Design of Precast-Prestressed Concrete Girders for Optimized Fabrication

Richard Brice, PE
Software Applications Engineer
WSDOT Bridge and Structures Office
Olympia, WA

Bijan Khaleghi, PE, SE
Bridge Design Engineer
WSDOT Bridge and Structures Office
Olympia, WA

Stephen Seguirant, PE
Vice President and Director of Engineering
Concrete Technology Corporation
Tacoma, WA

Introduction

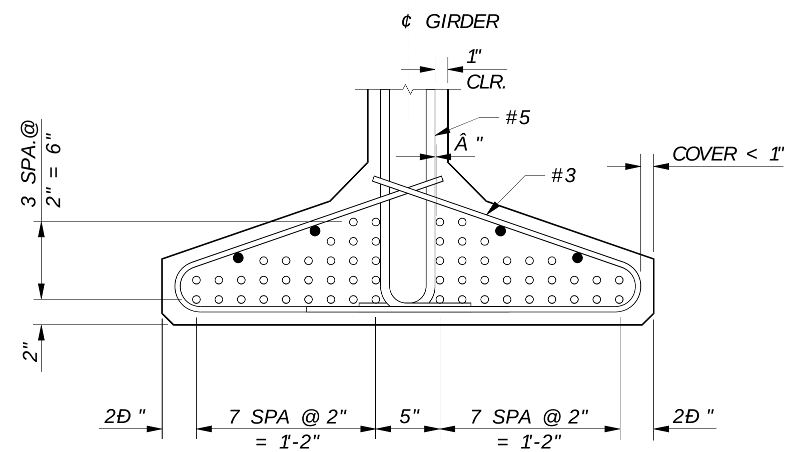
- WSDOT is updating its precast-prestressed girder detailing practices and design methodology to facilitate optimized fabrication of girder components
- Objective of Optimization
  - Reduce cost by saving material and reducing labor
  - Improve schedules by optimizing plant usage
  - Improving quality by avoiding interferences and tight tolerances

Detailing for Optimized Fabrication

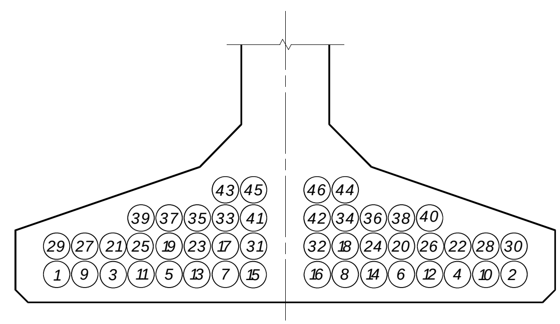
- Production efficiencies and enhanced quality can be achieved by detailing for optimized fabrication
  - Straight Strand Placement
  - Placement of Projecting Reinforcement
  - Reduction of End Ties
  - Splitting Reinforcement

Straight Strand Placement

- ~1/8” gap between strand and vertical shear reinforcement
  - Spacers required for accurate placement
- Violates clearance requirement for bottom flange confinement reinforcement



