2-span reinforced concrete beam strengthened with fibre reinforced polymer

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***Abstract*: The structural behaviour of reinforced concrete beams strengthened in flexure with FRP EBR (Fibre Reinforced Polymer - Externally Bonded Reinforcement) has been extensively investigated for isostatic beams. However, limited information on the behaviour of FRP strengthened continuous (hyperstatic) beams is available. In the following, a continuous concrete beam is considered with two spans of 5 meter. The flexural strength of this member can be increased by strengthening the field-spans or the middle support , or both. The non-linear behaviour of the beam is investigated. It is verified analytically in which degree moment redistribution is still present when applying this strengthening technique. Owing to the non-linear behaviour, there is a migration of the point of contraflexure. This will influence the stresses in the FRP that will change from compression to tension.**

***Keywords*: FRP EBR, Flexural strengthening, Hyperstatic beam, Moment redistribution**

I. Introduction

Structures may need to be strengthened for many different reasons, such as change in function and durability issues. There are different strengthening techniques available, among which the use of externally bonded reinforcement (EBR) with Fibre Reinforced Polymer (FRP).

This study focuses on the flexural strengthening of hyperstatic beams with FRP EBR. Herewith, carbon fibre laminates are glued on the bottom (in the field) or on the top (above the support) of a concrete beam. The use of FRP EBR will increase the capacity of the member, but additional mechanisms of failure may govern the ultimate state, among which bond failure between the laminate and the concrete.

Aim of this study is to obtain a better insight in the behaviour of reinforced concrete structures strengthened in flexure in a multi-span situation and translate this behaviour to an appropriate calculation method.

II. Loss of composite action

Bond failure in case of FRP EBR implies the loss of composite action between the concrete and the FRP reinforcement. This type of failure is often very sudden and brittle. According to Matthys [2] different bond failure aspects

can be distincted.

A. *Crack bridging*

The externally bonded FRP will need to bridge cracks. In regions with significant shear forces, shear cracks have a vertical (v) and a horizontal (w) displacement. The vertical displacement of the concrete causes tensile stress perpendicular to the FRP EBR, which initiates debonding of the laminate (figure 1).

For flexural cracks, debonding is less critical and remains local.

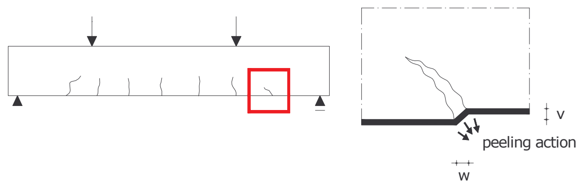

Figure 1: Peeling-off caused at shear cracks

B. *Force transfer*

The bond shear stress considered between two sections at a distance Δx (figure 2) equals to:

$$\tau_b = \frac{\Delta N_{fd}}{b_f \Delta x} \tag{1}$$

This value has to be smaller than the bond strength between the concrete and the FRP reinforcement.

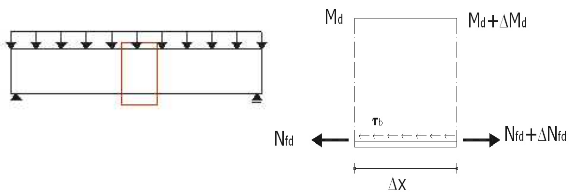

Figure 2: Peeling-off caused by force transfer

C. *Curtailment and anchorage length*

Theoretically the FRP reinforcement can be curtailed when the axial tensile force can be carried by the internal steel only. The remaining force in the FRP at this point needs to be anchored. The force that can be anchored increases as the available anchorage length increases, but reaches a maximum for an anchorage length l_{max}. For $l > l_{max}$ the anchorage capacity remains constant.

D. *End shear failure*

If a shear crack appears at the plate-end, this crack may propagate at the level of the internal steel reinforcement (figure 3). In this case the laminate as well as a thick layer of concrete will rip off.

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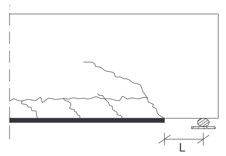

Figure 3: Concrete rip-off by plate end shear.

III. Results of Analytical Study

For the analytical study we consider a concrete beam with three supports and two point loads (figure 4). The height of the beam equals 400mm and the width 200mm. For internal steel reinforcement two bars (diam 14) are considered in the fields and four bars (diam 14) at the mid-support. The corresponding reinforcement ratio's are ρ_{sf} = 0.85 % and ρ_{ss} = 0.43 %.

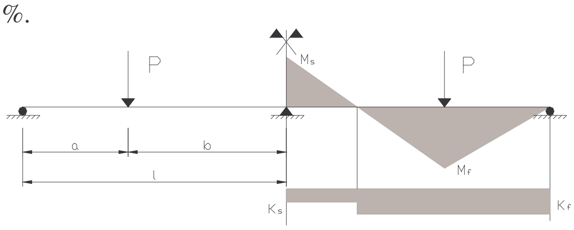

Figure 4: Hyperstatic beam used in analytical study.

