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Practical Experience with Modelling of Structural Concrete Members

Expérience pratique avec des modèles de barres pour des constructions en béton

Praktische Erfahrung bei der Anwendung von Stabmodellen im Betonbau

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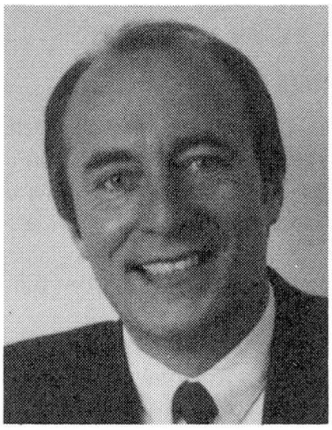

Dietger Weischede, born 1943, obtained his doctor's degree at the «Institut für Massivbau», University of Stuttgart, Germany, where he dealt with strut modeling. He is now a partner in the consulting firm Schlaich Bergermann & Partner.

SUMMARY

This report deals with examples of three actual projects where strut models helped to clarify the global flow of forces, to simplify the calculation and to develop structural details.

RÉSUMÉ

Trois projets vus à la lumière de différents modèles de barres permettent d'aider à comprendre le cheminement des efforts, de simplifier les calculs et de développer la conception des détails constructifs.

ZUSAMMENFASSUNG

Dieser Bericht zeigt am Beispiel von drei ausgeführten Projekten, wie bei der praktischen Arbeit das Modellieren von Stabwerken zum Verständnis des Gesamttragverhaltens, zur Vereinfachung der Bemessung und bei der Detailausbildung helfen kann.

1. INTRODUCTION

In the CEB-Bulletin d'Information 150: Detailing of concrete structures [1] a method was proposed how to perform methodically the practical design and detailing of concrete structures. Its main idea is expressed there: a deep understanding of the flow of forces is needed to design good structures, that means materially sound as well as beautiful.
This idea is still valid and over the last 10 years has caused further activities [2] ./. [5] to transfer this way of thinking into practical work.
Did it succeed? Is it accepted and does it help? Three examples will demonstrate that strut models can indeed help to understand the global flow of forces, to replace sometimes extensive calculation and to develop structural details.

2. MODELLING OF THE GLOBAL FLOW OF FORCES

Project: University of Kassel, Technik III [6]

The new building "Technik III" of the University of Kassel is divided in two: The southern part consists of halls for engineering tests and the northern part serves as an institute- and laboratory building (Fig. 1). It is about 170 m long and 6 storeys high. Its northern side exists of columns, which are inclined between level 0 and + 2. At the kinks high forces occur due to change of direction, and the effects of these forces have to be followed carefully (Fig. 2).
According to Fig. 3 the vertical force V, which results from the column load at level + 2 creates an equally distributed groundpressure σ_b below level - 1.
To transfer the load from the top to the bottom the following members are available (for one half of the building): The slab I at level + 2 collects the horizontal forces due to change of direction at the kink of the columns and transfers them concentrated into the vertical wall II. There they are taken to slab III, creating equilibrium with the horizontal forces at the kink of the columns at level $\pm$ 0. The vertical forces at that point are transferred continuously into the wall IV and form there into the bottomplate VI. In the walls V the horizontal forces are transferred into vertical ones, creating a moment at the edges of the bottomplate VI. This moment together with the vertical forces from the columns causes an equally distributed groundpressure σ_b, provided that the bending stiffness of the plate VI is big enough.
All the members, which are necessary to carry the loads, are shown in Fig. 4. They each can now be designed and detailed separately according to their geometry and loadings. Joined together the single members form a 3-dimensional strut model, which shows the global flow of forces of the whole structure in a transparent and demonstrative way (Fig. 5).

