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Strengthening of reinforced concrete beams in shear by the use of externally bonded steel plates: Part 2 – Design guidelines

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Abstract

Existing concrete structures may require strengthening or stiffening in order to increase their structural performance. One method for providing this enhanced capacity is to adhesively bond steel plates to the concrete surface. The results from experimental tests conducted to investigate the transfer of stress through a steel–concrete adhesive bond by Barnes and Mays [The transfer of stress through a steel to concrete adhesive bond. Int J Adhes Adhes 2001;21:495–502] combined with the shear strengthening and testing to failure of 30 reinforced concrete beams (Part 1 of this paper) was examined. By combining the results from each section of work, values for shear crack angle, effective anchorage length and mean shear stress levels in strengthened reinforced concrete beams were determined. These values were then used to develop a design method. This method can be used to determine the contribution to shear strength of continuous externally bonded steel plates in both rectangular and 'T' section reinforced concrete beams.

Keywords: Concrete; Shear; Strengthening

1. Introduction

In previous work by Barnes and Mays [1] a study of the transfer of stress through a steel-to-concrete adhesive bond was undertaken. This involved specimens which comprised a concrete block with steel plates bonded to two opposite faces using a two-part structural epoxy adhesive (see Fig. 1). By measuring the strain distribution in the steel plates when subjected to tensile load, the shear stress distributed within the adhesive and the effective anchorage length could be determined. The following conclusions were drawn from the results:

- the shear stress in a steel-to-concrete adhesive joint is distributed exponentially, peaking at the loaded end of the specimen
- for the specimen configurations used, the strain was distributed over a 130-mm anchorage length
- increases in either plate or adhesive thicknesses led to a general reduction in peak stress levels and an increase in total bond capacity

Two-dimensional nonlinear finite element analysis of these bonded steel-to-concrete specimens produced a realistic model upon which to base design, both in terms of stress levels and anchorage lengths. With an adhesive thickness of 1 mm the shear stress distribution derived from the finite element analysis more closely resembled the experimental results than a theoretical analysis based upon the method of Volkersen [2]. However, with the thicker adhesive layers (3 and 5 mm) both the Volkersen and the finite element analysis provided similar shear stress distributions. Both analysis methods are only applicable at lower load levels, where significant concrete cracking is not present.

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Nomenclature

τ	shear stress
γ_m	partial safety factor
a	shear span
A_p	area of both side plates
A_{sp}	area of both side plates
$A_{sp.eff}$	effective area of side plate
A_{st}	area of tension reinforcing bars
b	width
b_c	width of the concrete
b_s	width of steel plate
b_v	width of beam to be taken as b for a rectangular beam and as b_w for a flanged beam
b_w	width of rib or web of beam
d	distance from the extreme compression fibre to the centroid of the main steel reinforcement, effective depth
d_{sp}	depth of side plate,
E_c	modulus of the concrete
E_p	modulus of the plate material
E_{frp}	FRP elastic modulus
E_{steel}	Steel plate elastic modulus
f_b	Brazilian tensile strength of concrete
f_c	concrete cylinder compressive strength
f_{yp}	yield strength of side plates
G_f	fracture energy
h	height of plate
l_e	bond length
l_a	anchorage length (mm)
L_{min}	minimum bond length, taken as 100 mm
m	modular ratio E_p/E_c
t_c	thickness of the concrete
t_p	thickness of plate
t	thickness of FRP
t_s	thickness of steel plate
τ	local bond strength
τ_{ave}	average interface stress.
v	design shear stress
V	shear force
V_c	shear force resisted by concrete
$V_{frp,d}$	FRP contribution to shear capacity
V_{nsp}	shear capacity with no side plates
$V_{plated\ beam}$	overall shear capacity of a plated reinforced concrete beam
V_p	shear force resisted by the steel plate
V_{steel}	Steel plate contribution to shear capacity
V_{sv}	shear force resisted by the web steel
γ_{frp}	partial safety factor for FRP in uniaxial tension
ρ_{frp}	FRP area fraction = $2t/b_w$
ρ_{steel}	Steel plate area fraction = $2t/b_w$
$\varepsilon_{frp,e}$	effective FRP strain
$\varepsilon_{steel,e}$	effective steel plate strain
β	angle of principal fibre orientation to the longitudinal axis of the member

The steel–concrete adhesively bonded specimens provide a simple means for investigating shear stress transfer and their results are transferable to strengthened reinforced concrete beams in shear for design purposes (see Figs. 2 and 3). Many other researchers have used this specimen configuration to study the shear stress transfer between bonded plates and concrete [3–6] whilst other researchers have used different specimen configurations [7].

Chen and Teng [3] proposed that the bond length (l_e) be calculated from

$$l_e = \sqrt{\frac{E_p t_p}{\sqrt{f_c}}}, \tag{1}$$

where:
E_p = modulus of the plate material
t_p = thickness of plate
f_c = concrete cylinder compressive strength

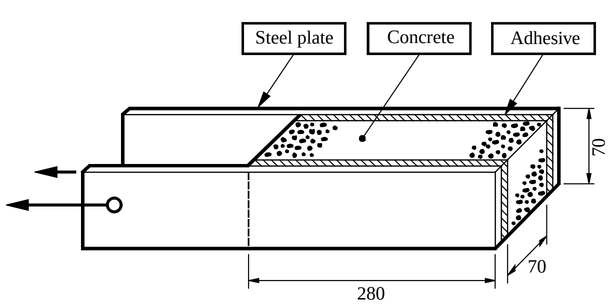

Fig. 1. Experimental specimen.

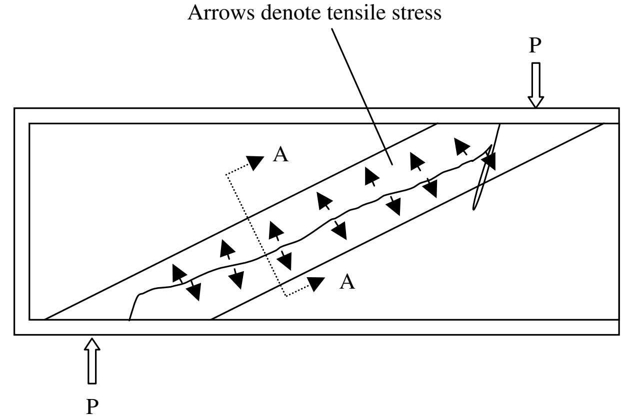

Fig. 2. Plated concrete beam under shear loading.