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Protchenko K.V.[15], *Ph.D student*
Warsaw University of Technology, Warsaw, Poland
Skrebnieva D.S., *Ph.D student*
National Aviation University, Kiev, Ukraine

ASSESSMENT OF STRENGTH CRITERIA OF RC SLABS STRENGTHENED WITH VARIOUS FRP STRIPS

This paper provides the analysis of the FRP materials, strengthening techniques, bond performance, factors accounting to performance of structural systems and implementation of Finite Element Analysis FEA in the strengthening process. The behaviour of bond between FRP and concrete may be the most fundamental one, because it plays a key role on the composite performances and the reliability of RC structures after being strengthened. Better comprehension of it will allow for more precise designs that will balance safety and cost.

Keywords: reinforced concrete, strengthening, plate, FRP, composite material.

Introduction. One of the biggest advances of the 20th century in Materials Science was the introduction of Fiber Reinforced Polymer FRP composites and their use in engineered composites. These materials immediately found acceptance in aerospace, construction, industrial process, where their unique properties brought value and new solutions to the practicing engineer.

In civil engineering FRP materials for repairing and strengthening of reinforced concrete RC structures has become an accepted practice due to their light weight, high strength-to-weight ratio, ease of handling and application, lack of requirement for heavy lifting, handling equipment and corrosion resistance.

The behaviour of bond between FRP and concrete may be the most fundamental one because it plays a key role on the composite performances and the reliability of r/c structures after being strengthened.

An experimental programme was conducted in order to analyze the behaviour of different structural solutions to strengthen reinforced concrete elements with FRP composites by EBR method. Several types of CFRP, GFRP and AFRP were used as reinforcement materials for RC slab under different loadings. During experimental programme, several assumptions were made, such as: atomic and molecular structure of all constituent materials is neglected; the stress-strain relationship for FRP is linear up to failure. The results from LIRA was compared with the existing test results, which was obtained from the laboratory.

Materials for frp strengthening. Composite materials can be classified based on the form of their constituents, number of layers, orientation of fibers, length of fibers etc. The main fiber types used are carbon CFRP, glass GFRP and aramid AFRP. GFRP comes in two types – E-glass and AR glass. Epoxy resins, polyester and vinyl ester are the most common polymeric matrix materials. They are thermosetting polymers with good processability and good chemical resistance. Depending on the size of the reinforcement, we can classify the composites as fibrous composites, particulate composites, powdered composites and nanocomposites. In fibrous composites, the reinforcements will be in the form of fibers in which the length of the fiber will be much higher than the cross sectional dimension.

FRP composites consist of a number of continuous fibers, bundled in a resin matrix. The main fiber types used are carbon (CFRP), glass (GFRP) and aramid (AFRP). GFRP comes in two types – E-glass and AR glass [1]. Epoxy resins, polyester and vinyl ester are the most common polymeric matrix materials. They are thermosetting polymers with good processability and good chemical resistance [2].

Some of the basic mechanical properties (typical properties are shown in Table 1) of FRP composites, such as longitudinal modulus, transverse tensile modulus and tensile strength, may be found by applying the “Rule of mixtures”.

The adhesive provides a shear load path between the concrete layer and the FRP reinforcing laminate as well as it can be used to bond together multiple layers of FRP laminates. The mechanical properties of some adhesives, which were analyzed, are shown in Table 2 [5].

Table 1
Typical mechanical properties for GFRP, CFRP and AFRP composites [3]

Unidirectional FRP composite / matrix	Fiber content, % by weight	Density, Kg/m^3	Young's tensile modulus, GPa	Tensile strength, MPa
GFRP laminate / polyester	50-80	1600-2000	20-55	400-1800
CFRP laminate / epoxy	65-75	1600-1900	120-250	1200-2250
AFRP laminate / epoxy	60-70	1050-1250	40-125	1000-1800

Table 2
Material properties of adhesive, which is utilized in this work [4]

Types of adhesive	Density, g/cm^3	Elastic modulus, GPa	Poisson`s ratio	Tensile strength, MPa	Flexural strength, MPa
Sikadur 330	2.25	4.50	0.30	32.00	38.00

Bond behaviour. The behaviour of bond between FRP and concrete may be the most fundamental one because it plays a key role on the composite performances and the reliability of r/c structures after being strengthened.

Many models have been proposed for a bond strength between FRPs laminates and concrete. Almost in all bond strength models, the stress state simulates a “pull” test on a specimen with bonded FRP plate (Figure 1.).