Three different cases are investigated: case A, the 2 span beam without external reinforcement, case B, the beam with FRP EBR above the middle support and case C the beam with FRP EBR in the field spans. The FRP laminates have following dimensions: t_f = 1,2mm and b_f = 100mm, that equals to $\rho_{ff} = \rho_{fs}$ = 0.17 %.

The moment redistribution is illustrated in Figs. 5 to 7. In each graph a linear curve and a non-linear curve is observed. The linear curve is the moment distribution calculated by the classic theory. Hereby, the relationship between the acting load and the internal moment is linear, as in the case of isostatic beams. The non-linear curve is the moment distribution calculated by the non linear theory. The non-linear relationship between acting load and internal moment relates to the variable stiffness along the length of the beam (and which also depends on the load level). This involves, in the case of hyperstatic beams, a significant redistribution of moments with respect to the linear situation. For simplifying we use two zones with each a constant flexural stiffness over the length of the zone. The first zone is located around the middle support and the second one is located in the field (figure 4).

In the three cases the field yield first. Without strengthening, the field span collapses first. With strengthening the location at the mid-support collapses first, in both strengthening cases.

In case A (unstrengthened) a plastic hinge is formed in each field span (vertical line in Fig.5 after yielding of reinforcement in the field spans). In case B (strengthened in the mid support, Fig. 6) the plastic hinge formation is similar to case A but extends to a higher load level due to the additional moment redistribution at the strengthened mid-support zone. In case C (strengthened in the field spans, Fig. 7) it is observed that the plastic hinge is formed at the mid-support in stead of the field spans, due to strengthening of the latter. The load which collapse is obtained is also higher.

It is remarked that the above analysis assumes full action between concrete and FRP EBR. In advanced analysis including debonding mechanisms will be developed as part of the PhD study.

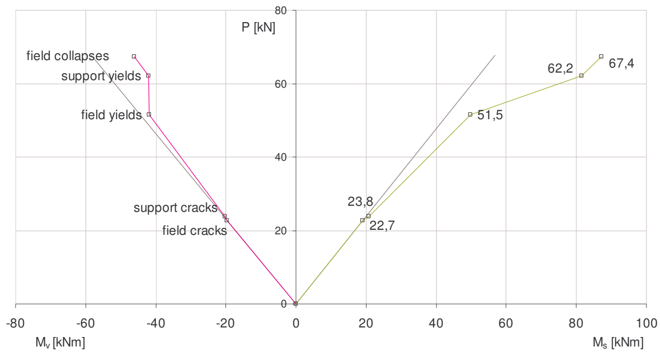

Figure 5: Case A: moment redistribution without strengthening.

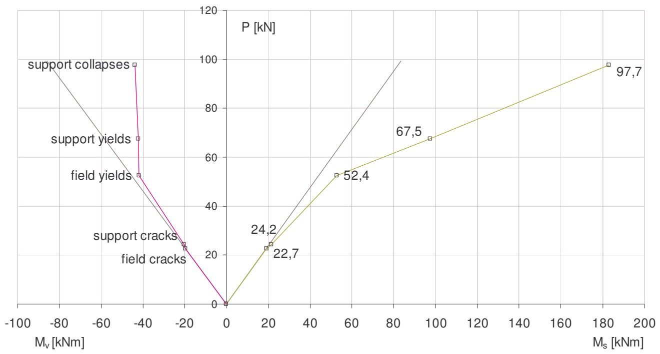

Figure 6: Case B: moment redistribution with FRP EBR above the middle support.

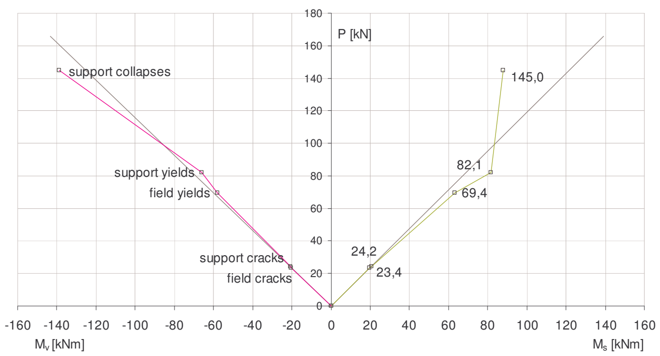

Figure 7: Case C: moment redistribution with FRP EBR in the field.

IV. Future Research

Further research in this PhD study will focus on following aspects:

- In hyperstatic beams there exist the possibility that positive moments appear at the end of a laminate. The location of curtailing the FRP EBR near the mid support will have a influence on the failure mechanisms and is currently not documented.
- Owing to the non-linear moment redistribution, the point of contraflexure (this is a point between the load and the middle support where the moment line is equal to zero) will move over a certain distance. If the laminate is situated in this zone, the change in the point of contraflexure will influence the shear stresses between laminate and concrete.
- The influence of FRP-EBR on the rotation capacity of the plastic hinges.

References

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