3. STRUT MODELS AS A REPLACEMENT FOR EXTENSIVE CALCULATIONS

Project: Extension of the Casino building of the Bayerische Rückversicherung [7]

The Casino building of the Bayerische Rückversicherung in Munich was extended in 1989 by three additional storeys. It is a cylindrical suspension house with slabs, which are suspended by 6 steel bars equally distributed along their edges. The suspension elements hang straight down from the edge of the ceiling of the last storey, above which they are inclined to the top of the concrete core (Fig. 6). During the erection stage this part existed only of radial girders between a concrete ring, which was formed polygonally at its interior edge.
The critical loading case for this member was an eccentric load, which created two horizontal forces of about 1100 kN each at the edge of the concrete ring. A strut model according to Fig. 8 was taken as a basis and yielded a reinforcement 13 $\emptyset$ 20, which was to be arranged polygonally from one support to the next one.
Unfortunately this result was just accepted as a predesign, but for the official calculations some more efforts were expected!
Therefore a computer calculation for the ring with radial girders and the geometric according to Fig. 7 was carried out. The resulting diagrams for the bending moments, normal- and shear forces in fact were quite impressive (Fig. 9) and stimulated to do a proper design calculation for support-, span- and especially shear reinforcement.

But the ambition was even stronger to show that strut models are competitive. Therefore the direction and the value of the resultant forces out of N and Q were determined and their location calculated from M and N. The result is shown in Fig. 10 and is now satisfying the strut model designer too.

4. DETAILING

Project: Ice Skating Hall, Munich

In the Munich Olympia area a further hall was built for the Skating-World-Championship in 1991 (Fig. 11). The hall is standing on concrete columns above a parking place with a raster of 10.80 m x 5.40 m. The slab is made out of prestressed concrete, with cantilevers on both ends of 6.75 m length, which are formed as T-beams (Fig. 12). Its webs are 0.60 m wide and 0.40 m high with a slab on top, which is 0.20 m thick. The distance of the webs amounts to 5.40 m. The cantilever is inclined to the horizontal level by 21° with the kink in a distance to the last column row of 1.35 m. There the value of the bending moment amounts to M = - 1800 kNm per T-Beam. With an internal lever arm z = 0,45 m the horizontal forces become 4000 kN each. Due to the change of direction at the kink, vertical forces occur, which are named $U_{(T)}$ and $U_{(C)}$ and are 1440 kN big. They are to be connected by stirrup reinforcement (1) according to Fig. 13.
The effective width of the tension area in the slab was determined to 1.40 m and therefore a part of the bending reinforcement (≈ 1/3) is arranged there. The reinforcement is shown in Fig. 14 and the expert, who already possesses long-term experience with reinforcing structures, which are - at least at the first glance - similar, e.g.: framecorners and staircases, will normally judge the reinforcement as correct and complete straight away.
But the careful study of the flow of forces in cross direction shows that important reinforcement is missing: the forces due to change of direction $U_{(T2)}$ in the side parts of the slab, are not taken over by any reinforcement (Fig. 15).
With the stirrup reinforcement (3) - (Fig. 16) - in the slab, which amounts to 65 cm^2/m^2 in this example and with the bending reinforcement (4) in cross direction as bottom reinforcement 13 cm^2/m the design is complete and equilibrium is now installed between the forces due to change of direction $U_{(T)}$ and $U_{(C)}$.

5. CONCLUSION

I am convinced that the method of strut modelling is able to produce the necessary knowledge to design good and harmonious structures. Unfortunately the method is constantly being underestimated: even the inexperienced designer expects quick results with a solution, which he can represent. That does not fit together! Confidence in the solution develops only after studying the problem intensively. This method needs its time for application too!

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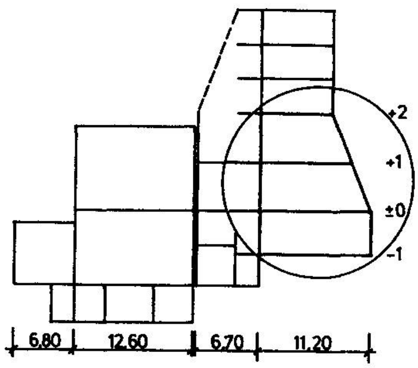

