SEISMIC CONNECTIONS IN PREFABRICATED SUPERSTRUCTURES

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Outline

- Scope
- Use of I-girders with Inverted-tee bent Cap
- Prototype bridge
- Experimental investigation
- Conclusions
Scope

- To understand the true seismic behavior of inverted tee cap-to-girder connections as currently used and the impact of such connections on the system response using both analytical and experimental means
- To mitigate the potential seismic hazard associated with these bridges
Precast concrete girders in seismic regions

- Advantages of precast concrete
  - Shop construction (improved quality, reduced cost)
  - ABC (reduced field time, reduced traffic divergence, reduced noise and air pollution)

- However, not widely used in seismic regions
  - Lack of a proven design methodology
  - Lack of experimental validation of structural details/connections
  - I-girder/Inverted tee system is not cost effective
I-girder with inverted-tee bent cap

Inverted Tee
Bent Cap

Column
Connection Details

Inverted Tee Bent Cap
Diaphragms Added

Inverted Tee Bent Cap

Diaphragm
Deck Added
I-Girder/Inverted Tee Connection

- As-built condition
  - Assumed to degrade to a pin connection (due to lack of positive moment connection between the cap and girders)
  - A plastic hinge at the column top is not expected
  - Thus requiring a larger diameter columns and large foundations making it less cost effective in comparison to a cast-in-place alternative
Contribution of research

- Analysis shows the as-built connection will act more like a fixed connection due to dowel bars going through the girders and integration of the connection using diaphragm and deck.
- An improved connection detail was explored as a possible detail for future bridge.
- After considering several options, the connection performance was improved by running grouted unstressed tendons in the bottom flange of the girders through the cap for the entire bridge length.
- Make this design option cost effective by allowing formation of a plastic hinge at the column top.
Prototype Bridge

- Four spans (no skew)
- Total length = 123 m
- 34 m interior spans

- AASHTO LRFD with CA amendments
- Caltrans SDC
- Caltrans Bridge Design Aids

Measured Along “A” Line

Abut 1
Bent 2
Bent 3
Bent 4
Abut 5
Region Modeled
Prototype Bridge - Section

- Designed by PBS&J, verified by ISU
- SS Depth = 1.93 m
- D/S = 0.0565

- 5 precast I-Girders with 1.67 m depth
- CONSPAN for service load analysis/design
Test Unit Configuration

- Center portion of prototype structure
- 50% dimensional scale
- Single column with inverted-tee cap beam
- Superstructure of five I-girders overlaid with deck
- As-built girder-to-cap connection on one side of cap beam and improved connection on other side
Test Unit - Connection Details

Improved

As-built
Construction of Girders and Cap
Inverted Tee

Connection reinforcement

Inverted-tee cap beam

Strand ducts
Construction at UCSD Laboratory
Test Phases

- **Phase I Testing**
  - Horizontal seismic testing
  - Evaluate system performance
  - Verify if both connections are adequate to form a plastic hinge at the column top

- **Phase II Testing**
  - Vertical load/displacement
  - Full exercise the girder-to-cap connections
Phase I Configuration

- Length of test unit was 66 ft
- Tie-downs and four vertical actuators simulated gravity effects
- Four horizontal actuators simulated the seismic action
Phase I Configuration

“Caltrans” “inverted tee”
Force-Displacement Response

- Good comparison with SAP analysis
- Results converge as structure softens through cracking and yielding
- Similar behavior in both directions
Girder Load Distribution (Improved Connection side)

- Center: 20%
- Intermediate: 25%
- Exterior: 15%

Compare to analysis:
- 22.8%
- 21.2%
- 17.4%
Girder load distribution

Exterior

Intermediate

Center

Horizontal displacement (in.)

Fractional strain distribution

(+)ve moment  
(comp. strains)  

(-)ve moment  
(tensile strains)
Girder load distribution
(Low load levels)

- First step to right of zero corresponds to +0.25 Fy
- Already significant load distribution occurring at this point
  - Cen: 26.0%
  - Int: 21.8%
  - Ext: 15.1%
Phase I General Performance

- Excellent overall performance for system and both as-built and improved connections
- Displacement ductility of 10 ($\Delta_h = \pm 7$ in.)
- Little degradation of positive as-built connection (contrary to current design guides)
- Very little degradation to improved connection
- As-built connection: behaved as fixed; Minimal measures required to ensure satisfactory performance of existing inverted-tee – I-girder bridges
Phase II Test Configuration

- Vertical load/displacement
- Full exercising of girder-to-cap connections
- Horizontal actuators – used for stability purposes
Phase II Testing
Phase II General Observations

- Maximum displacements:
  - Positive = 3 in. (upward)
  - Negative = 6 in. (downward)

- As-built connections exercised to full capacity

- Did not achieve full quantification of improved connection due to failure of the as-built connection and column hinges
Phase II – As-built Connection Region

Opening up of as-built connection under positive-moment loading

End of test
Phase II
Positive moment vs. displacement

- Noticeable difference between improved and as-built
- Improved: elastic and higher moment
- Similar stiffness in elastic region
Phase II

Negative moment vs. displacement

- Difference more subtle
- Decrease in strength on as-built side
- Larger displacements for as-built side reflect the observed deterioration
Conclusions

- As-built connection behaved as a fully continuous connection during horizontal seismic testing, but this detail is not recommended for new bridges.
- Only tops of columns in as-built bridges require retrofitting to prevent premature column damage, but note that column shear demand will be increased.
- Improved connection provided:
  - dependable behavior under both positive and negative moments
  - an integral connection design to develop a plastic hinge in the top of the column
  - a means to promote ABC of bridges in seismic regions
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