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Prestressed Post-Tensioned Composite Floor Slabs

Dalles de planchers précontraintes postérieurement tendues

Vorgespannte Verbundplatten

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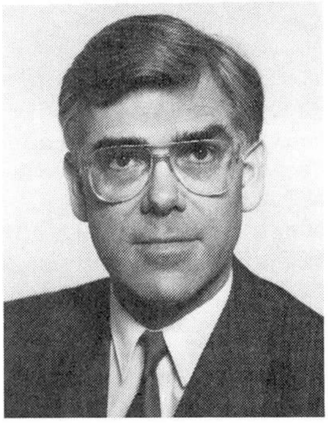
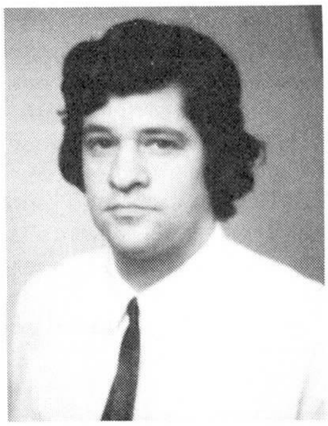




SUMMARY

This paper describes the results of a research program on a long span composite flooring system in which prestressing techniques have been used. Apart from the basic concepts and theoretical background of this new flooring system the motivation for the addition of the prestressing techniques will be also given. Calculation methods are proposed for determination of the maximum load capacity and the distribution of the shear stresses along the span length. A first impression of the results of the pilot experiment is presented.

RÉSUMÉ

Cet article décrit les résultats de recherches d'un système de construction de planchers mixtes de grande portée, dans lequel des techniques de précontrainte ont été utilisées. En dehors du prinicipe de base et du contexte théorique de ce nouveau système de construction de planchers, il fournit les raisons de l'utilisation supplémentaire des techniques de précontrainte. Des méthodes de calcul sont proposées afin de déterminer la capacité maximale de charge et la distribution des contraintes de cisaillement en travée. Cette étude présente une première impression des résultats de l'expérience pilote.

ZUSAMMENFASSUNG

Die Resultate eines Versuchsprogrammes an Verbundplatten grosser Spannweite unter Verwendung von Vorspannung werden beschrieben. Nebst den Grundlagen dieses neuen Verbundsbausystems werden die Gründe für deren Vorspannung erläutert. Rechenmethoden zur Bestimmung des Tragwiderstandes und der Verteilung der Verbundkräfte entlang der Spannweite werden vorgeschlagen. Erste Resultate des Pilotversuches werden dargestellt.

1. INTRODUCTION

Composite slabs consist of cold formed profiled sheeting with cast-in-place concrete. These composite decks are mainly used in short span situations. In the Anglo-Saxon countries this composite flooring system has become a popular method for medium- and high rise buildings. Its popularity is not only based upon construction speed and convenience but also on elegance of structure and dead load reduction compared with traditional pre-fab concrete slab floors. The corrugated steel deck functions as a permanent shuttering for the cast-in-place concrete and provides a working platform which supports the construction loads. The steel deck sections are relatively light and can be stacked and man-handled with ease. During the operation phase the two materials work together as a composite floor system in which the steel deck takes the tensile forces and the concrete takes the compression forces. Economic use of these composite floor slabs is seen as being limited to short spans up to 3 meters over two, three or more supports.

When the span increases towards six meter propping of the steel decks during the concreting phase becomes necessary. This results in a more un-economic flooring system as some of the advantages are eroded. The 'forest' of supporting falsework needed for the floor being cast, delays and postpones the finishing activities on the lower floors. This will decrease the speed of construction and increase the construction costs per net unit area. If the span increases towards 12 meters composite decks are totally replaced by pre-fab concrete (hollow) slabs. Figure 1. gives an impression of the load carrying capacity/span relation for a typical prefab concrete slab and a few typical cross sections.

