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Strengthening of Bending Concrete Elements with Epoxy-Bonded Plates

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Summary

The paper presents the results of four-point bending tests performed on short reinforced concrete beams strengthened in flexure by externally bonded steel as well as carbon fibre-reinforced plastic plates. For the gluing of the plates to the concrete surface the commercial epoxy adhesive was used. The localisation of the shear-peeling crack at the plate end, which initiated separation of the strengthening plate from the beam surface, occurred at both used types of external reinforcement at approximately the same flexural load. On the other hand, externally bonded plates held the concrete together and delayed and hindered crack development. Due to strengthening also considerable changes of strain distribution along the beam height at the middle of the beam were detected.

Keywords: bending strengthening, steel plates, CFRP plates, epoxy adhesive

1. Experimental programme

The aim of our experimental work was to study critical situation when peeling or/and shear failure prevailed over the flexural failure of the concrete reinforced (CR) beams strengthened in flexure with externally bonded plates. Also the influence of the external reinforcement to the global and local deformation ability of beams was studied. For these reasons four-point bending test was performed on short concrete beams (150x150 mm in cross-section and 1000 mm long) internally reinforced by two ribbed bars $\phi 12$ and stirrups. As external reinforcement, mild steel plates as well as CFRP plates (SikaCarboDur) were applied and for gluing the plates to the concrete surface the epoxy adhesive Sikadur-30 was used. For each type of the external reinforcement two beams were tested together with one reference specimen without externally bonded plate. The loading speed in the elastic range was equal to 5kN/min. During each test flexural forces and deformation characteristics of the test specimen were simultaneously measured and crack pattern was traced and registered. Deflection of the beam was measured by LVDT transducer and concrete strains along the beam height were measured by electronic deformeters. Strain gauges were used for the measurements of the concrete as well as plate strains at the lower surface of the beam.

2. Main test results and discussion

The steel plate considerably increased the stiffness of the beam up to the localisation of the shear-peeling cracks at the plate ends. In case of the CFRP plate the increase in the beam stiffness was not significant. On the other hand, both types of the externally bonded plates held the concrete together and delayed and hindered crack development. This is probably the cause for significant change of strain distribution along the central cross-section of the beams, detected during the tests. After the initiation of the strengthening plate separation, the shape of the strain diagrams changed from straight to bi-linear line. Precisely, along the lower 50 mm of the height of the cross-section concrete strains seem to be approximately constant (steel plate) or even declined towards the lower strains (CFRP plate - Figure 1).

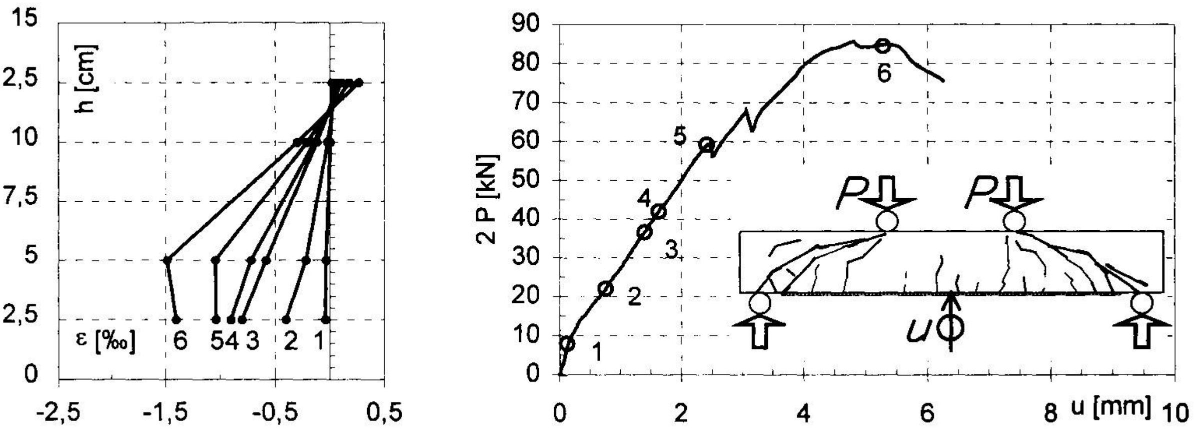

Figure 1: Concrete strains along the beam height at different flexural load levels and final crack pattern for the beam with externally bonded CFRP plate.

The typical failure mechanism of the test specimens with the externally bonded plates was as follows. Soon after the flexural cracks occurred in the middle span between the points of load application, flexural cracks at both ends of the plate were initiated. With increased loading this cracks transformed into diagonal tensile cracks, which were arrested by the internal stirrups. At the same time separation of the strengthening plate occurred due to the localisation of a shear-peeling crack in concrete just above the glue layer. This happened at both types of external reinforcement at approximately the same flexural load. As the process of the plate separation continued, one of the diagonal tensile cracks started to open and crack faces started to slide mutually. Due to relatively small spacing between the stirrups, beside the localised diagonal tension crack also more distributed shear cracks occurred in the shear span (Figure 1).

3. Analytical approach

The shear and peeling stresses at the end of the strengthening plate were estimated in a moment when the plate separation started. For this purpose the closed analytical formulae were used. The calculated peak shear stresses are considerably lower than the bond shear strength between the epoxy layer and the concrete. On the other hand, peeling stresses are close to the bond tensile strength between the glue layer and the concrete. Therefore, it can be concluded that high peeling stresses at the end of the strengthening plate were responsible for the separation of the steel as well as CFRP plate from the beam surface. As and example the calculated peeling stress are presented in Figure 2.

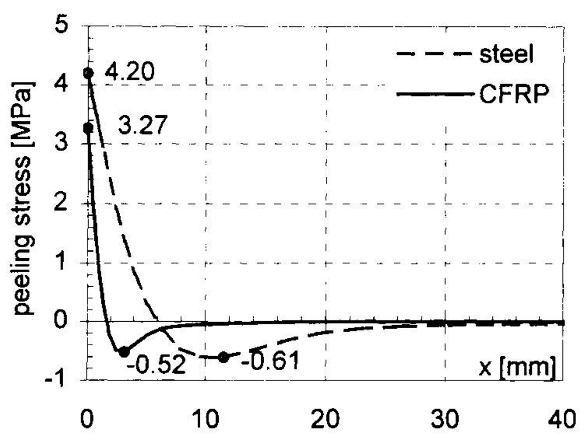

Figure 6: Peeling stresses at the end of the strengthening plate in the bond zone

Due to good agreement between the experimentally and the analytically obtained results it seems that the shear and peeling stresses in the bond zone could be controlled by theoretical calculations. This approach was already used for the design of long bending reinforced concrete elements with externally bonded steel and CFRP plates, in order to prevent shear-peeling failure before the bending load-bearing capacity of the elements would be exhausted.