

## Exercise 12: External strengthening

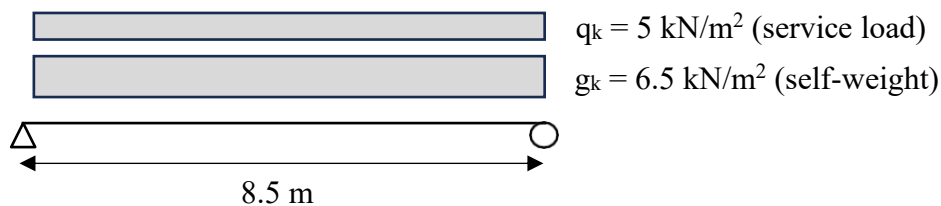
### Increasing bending resistance using bonded Carbon Fiber Reinforced Polymer (CFRP) laminates

#### Problem

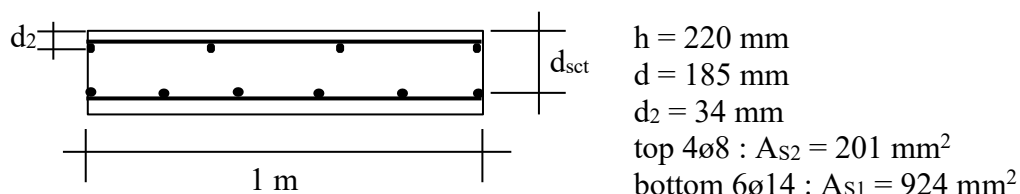
The structure is a reinforced concrete office building from the 1960's, 18 m high, which is changing use. The owner wants freedom in organizing the office spaces. When examining the reinforced concrete structure, part of one of the floor slabs shows insufficient resistance to bending. This slab is rectangular, with dimensions 9 x 8.5 m, it can be considered simply supported along all edges.

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):  $f_{ck,act} = 36 \text{ N/mm}^2$
- Tensile strength of the concrete (updated mean):  $f_{ctm,act} = 2.5 \text{ N/mm}^2$
- Reinforcing steel strength (updated charact. value, 5% fractile):  $f_{sk,act} = 400 \text{ N/mm}^2$
- 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 :  $\kappa_L = 0.8$
- Rectangular slab, cut along the shortest span to show the static system:



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



### **Work to be carried out**

1. To which fractiles correspond the compressive strength of concrete and the reinforcing steel ultimate elongation?
2. Bending verification of the slab using the Hillerborg strip method (see annex):
  - 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 "laminated 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, considering a partial resistance factor  $\gamma_M = 1.20$  (for the element composed of the laminates and the reinforced concrete) and check the cross-section with the selected laminates. Discuss the results.
  - a. First assume a compression block over 80% of the section's compressed height;
  - b. Repeat the calculation by adapting the Excel tool from Exercise 11;
  - c. Bonus: One can repeat the calculations using the S&P software (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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**Annex: Example of the strip method for a square, simply supported slab loaded with a uniform distributed load  $w$ , with the simplest choice for load distribution**

[1]

Extract from : Nilson, Darwin, and Dolan, ‘Chapter 15: Strip Method for Slabs’, in *Design of Concrete Structures*, Thirteenth Ed., New York, N.Y: The McGraw-Hill Companies, 2004, pp. 508–544.

The simplest load distribution is obtained by setting  $k = 0.5$  over the entire slab, as shown in Fig. 15.1. The load on all strips in each direction is then  $w \cdot 2$ , as illustrated by the load dispersion arrows of Fig. 15.1a. This gives maximum moments

$$m_x = m_y = \frac{wa^2}{16} \tag{15.4}$$

over the whole slab, as shown in Fig. 15.1c, with a uniform lateral distribution across the width of the critical section, as in Fig. 15.1d.

**FIGURE 15.1**  
 Square slab with load shared equally in two directions.