Fig. 1 Project: University of Kassel Technik III

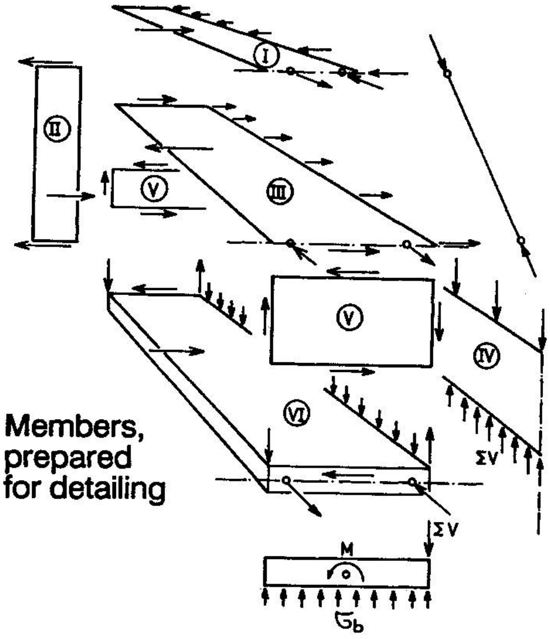

Fig. 4 Members, prepared for detailing

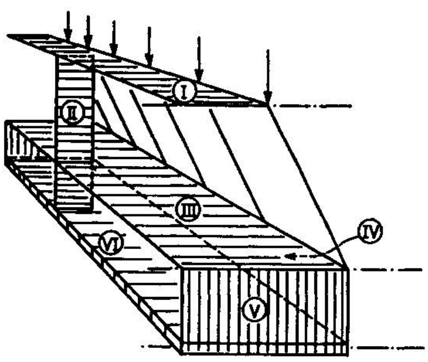

Fig. 2 Part of the laboratory building

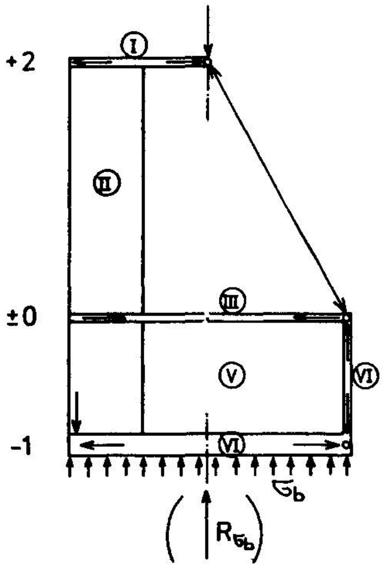

Fig. 3 Section through the laboratory building

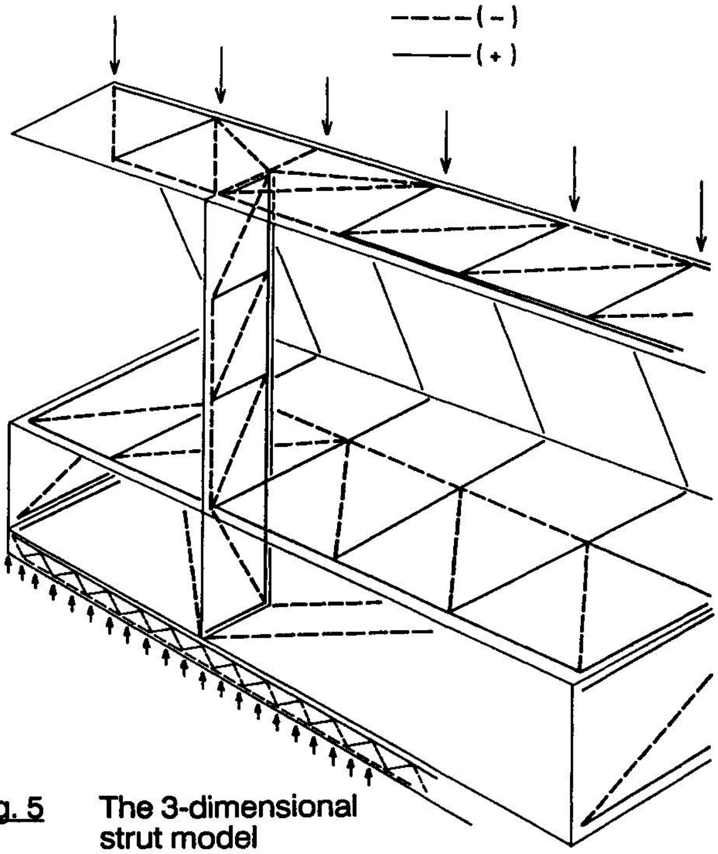

Fig. 5 The 3-dimensional strut model

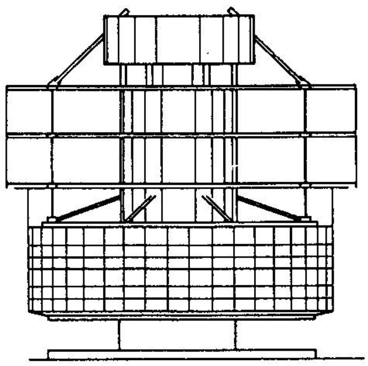

Fig. 6 Project: suspension building of the Bayerische Rückversicherung

