Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 62 (1991)

Artikel: Design of the support regions of concrete box girders
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DOI: https://doi.org/10.5169/seals-47646

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Design of the Support Regions of Concrete Box Girders

Dimensionnement des zones d'appui des poutres-caisson en béton

Bemessung der Auflagerbereiche von Beton-Hohlkästen

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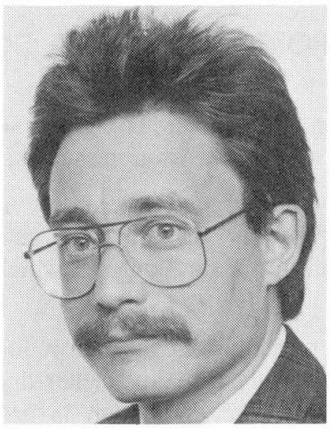

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SUMMARY

For dimensioning and detailing the support regions of concrete box girders, strut-and-tie-models are a valuable tool. In this paper it will be shown how a strut-and-tie-model for the transverse diaphragm can be developed and how in the model the interaction between the longitudinal and cross directions must be considered.

RÉSUMÉ

L'analogie du treillis faisant intervenir tirants et bielles constitue un outil très appréciable lors du dimensionnement des zones d'appui des poutres-caisson. Dans cet article, un exemple présente l'analyse d'un diaphragme à l'aide de cette analogie, ainsi que la nécessité d'une modélisation cohérente dans le cadre d'un calcul effectué dans les directions longitudinale et transversale.

ZUSAMMENFASSUNG

Für die Bemessung und konstruktive Durchbildung der Auflagerbereiche von Beton-Hohlkastenträgern sind Stabwerksmodelle ein wertvolles Hilfsmittel. In diesem Aufsatz wird anhand eines Beispiels die Entwicklung eines Stabwerksmodells für das Querschott und die Notwendigkeit konsistenter Modelle für die Bemessung in der Längs- und Querrichtung gezeigt.

1. INTRODUCTION

Support regions of concrete box girders are important and highly stressed parts of the structure. For dimensioning and detailing these D-regions strut-and-tie-models are a valuable tool. They allow to follow up the forces consistently from the B-regions (webs, flanges) to the supports as strictly required by Schlaich et. al. in /1,3,4/. Examples of basic strut-and-tie-models for these regions are shown in /3,4/.

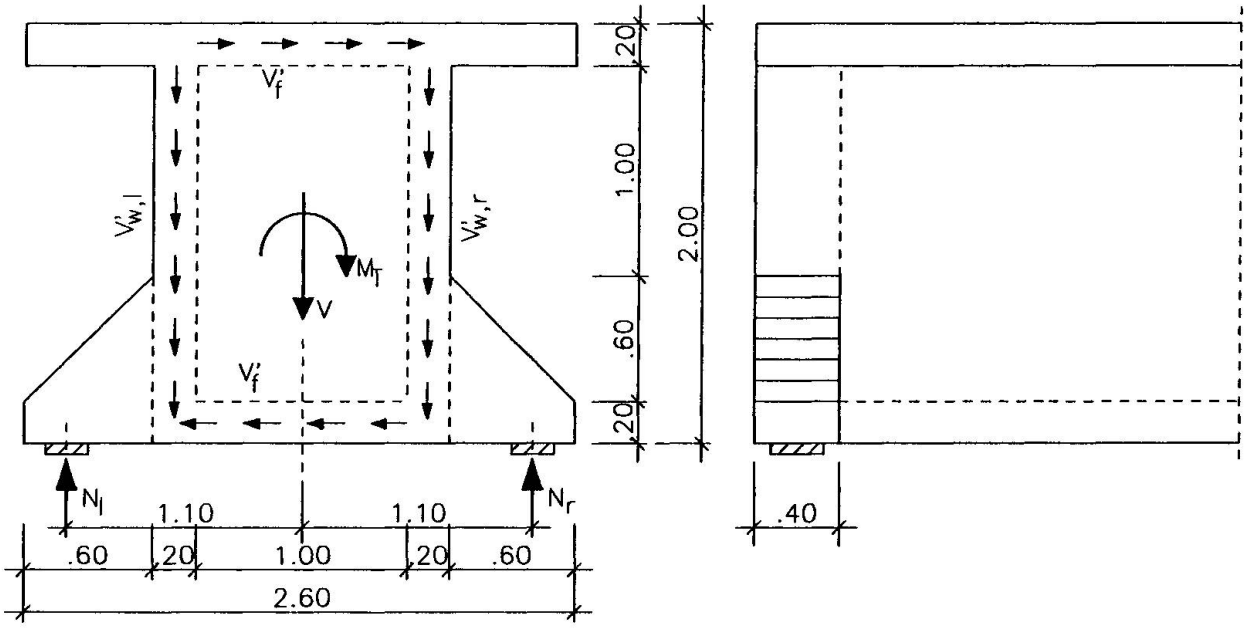
This paper shows how a strut-and-tie-model for the complicated diaphragm of a concrete box girder can be developed. The interaction between the load bearing behavior in the longitudinal and the cross direction is thereby considered.