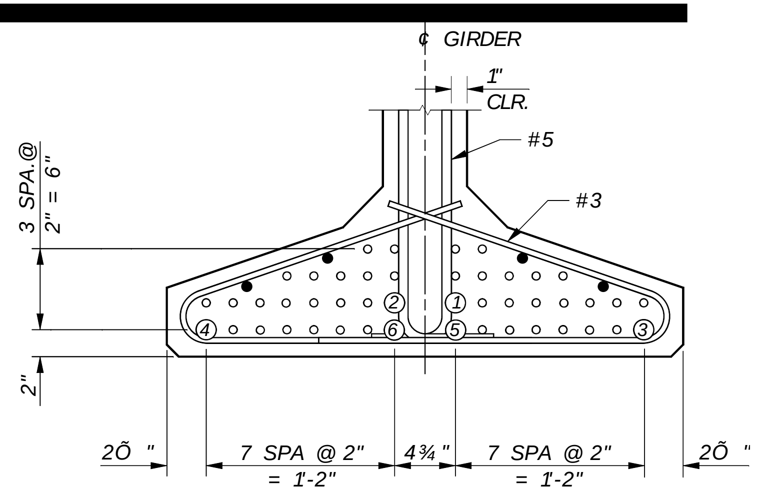
Original Strand Placement



Original Placement Sequence

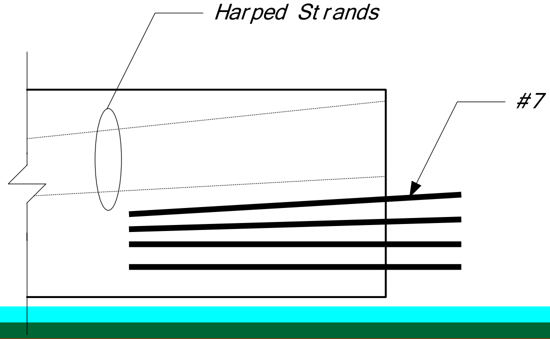
Optimized Strand Placement

- Strands become a template for placing vertical shear reinforcement
- 1” clear cover in webs is maintained
- Provides more clearance for bottom flange confinement reinforcement



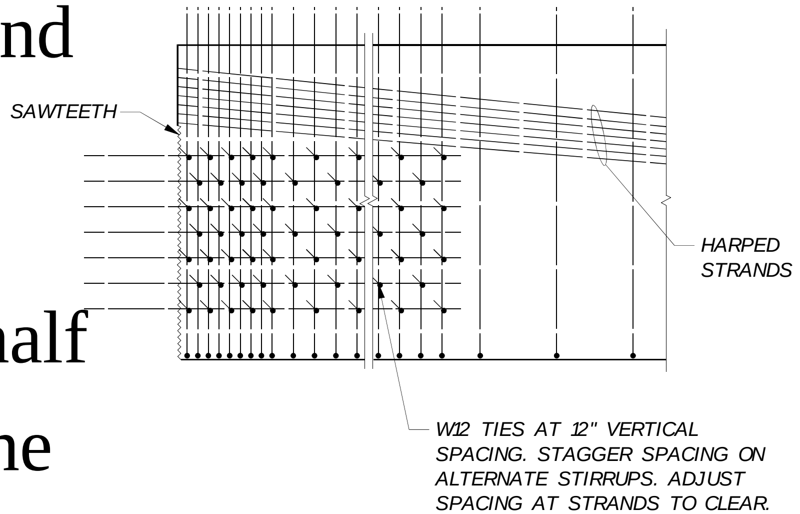
Placement of Projecting Reinforcement

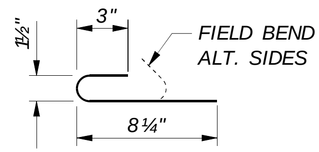
- Several #7 bars cross the shear friction interface between the girder ends and diaphragms or integral pier cap
- Easy fabrication difficulties by
  - Reducing # of harped strands
  - Keeping harped strands high in the section
  - Permitting fabricator to splay bars



Reduction of End Ties

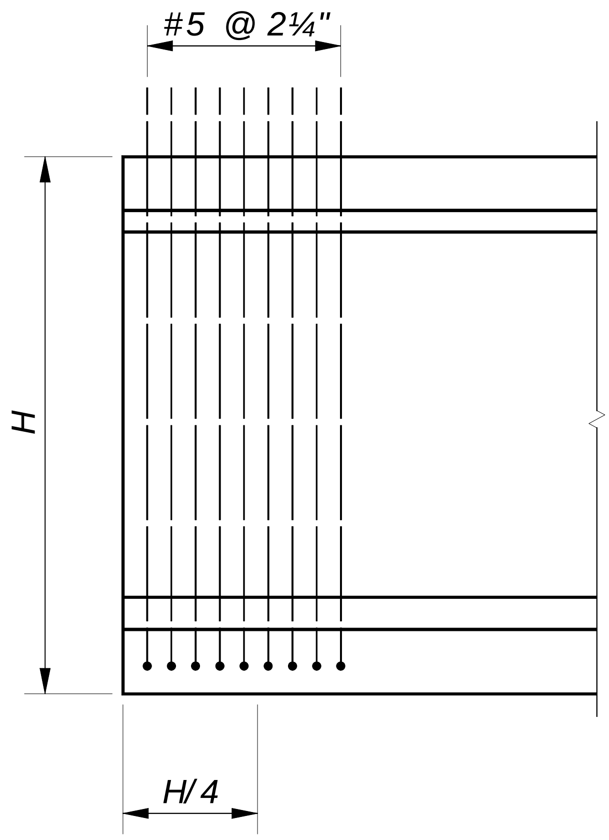
- W12 field bent wire ties in end regions
- Extremely labor intensive
- Reduced number of ties by half
- Possibly eliminate them in the future





