Exercise 12: External strengthening

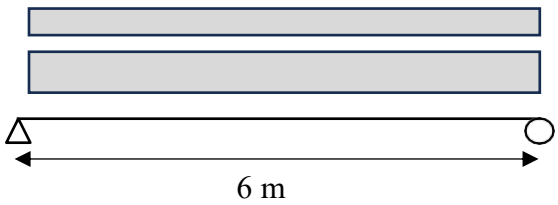
Increasing bending resistance using bonded Carbon Fiber Reinforced Polymer (CFRP) laminates

Problem

The structure is a reinforced concrete office building from the 1960's, 18 m high, which is changing use. The owner wants freedom in organizing the office spaces. When examining the reinforced concrete structure, one of the floor slab shows insufficient resistance to bending.

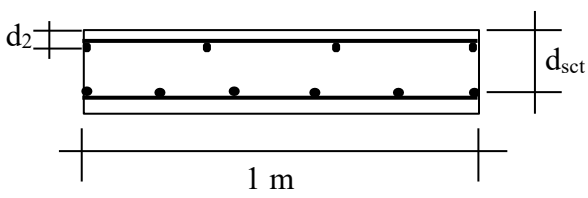
The aim of this exercise is to check the structural safety of a unit cross-section of this slab and design its external strengthening. The relevant material properties, the dimensions (nominal) and the actions on the slab (characteristic values) are given below. The risk scenario "failure of the slab due to fire" is to be considered.

- Compressive strength of concrete (updated value): $f_{ck,act} = 36\ N/mm^2$
- Tensile strength of the concrete (updated mean): $f_{ctm,act} = 2.5\ N/mm^2$
- Reinforcing steel strength (updated charact. value, 5% fractile): $f_{sk,act} = 400\ N/mm^2$
- Reinforcing steel ultimate elongation: $\varepsilon_{suk} = 5\ \%$
- Carbon fiber laminate (Sika Carbodur S512 laminate: width 50 mm, thickness 1.2 mm): Properties, see product data sheet Sika_Carbodur_S_2022.pdf
- Design bond coefficient : $\kappa_L = 0.8$
- Static system :



q_k = 5 kN/m (service load)
g_k = 6.5 kN/m (self-weight)

- Cross-section of the slab (of unit length 1 m):



h = 220 mm
d = 185 mm
d_2 = 34 mm
top 4ø8 : A_{S2} = 201 mm^2
bottom 6ø14 : A_{S1} = 924 mm^2

Work to be carried out

1. To which fractile correspond the reinforcing steel ultimate elongation ?

2. Bending verification of the slab using the Hillerborg strip method:

   - Determination of the updated moment $M_{Rd,act}$ of the slab before strengthening;

   - Determination of the updated maximum acting moment $M_{Ed,act}$ taking into account the load factor $\gamma_{G,act} = 1.20$ for permanent actions and verification of structural safety (determination of the degree of compliance).

3. Is the hazard situation "laminate failure due to fire" critical?

   Note: the office building is assumed to satisfy the required fire resistance time, usually R60 for medium size multistorey buildings of height > 11 m (see AEAI, directive 15-15, § 3.7).

4. Pre-dimensioning of the required cross-section of the carbon fiber laminates, taking into account a partial resistance factor $\gamma_M = 1.20$ (for the laminates and the reinforced concrete) and check the cross-section with the selected laminates. Discuss the results.

   Note: Either assume a compression block over 80% of the section's compressed height, or adapt the Excel file from Exercise 11, or use the S&P software (if suitable for slabs).

5. What other additional checks are essential before validating the additional reinforcement? Carry them out.

Note: this document is a translation and adaptation of the exercise 9, lecture notes Prof. Eugen Brühwiler "Structures existantes I : Examen et interventions – Bases", 2022 edition, course CIVIL-436, courtesy of Prof. Brühwiler.

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