2. DESIGN OF THE END-SUPPORT REGION OF A CONCRETE BOX GIRDER USING STRUT-AND-TIE-MODELS

Fig. 1 shows the end-support region of a concrete box girder subjected to shear and torsion. The bearings are spaced apart by means of "corbels" to avoid tension in the bearings under the given loading condition.

It is common use to treat "shear" and "torsion" separately and to superimpose the results later on. This, however, is unsatisfactory, as generally in structural concrete design the design-models cannot be superimposed. It is necessary to develop a single model which takes into account all the forces at the same time, as required by Breen /2/.

According to the basic assumption of a constant shear-flow for circulatory torsion, the in-plane forces due to shear and torsion are distributed uniformly along the center-lines of the individual webs V'_w and flanges V'_f. The following strut-and-tie-model for the diaphragm is based on the assumption that these forces are transfered evenly to the diaphragm. A corresponding model for the webs is shown in chapter 2.8.



Forces at support:

M_T = 960 kNm

V = 1200 kN

Support reactions:

N_{left} = 1200/2 - 960/2.2 = 164 kN

N_{right} = 1200/2 + 960/2.2 = 1036 kN

Distributed forces in the webs and flanges due to shear and torsion:

V'_f = 960/(2·1.8·1.2) = 222 kN/m

$V'_{w,left}$ = 1200/(2·1.8) - 222 = 111 kN/m

$V'_{w,right}$ = 1200/(2·1.8) + 222 = 555 kN/m

Fig. 1: End-support region of the box girder
Support reactions and forces in the webs and flanges due to shear and torsion

2.1 Modelling technique

To develop the strut-and-tie-model of the whole D-region it is sometimes helpful to compose this model of already wellknown and established "sub-models". Thus parts of the structure can be treated separately. However, at the intersections of the different, parts the sub-models have to correspond with each other and must compose to the overall consistent model. Equilibrium must be satisfied for each of the sub-models as well as for the resulting overall model. In the following a strut-and-tie-model for the diaphragm will be developed in such a way.

Those parts of the structure in which the internal forces are reasonably well known are :
- the upper part of the diaphragm
- the corbels.

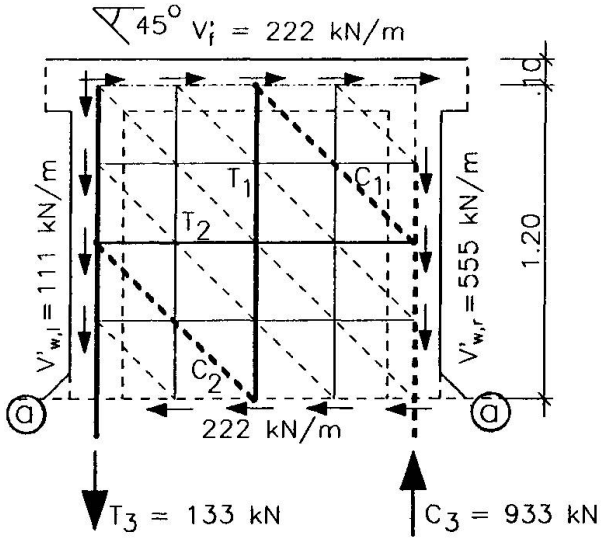
In the lower part of the diaphragm the state of stress is primarily unknown due to the geometric discontinuity.

