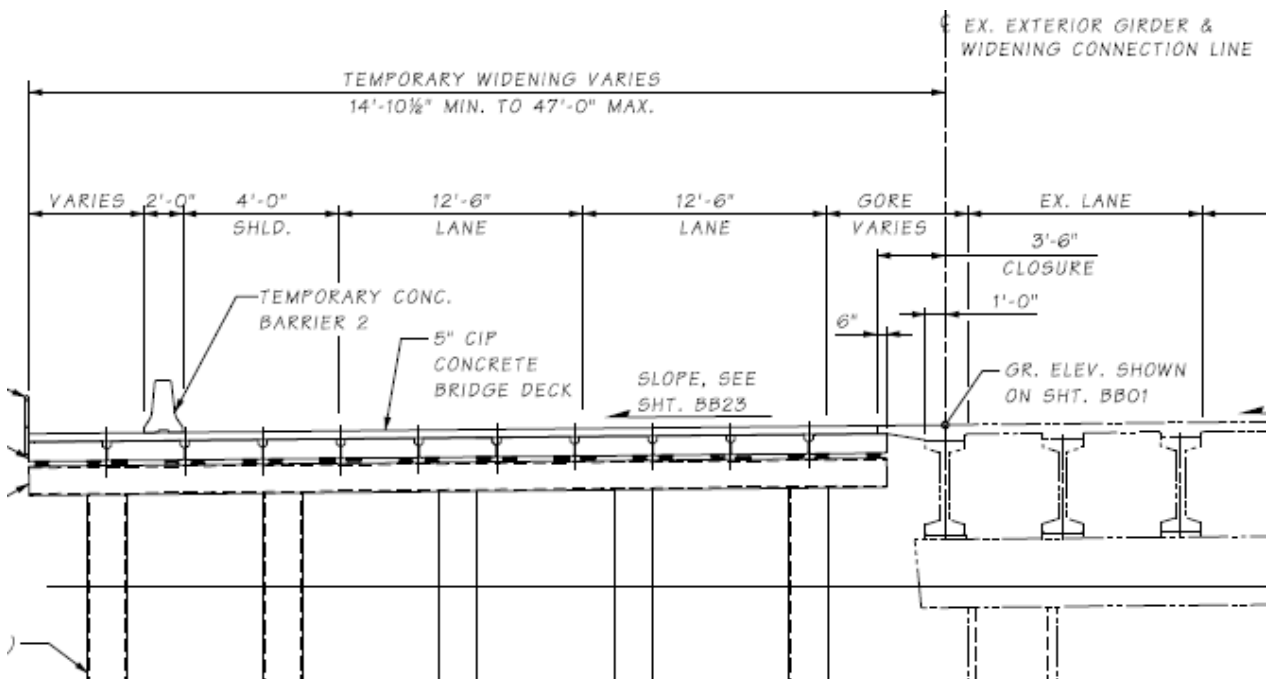


Fig. 3 Widened bridge section

With above considerations, for each 100 feet long simple support span of the existing bridge, one frame with three 33-4" continuous spans was arranged for the widening off-ramp bridge. WSDOT standard 12-inch precast prestressed slab girder is used and the 5" cast-in-place concrete bridge deck is applied. The total superstructure height is 17" for the widening bridge. Comparing to 64" superstructure height of the existing bridge, 47" space is saved to make it possible to build the crossbeam above-water and leave enough welding clearance for pile top-crossbeam connection, which is 3 feet minimum above water. The combined superstructure section is shown in the above figure, Fig. 3.

### LIVE LOAD DISTRIBUTION FACTOR (LLDF)

Two bridges with different span length, girder type and girder spacing are connected together through 2-foot wide bridge deck closure into integrated structure without joint. Determination of the live load distribution factor for either bridge is very critical for girder design. The live load distribution factor for regular bridge is specified in design code, AASHTO LRFD Bridge Design Specifications<sup>2</sup> (AASHTO LRFD Bridge). However, it is not applicable in this case for combined system of two different superstructures.

Two methods are applied to determine the live load distribution factor for combined section. The formula in AASHTO LRFD Bridge is used to preliminarily determine LLDF for each individual bridge. Its results were proven to be applicable for interior girders at a certain distance away from the connection; however it cannot be used to the girders close to the connection closure, especially to both bridge exterior girders. The bridge section gradually becomes 6 lanes from its original 4 lanes and the live load on one bridge will induce impact on another bridge. A more accurate method shall be utilized. In this design, the finite element method is used to verify and determine live load distribution factor for exterior girders. The 3D model for finite element analysis (FEA) is shown in the below figure, Fig.4. The cyan color part represents the widening bridge; the green part represents existing bridge; and pink lines represent bridge deck connection closure.

