State-of-the-art Report On FULL-DEPTH PRECAST CONCRETE BRIDGE DECK PANELS

(SOA -01-1911)
State-of-the-Art Report on Full-Depth Precast Concrete Bridge Deck Panels

Prepared by the PCI Committee on Bridges and the PCI Bridge Producers Committee
Under the direction of the Sub-committee for the State-Of-The-Art Report on Full-Depth Precast Concrete Bridge Deck Panels

Credit to

Vince Campbell
Former president of Bayshore Concrete Products Corporation, VA
STATE-OF-THE-ART REPORT ON
FULL-DEPTH PRECAST CONCRETE BRIDGE DECK PANELS

With the sponsorship of
PCI Committee on Bridges and the PCI Bridge Producers Committee
(Technical Activities Council)

Under the direction of the sub-committee for the
State-Of-The-Art Report on Full-Depth Precast Concrete Bridge Deck Panels

Joseph L. Rose, Chair
Carin Roberts-Wollmann, Vice Chair

Mohammad Alhassan  Barry E. Fleck  Claude S. Napier, Jr.
  Sameh S. Badie        Ken Fleck           Michael G. Oliva
  Shrinivas B. Bhide    Amgad Fawzy Girgis  Jerry Potter
  Heinrich O. Bonstedt  Chris Hill            Chuck Prussack
  Dale C. Buckner       Mohsen Issa          Gary E. Pueschel
  Vincent Campbell      Fouad Jaber           Hameed Shabila
  James W. Carter III   Troy Jenkins          Michael M. Sprinkel
  Reid W. Castrodale    Bijan Khaleghi        Maher K. Tadros
  John S. Dick          Mark Lafferty          Don Theobald
  Hussam “Sam” Fallaha  John S. Liles      Julius F.J. Volgyi, Jr.
  Lyman D. Feemon       Richard P. Martel
Those who served as authors and reviewers of the report through numerous stages of development were:

James W. Carter III, Chair

Sameh S. Badie
Shrinivas B. Bhide
Reid W. Castrodale
John S. Dick

Mohsen Issa
John S. Liles
Claude S. Napier, Jr.
Gary E. Pueschel

Carin Roberts-Wollmann
Joseph L. Rose
Michael M. Sprinkel
Maher K. Tadros

Corresponding Members

Farhad Ansari
Millard Barney
Michael Brown
Barry Bryant
Michael Campion
George Colgrove
Tommy Cousins
Michael Culmo
Rodney T. Davis
John E. Dobbs
Alvin C. Ericson
Jim Fabinski
Skip Francies
Benjamin Graybeal
Charles D. Newhouse

Edward J. Gregory
Joseph L. Hartman
Eddie He
Susan E. Hida
Mark B. Hoover
Michael Hyzak
Moussa A. Issa
Steven Iszak
Keith Kaufman
Andrew J. Keenan
Chad Keller
Manuel Linares
Scott Markowski
Michael Means

Mary Lou Ralls Newman
Larry Norton
Richard Potts
Basile G. Rabbat
Loren R. Risch
Joe Roche
Randy Romani
Chad A. Saunders
Andrea Schokker
Eric P. Steinberg
Chris Waldron
Gary Wilson
Dick Wells
Gregor Wollman
Several others that deserve special recognition for their contributions include: Vince Campbell for his vision to create a document on this topic; Nghi Nguyen, Parul Patel, and Sameh S. Badie who helped with the example in Appendix D and Kromel Hanna who assisted the technical editor to create the final publication.

PCI Staff Liaison to the Committee
John S. Dick

Technical Editor
Helmuth Wilden

Managing Director, PCI Transportation Systems
William N. Nickas
Table of Contents

A. Introduction, Concept & Advantages
B. Component of the FDDP*
C. Details of the FDDP*
D. Miscellaneous issues
E. Examples of successful projects
F. Available resources

(* FDDP = Full-Depth Precast Concrete Deck Panels)
Direction/Reinforcement

Transverse

Longitudinal
# Table of Contents

A. Introduction, Concept & Advantages

B. Component of the FDDP*

C. Details of the FDDP*

D. Miscellaneous issues

E. Examples of successful projects

F. Available resources

(* FDDP = Full-Depth Precast Concrete Deck Panels)
Full-Depth Precast Deck Panels (FDDP)
Full Depth Precast Panels Do not Crack

• Cracking of FDDP is substantially controlled

Because:

– Concrete is mature. It has already undergone most of its cement hydration temperature change, shrinkage and creep

– The panels can be prestressed in the plant and post-tensioned at the site, creating two-way precompression.
Fresh concrete shrinks because:

1. Temperature drops after the concrete sets (by as much as 80 degrees)
   
   \[ \varepsilon_{\text{Temp. drop}} = \alpha \cdot \Delta T = (6 \times 10^{-6})(80) = 4.8 \times 10^{-4} \]