2.2 The upper part of the diaphragm

The upper part of the diaphragm is shown in fig. 2 . Equilibrium requires that the horizontal shear force along line a-a has to balance the total shear force in the upper flange. The shear force along line a-a is also assumed evenly distributed.

The state of stress in this part of the diaphragm and the appropriate model is that of an ordinary rectangular diaphragm loaded by shear forces from the webs and top flange and directly supported under the webs /4/. The forces from the flanges V'_f have to be diverted by inclined struts C'_1 and vertical ties T'_1. For simplicity the inclination of the strut is assumed to be 45^o. To balance the horizontal components of the strut forces additional horizontal ties T'_2 are necessary. The vertical components of the strut forces and the forces of the webs $V'_{w,l}$, $V'_{w,r}$ sum up to give T_3 and C_3.

Note, that the struts and ties crossing the diaphragm represent stress-fields, therefore the reinforcement covering the tie forces has to be distributed accordingly.



Tie forces per unit length in the diaphragm
(for a 45^o inclination of the compression field):
$T'_1 = T'_2 = 222$ kN/m

Forces in the webs:
$C_3 = 555 \cdot 1.2 + 222 \cdot 1.2 = 933$ kN
$T_3 = -111 \cdot 1.2 + 222 \cdot 1.2 = 133$ kN

Fig. 2: Upper part of the diaphragm with forces and model

2.3 The corbels

Fig. 3 shows the corbels loaded by the bearing forces and by the vertical forces from the webs necessary to obtain equilibrium in the vertical direction. To ensure overall equilibrium the models require inclined struts C_6 resp. C_7, horizontal ties T_4 resp. T_5 and horizontal compression forces C_4 resp. C_5.

The concentrated node at the bearing plate is shown at the right corbel. The dimensions of this node are determined by the width of the bearing plate and by the reinforcement layout (node K6 acc. /4/). This critical concentrated node should already be checked at this early design state with respect to bearing pressure and anchorage of the reinforcement according to /4/.

