Eidgenössische Technische Hochschule Zürich
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Advanced Structural Concrete – Exercise 1

(101-0127-00L)

Topic: Stress fields **Dimensioning of a diaphragm (high slenderness)**

Hand out: 12. October 2023, HIL E 7

1 Dimensioning bases of this exercise

1.1 Introduction

The goal of this exercise is to learn how to apply stress fields and strut-and-tie models to a problem with 3D effects. Particular attention is paid to the presence of transversal reinforcement, the selection of suitable effective compressive strength, and proper detailing of the nodal zone.

In these tasks, the diaphragm of a hollow box girder bridge over a bridge pier should be dimensioned in accordance with the provisions of the design standard SIA 262 [1]. The box girder is supported above the pier by two bridge bearings arranged symmetrically with respect to the longitudinal axis of the bridge (see overview A1.1). The exercise consists of designing the diaphragm for the ultimate limit state.

1.2 Geometry

The dimensions can be taken from Figure A1.1. The diaphragm must be provided with an access opening, which provides access for material transport during the construction state and for inspections and repairs in the final state. The minimum dimensions of the opening are as follows: b x h = 0.8 m x 0.9 m.

1.3 Material

For the construction of the bridge, C40/50 concrete, B500B reinforcing steel, and Y1860 prestressing steel are used.

1.4 Exposure classes

The diaphragm is located inside the hollow box in an environment with relatively constant humidity and not exposed to de-icing salts. The design concrete cover amounts to c_{nom} = 45 mm.

1.5 Loads

The support reaction R_d per bearing is 6 MN (dimensioning value). To simplify, it can be assumed that each adjacent web element of the box girder carries an equal amount of shear to the supports (i.e. $V_{L1}= V_{L2}= V_{R1}= V_{R2}= R_d/2$, see Figure A1.2).

It is assumed that the diaphragm does not have to transmit torsion or horizontal forces. The dead weight of the cross member may be neglected.

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2 Tasks

2.1 Strut-and-tie model without prestressing

Determine the required dimensions of the diaphragm and develop a suitable strut-and-tie model, considering that no prestressing is used. Assume the two following extreme cases:

a) The entire load of the webs should be suspended to the top of the diaphragm. The necessary suspension reinforcement shall be arranged in the area shown in Figure A2.1.
b) No suspension reinforcement shall be used.

Determine the required reinforcement in each case and carry out the necessary verifications.

2.2 Activating the stirrup reinforcement in the intersection area

For many existing bridges, the "suspension reinforcement" was arranged in the area shown in Figure A2.2 and dimensioned accordingly. This detailing rule is based on experiments by Leonhardt and Rostásy and is still used today ([2], [3], [4]). If one examines the force flow with a stress field according to Task 1a), the "suspension reinforcement" outside the intersection area of the web and the diaphragm cannot be used for load suspension. With a stress field according to Task 1b), however, it is possible to activate the reinforcement outside the intersection area. Therefore, the reinforcement outside the intersection area contributes to the load-bearing resistance. Strictly speaking, this is not suspension reinforcement but rather strengthening shear reinforcement of the web and diaphragm.

This task consists of developing a stress field in which those parts of the "suspension reinforcement" according to Leonhardt/Menn (Fig. A2.2) outside the intersection area (Fig. A2.1) can be fully activated. Discuss the influence on the required tension chord force in the web.

2.3 Truss model with prestressing

Develop a strut-and-tie model suitable for the load transfer using the prestressing layout shown in Figure A3. Assume 27 strands (A_p = 150 mm^2, duct diameter $\varnothing_H$ = 121 mm) for the prestressing cable P1 and 15 strands (A_p = 150 mm^2, duct diameter $\varnothing_H$ = 106 mm) for the prestressing cable P2. Introduce the prestressing forces as anchorage and deviation forces. To determine the deviation forces, it may be assumed that the prestressing cables follow a parabolic path over the cross-section width with a maximum deviation of f_{P1} and f_{P2} defined in Fig. A3. Carry out the necessary structural safety checks and determine the necessary passive reinforcement.

3 Literature

[1] SIA 262 (2003), "SIA 262 Concrete Strucutres." Swiss Society of Engineers and Architects, 2013.
[2] F. Leonhardt, R. Koch, and F. Rostàsy S. (1971), "Aufhängebewehrung bei indirekter Lasteintragung von Spannbetonträgern, Versuchsbericht und Empfehlungen," *Beton- und Stahlbetonbau*, vol. 66, no. 10, pp. 233–241.
[3] European Committee for Standardization (2004), "Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings."
[4] E. Brühwiler and C. Menn (2003), *Stahlbetonbrücken*, 3rd ed. Springer.