2. Loss of hydration water (by as much as 300 micro strains)
   
   \[ \varepsilon_{\text{shrinkage}} = 3.0 \times 10^{-4} \]

Thus, total shrinkage strain, \( \varepsilon_{\text{total}} = 4.8 \times 10^{-4} + 3.0 \times 10^{-4} = 7.8 \times 10^{-4} \)

If concrete compressive strength, \( f'c = 1,000 \) psi at one day

Modulus of elasticity, \( E_c = 57,000 \) (Sqrt 1,000) = 1,800 psi

Tensile stress due to combined actions = \( \varepsilon_{\text{total}} \cdot E_c = 1,400 \) psi

Modulus of rapture = \( 7.5 \times \text{Sqrt}(f'c) = 237 \) psi

Since the deck concrete is restrained by girders, it cracks
<table>
<thead>
<tr>
<th>Advantage</th>
<th>FDDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Speed</td>
<td>High</td>
</tr>
<tr>
<td>Shrinkage cracking</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Hydration temperature cracking</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Formwork</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>Low</td>
</tr>
<tr>
<td>Structural integrity</td>
<td>Maintained</td>
</tr>
<tr>
<td>Adaptability for continuous span bridges</td>
<td>Yes</td>
</tr>
<tr>
<td>Initial cost</td>
<td>Relatively High</td>
</tr>
<tr>
<td>Service life</td>
<td>Long</td>
</tr>
</tbody>
</table>

Advantages of FDDP
Table of Contents

A. Introduction, Concept & Advantages
B. Component of the FDDP* 
C. Details of the FDDP* 
D. Miscellaneous issues 
E. Examples of successful projects 
F. Available resources 

(* FDDP = Full-Depth Precast Concrete Deck Panels)
Components of the FDDP

- Shear pockets
- Precast panels
- Shear key
- Transverse joints
- Longitudinal joint
- Overlay (may be omitted)
- Pockets for splicing longitudinal reinforcement
- Leveling bolts
- Post-tensioning steel
- Grout
- Studs
Table of Contents

A. Introduction, Concept & Advantages
B. Component of the FDDP*
C. Details of the FDDP*
D. Miscellaneous issues
E. Examples of successful projects
F. Available resources

(* FDDP = Full-Depth Precast Concrete Deck Panels)
Panel-to-Girder Connection

A positive connection between the precast panels and the supporting girders is required to create a composite deck-girder system.
Concrete Girders

- Dowel with 180 degree hook
- Blockout in precast panel for shear connectors
- Standard top flange reinforcement
- Bridge Girder
- 90 degree hook on shear reinforcement
- NE Bulb Tee Girder shown. (other Bulb Tee beams similar)
- Place non-shrink pourable grout in blockout and panel haunch.

NEW CONSTRUCTION WITH PROJECTING REINFORCING CONNECTION
Concrete Girders

NEW CONSTRUCTION WITH WELDED STUD CONNECTION
Concrete Girders

NEW CONSTRUCTION WITH COIL INSERTS AND COIL BOLTS
NEW CONSTRUCTION WITH PROJECTING DOUBLE HEADED STUD

Concrete Girders
Concrete Girders

- Blockout in precast panel for shear connectors
- Bridge Girder 1 1/2" min.
- Place non-shrink pourable grout in blockout and panel haunch.
- Embedment as per grout manufacturer's specifications
- Drill and grout horizontal shear reinforcement with chemical adhesive

Existing AASHTO beam

DECK REPLACEMENT
NEW CONSTRUCTION OR DECK REPLACEMENT WITH PROJECTING HEADED STUD
Types of Shear Pockets

FDDP with individual Open shear pockets

I-39/90 Bridge over Door Creek, MacFarland, Wis
FDDPs with continuously open channels for PT and composite connection

NCHRP 12-41
NUDECK System
Skyline Bridge, Omaha, Nebraska
FDDPs with individual hidden shear pockets

NCHRP 12-65

Live Oak Bridge, TX
Spacing Between Shear Pockets

S = 2 ft
ASSHTO LRFD

S = 4 ft
NCHRP 12-65
Wis. DOT

I-39/90 Bridge over Door Creek, MacFarland, Wis
The transverse edges of the precast panels are usually provided with shear keys. Typically, the shear key that extends along the transverse edges of a precast deck panel plays an important role in the service performance of the finished deck. The shear key must be designed to eliminate relative vertical movement between adjacent panels and to transfer the traffic load from one panel to the next.

