Laboratory Evaluation of Fiber-Reinforced Polymer Dowel Bars for Jointed Concrete Pavements

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Introduction

• LTE controls ride quality and structural life
• LTE by aggregate interlock or dowel bars
• Aggregate interlock reduced by
  – abrasion & shrinkage
  – slabs thermal contraction
• Steel dowel bars are susceptible to corrosion
• Low LTE $\rightarrow$ cracking & faulting
UCPRC Project on Dowel Bar Retrofit

• General objective: Evaluate DBR and best options for implementation

• Work components
  1. APT testing
  2. Lab testing
     – steel dowel corrosion
     – FRP
  3. Field Live Traffic Testing
  4. …Modeling (FEM, LCCA)
APT Testing
HVS testing, Ukiah

Results:

- No damage to any of the DBR joints, or loss of LTE
- Greater increase in deflections at non-DBR joints

Epoxy-coated steel dowels
HVS testing, Palmdale

Results:

- No damage to any of the DBR joints, or loss of LTE
- Fatigue cracking of the slab

1. Epoxy-coated steel
2. Hollow stainless steel dowels
3. Fiber-reinforced polymer (FRP)
Palmdale DBR

- Epoxy
- Hollow Epoxy
- Epoxy (3)
- FRP
- Epoxy
- FRP
- Epoxy
- FRP
- Epoxy
- FRP
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- Epoxy
- FRP
- Epoxy
- FRP
Dowel types in Palmdale DBR

1. Epoxy-coated steel
2. Hollow stainless steel dowel
3. Fiber-reinforced polymer (FRP)
Lab: Corrosion of steel dowels
Lab testing: corrosion

1. bare carbon steel
2. stainless steel clad
3. grout-filled hollow stainless steel
4. microcomposite steel
5. carbon steel coated with flexible epoxy (green)
6. carbon steel coated with non-flexible epoxies (purple)
7. carbon steel coated with non-flexible epoxies (gray)

Results:
1. Recommend that **uncoated carbon steel dowels** not be used
2. Epoxy dowels present risk of corrosion at scrapes and the ends
3. Recommend use of **stainless steel clad, hollow stainless steel, or micro-composite** for locations with risk of high chloride exposure
Regular steel dowels
Epoxy-coated steel

- Defects are inevitable
  - pinholes, voids and mechanical scrapes & scratches (macroscopic and microscopic)
- Localized corrosion initiated at the defects
  ➔ accumulated oxide will further lift the coat
Problems at joints w/corroded bars

- Corrosion products expand and lock the joints
  - Expansive products $\text{Fe(OH)}_2$, $(\text{Fe}_3\text{O}_4)$ and $(\text{Fe}_2\text{O}_3)$
    Volume 6 times greater

- Decreased LTE due to volume reduction after the corrosion products are washed away

- Cracking concrete
  Corrosion $\rightarrow$ spalling & transverse cracking
Lab: FRP Evaluation
FRP

- High strength-to-weight ratio
- Excellent resistance to electrochemical corrosion
- Used extensively to repair and strengthen reinforced concrete beams and columns
Caltrans’ Questions

• Are the mechanical properties of FRP dowels adequate to perform acceptably (compared to steel dowels)?

• Are the FRP mechanical characteristics negatively affected by environmental factors?
Experimental Set Up

• The study consisted of evaluating the flexural and shear properties of glass FRP dowel bars
• 1.5-in diameter and 18-in long, from 2 manufacturers
## Properties of the FRP dowel bars

<table>
<thead>
<tr>
<th></th>
<th>Type A</th>
<th>Type B</th>
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</thead>
<tbody>
<tr>
<td>Glass fiber content</td>
<td>70%</td>
<td>Min. 65%, typical 72-73%</td>
</tr>
<tr>
<td>Glass type</td>
<td>E-type glass</td>
<td>E-type glass</td>
</tr>
<tr>
<td>Matrix type</td>
<td>Polyester resin</td>
<td>Epoxy Vinyl Ester resin</td>
</tr>
</tbody>
</table>
Conditioning

1. Alkaline solution
   • glass FRP could be highly sensitive to alkaline attack
   • specimens submerged in alkali solution for 3 months
   • pH level for the alkali solution was 13.5

2. Water
   • Simulate high moisture content
   • submerged in water for 3 months in plastic tanks

3. Ultraviolet radiation
   • bond dissociation between fiber and matrix
   • bars exposed to direct sunshine for 2 months (July and August)
Results outline

- Flexural Tests
  - Flexural Stiffness
  - Flexural Strength
  - Flexural Fatigue

- Shear Tests
  - Shear Strength
  - Shear Fatigue

- Direct shear strength
1. Type B is 20% stiffer than Type A bars
2. Type A bars unaffected by conditioning processes
3. Stiffness in conditioned Type B bars decreased:
   - 4% for water conditioned
   - 6% for UV conditioned specimens

- 20°C
- Avg loading freq. of 2, 6, and 10 Hz
- Two replicates
- COV <2%
1. Type B is stiffer than Type A bars
2. Frequency (2 to 10 Hz) had no effect on dowel stiffness
3. Temperature effect
Stiffness versus temperature

At 40°C bars are softer than at 20°C.
→ 9% for Type A
→ 15% for Type B

Should not significantly impair the pavement’s performance:

FEM → max concrete stress is mostly unaffected when
dowel stiffness changes 10 – 20%
1. Type B strength is 80% greater than Type A
2. 1% < COV < 4%, except for one (two replicates).
3. Type B alkali conditioned bars:
   - COV =19% (four replicates)
   - More on that
Damage on Type B bars after exposure to alkaline solution

- Visible cracks on one or both ends of the dowel
- Cracks could be observed before any load application
- Only on alkali conditioned specimens
Flexural Fatigue

\[ n = 10^{(12.75 - 12.74S)} \] , \hspace{1cm} R^2 = 0.9475
Stiffness during flexural fatigue

All tested specimens tend to fail when the stiffness drop to 15 – 20 GPa
Shear strength

- Control
- Alkali conditioned
- Water conditioned
- UV conditioned

Shear Strength (MPa)
Shear fatigue life

Shear fatigue life, $n$ (cycles).

Type A > Type B bars in shear fatigue life
Direct shear
Direct shear strength

![Bar chart showing direct shear strength of Type A and Type B materials under control, alkali conditioned, water conditioned, and UV conditioned conditions.](chart)
Summary and conclusions

1. Stiffness for FRP bars:
   - It’s not influenced by loading frequency (in the range of 2 to 10 Hz)
   - It is affected by testing temperature (<20% at 40°C)

2. Type B bars are ~20% stiffer, 80% stronger in bending, and 100% stronger in shear than Type A bars

In bending, Type B are two times stronger than typical steel bars
Type A bars are ~30% stronger than steel
Summary and conclusions

3. Strength of Type B bars might be reduced by the high pH environment within the concrete slabs
   – Type A bars were not affected by any of the three conditioning types
   – Water and UV conditioning had no effect in either Type A or B bars
Summary and conclusions

4. Fatigue

- both types of bars offer similar flexural fatigue performance
- greater number of shear cycles can be expected from Type A bars
- At low stress ratio (0.3 to 0.4), both types of FRP bars will likely survive more than 100 millions wheel load repetitions
Thanks

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