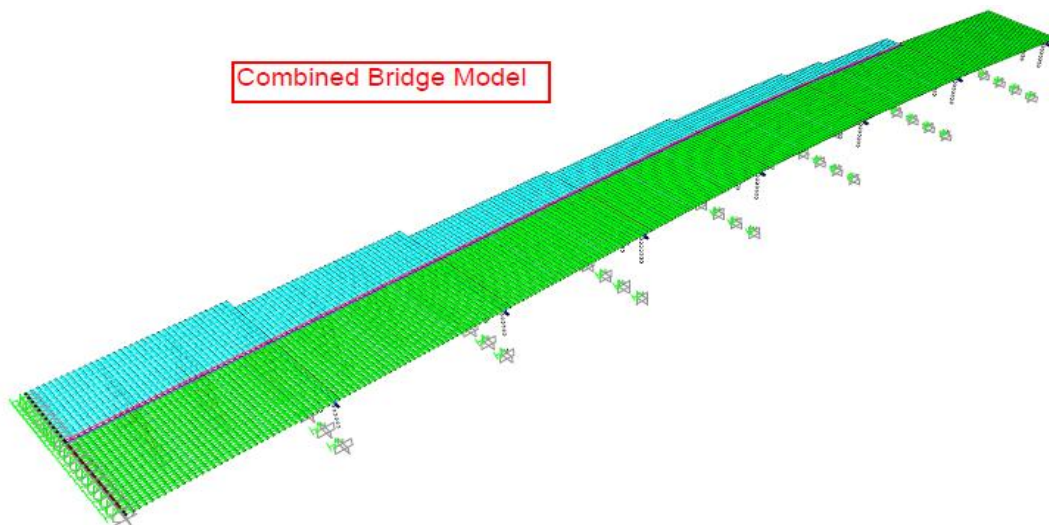


Fig. 4 FEA model for LLDF analysis



The widening bridge live load distribution factor results from both AASHTO LRFD Bridge formula and 3D finite element method are compared in the Table 1 below.

Table 1 LLDF for widening bridge

	Moment		Shear
	Interior Girder	Exterior	
AASHTO LRFD Bridge	0.340	0.401	0.708
3D FEA	0.363	0.462	0.897
Design	0.363	0.462	0.897

For moment distribution factor, interior girder results are close (<5%). However, for exterior girder, it shows that the factor from 3D finite element analysis is about 15% larger than that from AASHTO LRFD Bridge formula. For shear distribution factor, 3D FEA obtains result which is about 30% larger than that from AASHTO LRFD Bridge formula. Final design applied the 3D FEA results which are more realistic and safer.

**BRIDGE DECK CONNECTION**

The cantilever part of the existing bridge deck will be demolished and a 2-foot bridge deck closure is placed to connect both I-girder of existing bridge and slab girder of widening bridge, as shown in the Fig.5 below. A smooth integrated bridge deck surface is required for driving safety at the connection location that leads to the fixed deck connection -no hinge or joint at connection is allowed.