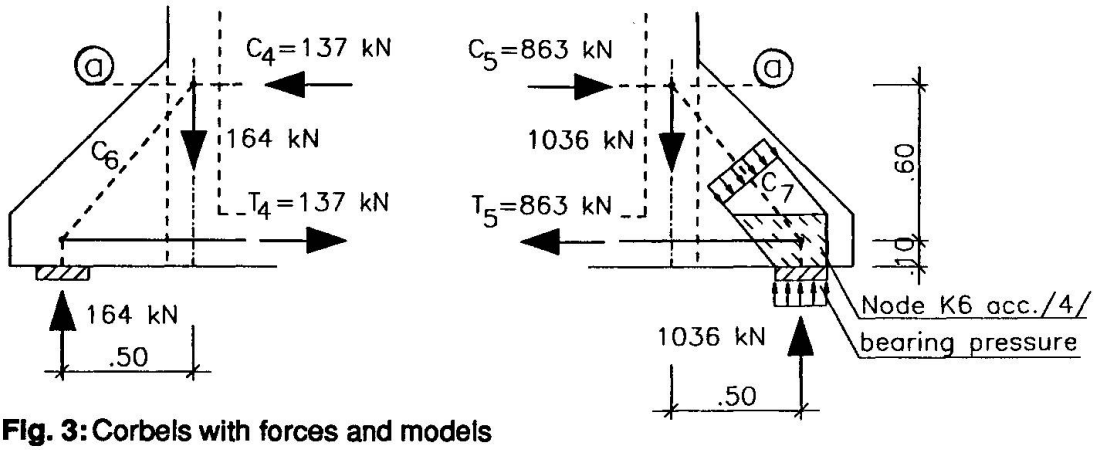


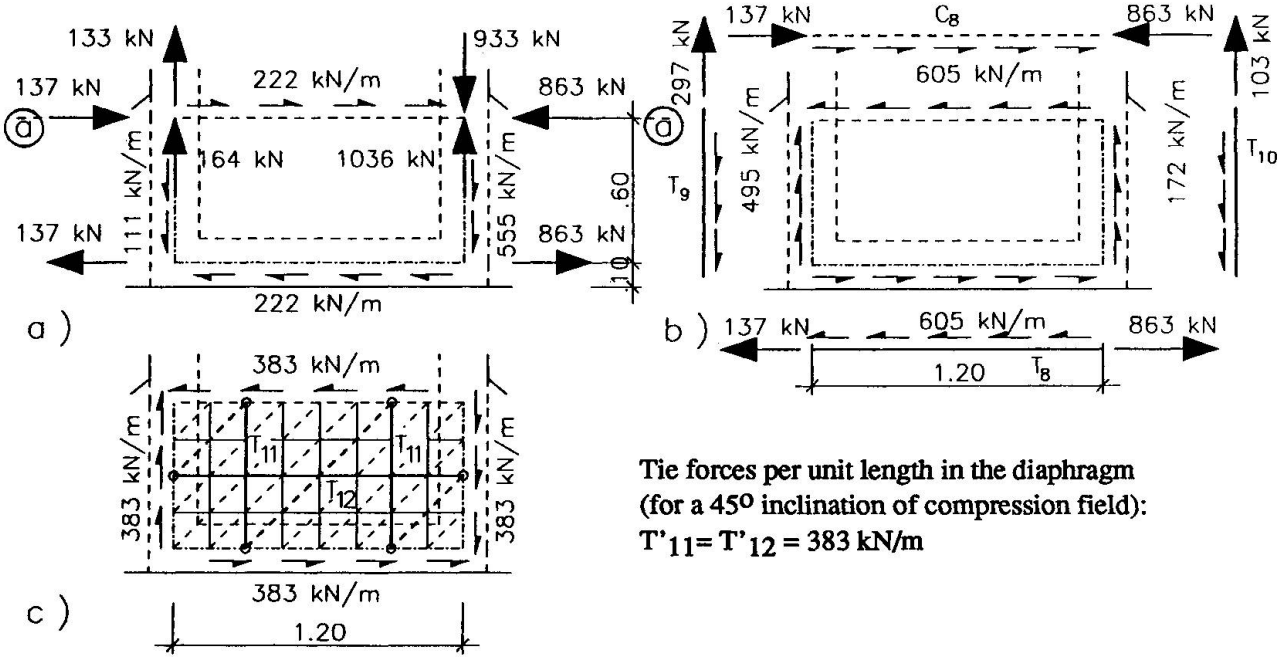
Fig. 3: Corbels with forces and models

2.4 The lower part of the diaphragm

The lower part of the diaphragm (fig. 4a) is loaded by the shear forces from the webs and bottom flange, by the forces from the upper part of the diaphragm and by the forces from the corbels.

A horizontal strut at the top C_8 and a horizontal tie at the bottom T_8 balance parts of the horizontal forces and further introduce evenly distributed forces along the horizontal edges of the lower part of the diaphragm. The concentrated vertical tension forces in the axis of the webs T_9, T_{10} are anchored in the diaphragm by reinforcement, and thus introduce distributed forces along the vertical edges of the diaphragm (fig. 4b).

What remains from all the forces (acc. to figs. 4a and 4b) is a "shear-wall" loaded along its edges (fig. 4c). The model for this shear-wall is of the same type as for the upper part of the diaphragm. For the inclination of the struts again 45° was assumed. Note, that the tie forces per unit length in the lower part of the diaphragm T'_{11}, T'_{12} are much higher than in the upper part ($T'_{11} = 1.73\ T'_1$)!