In composite slabs designed for spans over six meters, using steel decks available on the market today, the net tensile steel area of the profiled sheeting becomes too small and the concrete slab becomes too thick. Therefore additional reinforcement bars (and so extra costs) become necessary. The economic advantage of weight reduction diminishes as the percentage of 'open' space in the cross section becomes very small. In order to account for these problems a combination between composite slabs and pre-stressing techniques has been suggested.

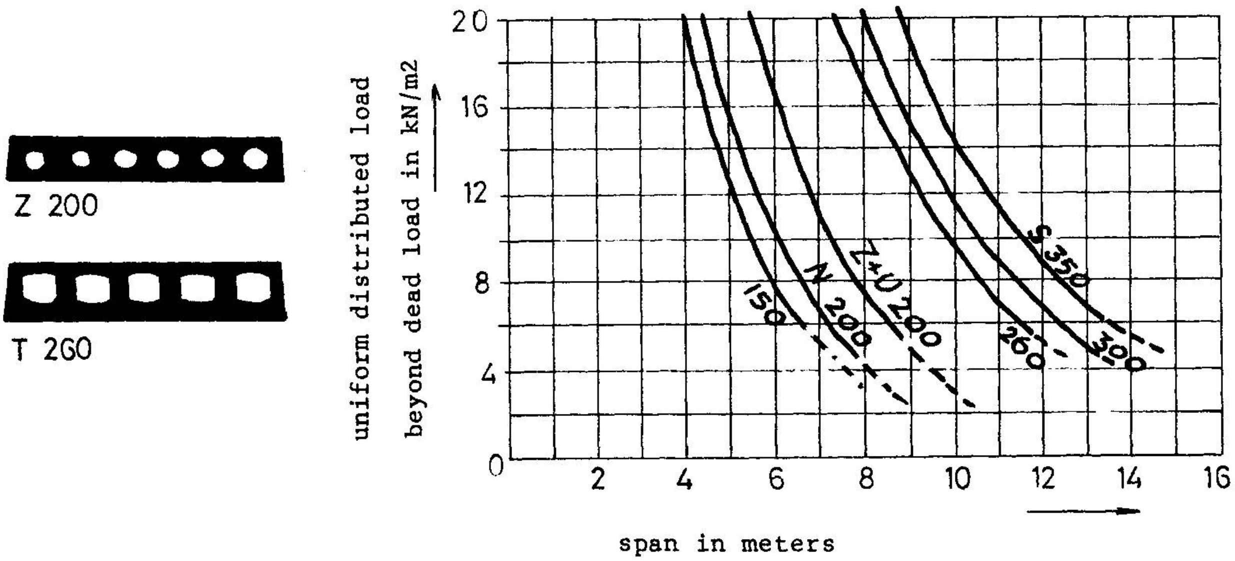


figure 1: load capacity/span relation of a typical prefab concrete slab

A comparison in costs per unit of tensile strength per running meter between normally applied steel grades, will put forward the relatively cheapness of prestressing steel. The following table (1) illustrates this.

	costs in guilders/meter/MN
prestressing steel	17 à 21
reinforcement bars	30 à 35
construction steel	48 à 55

When all aspects are taken into account the combination of composite floor slabs with prestressing techniques presents the following advantages:

- the corrugated steel plate acts as permanent shuttering and reinforcement in the floor system.
- the dead load and part of the permanent load is compensated by the upward pressure from the curved prestressing wire.
- The relation between dead load and other loads becomes more favourable which results, even for large spans from 7,2 up to 12,6 meter, in a rather small floor thickness in relation to the span.
- the dead load of the floor can be kept low due to the profiled steel sheeting. Sufficient possibilities are present for optimalisation of the corrugated steel plate in design, height, plate thickness etc.
- utilization of the relatively low cost of prestressing steel per unit of tensile strength per running meter. High costs for the prestressing activities and end-anchorages can be compensated by multi span floors.
- compared with the traditional use of composite floors, larger spans can be realized with less supporting structural steel and relatively small floor depths. Foundation costs can be reduced.
- as the concrete is cast-in-place, no finishing layer is necessary. The composite floor will not bend upwards after prestressing.

