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Alternative Reinforcement Materials for Lightly Loaded Concrete Structures

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Abstract: Traditionally, high yield steel has been the common method of providing reinforcement in concrete, primarily due to its high tensile strength. However, steel is susceptible to corrosion, particularly in aggressive environments, leading to potential durability concerns and high costs in repair and maintenance. A promising solution to the problem is the use of fibre reinforced polymers (FRP) as a replacement for reinforcing steel. The use of FRP as reinforcement offers the following advantageous properties: it is lightweight and has high tensile strength, corrosion resistance and flexibility. It is intended in this paper to study the effects of innovative fibre composite materials for reinforcing concrete. This study looks at the use of both basalt FRP rods and carbon FRP grid (C-Grid) as potential alternative reinforcement materials to address the problem of corrosion. The investigation includes an experimental program to evaluate the structural performance of concrete panels reinforced with new forms of reinforcing material and will compare the results against more traditional reinforcement techniques in terms of the panels' ultimate and service behaviour.

Key words: concrete, FRP reinforcement, CFRP grid, BFRP bars, flexural testing

INTRODUCTION

Traditionally, high yield steel has been the common method of providing reinforcement in concrete, primarily due to its high tensile strength. However it has become increasingly evident that the corrosion of steel reinforcement within concrete structures is largely due to the effects of de-icing salts particularly in aggressive environments, leading to potential durability concerns.The durability of concrete is the key factor in the life cycle of a structure due not only to its initial costs but also the cost of maintenance and repair (Neville, A.M., 1995).

Reinforced concrete structures over time can produce higher maintenance costs than designers originally envisaged due to problems associated with the corrosion effect of the steel within the concrete (Broomfield, J., 2002). This corrosion is down to the effects of carbonation or the attack from chlorides. Concrete with steel reinforcement bars do not corrode too easily generally due to a passive oxide film on the surface of the reinforcing steel, this film is produced by the highly alkaline conditions which concrete produces. When carbon dioxide in the atmosphere penetrates concrete along with the presence of moisture and reacts with calcium hydroxide to produce calcium carbonate this process is called carbonation (Concrete Society, 1995). The effect of this process causes the alkalinity of concrete to be reduced from a pH of 13 to as low as a pH of 8 the effect of this destroys the passivation oxide film and as the protection is lost the steel is likely to corrode in the presence of both oxygen and moisture. The passivity provided by the alkaline conditions can also be destroyed by the presence of chloride ions even though a high level of alkalinity remains in concrete some of the sources of chlorides are marine environments and de-icing salts. Once the chloride content in the concrete exceeds a threshold the oxide film will breakdown. As the moisture evaporates from the concrete surface the salt are left behind and when the chloride content reaches undesired levels corrosion of the reinforcement bars begin (Hansson, C.M., 2007). In Europe alone, the annual cost of repair and maintenance of the infrastructure is about 50% of the construction turnover, currently standing at more than €300bn.

In an attempt to eliminate the problems associated with steel reinforcement alternative means of reinforcement have been established. One of these means is the use of fibre reinforced polymer bars as an alternative to steel reinforcement. Fibre reinforced polymer (FRP) composites consist of a fibre which is encased by a polymer matrix (Cripps, A., 2002). The fibres are what provide the bar with its load carrying capabilities while the polymer is used to convey the loads and protect the fibres from external attacks. The main advantages of FRP bars are that they have excellent strength to weight properties, they will not deteriorate in harsh environments, and they have low maintenance requirements.

From previous experiments it is known that the basalt fibres have better tensile strength than the E-glass fibres, greater failure strain than the carbon fibres as well as good resistance to chemical attack, impact load and fire. When the FRP materials are placed in the concrete, another important concern is the resistance to high alkalinity from the surrounding concrete (Jongsung, S., 2005).

Recent research carried out on concrete panel slabs have identified that the serviceability behaviour in the concrete panel slabs reinforced with FRP is greater due to FRP bars low modulus of elasticity compared to that

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of steel reinforcement. This means that the deflection criterion tends to control the design of medium and long spanning concrete structures using FRP bars as reinforcement. However in steel reinforcement concrete structures it is usually the ultimate strength which governs the design of the concrete sections (Taylor, S.E., B. Mullin, 2005).

The objective of this paper is to present the results of laboratory tests on concrete panels, unreinforced and reinforced with both steel and basalt FRP bars and an innovative carbon FRP grid respectively. The overall aims of the tests were to compare the structural performance of the different reinforcement materials used in the concrete panels. Results gained from the tests were the ultimate moment mid-span deflection, failure modes of the panels and the ultimate moment capacity for each beam set. These particular test panels were chosen as they resemble sections currently employed by a precast concrete company for lightly loaded underground structures.

