# EXPERIMENTAL STUDY OF POROUS CONCRETE SLABS ON GRADE WITH DIFFERENT REINFORCING SCHEMES

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ABSTRACT: Porous concrete is being used as a pavement system due to its ability to drain, manage and collect storm water, and is thus regarded as a sustainable pavement system. This paper presents an experimental program conducted with the objective of investigating the structural performance of pavements made of porous concrete, as well as exploring several schemes for strengthening this type of pavements. Within the conducted experimental program, special mix proportions were used to yield porous concrete mix, then twelve porous concrete slabs having dimensions 1000 * 1000 * 150 mm were cast and tested. Two slabs were taken as reference, four slabs had 0.1% and 0.2% fibrillated polypropylene fibres added to the mix for reinforcement, four slabs were strengthened by two types of geogrid and the remaining two slabs were strengthened using glass fibre-reinforced polymer (GFRP) rods. The tested slabs were placed over a stiff rubber layer and the load was applied on a circular plate placed at the center of the slabs. The load was increased up to failure and the deformations and strains were recorded. The obtained results showed enhancement of the load carrying capacity, stiffness, toughness and ductility of the tested slabs containing the geogrid. The highest values for ultimate load were for slabs reinforced with GFRP rods, then for slabs reinforced with the two types of geogrid, and the lowest values were for slabs with fibrillated polypropylene fibres added to the mix.

## INTRODUCTION

Porous or pervious concrete is a special high porosity concrete used for applications that allows water to pass through. Porous concrete pavement is considered a sustainable road pavement system due to its ability to drain, manage and collect storm water in addition to other benefits such as noise reduction.  The pavement system consists of three layers: a top porous concrete layer, a sub base layer of aggregate for water storage in the middle and sub grade soil layer below. It has been in use for many years as pavement for low volume traffic applications, sidewalks, and parking lots[1].

Porous concrete was first reported to be used in the residential buildings walls in Europe in 1852. In the U.S., porous concrete is generally used in residential streets, driveways and paths, sidewalks, and parking lots for storm water management[1]. It has also been used in low volume highway applications in Minnesota and in Europe, Australia, and Japan. Porous concrete pavement is better than asphalt or ordinary concrete pavement environmentally. Its use has numerous environmental benefits including improved water quality, better maintenance of water levels, and improved land utilization [2]. Other benefits include reduced hydroplaning and glare, and reduced road noise compared to traditional pavements [1]. High penetration velocity of water into pervious concrete has led into using this kind of pavement in other cases such as hydraulic structures, tennis courts, greenhouses and as a base course of heavy traffic pavements [3]. However, because of lower durability and strength of porous concrete, compared to ordinary ones, its application is only in regions with low traffic congestion [3]. Since fine aggregates content is low or sometimes there are no fine aggregates in porous concrete, cement paste covers coarse aggregates and preserves integrity of voids. Void content of porous concrete is usually 15–25%, and it is compressive strength is about 2.8–28 MPa [4, 5].

This paper aims to investigate the structural behavior of porous concrete pavements under vertical loading conditions and explore the effectiveness of some suggested strengthening schemes. An experimental program was conducted, and the obtained results are presented and discussed.

## EXPERIMENTAL PROGRAM

An experimental program was conducted in order to investigate the structural behavior of slabs made of porous concrete and enhanced with different strengthening schemes under static vertical loads. The proposed strengthening schemes were made using fibrillated polypropylene fibers, geogrid and glass fiber-reinforced polymer (GFRP) bars, as described below. The experimental work was conducted in the Materials Testing Laboratory at the Housing and Building Research Center, Cairo, Egypt.

### *Materials and Mix Proportions*

The porous concrete mix used in the present work is chosen based on a previous research work by the authors where several porous concrete mixes were designed and tested in order to optimize the strength and permeability [6]. The mix having optimum properties was chosen for the present work, with the mix proportions given in Table 1.