Under traffic load, a panel-to-panel joint experiences two types of loading:

1. A vertical shear force that tries to break the bond between the panel and the grout filling the joint, and

2. A bending moment that puts the top half of the joint in compression and the bottom half of the joint in tension.
Male-Female (Tongue/Groove) Shear Key

Cracking, spalling & leakage were observed. Due to elevation adjusts and fabrication tolerances, the tongue/groove detail did not provide 100% match.
Female-to-Female Shear Key

Bulb Shape (NCHRP 12-41)
Female-to-Female Shear Key

Diamond Shape (NCHRP 12-41)

More flexible detail with higher level of mechanical interlocking capacity
Leveling Bolts

Live Oak Bridge, TX
Splicing Longitudinal Reinforcement

Case 1: Reinforcing Bars, No PT

Notes
- Extending bars outside the panels
- Bending diameter vs the panel thickness
- Use U-shape bars separate from panel reinforcement

Bill Emerson Memorial Bridge, Missouri DOT
Using HS Spirals
NCHRP 12-41
Using Open Steel Tubes
NCHRP 12-65
Notes
- Alignment of slots
- Tight fabrication tolerance
- Durability was enhanced by minimizing the exposed surface area of the grout (using hidden shear pockets and the open steel tube detail for splicing the longitudinal reinforcement)
Using Closed Steel Tubes (NCHRP 12-65)

Notes

- Tilting panels during installation
Splicing Longitudinal Reinforcement
Case 2: Longitudinal Post Tensioning

longitudinal PT is distributed over the width of the panel
I-39/90 Bridge over Door Creek, McFarland, Wis.

Notes
- Pocket is wide enough to allow for splicing of the ducts
Skyline Bridge
Omaha, Nebraska

Note:
Continuously open channel, one line of studs, visible strand for longitudinal PT

NUDECK
NCHRP 12-41

longitudinal PT is concentrated at girder lines
Transverse joints must be grouted before the longitudinal PT tendons are tensioned

I-39/90 Bridge over Door Creek, MacFarland, Wis
Special end panel is required for anchorage of the PT strands

- PT done with a small jack, borrowed from UNL Lab
- Contractor worker was trained by UNL technician
- Anchorage plate was locally fabricated

Skyline Bridge, Omaha, Nebraska
Longitudinal PT ducts are grouted I-39/90 Bridge over Door Creek, MacFarland, Wis
I-39/90 Bridge over Door Creek, MacFarland, Wis

Grout shear pockets and haunches
Panel-to-Panel Longitudinal Connection

It is recommended to create the connection in a positive moment area.
Panel to Panel Longitudinal Connection

TYPICAL SECTION – ROADWAY CROWN DETAILS WITH A NARROW CLOSURE POUR

Note: Rotate hook bar to provide adequate top cover.
Panel to Barrier Connection

NOTES: Refer to State standard for actual parapet reinforcing and layout.

Specify a tolerance of ± 1/4" on overhang width to improve appearance.

Standard cast-in-place concrete parapet

Roughen surface

Bridge deck wearing surface

Shear Key

Backer rod
Run rod to bottom chamfer to allow for grout placement to end of panel.

Specify a tolerance of ±1/4" on slab width to provide a smooth exposed edge

Precast deck panel

Stop Shear Key short of end

Drip Edge

TYPICAL SECTION – PARAPET DETAILS WITH EXPOSED EDGE
Panel-to-Barrier Connection

NOTES: Cast parapet over and beyond the end of the precast deck panel in order to provide a smooth edge, and to protect end cut-off of prestressing steel.

Refer to State standard for actual parapet reinforcing and layout

- Standard cast-in-place concrete parapet
- Roughen surface
- Effective width for parapet design
- Bridge deck wearing surface
- Shear Key
- Precast deck panel

Extend vertical reinforcing into overhang pour

1 - #4

5" + Drip Edge

TYPICAL SECTION - PARAPET DETAILS COVERING EDGE
Table of Contents

A. Introduction, Concept & Advantages
B. Component of the FDDP*
C. Details of the FDDP*
D. Miscellaneous issues
E. Examples of successful projects
F. Design Example
G. Available resources

(* FDDP = Full-Depth Precast Concrete Deck Panels)
How to Handle Skew
Building Grout Barriers for Transverse Connections
Grout Barriers for Haunches
(between the Deck and the Girders)
Using wood forms
Grout Barriers for Haunches
Using steel angles

Skyline Bridge, Omaha, Nebraska
Grout Barriers for Haunches
Using compressible material

Live Oak Bridge, TX
Figure 4.4.2-1. Wearing and protection systems include: (a) typical CIP deck (reference), (b) bonded concrete overlay, (c) waterproof membrane overlaid with asphalt, (d) epoxy overlay, (e) monolithic concrete overlay, (f) low permeability panel with no overlay.
Figure 4.4.2-1. Wearing and protection systems include: (a) typical CIP deck (reference), (b) bonded concrete overlay, (c) waterproof membrane overlaid with asphalt, (d) epoxy overlay, (e) monolithic concrete overlay, (f) low permeability panel with no overlay.
Overlay Options