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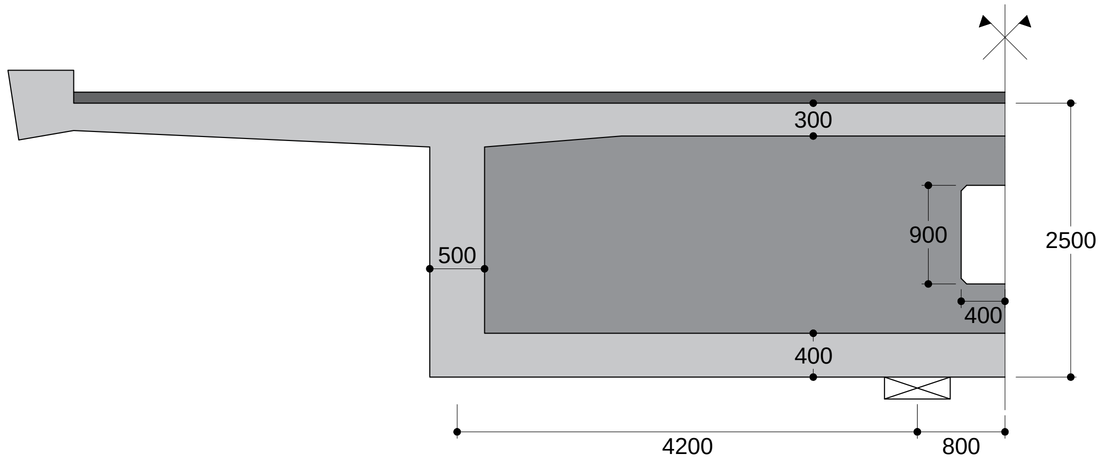
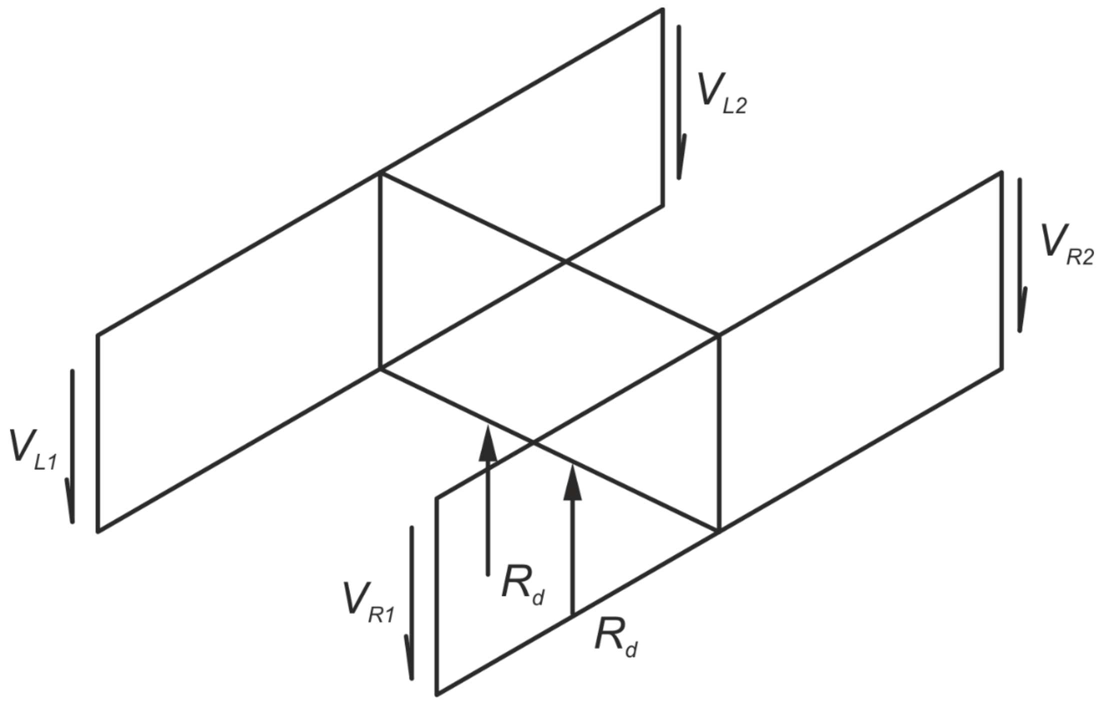
Appendix A - Figures

A1 Overview

A1.1 Cross-section of the hollow box girder (support region), diaphragm with high slenderness



A1.2 Flow of forces from the adjoining webs to the diaphragm.



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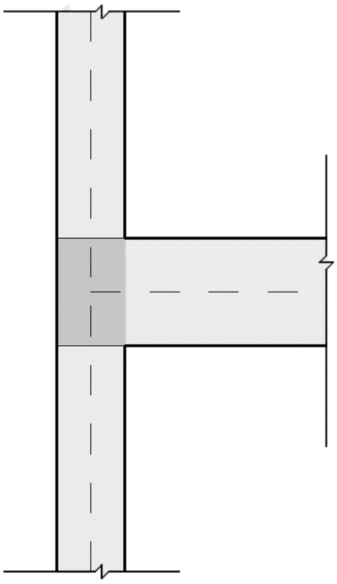
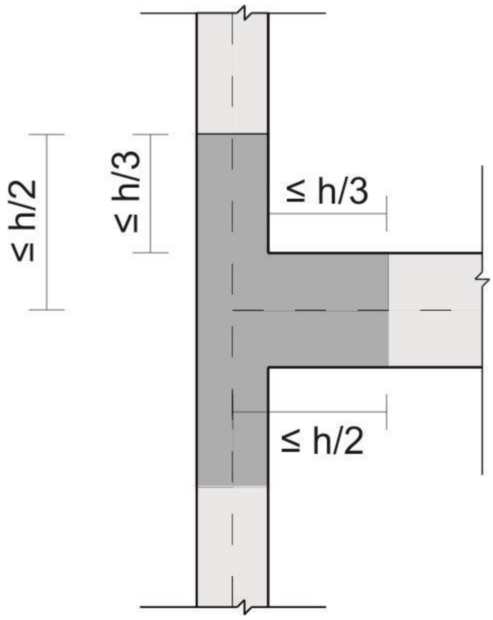
A2 Location for the suspension reinforcement

A2.1 Section for task 1 a)



A2.2 Section for task 2



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A3 Cross section with prestressing layout