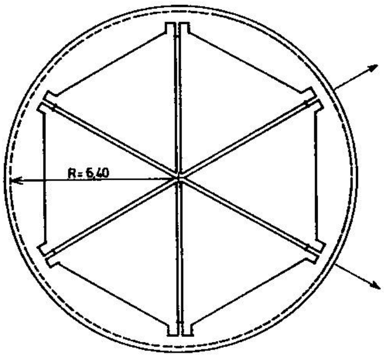

Fig. 7 Top slab at erection state with eccentric loading

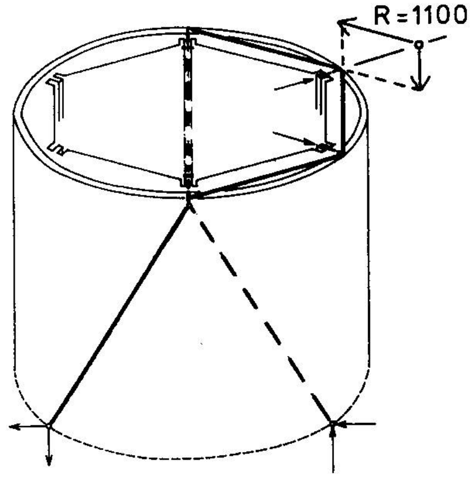

Fig. 8 Strut model for loading case acc. to Fig. 7

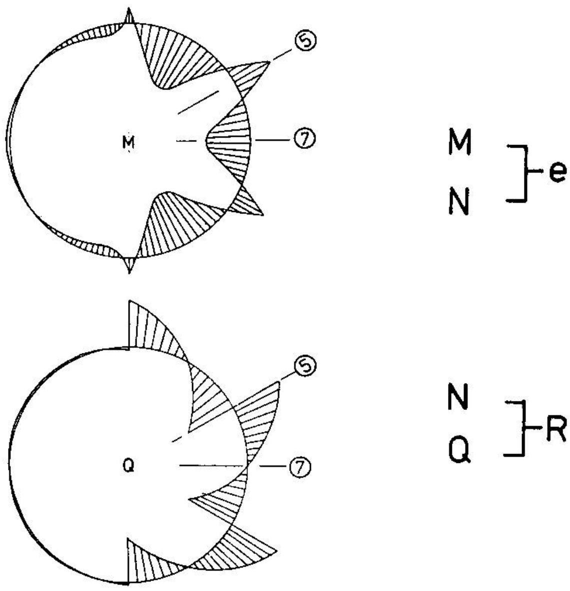

Fig. 9 Action effects acc. to Computer calculations
- Bending moments M
- Shear forces Q

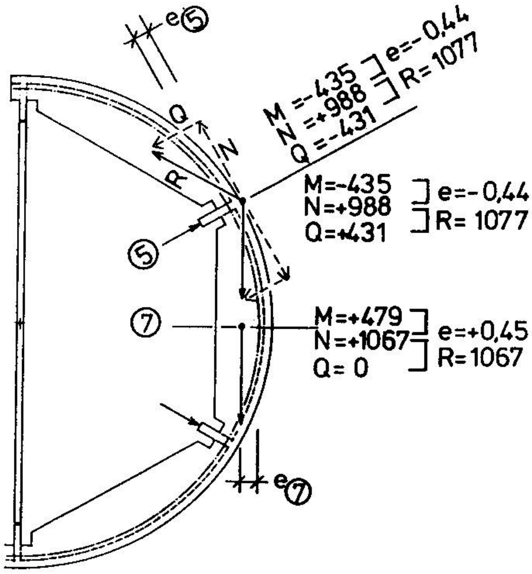

Fig. 10 The resultant forces and eccentricities. Compare with Fig. 8!