• The least expensive option is Option “f”. Provide an extra “wearing surface” thickness. Use standard roadway profiling grinders to smooth out the surface.
• Provide extra protection of the reinforcement.
• Discoloration due at grouted joints and pockets may be objectionable by some owners.
Table of Contents

A. Introduction, Concept & Advantages
B. Component of the FDDP*
C. Details of the FDDP*
D. Miscellaneous issues
E. Examples of successful projects
F. Design Example
G. Available resources

(* FDDP = Full-Depth Precast Concrete Deck Panels)
APPENDIX C – SUCCESSFUL PROJECTS

C.1 Woodrow Wilson Bridge; Washington, D.C. ...........
C.2 Skyline Bridge – NUDECK System; Omaha, Neb...
C.3 US-24 Mississippi River Bridge; Quincy, Ill. .................
C.4 Seneca Bridge; LaSalle County, Ill. ................................
C.5 George Washington Memorial Parkway over Dead Run and Turkey Run; Washington, D.C. ...........................
C.6 The 24th Street Council Bluffs, Iowa Bridge..
C.7 Utah Precast Deck Panel System .................................
C.8 Cable-stayed Bridges ..............................................
C.9 Required Post-tensioning Stress Across Longitudinal Joint .
C.10 Projects Using Longitudinal Joints ..............................
The list include information on about 60 projects about: Location (state, county), Year Completed, Girder Type, Rehab/New, Span Length, Skew.............
Table of Contents

A. Introduction, Concept & Advantages
B. Component of the FDDP*
C. Details of the FDDP*
D. Miscellaneous issues
E. Examples of successful projects
F. Design Example
G. Available resources

(* FDDP = Full-Depth Precast Concrete Deck Panels)
APPENDIX D – DESIGN EXAMPLE

ACKNOWLEDGEMENT

This example was originally developed by the following team of George Washington University, Washington D.C.: Sameh S. Badie, Ph.D., PE, Associate Professor, Nghi Nguyen, D.Sc., and Parul Patel, M.Sc., Former Graduate Students.

The prestress loss calculations were updated according to the 2008 Interim Revisions to the *LRFD Specifications* by Sameh S. Badie, Ph.D., PE, Associate Professor, George Washington University, and Kromel Hanna, Ph.D., Post-Doctoral Associate, University of Nebraska-Lincoln.
**Design Example Outline**

D.1 Design Criteria

D.2 Design of the Precast Deck Panel System

D.2.1 Design of the Positive Moment Areas between Girder Lines
   D.2.1.1 Estimate Required Prestress Force
   D.2.1.2 Estimate Prestress Losses
   D.2.1.3 Check of Concrete Stresses at Service Loads at the Positive Moment Area
   D.2.1.4 Check of flexural strength
   D.2.1.5 Check of maximum reinforcement limit
   D.2.1.6 Check of Minimum Reinforcement Limit

D.2.2 Design of Panel-to-Girder Connection for Full Composite Action

D.2.3 Design of the Negative Moment Areas over Interior Girder Lines

D.2.4 Design of the Overhang (negative moment section at exterior girder line)
   D.2.4.1 Case I: Due to Transverse Vehicular Collision Loads Using Extreme Event
      Limit State II
   D.2.4.2 Case 2: Due Dead and Live Loads

D.2.5 Design of Longitudinal Reinforcement

D.2.6 Miscellaneous Design Issues
   D.2.6.1 Check of Concrete Stresses at Time of Transferring the Prestressing Force
   D.2.6.2 Check of Concrete Stresses during Lifting the Panel from the Prestressing Bed

D.3 Details of the Precast Deck Panel System
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Introduction, Concept &amp; Advantages</td>
</tr>
<tr>
<td>B.</td>
<td>Component of the FDDP*</td>
</tr>
<tr>
<td>C.</td>
<td>Details of the FDDP*</td>
</tr>
<tr>
<td>D.</td>
<td>Miscellaneous issues</td>
</tr>
<tr>
<td>E.</td>
<td>Examples of successful projects</td>
</tr>
<tr>
<td>F.</td>
<td>Design Example</td>
</tr>
<tr>
<td>G.</td>
<td>Available resources</td>
</tr>
</tbody>
</table>

(* FDDP = Full-Depth Precast Concrete Deck Panels)
Available Resources

PCI (www.pci.org)


- **PCI Journal Papers** *(30+ papers, 1970s-2011)*. Citation of many of these papers is provided in the SOA report.
Available Resources

NCHRP reports [http://www.trb.org/NCHRP/NCHRPPProjects.aspx]

Available Resources

**Miscellaneous**

- DOT Reports
- Journal papers:
  - ASCE Bridge Journal,
  - ACI Structural Journal,
  - Concrete International.....