Tie forces per unit length in the diaphragm (for a 45° inclination of compression field):
$T'_{11} = T'_{12} = 383$ kN/m

Fig. 4: Lower part of the diaphragm
a) with forces acting on it
b) additional shear forces onto the diaphragm
c) remaining shear-wall with appropriate model

2.5 Complete model

Fig. 5 presents the overall model of the end-section resulting from the previous sub-models. The inclined struts in the corbels and the horizontal strut in the diaphragm along line a-a also require a certain width as indicated for the strut C_7 in the corbel (fig. 3).

2.6 Principal reinforcement layout

Fig. 6 shows the principal reinforcement layout for the end-section. Note again the additional horizontal and vertical reinforcement necessary in the lower part.

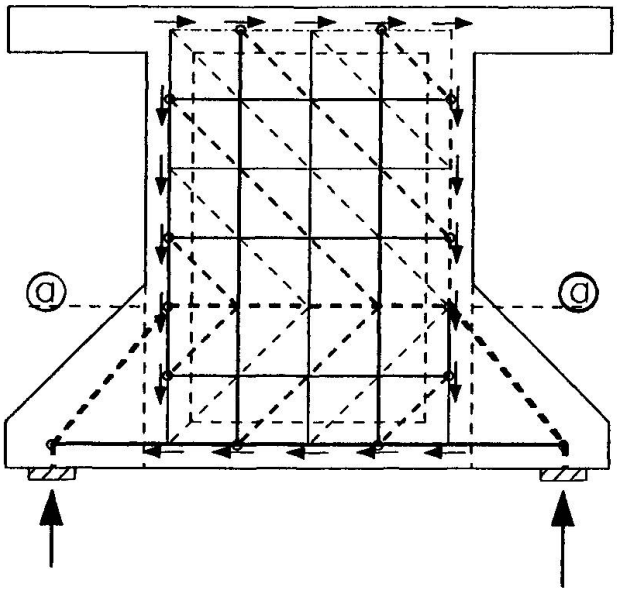


Fig. 5: Complete model

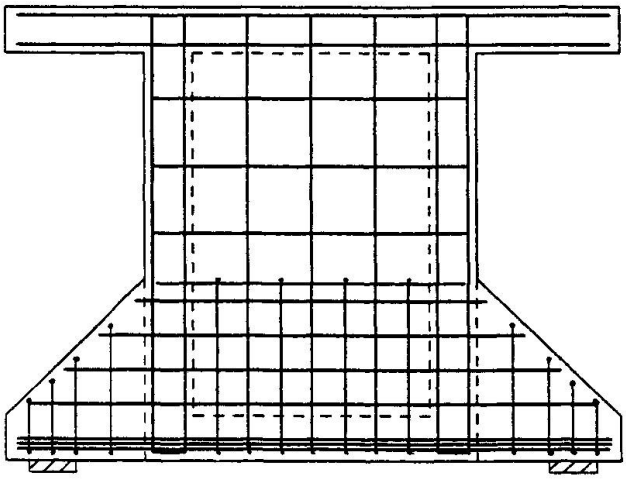


Fig. 6: Principal reinforcement layout

2.7 Check of concrete compression stresses

The highly stressed and rather concentrated struts C_6 resp. C_7 in the corbels have to be checked at the nodes at the bearing plates. This can be done according to regulations given by Schlaich et. al. in /4/ or by Sundermann in /6/. Within the remaining parts of the diaphragm only stress-fields occur in which the concrete stresses are not critical.

2.8 The strut-and-tie-model for the webs

An appropriate model for the webs for the above assumed evenly distributed vertical forces at the connection to the diaphragm V'_w is shown in fig. 7. This model has been developed on the basis of stress-fields and is explained in detail by Reineck et. al. in /5/. Here only the results are presented.

According to this model distributed longitudinal reinforcement T'_l is necessary over the full height of the web. Furthermore increased vertical reinforcement T'_w is required in the D-region. Locally the concrete compression stresses in the inclined stress-fields are twice as high as in the B-region.