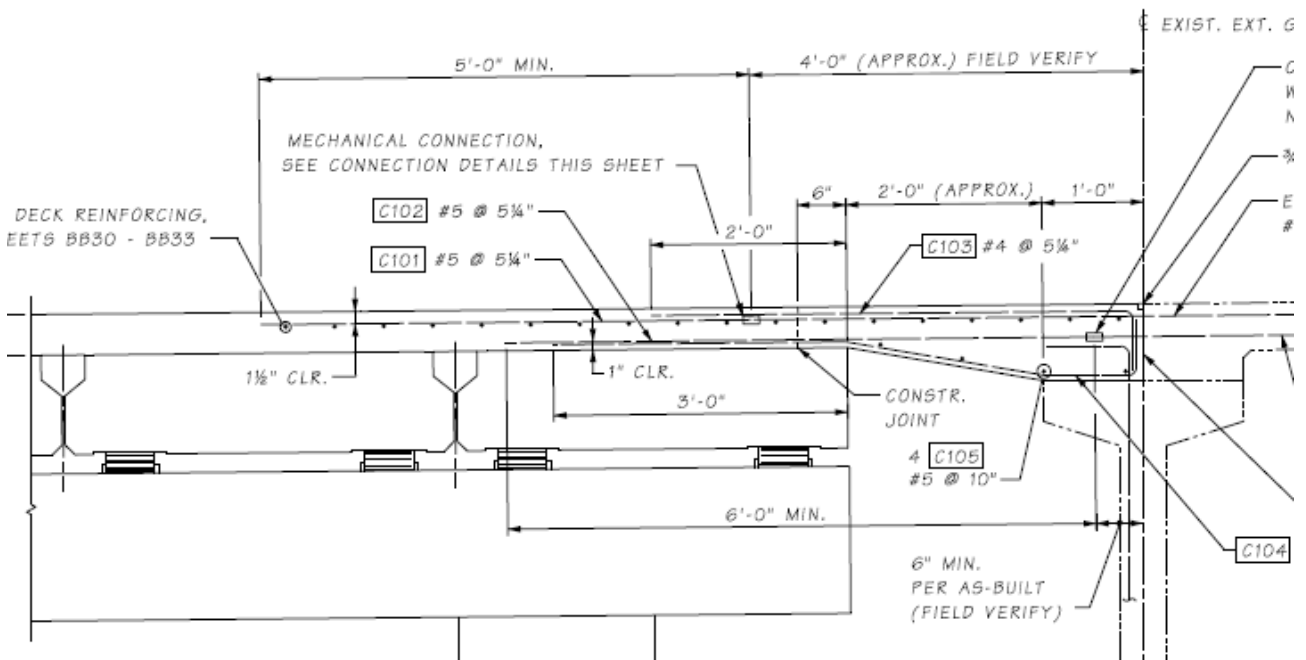


Fig. 5 Bridge deck connection

However, under live load there is larger vertical deflection at one-third span location of existing bridge and zero vertical deflection at the same location for widening bridge since it locates at the support location. The larger differential deflection will induce large live load effects. It is significant to evaluate and accommodate the live load effect on bridge deck connection due to the differential displacement.

#### DIFFERENTIAL LIVE LOAD DEFLECTION

From both the finite element analysis and girder design program, the live load deflection at one-third location of existing span was 0.75" before it is widened. At the same location, the live load deflection is close to zero for widening bridge. This difference will induce large bending moment and shear in the bridge deck connection zone. The existing bridge deck transverse bridge used #5 reinforcing steel with 40 ksi strength spaces 5.25" and will be remained after cantilever deck is demolished. The remained reinforcing steel will be extended into the new bridge deck; however, it is not adequate to carry the increased moment. The live load effect in bridge deck connection zone has to be reduced to minimize reinforcement amount.

#### Elastomeric Bearing Pad Stiffness

To reduce the deflection difference, thick elastomeric bearing pad is used at intermediate piers of the widening bridge corresponding to one-third span locations of the existing bridge. The bearing pad vertical stiffness is considered in the 3D finite element analysis. The bearing pad thickness is determined to obtain similar vertical deflection as the existing bridge under live load. It makes both bridge superstructures have close stiffness so that both bridges have similar deflection effect at the same locations. The Table 2 shows the deflection results under two different support conditions.

Table 2 Bridge deck connection deflection at one-third span of existing bridge

	Deflection, inch
Existing bridge only	0.75
Widening bridge with regular bearing (1" thick)	0.09
Widening bridge with 4.25" bearing	0.67

Since the widening and existing bridge has similar live load deflection effect, the bending moment at bridge deck connection is greatly reduced. The remained transverse reinforcing steel in the existing bridge deck will provide adequate resistance for deck connection zone.

#### CROSSBEAM AND PILE FOUNDATION

The purpose of using short span length and shallow superstructure is to save space for crossbeam construction above water. By using 12" prestressed slab girder, there is minimum 6 feet clearance between girder bottom and water surface. Crossbeam, i.e., pile cap, uses 22" built-up section, as show in Fig. 6 below. The built-up section is made of 1" top and bottom plate and double 20" webs. It leaves 4-foot clearance between water surface and pile cap bottom, which satisfies 3-foot minimum clearance requirement above water for field welding the pile to pile cap connection.

The built-up steel crossbeam is support by 24" driven steel pipe pile foundation. The application of driven pile foundation will accelerate foundation construction and benefit the removal of widening bridge in the end.

