DEVELOPMENT OF CONSTRUCTION SPECIFICATIONS FOR TWO-DIMENSIONAL (2-D) FRP GRIDS AS REINFORCEMENT IN THIN OVERLAYS, TOPPING SLABS AND SLABS-ON-GRADE

SUMMARY
This report presents the experimental work performed to study the feasibility of two-dimensional (2-D) fiber-reinforced polymer (FRP) grids as a non-corrosive alternative for reinforcement in thin overlays, topping slabs and slabs-on-grade. In order to optimize the application of FRP grids, experimental investigation was conducted to address: the optimal grid location in thin overlays, the optimal installation technique, the influence of the grid geometry, and influence of the placement of the grid on an existing substrate.

The reported experimental work was conducted during the period August to October 2005. A total of 17 slabs were poured in two different phases. The variables investigated were: grid density and location, and installation methods. The performances of the grid reinforced specimens were established by comparing them to control specimens. Such control specimens consisted of unreinforced overlays, as well as overlays reinforced with traditional welded-wire reinforcement (WWR), and slabs made with fiber-reinforced concrete (FRC).

Several variables were monitored: slump for the mix, surface temperatures (bottom and top) of the slabs, environmental temperature, and humidity. The performance of the reinforcement and its effectiveness in controlling shrinkage was monitored in term of location and size of the cracks.

The data, information, and understanding from of these experiments will be used in the drafting of construction guidelines for overlays to be reinforced with 2-D FRP grids. These guidelines will cover materials specification, storage, handling and installation process.
1. INTRODUCTION

The use of alternate, non-corrosive reinforcement such as fiber-reinforced polymers (FRP) bars and tendons has lately received much attention. There is limited information, however, with respect to the use of two-dimensional (2-D) FRP grids as reinforcement in thin overlays, topping slabs and slabs-on-grade.

Fiber-reinforced concrete (FRC) in construction of ground supported floor slabs has become common for a number of reasons that include ease of construction and potential cost savings (Fitzpatrick 1996; Knapton 1999). In addition, increases in the strength of concrete are sometimes expected with the use of fibers, resulting in the possibility of thinner floor slabs (Knapton 1999), while the promise of jointless floors has also been promoted (Hartmann et al. 1999).

The design and subsequent performance of slabs-on-ground is mainly affected by three parameters: 1) slab thickness and subgrade support, 2) type and spacing of joints, and 3) load transfer across joints and cracks. Other parameters such as concrete quality, warping or curling (Walker and Holland 1999), floor finishing, and moisture control do also play a role. Slab thickness is often emphasized in design, and depends on the magnitude and type of loading conditions, subgrade support, stiffness of slab, and concrete flexure strength. The main objective is to limit the estimated (elastic) tensile stresses in a plain (un-reinforced) concrete slab to an allowable value equal to the tensile flexure strength divided by an appropriate safety factor in order to reduce the likelihood of cracking in the slab (Westergaard 1926). Distributed steel in addition to appropriate joint spacing can then be used to control random cracking (ACI 2004; Farny 2001).

In order to study the feasibility of FRP grids as internal reinforcement of thin slabs, experimental work was conducted in the University of Missouri-Rolla during the period August to October 2005. A total of 17 slabs were poured in two different phases. For the first phase a total of eight slabs were poured, emphasizing the effect of grid density and grid location, while for the second phase the installation methods like chairing and rakes were studied. For both series, control slabs were also designed for comparison purposes. These control slabs consisted in overlays with no reinforcement, as well as reinforced slab with the traditional welded-wire reinforcement (WWR) (Bischoff et al. 2003) and slabs made with fiber-reinforced concrete (FRC).

Several variables were monitored: slump for the mix, surface temperatures (bottom and top) of the slabs, environmental temperature, and humidity. The performance of the reinforcement and its effectiveness in controlling shrinkage was monitored in term of location and size of the cracks.
2. EXPERIMENTAL WORK

2.1 Substrate
The present study is concerned to thin overlays and topping slabs poured over existing slabs. Two-phase was planed for a total of 17 slabs poured over an existing substrate. These substrate slabs were poured at the School of Mine of the University of Missouri-Rolla. Substrate consisted of two 30 x 30 ft slabs of 4-in depth reinforced with welded-wire steel reinforcement. Figure 1 shows the different phases of the substrate construction as a first stage for the experiments.

![Figure 1. Construction of the first Substrate.](image)

2.2 First phase

2.2.1 Test Matrix and Construction
This first phase of experiments was designed to determine the effect of the 2-D FRP grids density and location, and installation methods on the shrinkage. The FRP grids (See Appendix for technical information) are high performance reinforcement, light weight, high strength and non-corrosive manufactured by TechFab (http://www.techfabllc.com). Two different grids were used with different spacing: the grid types C5500-NX1 (2.0 x 2.0 in) and C2750-BX1 (2.2x 2.2 in). Table 1 shows the test matrix for this phase. Slabs are presented in the same order as they were poured in the field. Slabs number 2, 3 and 4 represent the control
slabs: 6 x 6 in welded-wire reinforcement (WWR), no reinforcement and Fiber-reinforced concrete (FRC).

