ALTERNATIVES TO OPEN GRID STEEL DECKS

Sam Fallaha, P.E.
FDOT Structures Research Center

Dr. Amir Mirmiran
Florida International University (FIU)

Dr. Kevin Mackie
University of Central Florida (UCF)

September 28, 2011
Disadvantages of open grid steel decks:

- Less skid resistance (*polish over time*);
- Costly to maintain and repair;
- High noise levels; and
- Susceptible to and vibrations and poor riding comfort.
- Fatigue issues

Research is needed to address the above mentioned issues
RESEARCH OBJECTIVES

Develop alternative deck systems with following attributes:

- **Solid** riding surface
- Weigh no more than 25 lb/ft² ➔ 17 lb/ft²
- No thicker than 4-5 in.
- Capacity for AASHTO LRFD HS 20 truck loading
- Ability to span at least 4 ft between stringers
CURRENTLY AVAILABLE SOLID DECKS

- DuraSpan® FRP Bridge Deck
- Concrete-Filled Steel Grid Deck
- EXODERMIC™ Bridge Deck
- Sandwich Plate System
CURRENTLY AVAILABLE DECKS: PROBLEMS

1- Fiber Reinforced Polymer (FRP) decks:
   + Delamination, debonding and cracking of wearing surface.

2- Epoxy concrete filled steel grid decks:
   + Bleeding of epoxy at higher temperature (durability issue, debonding skid resistant sand layer)

3- Steel grid decks with partially filled normal weight concrete:
   + Over weight (65 psf minimum)
PROPOSED SYSTEMS

- Ultra-High Performance Concrete (UHPC) Deck
- Aluminum Deck
- UHPC–FRP Deck
ULTRA-HIGH PERFORMANCE CONCRETE DECK
COMPOSITION OF UHPC

Ductal®

Developed by French companies Bouygues, Lafarge and Rhodia.

Features:

- High compressive strength: **24 to 33 ksi**
- High flexural strength: **4.5 to 7.2 ksi**
- High tensile strength: **0.9 to 1.7 ksi**
- Fibers minimize *micro cracking*
- Ductile behavior
- Thinner sections for longer spans
STRESS-STRAIN RESPONSE: UHPC

![Stress-Strain Graph](image)
STRESS-STRAIN RESPONSE: MMFX STEEL

\( f_y = 100 \text{ ksi}, \quad E = 29,000 \text{ ksi} \)
SINGLE UNIT, END ANCHORAGE

a) No Anchorage

b) Anchored with Welded End Plate

c) ACI Standard 180° Hook
FLEXURAL TEST RESULTS

1T1S-A

1T1S-H

1T1S-U
FLEXURAL TEST RESULTS

1T1S-TF

1T1S-Shear

1T1S-2#4

1T1S-1#4+2#3
FLEXURAL TEST RESULTS: COMPARISON

Deflection (in)

Load (kips)

1T1S-Shear
1T1S-H2
1T1S-1#4+2#3
1T1S-U
1T1S-2#4
1T1S-H1
1T1S-TF
1T1S-A
FLEXURAL TEST RESULTS

Load (kips) vs. Deflection (in.)

5T1S
DECK-TO-GIRDER CONNECTION: SHEAR TEST

Shear Demand = 7.8 kips

Load (kips)

Displacement (in)

Girder

Stud

3 in. x 2 in.

Plan View

3 in. x 2 in.

Deck
DECK-TO-GIRDER CONNECTION: UPLIFT TEST

Uplift Demand = 2.22 kips

Displacement (in.)

Load (kips)
DECK-TO-DECK CONNECTION: FLEXURAL TEST

Cross Section
LATERAL DISTRIBUTION OF LOAD

5T1S
10.3% 24.1% 31.3% 24.1% 10.3%

4T1S
10.9% 23.4% 36.4% 29.3%

4T2S
15.8% 35.4% 34.4% 14.4%

Simple-Span Deck to Deck Connection Specimen
FINITE ELEMENT ANALYSIS

- ANSYS® 12.0
- Concrete (SOLID65)
  - 8 noded solid element
  - 3 translational DoF at each node
  - Cracking and crushing capability
- Steel rebar (LINK8)
  - 2 noded spar element
  - Uniaxial tension and compression
- Perfect bond between concrete and steel
- Quarter portion of the deck was modeled
- Cracking and crushing was turned off
FATIGUE TEST

Deflection (in.) vs. Number of Load Cycles (Log Scale)

- Span 1: D4, D3, D2, D1
- Span 2: D8, D7, D6, D5

Number of Load Cycles (Log Scale)

Deflection (in.)

