Prestressed concrete research at the Institute of Structural Engineering, Swiss Federal Institute of Technology Zürich

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Torsion

Das Ziel des Forschungsprojektes bestand darin, das *Bruchverhalten von Stahlbeton- und Spannbetonbalken* unter Torsion und *Torsion in Kombination mit Biegung und Querkraft*, sowohl theoretisch als auch experimentell, abzuklären.

Die experimentellen Untersuchungen umfassten insgesamt 33 Balken, wovon drei vorgespannt waren. Die Hauptparameter waren Querschnittsform (voll, Hohlkasten, offen, Rechteck, T-Form), Längs- und Bügelbewehrung, Bewehrungsanordnung, Vorspannung. Die Versuche an den vorgespannten Balken hatten zum Ziel, den Einfluss der Vorspannung auf das Tragverhalten von torsionsbeanspruchten Tragwerken zu ermitteln.

Als wichtigstes *Ergebnis* dieses Forschungsprojektes kann die *Entwicklung eines Bruchmodells* bezeichnet werden, das mit den Versuchsresultaten recht gut übereinstimmt *und* eine sicherere und wirtschaftlichere Konstruktion torsionsbeanspruchter Tragwerke erlaubt. Im weiteren wurde festgestellt, dass für die Bestimmung des Bruchwiderstandes unter bestimmten Voraussetzungen vorgespannte Spannglieder analog der schlaffen Längsbewehrung eingesetzt werden können.

Das Forschungsprojekt konnte erfolgreich abgeschlossen werden.

Lampert P., Lüchinger P., Thürlimann B.: «Torsionsversuche an Stahl- und Spannbetonbalken», Versuchsbericht Nr. 6506-4.

Grob J., Thürlimann B.: «Wölbversuche an Stahlbetonbalken mit offenem Querschnitt», Versuchsbericht Nr. 6506-6.

Lüchinger P.: «Bruchwiderstand von Kastenträgern aus Stahlbeton unter Torsion, Biegung und Querkraft», Institutsbericht Nr. 69.

Prestressed concrete research at the Institute of Structural Engineering, Swiss Federal Institute of Technology Zürich

The Institute of Structural Engineering at the Swiss Federal Institute of Technology Zurich is led by Professors Dr. *H. Bachmann*, Dr. *C. Menn*, *J. Schneider* and Dr. *B. Thürlimann*. Currently there are twenty assistents and research fellows and a further eight associates and secretaries.

In 1976 the Institute moved to the *new building* of the Swiss Federal Institute of Technology at *Hönggerberg*. The experimental research until then had been carried out at the EMPA (Swiss Federal Material Testing Laboratories) in Dübendorf. This work can now be carried out in the *new research facilities* at Hönggerberg. In the *large testing hall*, which has been built for a variety of research work, there is a 10 m × 30 m *floor area with fixtures* for the mounting of various testing installations. Each mounting fixture in the floor has a holding-down capacity of 2 × 1000 kN. Extensive dynamic tests have been able to be carried out without disturbing other research work being conducted simultaneously in the hall. This is due to the *pneumatic suspension* of the floor slab. *Two fully acclimatized rooms* in addition to the research hall are also available for use. *Long term tests* can be carried out under *controlled temperature and humidity conditions*. For the conducting of the tests, there are steel framing elements fos the floor slab mounting fixtures, an electrohydraulic closed-loop testing system, further testing installations and also electronic measuring systems.

At the Institute of Structural Engineering, theoretical and experimental investigations have been carried out for many years. The primary goal of these research projects consists in presenting new practical bases for various fields of structural design for use in engineering practice. Many results have been incorporated in the Swiss Specifications and also in International Codes. The research findings are continuously published in the institute's reports (Birkhäuser Publishers, Basle) as well as in various technical and scientific publications.

The *research work* in the area of prestressed concrete has included research into

- the bending and punching shear behavior of bonded and unbonded prestressed slabs,
- the bending and shear behavior of partially prestressed beams of normal- and lightweight concrete,
- the torsional behavior of open and hollow box cross-sections.