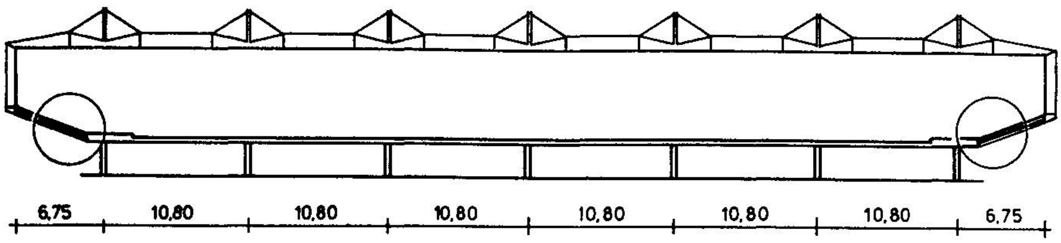

Fig. 11 Project: Skating hall in Munich

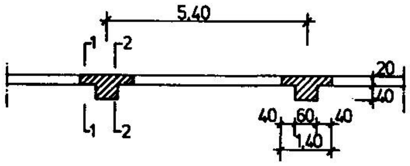

Fig. 12 T-beams at the cantilevers

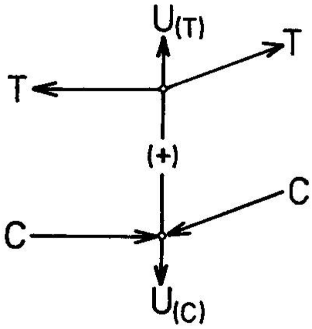

Fig. 13 Forces U due to change of direction

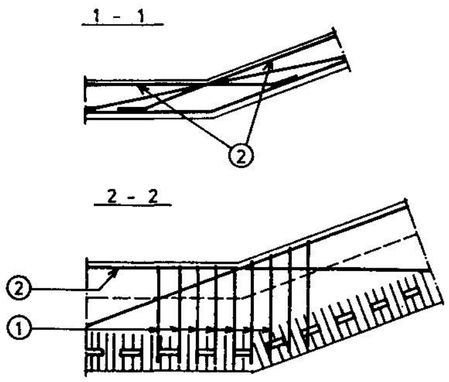

Fig. 14 Reinforcement acc. to Fig. 13

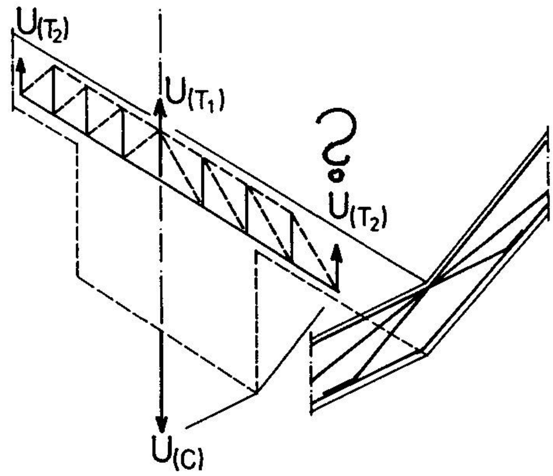

Fig. 15 A 3-dimensional effect!

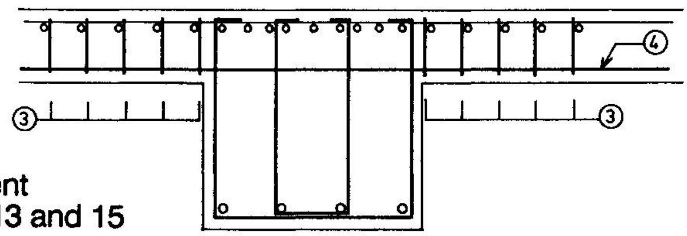

Fig. 16 Reinforcement acc. to Fig. 13 and 15