Splitting Reinforcement

- Splitting reinforcement to resist 4% f_{pt} within $h/4$ from end of girder
- Difficult to squeeze that much rebar in $h/4$
  - Designers have specified larger and bundled bars
- WSDOT limits placement to #5 @ 2¼” and can extend beyond $h/4$

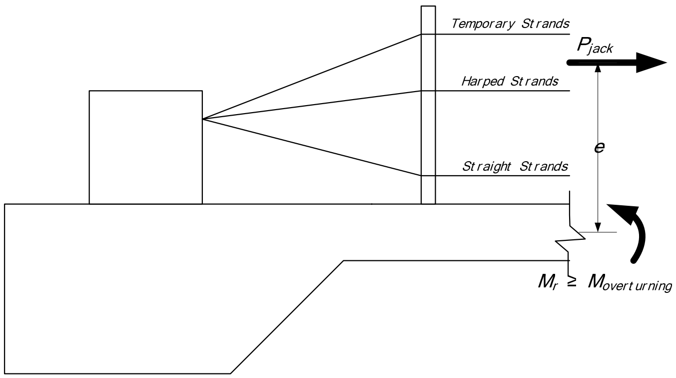


Designing for Optimized Fabrication

- Give fabricators the flexibility necessary to maximize the usage of their prestressing plant
- Long span HPC girders with 0.6” diameter strands are commonly produced
- There are handling and shipping challenges with long slender girders
  - Temporary top strands are commonly used to improve stability

Limiting Capacity of Prestressing Lines

- Jacking Capacity
- Overturning of Anchorages
- Factors contributing to increased demand on stressing beds
  - Deeper girder sections
  - More permanent strands
  - Larger strand size
  - Temporary top strands (large eccentricity)



Design Procedure

1. Design for Final Service Conditions
2. Design for Lifting without Temporary Top Strands
3. Design for Release without Temporary Top Strands
4. Estimate Temporary Top Strand Requirement
5. Design for Lifting with Pretensioned Temporary Top Strands
6. Design for Lifting with Post-Tensioned Temporary Top Strands
7. Design for Shipping
8. Check Final Service and Strength Conditions

Design for Final Service Condition

- Design outcome
  - Final prestress force

$$P = -\frac{f_{bottom}^{ServiceIII}}{\left(\frac{e}{S_b} + \frac{1}{A_g}\right)}$$

  - Number of strands

$$N = \frac{P}{a_{ps}\left(f_{pj} - f_{pT}\right)}$$

  - Final concrete strength

$$f_c' = \frac{\left(f_{top}^{ServiceI} + f_{top}^{prestresss}\right)}{0.6}$$

Lifting without Temporary Top Strands

- Fabricators have option of Post-tensioning Temporary Top Strands
- TTS can be added after lifting
- Balances stresses at HP, Lift point and PS Transfer point
- Design outcome
  - Straight to harped strand ratio (start w/ 2s:1h)
  - Lift loop locations
  - Release strength, f'_{ci} (maximum required)

Release without Temporary Top Strands

- Form stripping strength
- Permits crew to begin turning over the production line for the next girder when strength is not quite at the lifting strength
  - Strength will continue to increase during this work
- Fabricators are cautioned to not strip forms at this strength unless there is a high degree of confidence that the strength targets for lifting and final strength can be attained
- Girder can be lifted when:
  - Lifting with TTS strength is achieved (highest required f'_{ci})
  - After PT TTS are installed and lifting strength is achieved (intermediate f'_{ci})

Estimate Temporary Top Strand Requirements

- Girder is evaluated for stresses and stability
  - Prestress force depends on losses
  - losses are a function of f'_{ci}
  - f'_{ci} for lifting with TTS is not known at this time so it must be estimated
  - Shipping with TTS will be re-evaluated when f'_{ci} is known
- Design Aids can be used
- Design Outcome
  - Number of temporary top strands
  - Shipping support location

Lifting with Pretensioned Temporary Top Strands

- When TTS are required for shipping, they have a favorable influence on lifting
  - Lifting stability is improved so lift points can be moved closer to the girder ends
  - Increases dead load moment at harp point
  - Increased dead load stress more effectively counteracts stress due to prestressing
  - Lowest release strength requirement
  - Highest demand on stressing bed
- Design Outcome
  - Release strength, f'_{ci} (minimum required)

