ветствует теоретической возможности при возведении зданий снижения до 20 % расхода стенового материала.

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SHEAR DESIGN METHODS FOR RC BEAMS STRENGTHENED WITH FRP SHEETS

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1. Introduction

The rehabilitation of concrete structures using fibre reinforced polymer (FRP) materials has become a growing area in the construction industry over the last few years. Many research projects in the world were carried out to promote this efficient repair technique to extend the service life of existing concrete structures.

The lightweight and formability of FRP reinforcement make these systems easy to install. The materials used in these systems are non-corrosive, non-magnetic and generally resistant to chemicals and they are an excellent option for external reinforcement.

FRP composite materials generally consist of carbon (C), aramid (A) or glass (G) fibre in a polymer matrix (e.g. epoxy resin). The sheets are dry or pre-impregnated with resin and cure after installation onto concrete surface. This installation technique is known as wet lay-up. Currently, this method has been implemented to strengthening of varied structures, such as columns, beams, slabs, walls, chimneys, tunnels and soils. The carbon fibre reinforced polymers (CFRP) sheet is suitable to use for increasing shear capacity of RC beams. The design aspects to predict contribution of CFRP sheets on increasing shear capacity of RC strengthened beams are aims of many investigations.

Several researchers have developed design equations and analytical models to evaluate specifically the FRP contribution of the shear strength of RC beams [1], [2], [3].

The aim of this paper is to review and discuss three recently published FRP shear design approaches. Shear capacity according to MBrace design guide [4] is discussed too. Experimental test results from a two different series of RC beam specimens (with and without internal stirrups) with various strengthened pattern of the external CFRP shear reinforcement (S&P C Sheets 640) are used in this study to compare the predicted loads from every model investigated.

2. Experimental program

For experiment, two different series of RC beams were made (3 beams for series A and 3 beams series B).

The A series has internal shear reinforcement (stirrups). RC beams of the first series A were loaded to the point of shear breaking and shear cracks creation. Then, the corrupted beams were repaired (closing shear cracks) and strengthened by added external shear reinforcement. The pattern of adding carbon sheet and the shape of the RC Beams –series A are shown in fig. 1.

The B series (fig.2) had not internal shear reinforcement. The traditional shear reinforcement was replaced by external bonding S&P C Sheet 640.

For the concrete strength verification, 12 cubes with dimensions 150 x 150 x 150 mm were made. Compressive strength after 28 days was determined on 3 cubes. During tests, compression strength after 213 days was determined on remaining 9 cubes.

According to compressive test, the properties of concrete are: $f_{ck} = 46.652$ MPa; $f_{cd} = 46.652/1.5 = 24.881$ MPa; $E_{cm} = 33\,870.79$ MPa; $f_{ctk,0.05} = 2.345$ MPa.

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According to tensile test, the properties of the used stirrups are: $f_{y,k} = 565.278$ MPa; $f_{y,d} = 565.278/1.15 = 491.564$ MPa.