Experimental Programme:

Concrete panels were subjected to four-point bending in order to measure their response to flexural loading. The panels chosen were representative of sections through precast concrete underground service chambers, which are currently being produced. The aim of this research was to investigate whether FRP reinforcement could be used as an alternative to the traditional steel reinforcement, thereby providing better durability performance and allowing a reduction in section size for these lightly loaded members, thus reducing their production costs.

The test panels measured 1050 mm in length, 350 mm in width and 100 mm in height with an overall span of 900 mm. Panel set 1 consisted of three unreinforced concrete panels which were ultimately used as a control panel to compare the results of the reinforced panel sets. Panel set 2 consisted of reinforcing the concrete panels with three 12 mm high yield steel reinforcement bars. These bars were located 65 mm from the top of the panel to the centre of the reinforcement bars, providing 30 mm of cover at the soffit of the panels, while panel set 3 had three similar concrete panels reinforced with three 12 mm diameter basalt FRP bars, three panels wereagain cast with the location of the centre of the reinforcement material 65 mm from the top of the panel.The fourth set consisted of 2 panels reinforced with C-Grid, a commercially produced carbon FRP reinforcing grid. A summary of the details of the concrete panels tested is provided in Table 1.

Table 1: Details of Test Panels.

Panel Type	Panel Size (mm)	Type of Reinforcement	Distance from soffit to Reinforcement
Unreinforced Panel	1050 x 350 x 100 mm	None	None
Steel Reinforced Panel	1050 x 350 x 100 mm	3 No. 12 mm high yield steel bars	35 mm
Basalt FRP Bar Panel	1050 x 350 x 100 mm	3 No. 12 mm Basalt FRP bar	35 mm
C-Grid Reinforced Panel	1050 x 350 x 100 mm	C50 – 2.36 x 2.36 CFRP C-grid	30mm

The concrete used had a design strength of 40N/mm^2 and each of the panels was painted white prior to loading to aid with observation of crack patterns. Figure 1 shows the test setup.

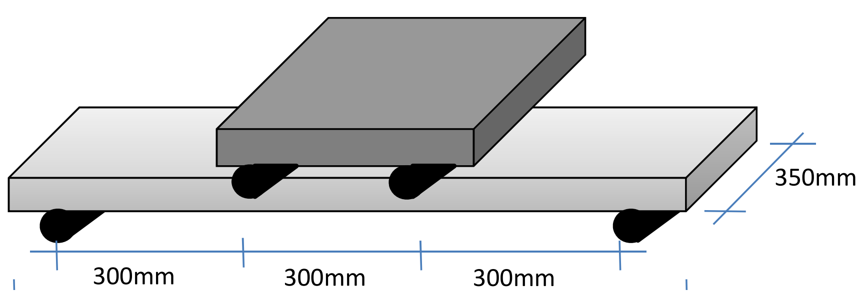

Fig. 1: Diagrammatic Representation of Test Setup.

Results:

Table 2 presents a summary of the results from the flexural testing. The values presented represent the average values for each panel type, while Figure 5 shows the average load-deflection performance for each set of panels.

Table 2: Results from Flexural Testing.

Panel Type	Compressive Strength of Concrete [N/mm^2]	Load at First Crack [kN]	Failure Load [kN]	Deflection at Failure Load [mm]	Observed Failure Mode
Unreinforced	57.1	13.8	13.8	1.02	Flexural Tension
Steel	57.1	14.6	56.3	8.5	Flexural Tension & Concrete Crushing
BFRP	57.1	13.0	45.9	28.2	Concrete Crushing
C-Grid	45.7	13.2	27.5	17.2	Flexural Tension

Onset of Cracking:

Figure 2 presents the results of the average recorded loads at onset of cracking and ultimate failure respectively for each of the sets of test panels. Each of the four sets displayed roughly similar load levels at onset of cracking, ranging from 13.0kN to 14.6kN.

Ultimate Failure:

By contrast, there was a large discrepancy between the recorded ultimate loads for each sample set. The unreinforced sections failed instantaneously once cracking began, as expected. The steel reinforced panels meanwhile increased to a failure load of 56.3kN, with the BFRP and C-Grid panels recording 45.9kN and 27.5kN respectively. The corresponding moments at failure are thus shown in Figure 3. Also shown in Figure 3 is the actual design moment required for the underground service chambers, upon which the sample panels were based. It can be seen that the design ultimate moment of 3.207kNm was comfortably achieved by each of the steel, BFRP and C-grid reinforced panels indicating that the alternative reinforcement materials had potential for use in these sections.