Lifting with Post-Tensioned Temporary Top Strands

- TTS are post-tensioned when stressing bed does not have capacity to pretension them in addition to the permanent strands
- Three scenarios for PT-TTS
  1. TTS required for shipping only (lift girder and add TTS later)
  2. Lifting at a reduced f'_{ci} (f'_{ci} is not at strength required for lifting without TTS)
  3. Minimum release strength, stressing bed cannot handle PS TTS
- Design Outcome
  - Lifting location (use same as lifting w/o TTS)
  - Release strength, f'_{ci} (intermediate)

Design for Shipping

- Using the release strength, f'_{ci}, for lifting with pretensioned TTS, re-evaluate the shipping stress and stability requirements
- Design Outcome
  - Confirmation of temporary top strand requirement
  - Required final strength, f'_c
    (could control over in-service requirement)

Check Final Service and Strength Conditions

- Check temporary stress conditions
  - Non-composite girder with TTS removed
  - Non-composite girder carrying weight of wet deck and diaphragms
- Check final stress conditions
  - Composite girder carrying superimposed dead loads
  - Composite girder carrying live load
- Check ultimate moment capacity
  - $M_u < \phi M_n$

Design Summary

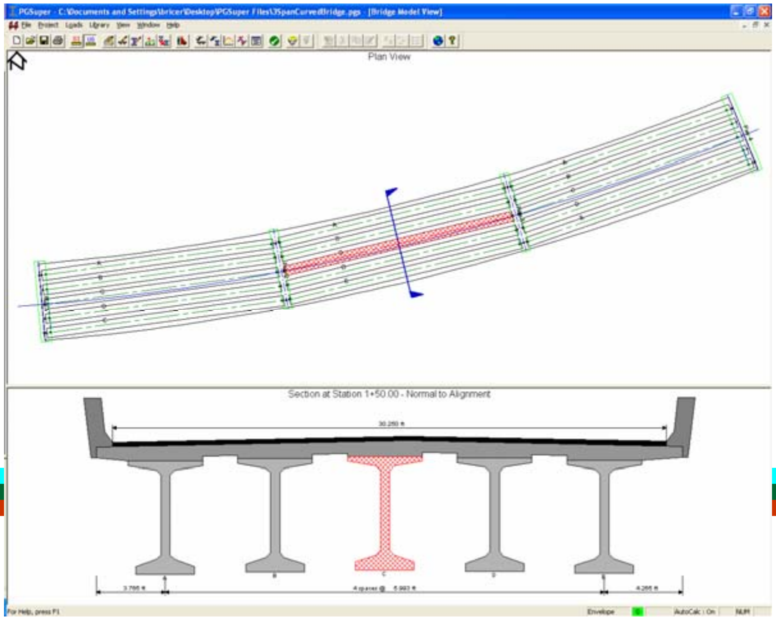
- Number of Permanent Strands and Final Strength f'_c
- Form Stripping Strength, f'_{ci}
- Lifting location and Release Strength for no TTS
  - Maximum required f'_{ci}
- Lifting location and Release Strength for pretensioned TTS
  - Minimum required f'_{ci}
- Number of Temporary Top Strands
- Lifting location and Release Strength for PT-TTS
  - Intermediate f'_{ci}
  - Same lift location as for no TTS
- Shipping location and f'_c

Impact on Camber

- Permanent strand configuration, release strength, and TTS requirement significantly influence camber
- Slab haunch is set based on the anticipated camber
  - For girders with wide top flanges, such as the WSDOT WF-series girder (w_{tf} = 4'-1"), deviations from predicted camber result in significant changes in slab concrete quantities
- WSDOT gives contractor an expected range of camber for deck placement at 40 days and at 120 days
  - Contractors use this information to asses their risk of increased concrete quantities for accelerated construction schedules
- It is undesirable to significantly alter the predicted camber after a design is advertised and bid
- The time to optimize for fabrication is during design

Design Tools

- PGSuper Version 2.0 added design for optimized fabrication
- Free download from WSDOT
  - www.wsdot.wa.gov/eesc/bridge/software



Conclusion

- WSDOT is changing its design and detailing practices to facilitate optimization of the girder fabrication process
- Fabrication of long span HPC girders can be optimized by giving fabricators the flexibility to adjust release strengths and girder handling scenarios
- Cost reductions and schedule improvements are the anticipated benefits