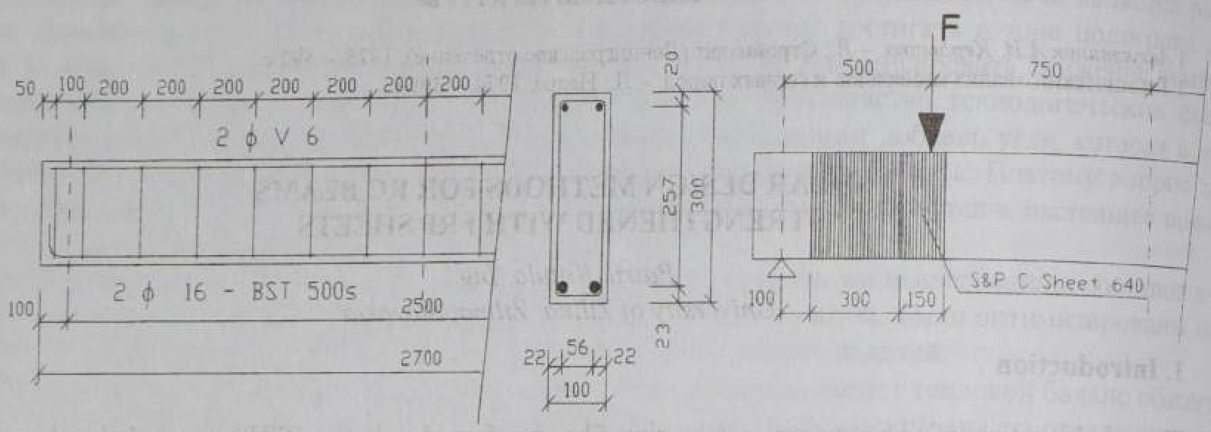

Fig.1 RC beams – A Series

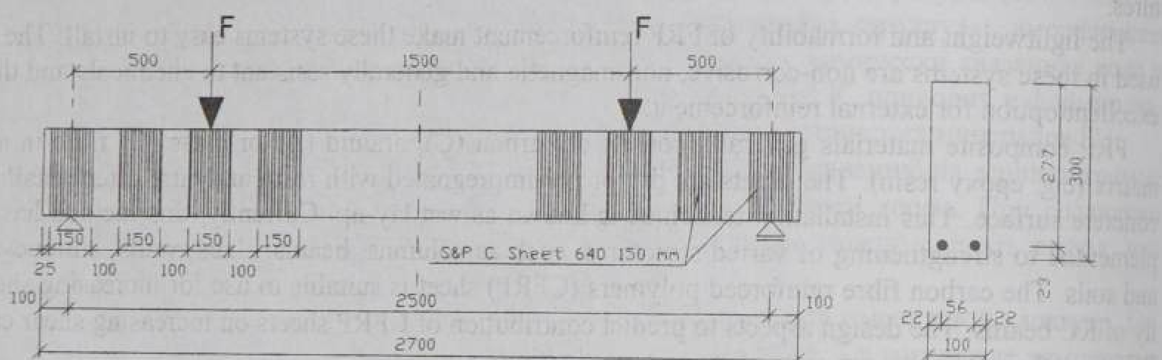

Fig.2 RC beams – B Series

S&P C Sheet 640 was used for shear strengthening. This product is appropriate for absorbing tensile forces with minimum elongation of the fibres.

Properties of the S&P C Sheet 640 are: $E_{f,k} = 640$ GPa; tensile strength $f_{fy} = 2.650$ MPa; ultimate elongation $\varepsilon_{fu} = 0.004$; theoretical thickness $t_f = 0.190$ mm.

For design, the maximum strain shall not exceed 0.2 ~ 0.3 %. Partial safety factor γ_{sf} was considered 1.2 for wet lay-up installation technique [4].

3. Design shear equations

The nominal shear strength V_n is expressed as the sum of three contributions given by the concrete (V_c), the shear steel reinforcement (V_s) and the FRP reinforcement (V_f):

$$V_n = V_c + V_s + V_f \tag{1}$$

First two terms of Eq. (1) according to Eurocode 2 [5] may be rewrited:

$$V_c = V_{cd} = V_{Rd1} = [\beta\tau_{Rd}k(1.2 + 40\rho_1) - 0.15(N_{sd}/A_C)]b_w d \tag{2}$$

$$V_s = V_{wd} = \rho_{sw} f_{ywd} b_w (0,9d) \tag{3}$$

Taking into account two basic failure modes i.e. FRP fracture and delamination of the sheet, the third term of Eq. (1) is calculated.

The design approach based on fracture of the FRP sheet is quite similar to the approach used to compute the contribution of steel shear reinforcement. Triantafillou [1] has presented the equation to express FRP sheet contribution based on the stress concentrations in the sheet. If the level of the strain at rupture is considered as the effective strain, ε_{fe}, the contribution of externally bonded FRP sheets to the shear capacity of the RC beam may be computed using Eq. (4).

$$V_f = \rho_f E_f \varepsilon_{fe} b_w 0.9d(1+\cot\beta)\sin\beta \quad (4)$$

where: $\rho_f = (2t_f w_f)/(s_f b_w)$ – is FRP shear reinforcement ratio,

β – is the angle between the principal fiber orientation and longitud. axis of the beam,

t_f – is the thickness of the FRP sheet on one side of the beam,

w_f – is the width of the FRP strip,

b_w – is the width of the beam cross section,

s_f – is the spacing of the FRP strips.