The cement used for the experimental work was Portland cement CEM type I 42.5 N (El-Suez Cement Company) meeting the requirements of ES 262/1988. The coarse aggregate used for concrete mixes was natural gravel of nominal maximum size 10 mm for aggregate size 1. Natural siliceous sand with a round particle shape and smooth texture with fineness modulus of (2.75) was used, with grading curve lies between the upper and the lower limits of BS 1377, BS 812 requirements. The specific gravity and volumetric weight of the used sand were 2.6 and 15 kN/m³, respectively. Super plasticizer admixture type R 2004 from Sika was used with 0.5% by weight of cement, and tap water was used for mixing and curing of test specimens.

As strengthening techniques for the slabs, fibrillated polypropylene fibres were added to the mix by percentage 0.1% by weight of cement for two slabs and by 0.2% for two slabs. Geogrid of two types was used for strengthening, type I has aperture size (50x50 mm) and type II (30x30 mm). The GFRP rods have the mechanical characteristics listed in Table 2. Thw strengthening materials are shown in Figure 1.

Table 1: Mix proportions for one cubic meter of porous concrete

| *Cement* $kg/m^3$ | *Coarse aggregate* $kg/m^3$ | *Fine aggregate* $kg/m^3$ | *Water content* $kg/m^3$ | *Super plasticizer* $lt/m^3$ |
|---|---|---|---|---|
| 558 | 1561.12 | 212.88 | 150.8 | 2.8 |

Table 2: Properties of glass fiber polymer (GFRP) bars

| *Diameter (mm)* | *Ultimate tensile stress* $f_u$ *(N/mm²)* | *Modulus of elasticity* $E_f$ *(kN/mm²)* | *Rupture strain* $\varepsilon_{fu}$ |
|---|---|---|---|
| 12 | 347.50 | 32.67 | 0.05 |

(a) (b) (c) (d)

Figure 1. The used strengthening materials: (a) fibrillated polypropylene fibers, (b) geogrid type I, (c) geogrid type II and (d) GFRP bars

### *Specimens Preparation*

The test specimens were 12 (twelve) square slabs with dimensions (1000 x 1000 x 150 mm). Constituents for all mixes were weighed according to the mix proportions shown in Table 1. Mixing was made in a pan-type mechanical mixer at room temperature, and the concrete was cast in clean wooden moulds coated with oil. The concrete was hand compacted inside the forms and left for 24 hours before removal. For curing, the concrete slabs were kept at room temperature, sprinkled with water for 24 hours and covered with wet burlap for 28 days until the day of testing.

Table 3: Experimental program

| *Notation* | *Description* |
|---|---|
| M1 SL1, M1 SL2 | Control specimens |
| M2 SL1 , M2 SL2 | Fibrillated polypropylene fibers added to the mix 0.1% of cement weight |
| M3 SL1, M3 SL2 | Fibrillated polypropylene fibers added to the mix 0.2% of cement weight |
| M4 SL1, M4 SL2 | Reinforced with geogrid type I (50x50 mm). |
| M5 SL1, M5 SL2 | Reinforced with geogrid type II (30x30 mm) |
| M6 SL1, M6 SL2 | Reinforced with GFRP rods 12 mm diameter |

(a) (b) (c)

Figure 2. Casting of slabs reinforced with (a) geogrid type I, (b) geogrid type II and (c) GFRP rods

### *Testing Procedure and Instrumentation*

The concrete slabs were tested in flexure using AMSLER compression testing machine of 5000 kN capacity, connected to a data acquisition system as shown in Figure 5. A layer 50 mm thick of stiff rubber is placed under the slab to resemble the subgrade reaction. A vertical concentrated load is applied at the center of slab by a circular plate of radius 125 mm.

The deformations were monitored using Linear Variable Distance Transducers (LVDT), shown in Figure 6 (a), connected to the data acquisition system. Also, for measurement of stains, strain bi-gauges were installed, shown in Figure 6(d), connected to the data acquisition system. Special surface treatment was made to the slab sides to allow accurate data capture as shown in Figure 6(c).