Figure 2 shows the setup for slabs 1, 3, 5 and 7 (from right to left in the picture). These slabs were poured the same day. The rest of the slabs (2, 4, 6 and 8) were cast the next day. Grid for slabs 1 and 5 are at the bottom. Slab 3 corresponds to control slab (no reinforcement), so the grid in the Figure 3 was remove before the pouring. Figure 3 shows the poring of slab 7, NX1 placed at the center. It was poured half of the depth (one inch). After that the grid was collocated and finished with the additional one-inch of concrete. Figure 4 shows the finishing of the slabs.

Slabs number 2, 4, 6 and 8 were poured the next day with no additional control slabs. Slab 6, where the grid was pushed down from the top collocation can be seen in Figure 5. A third pouring was done for the fiber reinforced concrete (FRC) slab. The material used was Fibermesh polypropylene fibers 4.5 in long at a proportion of 4.5 pound per concrete cubic yard. Figure 6 shows the installation of thermocouples for the monitoring of internal temperature in the concrete. Four thermocouples per slab were installed, two on top and two at the bottom. In Figure 7 shows all the cured slabs and the thermocouples.

Table 1. Test Matrix

<table>
<thead>
<tr>
<th>Slab No.</th>
<th>Thickness (in)</th>
<th>Grid Description</th>
<th>Grid Description</th>
<th>Grid Location</th>
<th>Method of Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>C2750-BX1</td>
<td>2.0” x 2.0”</td>
<td>Bottom</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>WWR</td>
<td>------</td>
<td>Center</td>
<td>Chairs</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>None</td>
<td>------</td>
<td>------</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>FRC</td>
<td>------</td>
<td>------</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>C5500-NX1</td>
<td>2.2” x 2.2”</td>
<td>Bottom</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>C5500-NX1</td>
<td>2.2” x 2.2”</td>
<td>Top (1/4” down)</td>
<td>Pushed down</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>C5500-NX1</td>
<td>2.2” x 2.2”</td>
<td>Center</td>
<td>Placed in center</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>C5500-NX1</td>
<td>2.2” x 2.2”</td>
<td>Center</td>
<td>Bottom</td>
</tr>
</tbody>
</table>

Figure 2. Setup for slabs
Figure 3. Setup for slabs of 7: Center Placed.

a) Pouring of half of the slab
b) Collocation of the Grid at Center

Figure 4. Construction of Slabs.

a) Pouring of Slab 5: NX1 Bottom
b) Finishing for Slabs

Figure 5. Setup for slabs 6: Nx1 pushed from the top.
a) Installation of Thermocouplers  
b) Data Acquisition System  

Figure 6. Internal temperature Monitoring.

Figure 7. The first phase of slabs.

2.2.2 Concrete Slump.  
Being workability a critical issue in the installation of FRP grids in thin slabs, super plasticizer was used to control the slump for the three different pouring. Figure 8 shows the slump control for one of the pouring. Limitation due to potential segregation of the concrete limited the slump. Table 2 shows the slump for the three pouring.

<table>
<thead>
<tr>
<th>Pouring</th>
<th>Slabs</th>
<th>Slump (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 3, 5, 7</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>2, 4, 6, 8</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>3 (FRC)</td>
<td>8.25</td>
</tr>
</tbody>
</table>
2.2.3 Concrete Strength.
Cylinders were taken for the three pouring and tested for 1, 3, 7, and 28 days. Figure 9 shows a cylinder test after one day of pouring. Table 3 shows the results for the cylinder tests.

![Figure 9. Cylinder Test after One Day](image)

<table>
<thead>
<tr>
<th>Pouring (day): Slabs</th>
<th>Cylinders Strength Through Time (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 day</td>
</tr>
<tr>
<td>First (09/07/05): 1, 3, 5, 7</td>
<td>2623 2061</td>
</tr>
<tr>
<td>Second (09/08/05): 2, 6, 8</td>
<td>1083 1018</td>
</tr>
<tr>
<td>Third (09/08/05): 4 (FRC)</td>
<td>2493</td>
</tr>
</tbody>
</table>
2.2.4 Cracks Monitoring.

Cracks were monitored hourly (Figure 10), and their average depth determined by using a crack scope (Figure 11). The use of water allowed visualizing some crack patterns not otherwise visible (Figure 12). Crack mapping and average crack size are summarized in Figure 13
Figure 12. Crack Pattern in Slabs
2.3 Second phase of experiments.

2.3.1 Test Matrix and Construction.

The second phase of experiments was designed to determine the effect of installation methods. The grids, type C5500-OX1 (2.9 x 2.9 in) and C5500-NX1 (2.2 x 2.2 in) were installed at center of 2 and 3-in slabs using chairs and rakes to determine their effects on the shrinkage. Table 4 shows the test matrix. Similar to the first phase, three pouring were made. Specimens are presented in the same order they were poured in the field. Slabs number 1, 3, 8 and 9 represent the control slabs: no reinforcement (first and second pouring), 6 x 6 in welded-wire reinforcement (WWR), and Fiber-reinforced concrete (FRC).

