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.

a) Laying of Steel Reinforcement

b) Pouring of Concrete

c) Texturing

d) Protection Against the rain

Figure 1. Construction of the first Substrate.

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

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

Figure 2. Setup for slabs

a) Pouring of half of the slab

b) Collocation of the Grid at Center

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

a) Pouring of Slab 5: NX1 Bottom

b) Finishing for Slabs

Figure 4. Construction of 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 2. Concrete Slump

Pouring	Slabs	Slump(in)
1	1, 3, 5, 7	5.5
2	2,4,6,8	7.5
3	3 (FRC)	8.25

Figure 8. Slump Control.

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

Table 3. Concrete Strength

Pouring (day): Slabs	Cylinders Strength Through Time (psi)			
	1 day	7 days	14 days	28 days
First (09/0705): 1, 3, 5, 7	2623 2061	2851 2813 2809	3626 3777	4814 4779 4543 4484
Second (09/08/05): 2, 6, 8	1083 1018	2237 2227 1938	3029 3015 2874	3315 3271 3246 2919 2787
Third (09/08/05): 4 (FRC)	2493	4532	---	5396

2.2.4 Cracks Monitoring.

a) Monitoring of Cracks During Night

b) Monitoring of Cracks During Day

Figure 10. Monitoring of Cracks.

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 11. Average Crack width using Crack Scope.

a) Transversal Cracks in Slabs

b) FRC Slab

c) Cracks for Slabs 6 (Pushed down)