0.00 0.04 0.08 0.12 0.16 0.20

1 100 1,000,000 100,000,000
RESIDUAL STRENGTH TEST-A

Graph showing load (kips) vs. deflection (in.) for different spans. The graph includes labeled points D1, D2, D3, and D4 for each span.
PULLOUT TEST SCHEMATICS

Section A-A

PVC Tube

Embedded Length

#3 or #7

12 in.*

1/2 in.

2 in.

1/2 in.

#3 or #7

#3 or #7
**BEAM TEST SCHEMATICS**

**Instrumentation Plan**

- **Slip Measurement**
  - $l_e$ = Embedment Length

- **Deflection Measurement**
  - 46 in.
  - 48 in.

- **Strain Measurements**
  - Section A-A
  - 1 in.
  - 2 ½ in.
  - #2 Stirrups

- **Pin Support**
  - PVC Tube
  - $a = 17$ in.
  - $P/2$

- **Pin Support**
  - #2@1.5 in. c/c

- **Strain Gauge on Rebar**

---

*Note: The image contains detailed schematics of beam test instrumentation, including measurements and annotations.*
MODES OF FAILURE: BEAM TESTS
SUGGESTED DEVELOPMENT LENGTHS

Normalized Embedment Length ($l_e/d_b$)

Strain in Steel Rebar

Yield Strain of MMFX Rebars

Trendline for #3 Pullout

Trendline for #7 Beams

12 $d_b$, Present Study for #3

15 $d_b$, ACI 408R-03 for #3

18 $d_b$, Present Study for #7

20 $d_b$, ACI 408R-03 for #7

21 $d_b$, ACI 318-08 for #3

45 $d_b$, ACI 318-08 for #7

15 $d_b$, ACI 408R-03 for #3

20 $d_b$,  ACI 408R-03 for #7

21 $d_b$, ACI 318-08 for #3

45 $d_b$, ACI 318-08 for #7

#3 Pullout

#7 Pullout

#3 Beam

#7 Beam
UHPC-MMFX DECK

- A viable alternative to open grid steel decks ready for implementation.
- Deck panels and connections endured 2M cycles of fatigue loading with residual strength 47% higher than target load.
- Tongue and groove connection needs epoxy grouting.
- Use standard 180° hooks to avoid bond failure.
- Shear reinforcement not needed.
- The rib under the load takes 34% of the total load.
- Development lengths for #3 and #7 rebars were found as 12d_b and 18d_b, respectively, close to ACI-408R-03 recommendations.
- FE model showed reasonable agreement with test results.
- Future work needed: evaluation of UHPC as wearing surface, Field implementation and monitoring under traffic, and optimizing the section for lower weight.
ALUMINUM BRIDGE DECK
INTRODUCTION

- Developed by **SAPA group** of Sweden
- Self-weight = **14 lb/ft²**
- **Corrosion resistant**
- Check the system for **American loading conditions** (HS 20 truck loading)
<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Description of Test</th>
<th>Schematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flexural Tests</td>
<td><img src="image1" alt="Schematics" /></td>
</tr>
<tr>
<td></td>
<td>• Simple-Span Test</td>
<td><img src="image2" alt="Schematics" /></td>
</tr>
<tr>
<td></td>
<td>• Two-Span Continuous Test</td>
<td><img src="image3" alt="Schematics" /></td>
</tr>
<tr>
<td></td>
<td>• Simple-Span Inverted Panel Test</td>
<td><img src="image4" alt="Schematics" /></td>
</tr>
<tr>
<td>2</td>
<td>Shear Test for Connectors</td>
<td><img src="image5" alt="Plan View" /></td>
</tr>
<tr>
<td></td>
<td>Test Description</td>
<td>Diagram</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>2</td>
<td>Shear Test for Connectors</td>
<td><img src="#" alt="Plan View" /></td>
</tr>
<tr>
<td>3</td>
<td>Uplift Test for Connectors</td>
<td><img src="#" alt="Elevation" /></td>
</tr>
<tr>
<td>4</td>
<td>Lip Test (Tongue and Groove Test)</td>
<td><img src="#" alt="Plan View" /></td>
</tr>
<tr>
<td>5</td>
<td>Fatigue and Residual Strength Tests</td>
<td><img src="#" alt="Plan View" /></td>
</tr>
<tr>
<td></td>
<td>- Fatigue Test</td>
<td><img src="#" alt="Plan View" /></td>
</tr>
<tr>
<td></td>
<td>- Residual Strength Tests</td>
<td><img src="#" alt="Plan View" /></td>
</tr>
</tbody>
</table>
SIMPLE-SPAN TEST