2. BASIC CONCEPTS

Concrete is a perfect material to deal with compression but unfortunately has a very low resistance against tension. The basic idea behind prestressed concrete is that the simultanious action of additional eccentraly placed compression forces, the dead load and part of permanent load will not result in tensile stresses at the upmost fibres. The allowable compression stresses at the bottom concrete fibres also may not be exceded. When the element is loaded by live and remaining permanent loads, compression stresses will occur at the upper fibres and tension stresses will occur at the lower fibres. The sum of the stresses at upper part of the cross section are taken by the concrete and the summation of stresses at the bottom are taken by the steel area. In our case pre-stressing steel and corrugated steel deck.

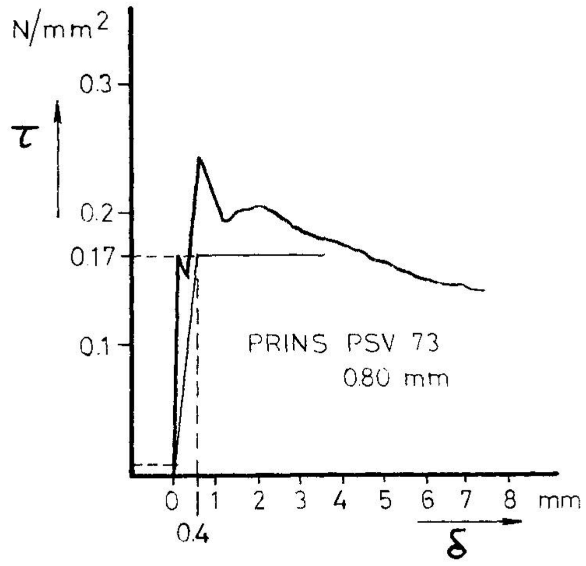
The compression forces are created by a post- or pre-tensioned high grade steel cable anchored at the ends of the element. Due to shrinkage, creep and relaxation of the prestressing steel, the compression forces will slowly decrease. Special high grade prestressing steel (tensile strength 1600 -1900 N/mm2) stressed to a high degree is therefore a necessity. In combination with these steel grades high concrete grades (K45 and up) are used.
In order to avoid tensile stresses in the upper fibres near the ends of the element, the prestressing cables are anchored in or near the neutral axis of the cross section. This curved parabolic path of the cable also introduces the positive effect of an upward pressure which acts against the downward directed dead and permanent load.

The first purpose of this initial research program is to receive an idea of the behaviour and load capacity of this new flooring system. For this reason steel decks available on the market are utilized. As a result of this choice, the steel decks used doesn't have the optimal cross section in relation to the span. An optimalization will be conducted during a following research program.

3. THEORETICAL BACKGROUND

Composite action depends on an adequate transfer of the horizontal shear forces between the steel sheeting and the concrete slab. Failure of composite slabs is mainly a combination of diagonal tension shear failure and steel-concrete bond failure. Apart from these two failure modes, two other failure criteriums should be taken into account ie maximum moment capacity of the cross-section and diagonal bending shear failure.
When composite action is combined with pre-stressing techniques some questions will arise about the influence of the large concentrated prestressing forces on the ultimate strength and failure mode of the slab. The distribution of the shear stresses along the span, the load-slip behaviour and the placement and capacity of the shear-connectors also call for a thorough investigation.