Triantafillou [1] has observed the effective strain to be a function of the axial rigidity of the FRP sheet ($\rho_f E_f$). Hence, the effective strain of FRP sheet ε_{ef} may by computed:

$$\varepsilon_{ef} = 0.0119 - 0.0205(\rho_f E_f) + 0.0104(\rho_f E_f)^2 \quad \text{for} \quad 0 \le \rho_f E_f \le 1\text{GPa} \quad (5a)$$

$$\varepsilon_{fe} = 0.00245 - 0.00065(\rho_f E_f) \quad \text{for} \quad \rho_f E_f > 1\text{GPa} \quad (5b)$$

Khalifa [3] modified Eq. (5a) and (5b) by reduction factor R, which was obtained from additional simple tension experiments. The reduction factor R may be assumed as the following three values:

$$R = 0.006/\varepsilon_{fu} \quad (6a)$$

$$R = 0.5622(\rho_f E_f)^2 - 1.2188(\rho_f E_f) + 0.778 \quad (6b)$$

$$R = 0.0042(f_{cm})^{2/3}/((E_f t_f)^{0.58}\varepsilon_{fu}) \quad (6c)$$

where: ε_{fu} – is the ultimate tensile strain of fiber material in the FRP composite.

The effective width (w_{fe}) of FRP sheet is given:

$w_{fe} = d$ for sheets wrapped around the beam (7a)

$w_{fe} = d - L_e$ for U-jacked bonded of the sheet (7b)

$w_{fe} = d - 2L_e$ for side bonded of the sheet (7c)

The effective bond length (L_e) according to Maeda [2] is given:

$$L_e = e^{6.134 - 0.58\ln(t_f E_f)} \quad (8)$$

The Eq. (4) may by rewrited:

$$V_f = \rho_f R f_{fu} b_w 0.9d(1+\cot\beta)\sin\beta \quad (9)$$

where: – f_{fu} is the ultimate tensile strength of FRP composite ($f_{fe} = R f_{fu}$).

Maeda [2] has investigated the bond behaviour between FRP sheet and concrete surface. Based on the experimental data, an exponential equation was proposed to predict the effective bond length. This equation is given as Eq. (8) and it is a function of the thickness of the FRP sheet and the elastic modulus of the FRP. As the stiffness of the sheet increases, the effective bond length decreases. Further experimental data indicates that the bond stress at failure is a linear function of the stiffness. The compressive strength of concrete used in the experiments by Maeda [2] was consistently 42 MPa. Horiguchi [6] noted that bond strength between the FRP sheet and the concrete surface is a function of nominal concrete compressive strength $(f_c^{'})^{2/3}$. The average bond strength (τ_{bu}) is given by Eq. (10).

$$\tau_{bu} = (f_c^{'}/42)^{2/3} E_f t_f \quad (10)$$

The contribution of the FRP sheet to the shear capacity may by calculated [2]:

$$V_f = \frac{2L_e w_f \tau_{bu} w_{fe}}{s_f} \tag{11}$$

According to [4], the Eq. (4) may be rewrited:

$$V_f = \rho_f \frac{E_{f,k}}{\gamma_{sf}} \varepsilon_{fe} b_w 0.9d(1+\cot\beta)\sin\beta \tag{12}$$

4. Comparison between analytical models and test results

The ultimate load obtained from the test of each strengthened RC beam and values calculated according to presented design approaches are shown in Tab.1. The contribution of the FRP sheet to the shear capacity of the beams obtained from experiment and relationship between measured and calculated values are shown in Tab.2.

The ultimate load obtained from the test of each strengthened RC beam and values calculated according to presented design approaches are shown in Tab.1. The contribution of the FRP sheet to the shear capacity of the beams obtained from experiment and relationship between measured and calculated values are shown in Tab.2.