(a) (b) (c)

Figure 3. Testing and instrumentation: (a) test setup, (b) LVDT and (c) strain bi-gauge

## EXPERIMENTAL RESULTS AND DISCUSSION

### *Ultimate Loads and Displacements*

The results of ultimate load and maximum vertical displacements for all the tested slabs are given in Table 4, as well as calculation of stiffness and toughness. For the studied slabs, the ultimate load ranged between 152.7 and 357.4 kN and the maximum displacement was in the range 11.65 to 16.65 mm.

Table 4. Experimental results – ultimate loads and displacements

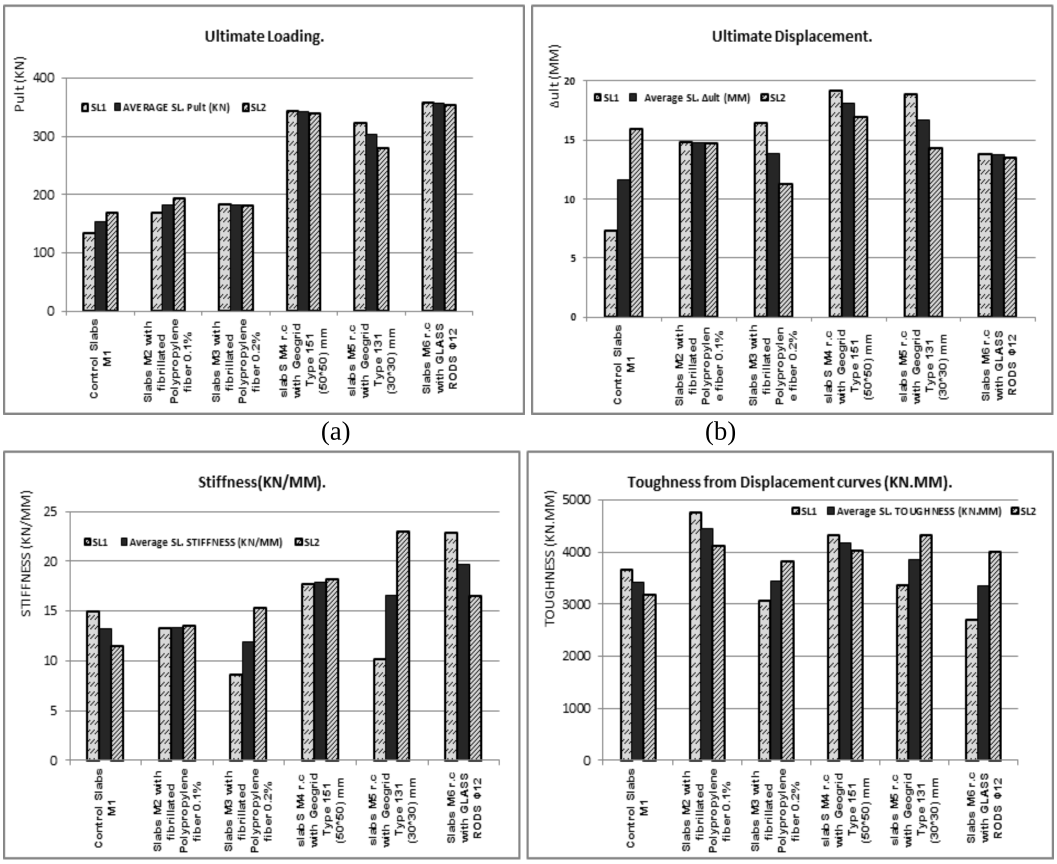
| *Slabs* | *Slab type* | *Pult (kN)* | *Avg. Pult (kN)* | *Δmax (mm)* | *Avg. Δult (mm)* | *Sttiffness (kN/mm)* | *Avg. stiff. kN/mm* | *Toughness (kNmm)* | *Avg. tough. kNmm* |
|---|---|---|---|---|---|---|---|---|---|
| M1SL1 | M1 | 135.1 | 152.70 | 7.39 | 11.65 | 15 | 13.214 | 3675.5 | 3431 |
| M1SL2 | | 170.3 | | 15.91 | | 11.429 | | 3186.0 | |
| M2SL1 | M2 | 170.2 | 182.20 | 14.89 | 14.79 | 13.220 | 13.341 | 4773.5 | 4447 |
| M2SL2 | | 194.2 | | 14.69 | | 13.462 | | 4121.2 | |
| M3SL1 | M3 | 183.3 | 182.50 | 16.45 | 13.86 | 8.609 | 11.943 | 3076.6 | 3457 |
| M3SL2 | | 181.7 | | 11.28 | | 15.278 | | 3837.5 | |
| M4SL1 | M4 | 344.9 | 342.55 | 19.18 | 18.06 | 17.647 | 17.936 | 4336.5 | 4181 |
| M4SL2 | | 340.2 | | 16.94 | | 18.224 | | 4026.3 | |
| M5SL1 | M5 | 324.6 | 302.75 | 18.93 | 16.65 | 10.204 | 16.602 | 3374.3 | 3860 |
| M5SL2 | | 280.9 | | 14.37 | | 23 | | 4345.6 | |
| M6SL1 | M6 | 359.9 | 357.40 | 13.87 | 13.71 | 22.794 | 19.639 | 2705.3 | 3355 |
| M6SL2 | | 354.9 | | 13.54 | | 16.484 | | 4005.5 | |