d) Transversal Crack in Control Slab

Figure 12. Crack Pattern in Slabs

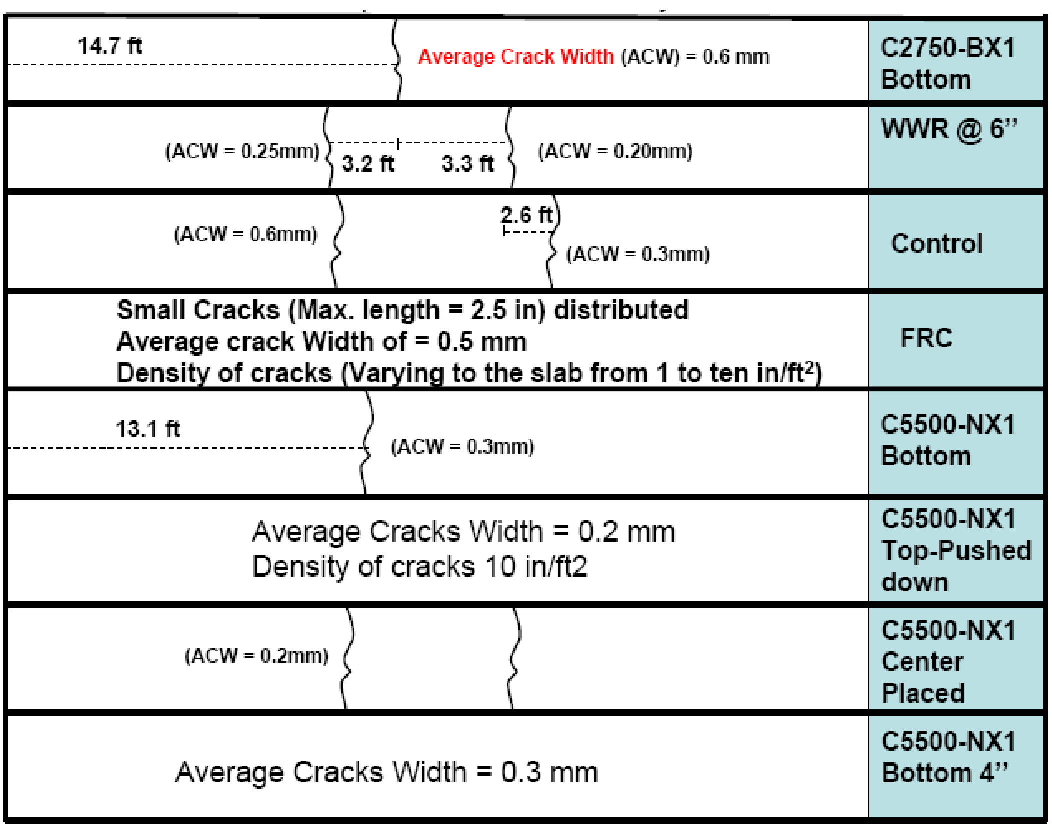


Figure 13. Map of Cracks after 28 Days

2.3 Second phase of experiments.

2.3.1 Test Matrix and Construction.

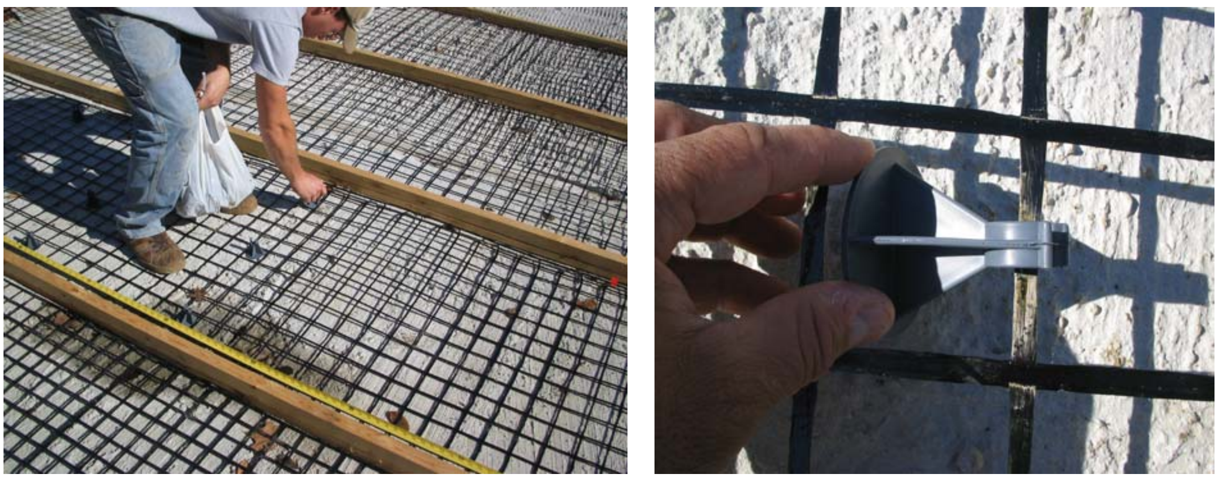
The second phase of experiments was designed to determine the effect of installation methods. The grids, type C5500-OX1 (2.9 x 2.9 in) and C5500-NX1 (2.2 x 2.2 in) were installed at center of 2 and 3-in slabs using chairs and rakes to determine their effects on the shrinkage. Table 4 shows the test matrix. 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.

Table 4. Test Matrix

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



a) Chairs separate at one foot

b) Collocation of Plastic Chairs

Figure 14. Setup for slabs with Chairs

a) Bending of the Grid with Chairs

b) Leveling of Slabs

Figure 15. Pouring of slabs with Chairs

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.

a) Collocation of Grids with Rakes b) Break of the Grids

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 5. Concrete Slump

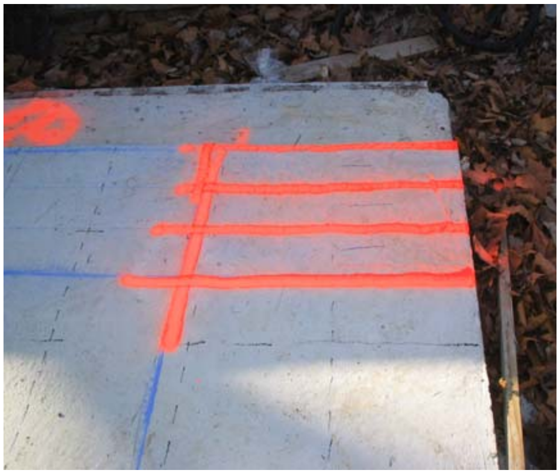
Pouring	Slabs	Slump(In)
1	1, 2, 4, 7	6.25
2	3, 5, 6, 8	6.5
3	9 (FRC)	7

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 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.

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

American Concrete Institute (ACI) (2004). ‘‘Guide for Concrete Floor and Slab Construction.’’ ACI 302.1R-04, Detroit.

Bischoff, P. H., Valsangkar, A. J., and Irving, J. (2003). “Use of Fibers and Welded-Wire Reinforcement in Construction of Slabs on Ground” practice periodical on structural design and construction, ASCE, 41-46

Farny, J. A. (2001). ‘‘Concrete floors on ground.’’ Engineering Bulletin EB075, 3rd Ed., Portland Cement Association, Skokie, Ill.

Fitzpatrick, R. (1996). ‘‘Designing durable industrial floor slabs.’’ Concr. Int., 18(1), 38–39.

Hartmann, V., Rothenbacher, W., and Schwenk, E. (1999). ‘‘Fugenloser Industriefussboden aus Hochleistungsbeton B85 (Jointless industrial floors with high performance 85 MPa concrete).’’ Industrial Floors ’99, Proc., 4th Int. Colloquium, P. Seidler, ed., Technische Akademie, Esslingen, Germany, 215–217.

Knapton, J. (1999). Single pour industrial floor slabs: Specification, design, construction and behavior, Tomas Telford, London.

Walker, W. W., and Holland, J. A. (1999). ‘‘Design, materials, and construction considerations for reducing the effects of concrete floor curling (warping) and shrinkage.’’ Industrial Floors ’99, Proc., 4th Int. Colloquium, P. Seidler, ed., Technische Akademie, Esslingen, Germany, 171–180.

Westergaard, H. M. (1926). ‘‘Stresses in concrete pavements computed by theoretical analysis.’’ Public Roads, 7(2), 25–35.

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

CONTACT

Nestore Galati, Ph.D.
Research Engineer
University of Missouri - Rolla
Tel: (573) 341-6223 Fax: (573) 341-6215
Email: galati@umr.edu

Antonio. Nanni, Ph.D., P.E.
Jones Professor of Civil Engineering
University of Missouri - Rolla
Tel: (573) 341-4553 Fax: (573) 341-6215
Email: nanni@umr.edu