Tab. 1 – **The review of the results from the test and analytical calculation**

	V_{cd} [kN]	V_{wd} [kN]	V_f [1] [kN]	V_f [3] [kN]	V_f [2] [kN]	V_f [4] [kN]	$R_{D3,f}$ [1] [kN]	$R_{D3,f}$ [3] [kN]	$R_{D3,f}$ [2] [kN]	$R_{D3,f}$ [4] [kN]	V_{exp} [kN]
A1											**110.25**
A2	38.61	34.63	40.57	64.32	32.14	60.63	113.82	137.56	105.38	133.87	**105.00**
A3											**86.00**
B1											**45.00**
B2	38.61	-	47.35	54.53	19.32	101.05	85.96	85.96	57.93	139.05	**61.75**
B3											**80.75**

Tab. 2 – **Relationships between measured and calculated contributions of the used CFRP sheet**

	$V_{f,exp}$ [kN]	$V_{f,exp}/V_f$ [1]	$V_{f,exp}/V_f$ [3]	$V_{f,exp}/V_f$ [2]	$V_{f,exp}/V_f$ [4]
A1	37.01	0.91	0.58	1.15	0.61
A2	31.76	0.78	0.49	0.99	0.52
A3	12.76	0.31	0.19	0.39	0.21
B1	6.39	0.13	0.11	0.33	0.06
B2	24.14	0.51	0.44	1.25	0.23
B3	42.14	0.89	0.77	2.18	0.41

Comparison between the results provided by theoretical models and the experimental results shows that all the models (except Maeda [2]) predict higher values of the ultimate load then the experimental ones. The fact that the ultimate shear capacity of the experimental beams is lower then the predicted by the analytical models may be addressed to the bond behaviour.

Except the beam "B3", the failure mode of the used CFRP sheet was the delamination of the sheet from the concrete surface. Consequently, the design approach based on bond mechanism [2] gives corrected ultimate load values. The lower values of the beam "B1" is caused by under-work at the application of the FRP sheet by wet lye-up technique. Failure of the beam "B3" was caused by partial rupture of the FRP sheet and delamination of the used CFRP sheet.

The anchorage of the FRP sheet in compressed zone of the beam is the critical point of this strengthening method. The author's future research will be pointed on the numerical modeling of the strengthening and analysis of the stress distribution in the FRP sheet.

5. Conclusion

A better understanding of the effective bond length is a critical point for the achievement of more precise anchoring specification. The stress distribution in the perpendicular direction to the prime fibre orientation in the FRP composite will be subject of future analyze.

Analytical models based on bond mechanism better represent the real behaviour of the RC beams strengthened with externally boned FRP sheet than the approaches based on FRP fracture mechanism.

In spite of the lower values of the strengthened RC beams obtained from the test compared to calculated values, the strengthening concrete constructions with externally bonded FRP composites may by used to increase shear capacity of the concrete members.

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NEW CONCEPT OF RAILWAY BRIDGE MANAGEMENT IN SLOVAKIA

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1. Introduction

The modernization of the transportation infrastructure, which consists of the highway and the railway network, has the significant sense for economic of every country. On this account, the phase of the infrastructure rehabilitation of existing railways has begun. The part of the railways is rebuilt to the high-speed railways and the rest one is rehabilitated.

In term of transformation and restructuralization of the Slovak Railways infrastructure [1], the computer-aided Bridge management system was created by the Department of Structures and Bridges in Žilina. The methodology of existing bridge diagnostic and evaluation has been presented in this computer-aided system without subjective decision-making process.

In season, the computer-aided Bridge management system should replace the actual out of date Bridge management system of railway bridges, which is based on the guideline ČSD S5 „Administration of bridges", [2]. The code takes into account the level of knowledge in the area of bridge engineering from the beginning of 80's years. On this account, the old system is based on empirical approaches using information obtained from regular inspections with its processing based on experience of responsible workers. In such a case the decision-making processes are subjective due to significant influence of the bridge evaluator's knowledge and his experiences.

The main aim of the new computer-aided Bridge management system is to reach objective model of funds planning on the basis of diagnostic information concerning to actual bridge condition, to process this information, to calculate loading capacity and to determine the passage of actual traffic railway load. Obtained results processed by criterion aspects enable to define priorities and to determine the objective

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