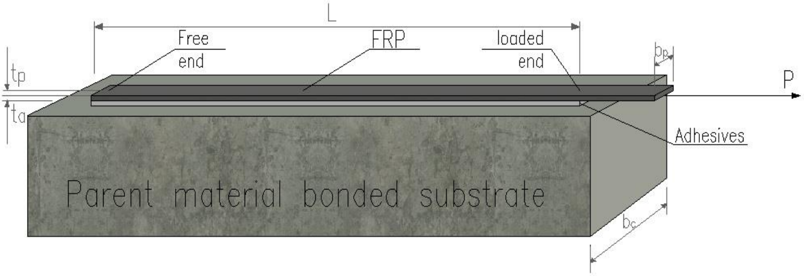

Figure 1. Schematic of the bond strength test for a concrete with bonded FRP plate

Reinforced concrete members with bonded FRP plates commonly suffer intermediate crack-induced interfacial debonding. Many researchers performed various investigations on this mode of failure. Chen and Teng proposed a simple ultimate bond strength model, established by means of nonlinear fracture mechanics solution for FRP-concrete joints and analyzing of a large number of test data [6], [7].

$$P_u = \alpha \beta_p \beta_L \cdot \sqrt{\frac{E_p \sqrt{f_c'}}{t_p}} \tag{1}$$

$$\beta_p = \left[\frac{2-(b_p / b_c)}{1+(b_p / b_c)} \right]^{\frac{1}{2}} \tag{2}$$

$$\beta_L = \begin{cases} 1, & L \geq L_e \\ \sin\left(\dfrac{\pi L}{2L_e}\right) & L \prec L_e \end{cases} \tag{3}$$

where:

α - is an empirical factor, [0.38 to 0.43]; b_p and b_c refer to the FRP plate and concrete element width respectively; E_p and f_c' are the elastic modulus of the FRP and the concrete compressive strength, respectively; t_p - is FRP thickness; L - is the length of FRP beyond the maximum moment location; L_e - is the effective length:

$$L_e = \sqrt{\frac{E_p t_p}{\sqrt{f_c'}}} \tag{4}$$

Experimental programme. Experimental programme was prepared in the Watkins Haggart Structural Engineering laboratory at the University of Pittsburgh (Figure 2.). This work presents the testing of five specimens inclusive of a Specimen without strengthening and comparing of results with obtained results in LIRA.

(a) Specimen S-2 (strengthened with AS4 3501) **(b) Specimen S-4** (strengthened with AS4 3501)

Figure 2. Typical retrofitted slab specimen

Simply supported concrete slabs were tested under different loading (Table 3). The slabs were 1270 mm x 762 mm and 76 mm deep. Four slabs strengthened with different arrangements of CFRP composite strips as described further and one of them was left as “reference”. Details of retrofitted slab specimens presented in Figure 3.

Results and discussion. To verify and measure the accuracy of the FEM model, the current model results in LIRA for all test specimens bonded with CFRP were compared with results from the Watkins Haggart Structural Engineering laboratory (Figure 4).

Table 3
Parameters of slab specimens

Specimen	Dimensions of slab, mm	Number of strips	Strip width, mm	Strip spacing, mm
Without strengthening	1270 x 762 x 76	0	0	0
S - 1		1	102	0
S - 2		2	102	254
S - 4		4	50	152
S - 8		8	25	84

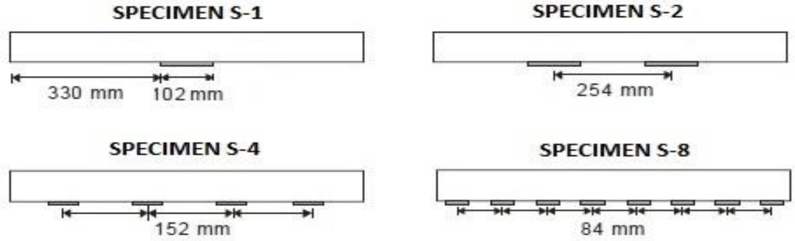

Figure 3. Details of retrofitted slab specimens

Conclusions. In this paper the influence of the number and width of FRPs strips, their orthotropic properties on load-carrying capacity, bond performance of FRP-to-concrete were investigated to understand the behaviour of complete structural system of strengthened mechanism. An analysis model is presented for RC slabs externally reinforced with fiber reinforced polymer (FRP) laminates using finite elements method adopted by LIRA.

The results obtained from the LIRA finite element analysis are compared with the experimental test results for specimens with different conditions.

The load-deflection curves from the finite element analysis agree well with the experimental results in the linear range, but the finite elements results are slightly stiffer in cases where width of FRP to width of substrate ratio is higher than that from the experimental results and more flexible for smaller ratio. The maximum dissimilarity comparing with experimental test results for all specimen is 9.5%.