![Graph of Load vs. Deflection for Simple-Span Test](image)

- **Load (kips)**
  - 0 to 80
- **Deflection (in.)**
  - 0.0 to 2.0

The graph shows the relationship between load (kips) and deflection (in.) for a simple-span test.
TWO-SPAN CONTINUOUS TEST

Load (kips)

Deflection (in.)
SIMPLE-SPAN INVERTED TEST

![Graph showing load vs. deflection](image)

- **Load (kips)** range from 0 to 40
- **Deflection (in.)** range from 0 to 3

The graph illustrates the relationship between load and deflection in a simple-span inverted test.
DECK-TO-GIRDER CONNECTION: SHEAR TEST

- Shear Demand (0.70 kips)
- Failure of First Clamp
- Failure of Second Clamp

Graph showing the relationship between load (kips) and displacement at the top (in.).
DECK-TO-GIRDER CONNECTION: UPLIFT TEST

- Load (kips) vs. Deflection (in.)
- Required Capacity from One Clamp

Photos of uplift test equipment.
DECK-TO-DECK CONNECTION

Required Capacity for HS 20 Wheel Load (37.24 kips)
FATIGUE TEST

Number of Load Cycles (Log Scale)

Deflection (in.)

Span-1

Span-2

D1
D2
D3
D4
D5
D6

1,000 10,000 100,000 1,000,000 10,000,000
RESIDUAL STRENGTH TEST: LOAD ON THE JOINT

Load (kips) vs. Deflection (in.)

- **D4**
- **D5**
- **D6**

Load on Lip Joint

*Image of equipment setup for load test.*
RESIDUAL STRENGTH TEST: LOAD BETWEEN THE JOINTS

![Graph showing load versus deflection for joints D1, D2, and D3.](image)

- **D1**: Load between Joints
- **D2**: Load between Joints
- **D3**: Load between Joints

- **Deflection (in.)** range: 0.0 to 0.6
- **Load (kips)** range: 0 to 120

---

The graph illustrates the relationship between the load applied between the joints and the resulting deflection. Each joint (D1, D2, D3) shows a different line, indicating how the deflection changes with applied load.
Aluminum bridge deck panel is a feasible alternative to the open grid steel decks.

Two million cycles of AASHTO-specified fatigue loading on deck panels did not show any sign of global or local failure in the deck panels. Failure of a bolted connection during the fatigue testing was attributed to the fact that only half of the manufacturer-specified bolted clamps were used.

Even though deck panels were loaded up to 100 kips in the two residual strength tests, the extreme fiber stresses remained well within their elastic range.

Deck-to-girder connections proved adequate for the braking force and the uplift wind.

Future work needed: Evaluation of available wearing surfaces, such as Acrydur®, poured mastic asphalt, or UHPC, and Field monitoring of aluminum deck under ambient traffic and designated truck loading.
UHPC-FRP TUBES DECK
INTRODUCTION

- Hollow core deck
- Steel-free
- Preliminary experimental work
TEST MATRIX

Uniform Deck Section

Tapered Deck Section
SCHEMATICS OF SPECIMENS

Uniform Deck Section

4-¼ in. 12 in.

Tapered Deck Section

5 in. 1 in. 1 in. 13 in.

Support Section

4 in. 1-½ in. 13 in.

Mid-Span Section
TEST RESULTS: UNIFORM SECTION

Load (kips) vs Deflection (in)

- Slip
- D1
- D2
- D3
TEST RESULTS: TAPERED SECTION

Load (kips) vs. Deflection (in) graph showing:
- D3
- D1, D2
- Slip

Additional images of the test setup and results.
The system has shown good promise to replace the conventional open steel grid decks. Based on the ultimate loads of the two simple-span specimens, it can be inferred that the multi-unit system will achieve the target load.

Both specimens failed suddenly in compression. However, the uniform section deck specimen had significant tensile cracks, as opposed to the tapered section deck that developed no tensile cracks.

Greater composite behavior between UHPC and FRP tubes was observed for the uniform section deck specimen, mainly because the FRP tubes were fully encased in UHPC throughout the span length.

Future work needed: revised section to integrate the two components better, develop connections, and assess fatigue behavior.
GOING FORWARD

- Optimizing UHPC Deck
- New Generation of UHPC – FRP Deck
- Field Implementations
THANK YOU

QUESTIONS?