SHEAR BEHAVIOR OF SHALLOW WIDE BEAMS STRENGTHENED WITH EXTERNALLY BONDED CFRP STRIPS

By

Ahmed Aboul-Ela Mostafa Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
STRUCTURAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

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Key Words:
Shallow wide beam; CFRP; shear strength; shear reinforcement ; volumetric ratio

Summary:

Shallow wide beams are frequently used as transfer elements where the total structural depth must be kept to a minimum. ECP 203-2007 has considered that beams to be shallow and wide if the depth is less than the largest of three values: 250 mm, 2.5 times the thickness of the flange, or half the width of the web. In this case, the nominal shear stress in shallow wide beams is less than the concrete shear strength, and ECP 203-2007 considers that the shear strength provided by concrete for shallow wide beams to be equal to 67% of the concrete shear strength for ordinary beams.

This experimental program consists of twelve specimens. All specimens are 500 mm width, 170 mm thickness, and have a clear span between supports equal to 1300 mm. All beams have the same flexural reinforcement. The beams are divided into three groups. The first group contains two beams without vertical stirrups, and one of them is strengthened in shear with externally bonded CFRP strips. The second group contains six beams with the same volumetric ratios of vertical stirrups where five of them are

strengthened with different ratios of CFRP strips. The third group contains four beams with the same volumetric ratio of vertical stirrups, which is higher than the beams in group two, where three of them are strengthened with different ratios of CFRP strips. The studied parameters are as follows: stirrups volumetric ratio, CFRP strips volumetric ratio, strip-width to strip-spacing for the same CFRP strips volumetric ratio, and the removing of strip with small anchorage length. This research aims to study simultaneously, the effect of vertical stirrups on the shear behavior of shallow wide beams, as well as shear behavior of shallow wide beams strengthened in shear with externally bonded CFRP strips. Based on the results of the experimental work, the contribution of shear reinforcement (vertical stirrups) of shallow wide beams with stirrups is significant and must be taken into consideration when calculating the shear strength of beams, The increase of stirrups volumetric ratio increases the shear capacity of shallow wide beams; Strengthening using narrower strips with smaller spacing is better than strengthening using wider strips with bigger spacing for the same CFRP strips volumetric ratio; Removing the CFRP strip with small anchorage length reduces the shear capacity of concrete beams; Increasing the stirrups volumetric ratio in the concrete beams reduces the shear strength due to CFRP strips strengthening; Finally increasing CFRP strips volumetric ratio increases the shear capacity of concrete beams.

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This research project was carried out in the Housing and Building National Research Center, and could not have been completed without the help and support of many people.

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I would like to thank my dear friends and colleagues who helped me, supported me, and encouraged me to completing this study.

Finally but not least, sincere gratitude must go to my family for their help, support, and encouragement over my life.

Dedication

Special thanks to my wife, the best one I have ever seen for helping me to make this research, I wish you have happy life full of success, joy, and health.

Table of Contents

List of Tables

List of Figures

Nomenclature

a	Shear Span Length
b	Width of the Section
b_v	Width of the Section
b_w	Width of the Web on T, I or L Beams
d	Effective Depth of Section
d_f	FRP laminates effective depth
d_F	FRP laminates effective depth
f_c'	Concrete Cylinder Compressive Strength
f_{cu}	Concrete Characteristic Strength
f_{yt}	Specified yield strength of non-prestressed reinforcement
f_y	Yield Strength of Stirrups
n	Number of layers of FRP
q_{cu}	Concrete Shear Stress in Beams
q_{su}	Ultimate Shear Stress Provided by Shear Reinforcement
q_{fu}	Ultimate Shear Stress provided by FRP reinforcement
q_u	Nominal Ultimate Shear Stress
s	Spacing Between Stirrups
s_f	Spacing between FRP strips
s_F	Spacing between FRP strips
t	Thickness of Section
t_f	Thickness of FRP strips or sheets
w_f	Width of FRP strips or sheets
w_{fe}	Effective width of FRP strips or sheets
v_c	Shear stress resistance attributed to the concrete
v_s	Shear stress resistance provided by shear reinforcement
A_s	Area of Steal
A_{st}	Area of All Vertical Branches in One Stirrup
A_{sv}	Area of Vertical Branches in One Stirrup
A_v	Area of Shear Reinforcement
A_f	The cross section area of FRP laminates
A_F	The cross section area of FRP laminates
A_{fv}	The cross section area of FRP laminates
E_f	Modulus of elasticity for FRP
E_F	Modulus of elasticity for FRP
L_e	Effective anchorage length
M_u	Corresponding ultimate moment at the studied section
P_{cr}	Applied Load at First Crack
P_{max}	Applied Load at Failure
Q	External Shear Force
Q_u	Ultimate Shear Force
Q_{ay}	Vertical Component of the Aggregate Interlock
Q_{cz}	Shear Resistance of the Uncracked Concrete
Q_d	Dowel Force in the Tension Reinforcement
Q_s	Shear Resistance Carried by the Shear Reinforcement
Q_a	Force transmitted along the crack surface
Q_f -	Shear force transferred by tension in the FRP

V_u Ultimate shear force
V_n Nominal shear force
V_c Nominal shear force provided by concrete
V_s Nominal shear force provided by web reinforcement.
V_f Nominal shear force provided by FRP reinforcement.
γ_c Partial Safety Factor for Concrete
β Shear slip factor
γ_s Partial Safety Factor for Steel
ε_{ef} Effective strain of FRP laminates
ε_{fe} Effective strain of FRP laminates
ε_F Effective strain of FRP laminates
τ_{eff} Bond shear stress
¥ Additional reduction factor to FRP contribution.
θ Angle Between Concrete Compression Struts and the Main Tension
μ Stirrup Volumetric ratio
μ_s FRP strips Volumetric ratio
ρ_l Reinforcement Ratio for Longitudinal Reinforcement
ρ_w Longitudinal Steel Ratio
Φ Strength Reduction Factor
Φ_c Resistance factor for concrete
Φ_s Resistance factor for steel
Φ_f Resistance factor for FRP
Δ_{cr} Deflection Value at First Flexural Crack
Δ_{max} Value at Failure

Abbreviations

FRP Fiber reinforced polymers
CFRP Carbon Fiber reinforced polymers
ST Shear tension Failure
SC Shear Compression Failure
FD CFRP Debonding Failure
FR CFRP Rapture
NB1 Specimen without stirrups and non-strengthened
NB2 Specimen with stirrups (volumetric ratio=0.113%) and non-strengthened
NB3 Specimen with stirrups (volumetric ratio=0.201%) and non-strengthened
SB1 Specimen without stirrups and strengthened (as shown in chapter 3)
SB2-1 Specimen with stirrups as NB2 and strengthened (as shown in chapter 3)
SB2-2 Specimen with stirrups as NB2 and strengthened (as shown in chapter 3)
SB2-3 Specimen with stirrups as NB2 and strengthened (as shown in chapter 3)
SB2-4 Specimen with stirrups as NB2 and strengthened (as shown in chapter 3)
SB2-5 Specimen with stirrups as NB2 and strengthened (as shown in chapter 3)
SB3-1 Specimen with stirrups as NB3 and strengthened (as shown in chapter 3)
SB3-2 Specimen with stirrups as NB3 and strengthened (as shown in chapter 3)
SB3-3 Specimen with stirrups as NB3 and strengthened (as shown in chapter 3)