Figure 14 shows the setup for slabs 1, 2, 4 and 7 of the first pouring, corresponding to grids with chairs. Figure 15 shows the pouring of the slabs utilizing chairs and points out problems occurred during the installation.

The slabs 5 and 6 were cast the next day and correspond to grids to be placed at center by rakes. Additional control slab was cast (number 3 in the matrix). Figure 15 shows the pouring of slabs with chairs, separated longitudinally and transversally by one foot. Figure 15-a shows that by using this method, only the region close to the chair remain in the center while the rest tend to bend under the weigh of the concrete.

![Figure 13. Map of Cracks after 28 Days](image-url)
Table 4. Test Matrix

<table>
<thead>
<tr>
<th>Slab No.</th>
<th>Thickness (in)</th>
<th>Grid Description</th>
<th>Grid Description</th>
<th>Grid Location</th>
<th>Method of Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>None 1st Pouring</td>
<td>------</td>
<td>------</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>C5500-OX1 2.9’’x 2.9’’ Center Chairs</td>
<td>-----</td>
<td>-----</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>None 2nd Pouring</td>
<td>------</td>
<td>------</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>C5500-OX1 2.9’’x 2.9’’ Center Chairs</td>
<td>-----</td>
<td>-----</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>C5500-NX1 2.9’’x 2.9’’ Center Rakes</td>
<td>-----</td>
<td>-----</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>C5500-NX1 2.2’’x 2.2’’ Center Rakes</td>
<td>-----</td>
<td>-----</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>C5500-NX1 2.2’’x 2.2’’ Center Chairs</td>
<td>-----</td>
<td>-----</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>WWR ------</td>
<td>------</td>
<td>Center Chairs</td>
<td>Chairs</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>FRC ------</td>
<td>------</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Figure 14. Setup for slabs with Chairs

- a) Chairs separate at one foot
- b) Collocation of Plastic Chairs

Figure 15. Pouring of slabs with Chairs

- a) Bending of the Grid with Chairs
- b) Leveling of Slabs
A third pouring was done for the fiber reinforced concrete (FRC) slab. Material and the proportion are the same described in section 3.2.1. Finally Figure 16 shows the installation of the grids by rakes; such installation technique should be avoided since the grids brake during the lifting even with very viscous concrete.

![Image](image1.png) ![Image](image2.png)

**Figure 16. Installation of Grids with Rakes**

**2.3.2 Concrete Slump.**
Superplasticizer was used to control the slump for the three different pouring. Table 5 shows the final slump for the three pouring.

<table>
<thead>
<tr>
<th>Pouring</th>
<th>Slabs</th>
<th>Slump(In)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2, 4, 7</td>
<td>6.25</td>
</tr>
<tr>
<td>2</td>
<td>3, 5, 6, 8</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>9 (FRC)</td>
<td>7</td>
</tr>
</tbody>
</table>

**Table 5. Concrete Slump**

**2.3.4 Cracks Monitoring**
The second phase of experiments was performed in middle October. Even though the pouring was performed at a temperature of 68 F, the temperature decreased after three days to 40 F and less. For this reason, in the month of December no cracks had appeared for the slabs.
3. DESTRUCTIVE TESTS

Figure 17 shows the process for extraction of specimens for beam tests. The testing of these samples together with the pull-out tests was unsuccessful since no bond was found between the overlay and the substrate (see Figure 18).

a) Marks for beam test  
b) Cutting of Samples

**Figure 17. Extraction of Specimens for Testing**

**Figure 18. Disbond between substrates**
4. PRELIMINARY CONCLUSION

This report presents the experimental work performed to study the feasibility of two-dimensional (2-D) fiber-reinforced polymer (FRP) grids as a non-corrosive alternative for reinforcement in thin overlays, topping slabs and slabs-on-grade. The data, information, and understanding from these experiments will be used in the drafting of construction guidelines for overlays to be reinforced with 2-D FRP grids. These guidelines will cover materials specification, storage, handling and installation process.

For the first phase, intended to determine the effect of grid density, grid location on the shrinkage, 8 slabs were poured: 5 slabs using FRP grids and three control slabs (no reinforcement, WWR and FRC) were done. The common pattern consisted in a crack through the entire section at approximately mid span. Nevertheless, for FRC and slab where the grid was pushed down from the top presented a more distributed pattern of cracks. This could have been induced by remain void after the workers pushed down the grid walking over it. This is the worse in term of cracking but not “difficult” in terms of installation. Slabs where grids were located at the bottom, only one crack appear in contrast with the two-crack pattern showed for control slab (no reinforcement and WWR).

Workability in thin overlays by using super plasticizer is limited due to the potential segregation of the concrete.

In second phase, where installation methods were emphasized, the uses of rakes break the grids and made the operation difficult. Plastic chairs are difficult because they tend to bend and the floating of the grid can not be avoided.

A great potential was found in terms of performances and installation for very thin overlays in which the grid is laid directly on the substrate. More experimental evidences are however needed to confirm such conclusion.
5. REFERENCES


WANT MORE INFORMATION?
Details on this test program and additional data can be found in the final report.

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