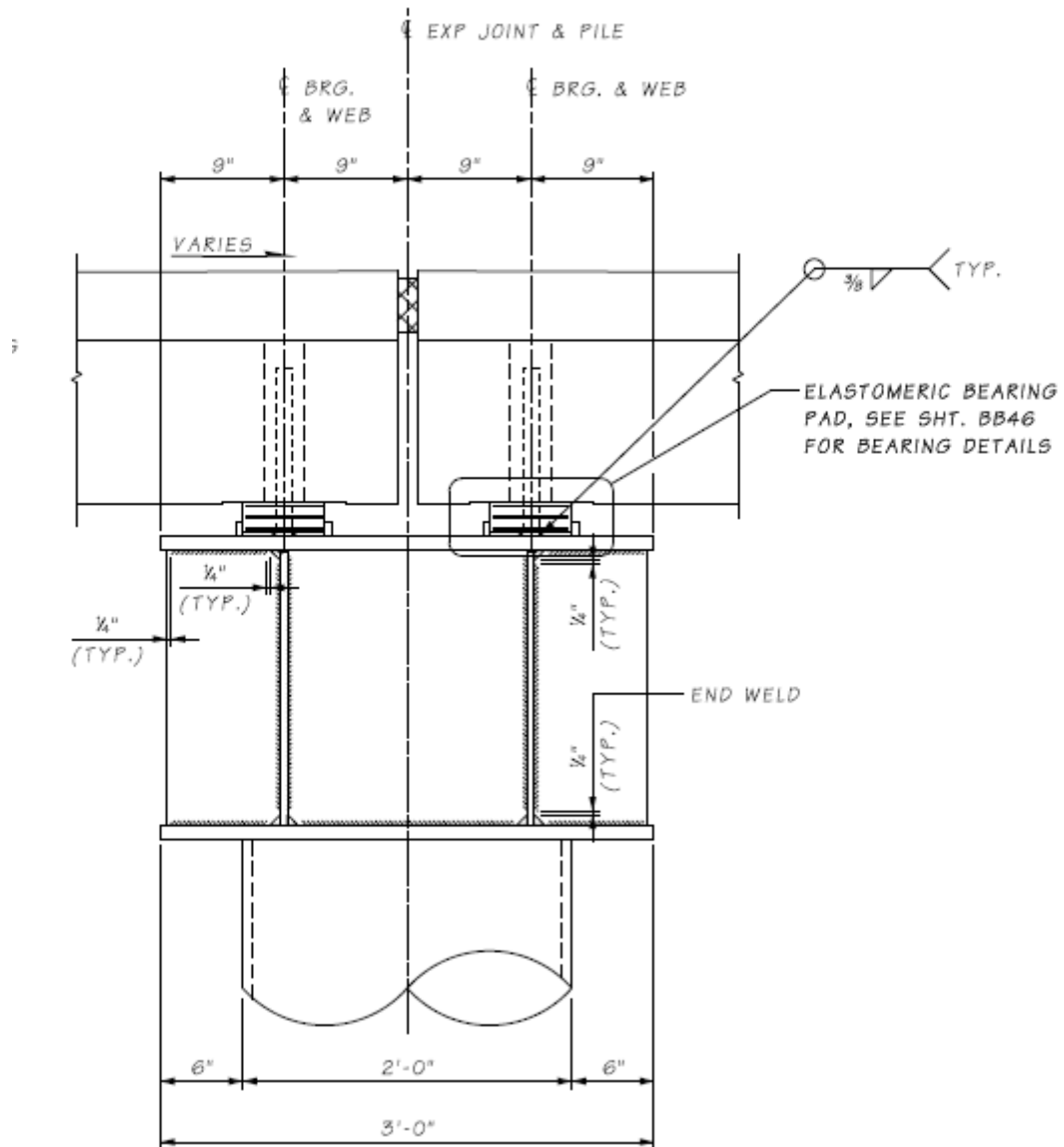


Fig. 6 Crossbeam section

CONSTRUCTION WORK BRIDGE ON CROSSBEAM

Due to cost and environmental considerations, it is required to build the widening bridge without using cofferdam, extra work bridge or barge shipping. The interruption or closure of traffic on the existing bridge is not expected.



The crossbeam will be used as work bridge support for driving pile and girder placement of widening bridge self. The construction will start from Pier 1 abutment and Pier 2 on ground. After abutment and pier 2 crossbeam are built, the temporary girders will be placed supported by abutment and pier 2. Construction material and equipment then use first span to drive Pier 3 piles and install its crossbeam, and then place span 2 temporary girders. Repeat this procedure until end of all pier pile and crossbeam. After all pile foundation are built, the slab girders may be placed start from span 18 and backwards to span 1.

## SEISMIC DESIGN

The bridges locate at seismic zone 4 area and the existing bridge was designed prior to the adoption of the seismic codes. The widening bridge is considered as a temporary structure of maximum 5 years life so that a 2.5 reduction factor for seismic response spectrum can be used in accordance with AASHTO LRFD Guide. It is required that the seismic demand on the existing bridge cannot be increased due to widening bridge construction. However, both widening bridge superstructure and substructure are different from existing bridge. This design will adjust widening bridge foundation layout make its seismic response be close to the existing bridge foundation by using combination of plumb and battered piles at each pier, see Fig. 7 below.