The obtained results show increase of ultimate load and maximum displacement for all different types of reinforcement compared to control slabs as shown in Figure 4. Adding 0.1% and 0.2% fibrillated polypropylene fibres to the mix gave slight increase of ultimate load by 19.32% and 19.52%, respectively. Slabs reinforced by GFRP rods showed the highest increase in ultimate load of 134.05% over control slabs M1.

### *Load-Displacement and Stress-Strain Relations*

The load-displacement curves are plotted in Figure 5 for the strengthened slabs compared with the control slab. Using the values of recorded strains and stresses from the beginning of the experiment until failure, the stress-strain curves as average of two slabs of each type are plotted in Figure 6.

The experimental results of the maximum strains recorded prior to failure indicate that slab types M2 and M3 enhanced with fibrillated polypropylene fibers 0.1% and 0.2% show increase of ultimate stress and by 111.75% and 75.82%, and decrease of ultimate strain by and 17.86% and 14.29% respectively, compared to the average of two control slabs M1. Slabs M4 and M5 reinforced with geogrid and show decrease of ultimate stress by 45.15% and 20.17%. Slabs M6 reinforced with GFRP rods show increases of average ultimate stress and Young's modulus by 55.03%, 206.9%, and decrease of maximum strain by 14.29% compared to control slabs M1.




(a) (b)

(c) (d)

Figure 4. Effect of different reinforcement types on (a) ultimate load, (b) maximum displacement, (c) stiffness and (d) toughness