Further current projects are being made in the following areas of research:

- Concrete Columns,
- Dynamic Behavior of Concrete and Lightweight Concrete Structures,
- Behavior of Concrete and Lightweight Concrete Members under Earthquake Actions,
- Response and Strength of Reinforced and Prestressed Concrete Beams under Dynamic Loading,
- Fatigue of Concrete and Prestressed Concrete,
- The Rotational Capacity of Brickwork,
- Rational Basis for the Safety Theory of Structures,
- Case Studies.

In the following the research projects concerning prestressed concrete are presented.

Working load and ultimate load behavior of prestressed slabs

The working load and ultimate load behavior of bonded and unbonded slabs loaded in bending and also for punching shear are studied both theoretically and experimentally.

Until now two test series have been carried out. To establish the flexural behavior of prestressed unbonded slabs *a square slab* and *five slab strips* were tested in the first test series. The main parameters for the slab strips were the restraint against lateral movement, the additional unstressed reinforcement required and the slab's slenderness ratio. In the second series the localised punching shear behavior of two slab segments and six slab strips was tested. The main parameter for the slab segments was stirrup reinforcement. For the slab strips the main parameters were the percentage of longitudinal reinforcement, the amount of prestress, the shear reinforcement and the restraint against lateral movement.

For *bending* the following significant *results* were obtained: slabs with bonded prestress can be designed analogously to slabs with unstressed reinforcement according to the current methods in use, based upon either elastic or plastic theory. With unbonded prestressed slabs the loads are not taken by bending, but through a combined system consisting of concrete and steel membranes. The limit state of serviceability is often the critical criterion for these prestressed slabs.

For the *shear behavior* of prestressed slabs the following *results* were found to be important: the safety factor for punching shear failure can be significantly improved if a sufficient number of cables are carried over the columns.

Through the *placement* of stirrups in the column regions of flat slabs, the shear capacity and the ductility can be notably increased. Then under applied loading a visible gradual failure with large deformation instead of a sudden brittle failure will take place.

In addition to the tests already carried out further work is planned: supplementary work concerning the behavior model for shear taking into account the deformations occurring; tests on the combined effects of bending and shear behavior in flat slabs; proposals for design procedures and recommendations.

Partial prestressing

In this design project the *working load and ultimate load behavior* of partially prestressed *concrete and lightweight concrete beams were investigated for shear and bending*. In addition, the *long-term behavior* was tested.

The experimental tests stretched out over six test series with a total of 26 concrete beams and five lightweight concrete beams being tested. Two of the lightweight concrete beams were loaded

with a long-term loading. The main parameters for the investigations into bending behavior were: degree of prestress, shape of cross-section, percentage of reinforcement in the tension zone, diameter and cover of the reinforcement. For shear behavior the main parameters were: type, diameter, spacing and amount of shear reinforcement, size and inclination of the prestressing cables. The short- and long-term loaded lightweight concrete beams were duplicates of the corresponding concrete beams. Here, the influence of the particular concrete qualities was of primary interest.

The obtained *results* can be summarized as follows.

Bending behavior: The ultimate moment of partially prestressed concrete and lightweight concrete beams can be calculated on the basis of normal assumptions. The yield moment can be determined adequately with working stress design methods. The crack behavior of the partially prestressed concrete beams is significantly better than that of corresponding normally reinforced concrete beams. Under serviceability conditions the crack widths are for normal detailing, smaller than 0.2 mm. The deflections are significantly smaller than those of corresponding reinforced beams. In the uncracked region the deflections of the lightweight concrete beams are approximately 40% larger than those of the corresponding normal concrete beams. After the beginning of cracking, this difference for a greater part disappeared.

Shear behavior: The yield load of the shear reinforcement can be predicted with the Code SIA 162, Specification 17. The ultimate shear load can be determined with Specification 34 of the same Code with sufficient accuracy. The shear crack behavior under service loads is totally normal; the maximum crack width remains for detailing, smaller than 0.2 mm.