During the research program a method has been developed to calculate the shear distribution at the steel-concrete interface for both centrally and excentrally positioned prestressing forces at the ends of the floor. This calculation method has been developed into a computerprogram to support an easy use. The basic idea behind the calculation model is, that after a certain 'transferlength' the total prestressing force will be distributed over concrete- and steel area according to their E-modules weighted area. At this point the relative movement between steel sheeting and concrete will be reduced to zero. The transferlength was for discreteration purposes divided in small elements dx. Over each element dx the shear stress, strain and changes in concrete- and steel stresses were calculated If the choice of the supposed transferlength is correct the stress in the last element dx (near the supports!) will be reduced to zero. In this case the concrete-stress will be equal to the prestressing force divided by the area of the end-anchorage. The complete calculation will be repeated till this condition is satisfied.



An important feature in this process is the load-slip behaviour and interaction curve for the steel deck used in the composite floor. This load-slip characteristic is typical for each manufacturer's product. In the calculations and experiments the Prince PSV-73 steel decks were used and the load-slip behavior was taken from available literature. See figure 2 on the left.

For the determination of the ultimate strength and deflection properties of these prestressed composite floors a design method has been developed. This method was based upon existing composite floor calculation techniques as stated in Eurocode 4 "Composite steel and concrete structures" and normal prestressing practice as can be found in relevant design codes and literature.

4. EXPERIMENTS

Predicted behaviour such as slip, deflections and load carrying capabilities were checked in a pilot laboratory test program. Distribution of steel strains and stresses, endslip and differences in slip between steel and concrete have been recorded. In addition, development and progression of cracks has been observed and recorded. The bonding between prestressing steel cable and concrete was guaranteed by the injection of mortar between cable and cover.
The experiment consisted of a four point bending test with extra long 'sides' to prevent steel concrete bond failure. The location of the prestressing cable in the cross section was kept unaltered over the constant moment area.

The test piece had the following characteristics:

length between supports:	7200 mm	steel deck:	PRINS PSV 73
total width:	1700 mm		area 1530 mm2/m
total floor depth:	201 mm		yield stress 285 N/mm2

concrete quality K45 — pre-stressing steel FeP 1770, in 3 cables (15,7 mm) spaced evenly over the width with 200 kN/cable

Figure 3 (below) gives a good impression of the test piece and the test frame. Steel stresses were measured both during the application of the prestressing forces and the test loading. Electrical strain gauges were equally placed over the span at top and bottom of the trapezium formed cross section of the steel deck. Displacement transducers were positioned at the ends of the span and at the bottom of the steel plate to record end-slip and movements between steel deck and concrete. The behaviour under loading conditions, stiffness, maximum load capacity and deformations and distribution off shear stresses showed good prospects. Tables and graphs of end-slip, steel/concrete strains and stresses, load-deformation relations etc. will be presented during the conference.