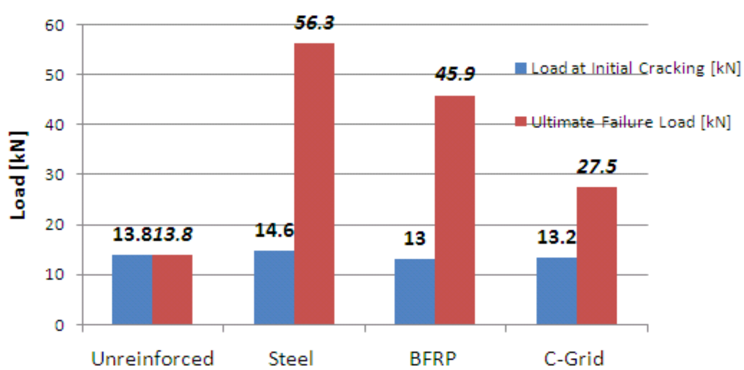

Fig. 2: Average Loads at Onset of Cracking and Ultimate Failure.

Serviceability Performance:

Observation of the response of the C-Grid reinforced panels reveals several steps in the load-deflection response. Each of these steps corresponded to the formation of additional flexural cracks parallel to the initial cracks in the test panels. A similar, but less noticeable trend is observed in the BFRP reinforced panels. Figure 4 shows the typical multiple crack pattern observed in these BFRP reinforced panels after testing.

Figure 5 shows the recorded load-deflection performance of each of the panel sets. While each of the panels performs similarly up to the point of onset of cracking, they all behave extremely differently thereafter. In the case of both the BFRP reinforced and the C-Grid reinforced panels, the deflections are significantly greater than the traditional steel reinforced panels.

The deflections at ultimate load are 8.5mm, 28.2mm and 17.2mm for the steel, BFRP and C-Grid reinforced panels respectively. Examination of the load-deflection performance at the equivalent load for the required design moment of 3.207kNm (approximately 17.4kN) reveals the variation in measured deflections for the different panel sets at this load. The steel reinforced panels deflect by approximately 2mm, while the C-Grid reinforced panels deflect by up to 9mm. This value for the C-Grid reinforced panels, represents Span/100 approximately, which is well in excess of accepted limits of approximately Span/360. This indicates that, although the ultimate load capacity of the BFRP and C-Grid reinforced panels meet the design requirements, the excessive deflections recorded may prove problematic.

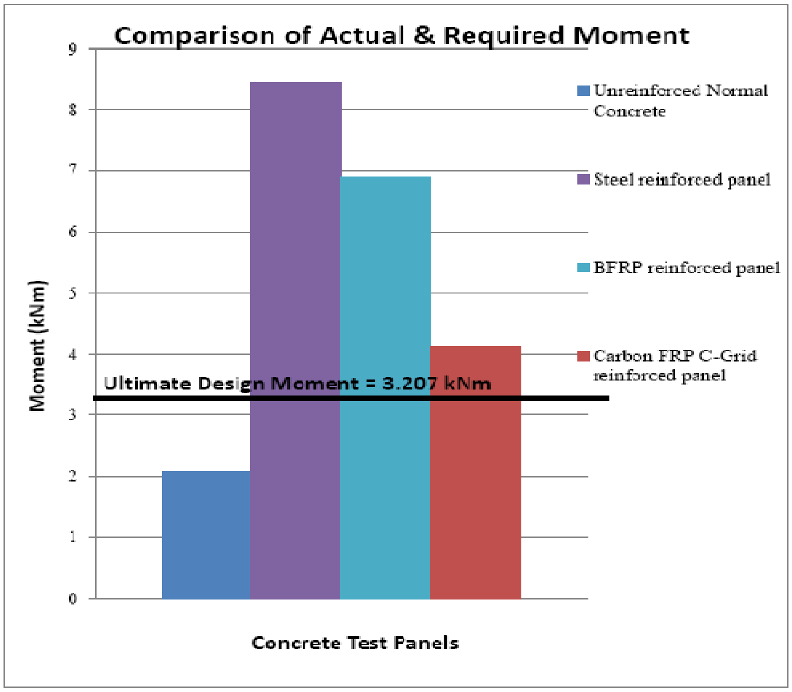

Fig. 3: Design and Ultimate Failure Moments of Panels.