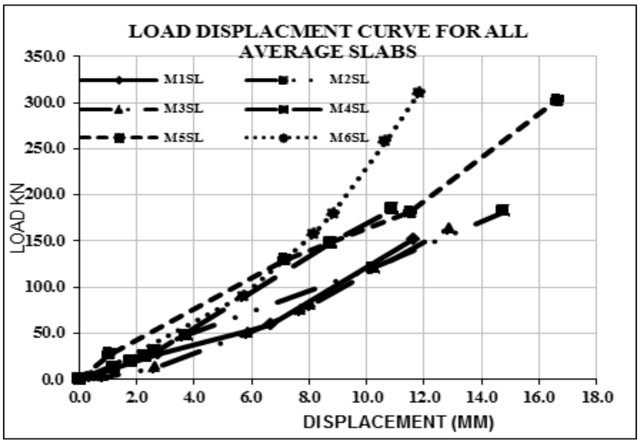



Figure 5. Load-displacement relations for all slab types

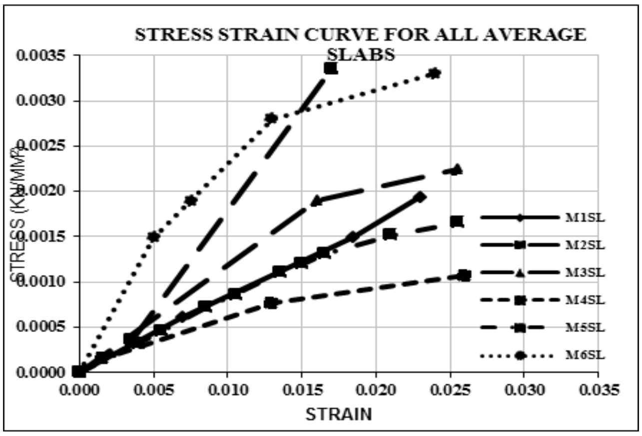



Figure 6. Stress-strain relations for all slab types

### *Crack Patterns*

For all the tested slabs, vertical cracks started to appear at the edges of the slab starting from the bottom and propagating in an inclined direction and towards the center of slab. The cracks forming on the control slab M1SL1 are shown in Figure 7.

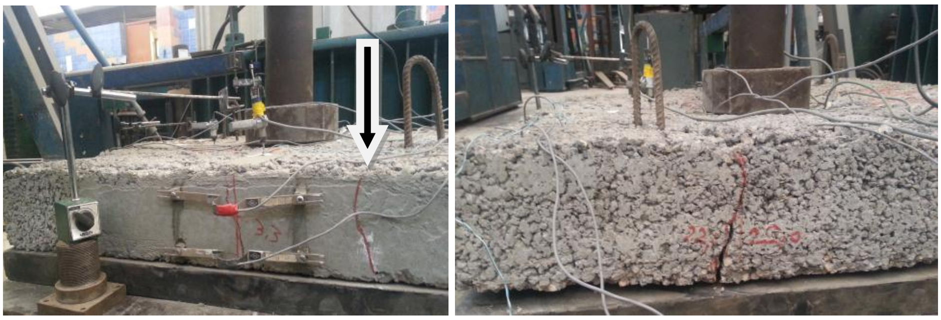


Figure 7. Crack pattern of control slab M1SL1under central vertical load

## CONCLUSIONS

Based on the obtained experimental results, the following main conclusions can be drawn.

1) The studied strengthening schemes were addition of fibrillated polypropylene to the mix by 0.1% and 0.2% by weight of cement, reinforcing the slabs with geogrid with two aperture sizes, and reinforcing with 12 mm diameter glass fibre reinforced polymer (GFRP) rods in two directions.

2) For all the studied slabs, the ultimate load ranged between 152.7 to 357.4 kN and the maximum displacement ranged between 11.65 to 16.65 mm.

3) Addition of fibrillated polypropylene fibres to the mix by 0.1% and 0.2% slightly increased the ultimate load by 19.32% and 19.52% respectively compared to control slabs.

4) Reinforcing slabs by geogrid type I (50 x 50 mm aperture size) and type II (30 x30 mm) increased the ultimate load than control slabs by 124.33% and 98.26% respectively. Reinforcement by GFRP rods increased the ultimate load 134.05% more than control slabs.

5) The slabs reinforced with geogrid type I (50 x50 mm) increased ultimate load by 26.1% than type II (30 x 30 mm).

6) The ultimate load gave the highest values for slabs reinforced with GFRP rods, then for slabs reinforced with geogrid, and the lowest values for slabs enhanced with 0.1% and 0.2% fibrillated polypropylene fibers.

7) All the studied strengthening schemes contributed to increase in ultimate capacity, stiffness and toughness compared to unstrengthened slabs.

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