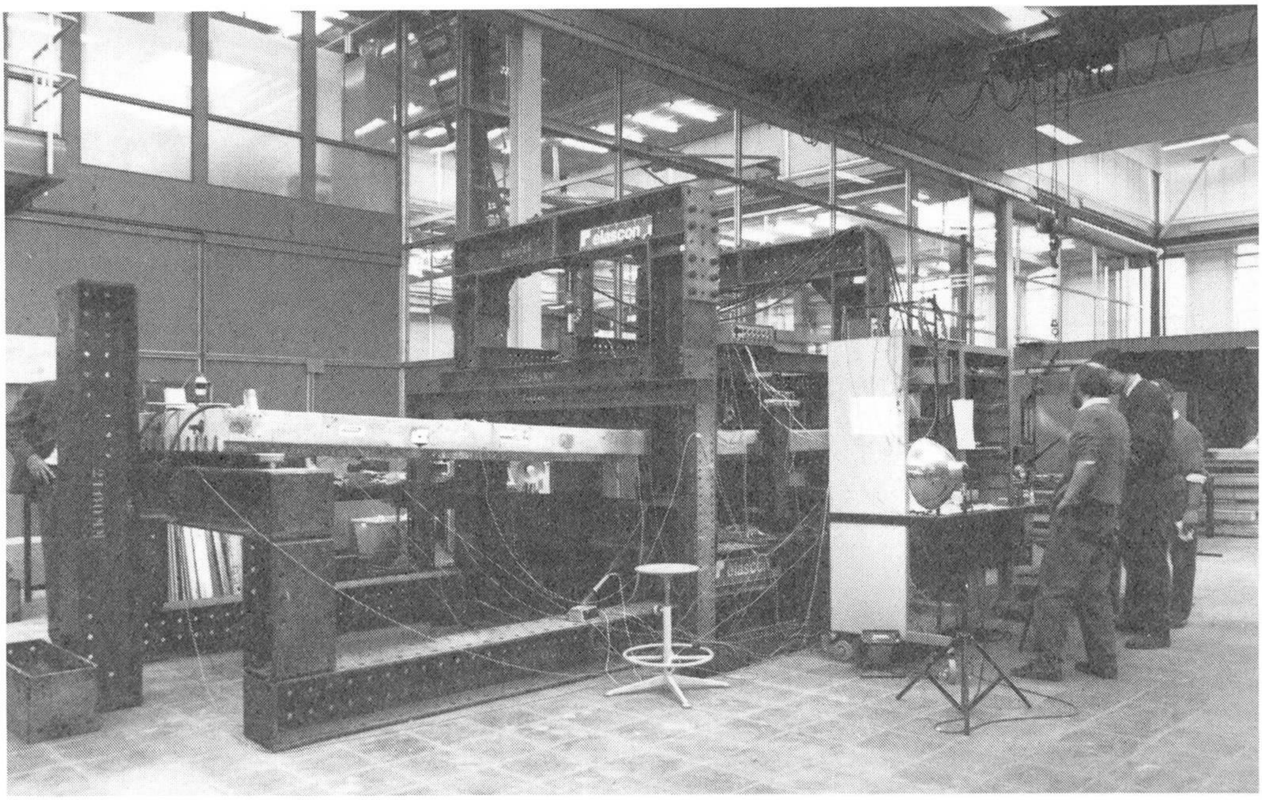


figure 3: test piece during the experiment

5. THEORETICAL IMPLICATIONS AND CONCLUSIONS

To this date the analyses of the test results are still in full progress. So far no unexpected events have occured. The test results are, as can be seen from analysed data sofar, in good agreement with the calcuted values for stresses and deflections. The stresses behind the anchorages are not completely in line with the existing codes due to the limited concrete area near the neutral axis. Further investigation is necessary.

The test results indicate a larger floor stiffness then the values calculated with the existing design codes for these kinds of floors. A suggestion for an adjusted formula may result from these experiments.

6. PRACTICAL APPLICATIONS

Attention is also given to an optimalization of the load-carrying capabilities and economic use of the flooring system. New cross sections will be developed and maximum load capacities calculated. Adequate answers are being thought up for the omission of intermediate supports during the erection phase for medium and long span applications.

7. ACKNOWLEDGEMENT

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REFERENCES

1. DANIELS J., Shear bond pull-out tests for cold-formed-steel composite slabs. ICOM publication 194, June 1988.

2. EUROCODE 4, Composite steel and concrete structures. Issue 1989

3. NEN 3880. Voorschriften beton VB 1974/1984 (Dutch regulations for concrete) part F: Bepalingen Voorgespannen beton (Prestressed concrete)

4. RSBV 1984. Richtlijnen voor het ontwerp en de vervaardiging van staalplaat-betonvloeren. (Dutch design code for composite floors)

5. BRUGGELING A. S. G., Theorie en praktijk van het voorgespannen beton, part I and II. Delft University Press 1986.

6. IBBC/TNO, Delft. Push-out proef op de PRINS PSV 73 plaat. December 1975.

7. LEONHARDT F., Vorlesungen uber Massivbau; Spannbeton teil 2 und 5 Springer Verlag 1973.