This research project has been terminated.

Torsion

The aim of this research project consisted in the *explanation of the failure behavior of reinforced and prestressed concrete beams under torsion and combined torsion, bending and shear.*

The experimental tests included 33 beams of which three were prestressed. The main parameters were cross-sectional shape (full, box, open, rectangular, T-shaped), longitudinal and stirrup reinforcement, the reinforcement arrangement, and prestress. The tests of the prestressed beams had as an aim the establishment of the influence of prestress on the carrying capacity and behavior of the beams.

The most important *result* of this research project was the *development of a failure model.* This model furnishes values in fair agreement with the test results and also allows a safe and economic design of torsionally loaded structures. Furthermore it was established that for the calculation of the ultimate strength the prestressed steel can be treated like a normal reinforcement with an equivalent yield strength.

No further work on the project is planned.

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La contribution de l'Ecole Polytechnique Fédérale de Lausanne (EPFL) au développement du béton précontraint

Par **Renaud Favre,** Lausanne

Bref aperçu historique de l'Ecole

En *1853,* deux professeurs de l'*Académie de Lausanne* et trois ingénieurs, qui avaient fait leurs études à *Paris,* fondèrent sur une base privée l'*Ecole Spéciale de Lausanne.* Celle-ci fut incorporée à l'Académie de Lausanne en 1869. En 1890, l'Académie devient l'*Université de Lausanne* et la *Faculté technique* devient *une section de la Faculté des Sciences,* sous le nom d'*Ecole d'Ingénieurs.* En *1946, ensemble* avec l'*Ecole d'architecture,* est fondée l'*Ecole Polytechnique de l'Université de Lausanne* (EPUL), établissement officiel du Canton de Vaud, autonome dans le cadre de l'Université.

Etant donné que la charge d'une telle Ecole dépasse de plus en plus les moyens d'un canton et que de grands investissements sont inéluctables si l'on veut maintenir le haut niveau de l'Ecole, celle-ci change de statut en *1969* et devient l'*Ecole Polytechnique Fédérale de Lausanne (EPFL).* Cela signifie que, dès cette date, l'EPFL est financée par la Confédération Helvétique au même titre que la «Eidgenössische Technische Hochschule» de Zürich (ETHZ). Il existe donc actuellement deux Ecoles Polytechniques Fédérales, l'une à Zurich, l'autre à Lausanne. L'organisation de ces deux Ecoles ainsi que l'enseignement qui y est offert sont très semblables; la différence essentielle réside dans la langue.

Activité de l'Institut du Béton Armé et Précontraint (IBAP)

Cet institut est rattaché au *Département de Génie Civil* et comprend une vingtaine de collaborateurs. Il est dirigé par les Professeurs *R. Favre* et *R. Walther,* en collaboration avec le Professeur *J.-P. Delisle,* et dispose de deux planchers d'essais. L'un de ces planchers avait été créé en 1969 par feu le Professeur *F. Panchaud* et se trouve dans une halle entièrement climatisée, attenante au *Département des Matériaux* (fig. 1). L'autre est en construction et est situé dans les nouveaux locaux de L'EPF à *Ecublens* (fig. 2).

L'activité de l'Institut du Béton Armé et Précontraint est orientée aussi bien vers des *recherches de base* que vers des *recherches appliquées.* Celles-ci répondent à des demandes de l'industrie de la construction et comprennent des essais sur modèles de grandes dimensions aussi bien dans le domaine des bâtiments que dans celui des ponts et des centrales nucléaires. Il s'agit presque toujours de structures précontraintes.

La recherche de base est principalement axée vers l'étude de la qualité des ouvrages, c'est-à-dire le comportement à l'état d'utilisation. A cet effet, une vaste recherche a été entreprise pour étudier les *déformations réelles de longue durée de poutres et dalles en béton coulé en place, avec ou sans précontrainte,* ainsi que le *comportement de longue durée de*

Fig. 1. Essai de poutre à voussoirs
Test of segmental beam