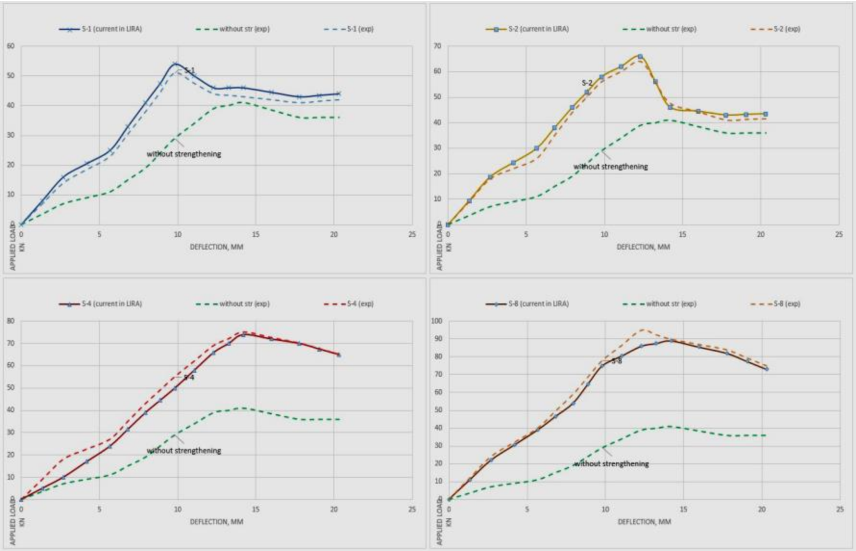

Figure 4. Load vs. Deflection curves for all test specimens bonded with AS4 3501 CFRP plate (s)

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Анотація

В статті проведено аналіз використання полімерних волокнисто-армованих матеріалів (ВАП), методи їх зміцнення, проаналізовані фактори, що враховуються при виконанні структурних систем матеріалу і реалізації методу скінчених елементів (МКЕ) в процесі зміцнення. Щеплення між ВАП і бетоном може бути найбільш ефективним, так як воно відіграє ключову роль для композиційних характеристиках і надійності залізобетонних структур матеріалу після зміцнення. Результати досліджень дозволяють забезпечити краще щеплення волокнисто-армованих матеріалів з бетоном, шо дозволить збалансувати безпеку і вартість для конструкцій будівель та споруд.

Ключові слова: залізобетон, зміцнення, волокнисто-армовані полімери (ВАП), композиційний матеріал.

Аннотация

В статье проведен анализ волокнисто-армированных полимерных материалов, методы их усиления, эффективность сцепления, факторов, которые учитываются при выполнении структурных систем и реализации метода конечных элементов (МКЭ) в процессе усиления. Сцепление между ВАП и бетоном может быть одним из наиболее значимых факторов, так как оно играет ключевую роль в композитных характеристиках и надежности железобетонных структур после усиления. Результаты эксперимента доказывают, что лучшее сцепление волокнисто-армированных полимерных материалов и бетона позволит *сбалансировать безопасность и стоимость конструкций зданий и сооружений.*

Ключевые слова: железобетон, укрепление, волокнисто-армированные полимеры (ВАП), композиционный материал.

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Стороженко Л.І.[16], *д.т.н., професор*
Єрмоленко Д.А., *д.т.н., професор*
Мурза С.О., *к.т.н., докторант*
Полтавський національний технічний університет імені Юрія Кондратюка, м. Полтава, Україна

СТАЛЕЗАЛІЗОБЕТОННІ СТІЙКИ ОДНОПОВЕРХОВИХ ВЕЛИКОПРОЛІТНИХ БУДІВЕЛЬ І СПОРУД АЕРОПОРТІВ

У статті розглянуто можливість і доцільність використання сталезалізобетонних конструкцій у якості стійок одноповерхових великопрольотних будівель і споруд аеропортів. За рахунок використання специфічних особливостей матеріалів, що застосовуються, можливо отримати значну економію сталі та бетону, що приводить до зменшення поперечного перерізу елементів конструкцій і, як наслідок, до зниження їх ваги й транспортних витрат.

Ключові слова: сталезалізобетон, трубобетон, стійка, колона, одноповерхова великопролітна будівля.

Вступ. Розвиток будівельних конструкцій, що використовуються для будівель і споруд аеропортів, характеризується пошуком нових видів сполучень сталі і бетону для їх раціональної спільної роботи. Це дуже перспективний напрям, що забезпечує економію матеріалів, енергозатрат і трудомісткості. Усім цим вимогам відповідають комплексні сталезалізобетонні конструкції, до складу яких входять прокатні профілі, стрижнева арматура та бетон. Сталезалізобетонні