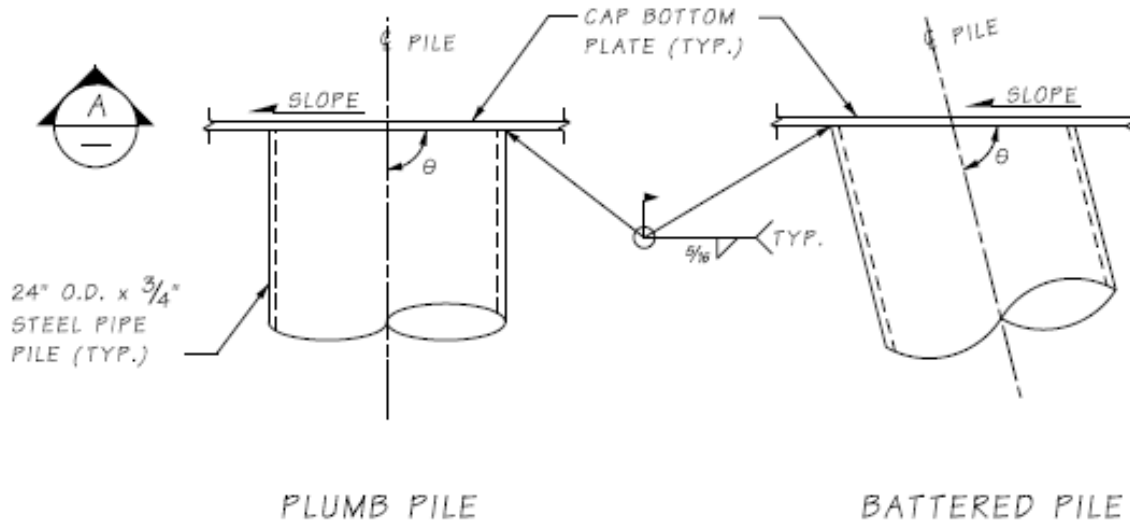


Fig. 7 Pile foundation

## Period and Seismic Displacement

Pile foundation is made of plumb pile and battered pile for widening bridge. Pile spacing and batter pile location is optimized to adjust the widening bridge seismic characteristics. The Table 3 below

shows the first two mode period and displacement and seismic force change in existing bridge foundation. It shows the seismic force does not transferred to existing bridge; instead, it reduced 10% in longitudinal direction and 2% in transverse direction.

Table 3 Seismic analysis

Mode	Direction	Period (sec)	Displacement (in)	Base shear change for existing bridge
1, Longitudinal	Existing	1.01	4.52	-10% (reduction)
	Widening	0.92	4.01	
	Combined	0.95	4.20	
2, Transverse	Existing	0.56	1.80	-2%(reduction)
	Widening	0.51	1.62	
	Combined	0.53	1.74	

## CONCLUSIONS

Several conclusions are obtained from this widening bridge project as below. It provided an approach to widen the existing bridge by using different structural system; also provided solution for special requirements for deck connection and seismic response between two bridges

1. The existing bridge is widened by using a different span length, girder type and spacing. The shorter span length and 12” slab girder dramatically reduce the structural height which satisfies the requirements that all construction shall be built above water and no cofferdam is needed.
2. Determination of live load distribution factor is critical to prestressed slab girder design. 3D finite element analysis is applied to obtain accurate live load distribution factors and also compared to results from the conventional method by using AASHTO LLFD Bridge formula.
3. The bridge deck jointless connection design is critical to driving safety requirement of bridge deck system. at 3D finite element analysis is conducted to obtain live load effect at and bearing pad stiffness is used to reduce live load effect in deck closure zone.
4. Steel built-up crossbeam is used to save space for field welding operation above water surface. The construction sequence is recommended to avoid use cofferdam, extra work bridge, barge ship, and traffic interruptions.
5. Pile foundation uses combination of plumb and battered 24” driven steel pipe piles. By adjusting pile spacing and pile layout, the widening bridge has similar seismic characteristic as the existing bridge so that no seismic force is transferred to the existing bridge...

## REFERENCES

1. AASHTO Guide Specifications for LRFD Seismic Bridge Design, 2<sup>nd</sup> Edition, 2011
2. AASHTO LRFD Bridge Design Specifications, 6<sup>th</sup> Edition, 2012