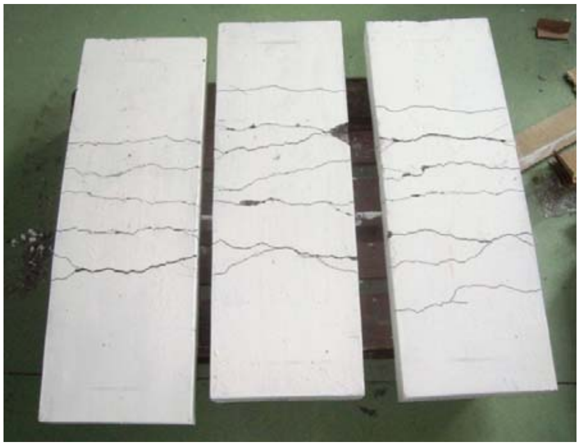

Fig. 4: Typical Crack Pattern on Reinforced Concrete Panels.

Nonlinear Finite Element Modelling of Slabs:

Separately from this particular work, nonlinear finite element models of each of the test panels were developed (Tharmarajah, G., P. Archbold, 2012; Tharmarajah, G., P. Archbold, 2013). These models did not accurately capture the magnitude of the deflections being experienced by the BFRP and C-Grid models and raised the issue of accurately predicting the behaviour of thin panels reinforced with alternative materials such as the BFRP and C-Grid, which have lower moduli of elasticity than traditional steel reinforcement. This work is ongoing in AIT at present.

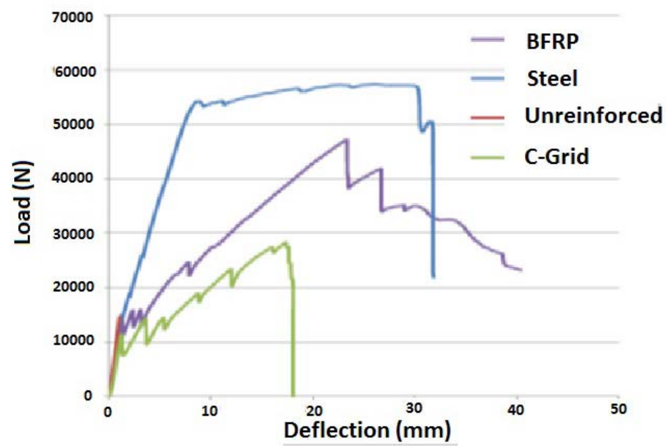

Fig. 5: Load-deflection performance of each set of panels.

Conclusions:

Durability concerns place limitations on the optimisation of steel reinforced structures, even when subjected to relatively light loads. FRP composite materials, which are non-corrosive, offer potential advantages over steel reinforcement, including the ability to reduce the depth of cover provided to reinforcement, which could lead to savings in both material and transport costs of lightly loaded concrete structures. A local precast company currently produce such structures in the form of underground structures. In order to investigate the possibility of replacing the traditional steel reinforcement with non-corrosive alternatives, two separate FRP composite reinforcement materials were investigated. The materials consisted of basalt fibre reinforced polymer (BFRP) bars and a carbon fibre reinforced polymer grid material (C-Grid). Test panels utilising steel, BFRP and C-Grid reinforcement arrangements were subjected to flexural loading to determine the structural response to loading. While the FRP composite reinforcement performed well in terms of achieving the ultimate design moment for the panels, the rather large delections recorded at both service and ultimate loads may prove problematic for manufacturers of these sections. Further, the exact nature of the load-deflection response of such thin panels is not well understood and is currently being investigated by research teams in AIT.

REFERENCES

Broomfield, J., 2002. Corrosion of Steel in Concrete: Understanding, investigation and repair, Taylor & Francis, ISBN 0203475283.

Concrete Society, 1995.

Cripps, A., B. Harris, T. Ibell, 2002. Fibre Reinforced Polymer Composites in Construction. *CIARA*.

Hansson, C.M., A. Poursaee and S. Jaffer, 2007. Corrosion of Steel in Reinforced Concrete, Portland Cement Association (PCA), PCA R&D Serial No. 3013, 2007.

Jongsung, S., P. Cheolwou, M. Do Young, 2005. Characteristics of Basalt Fibre as a Strengthening Material for Concrete Structures.

Neville, A.M., 1995. Properties of Concrete, Prentice Hall, ISBN 0273786326.

Taylor, S.E., B. Mullin, 2005. Arching Action FRP Reinforced Concrete Slabs, Journal of Construction & Building Materials, 20(1).

Tharmarajah, G., P. Archbold, 2012. Nonlinear finite element analysis of FRP reinforced concrete element, Proceedings of the Joint Symposium on Bridge and Infrastructure and Concrete Research in Ireland, TCD & DIT, September 2012.

Tharmarajah, G., P. Archbold, 2013. FRP reinforcement in precast underground service chambers, Proceedings of the11th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures, Guimaraes, Portugal, June 2013.