The flanges are loaded by the in-plane shear forces V'_f due to torsion as well as by the longitudinal forces $V_w \cot\vartheta$ resp. $V'_w \cot\vartheta$ from the webs. Developing the complete model for the flanges would exceed the limits of this paper. Separate models for either the shear force or the longitudinal forces are shown in /4/.

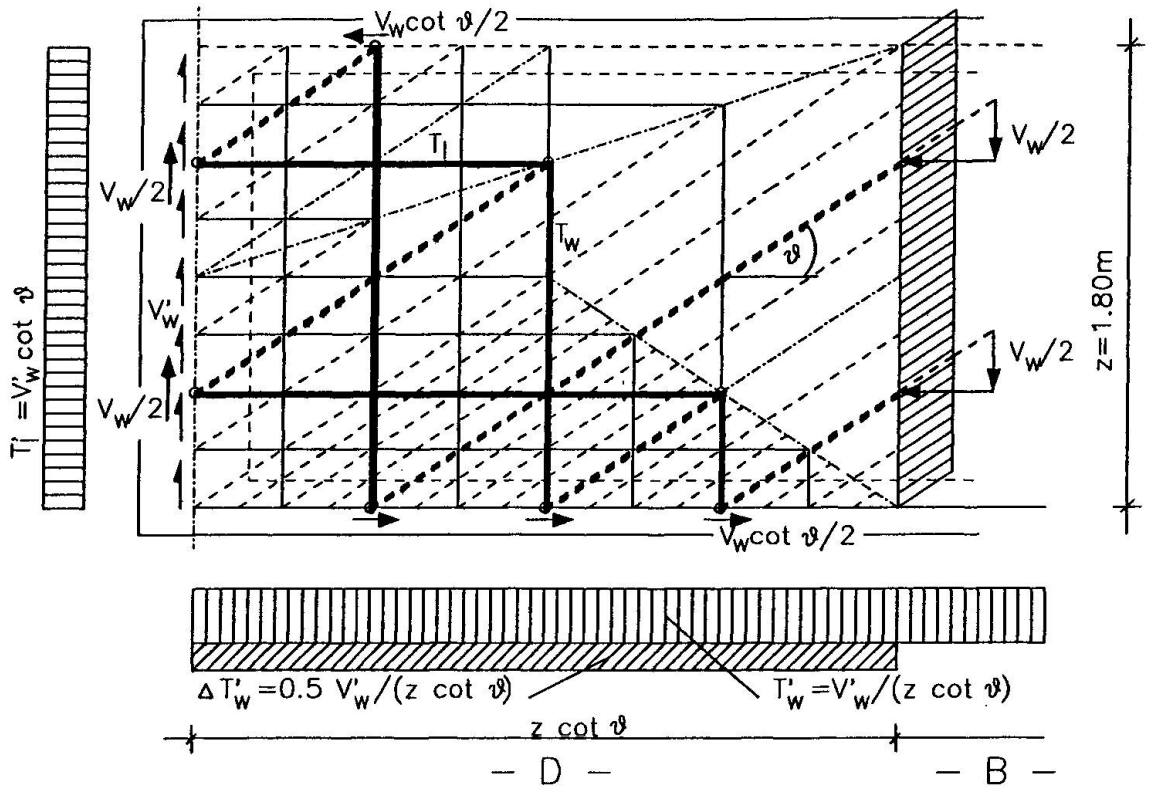


Fig. 7: Strut-and-tie-model for the webs acc. to /5/

3. CONCLUSIONS

This example demonstrates how a consistent model for the complicated diaphragm of a concrete box girder can be developed. For proper modelling and detailing of the D-region it is necessary to consider distributed forces by using stress-fields, in order to distribute the reinforcement accordingly. The complete model for the diaphragm can be composed of established and wellknown "sub-models". The models for the webs and flanges must be consistent with the model for the diaphragm. With this modelling-technique a safe design and a proper detailing of this complicated D-region can be guaranteed.

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