EXPERIMENTAL IDENTIFICATION OF THE GRADE OF PRESTRESSING OF A REINFORCED CONCRETE SLAB WITH UNBONDED PRESTRESSING

EXPERIMENTELLE ERMITTLUNG DES VORSPANNGRADES EINER STAHLBETONDECKENPLATTE MIT VORSPANNUNG OHNE VERBUND

DETERMINATION EXPERIMENTALE DU DEGRE DE PRECONTRAINTE D'UNE DALLE EN BETON ARME SOUS PRECONTRAINTE NON ADHERENTE

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SUMMARY

After removing the formwork of a monolithic fabricated and prestressed (unbonded prestressing) concrete slab with a cantilever, the measured deformations in the direction of the applied load at the end of the cantilever did not correspond to the calculated values for the required prestressing force. Therefore a non-destructive test in order to determine the existing prestressing force was necessary. The subsequent grab of the ends of the tendons was not possible, because the strands have been cut almost directly behind the wedges. This report describes a procedure, which offers the possibility to identify the existing prestressing force by measuring an applied transversal displacement of the tendon under a defined force.

ZUSAMMENFASSUNG

Nach dem Ausschalen einer monolithisch gefertigten, vorgespannten (Vorspannung ohne Verbund), auskragenden Stahlbetondeckenplatte wurden am Kragarmende Verformungen in Belastungsrichtung gemessen, die nicht den berechneten Werten für die planmäßig aufzubringenden Vorspannung entsprachen. Aus diesem Grund wurde eine möglichst zerstörungsfreie Prüfung der vorhandenen Vorspannkraft erforderlich. Ein nachträgliches Fassen der Spanngliedenden hinter der Ankerplatte mittels Spannpresse war nicht mehr möglich, da die Litzen bereits unmittelbar hinter der Keilverankerung abgetrennt wurden. In diesem Beitrag wird ein Verfahren beschrieben, das es ermöglicht, die im Spannglied vorhandene Spannkraft durch eine Querauslenkung, unter Messung des Auslenkweges und der dazugehörigen Kraft, zu bestimmen.

RESUME

Après le décoffrage d'une dalle monolithique en encorbellement en béton précontraint (précontrainte non adhérente), les déformations mesurées à l'extrémité de la dalle ne correspondaient pas aux valeurs calculées pour la précontrainte projetée. Un dispositif d'essai non destructif permettant de déterminer la force de précontrainte réelle fut nécessaire car les extrémités des câbles n'offraient plus de prise, ayant été sectionnées derrière les coins d'ancrage. Dans cet article est présenté un procédé permettant de déterminer la force de précontrainte du câble en mesurant le déplacement transversal dû à une force définie.

KEYWORDS: Unbonded prestressing, grade of prestressing, measurement of prestressed loads

1. INTRODUCTION

Prestressing of structures is normally applied in order to superpose the stresses due to external loading with intended counteracting stress states.

Besides a possible increase in capacity of slender structural elements, the advantage of prestressed concrete is that even under working loads no cracks emerge respectively only such with minor crack width. Depending on the bond between steel and concrete the following methods of prestressing may be applied.

- Unbonded prestressing: the prestressed tendons are located outside (external) or inside (internal) the concrete member without bond in the concrete cross section.
- Prestressing with immediate bond: after prestressing the tendons, they are incorporated into the concrete in that manner that during the hardening of the concrete the bond will develop.
- Prestressing with subsequent bonding: at first the prestressing force is applied to the hardened concrete structural element without bond between the prestressed tendons and concrete; the bond will develop afterwards grouting of the conduits.

The structural element described in this report is a reinforced concrete slab with unbonded prestressing in a building of an electronic data processing center of the University of Stuttgart. This slab is the roof of the building, see fig. 1.

The structural system of the slab is a single-span girder with a cantilever. At the end of the cantilever the loads are applied by tensioned columns (Fig. 1).

In order to reduce the selfweight of the roof slab it was designed as a hollow core slab with unbonded prestressing, see fig. 3.

The configuration of the prestressed tendons is linear. The prestressed tendons are anchored at the neutral axis of the slab by anchor plates and conical wedges. Above the supporting columns the distance between prestressed tendons and neutral axis of the slab is 32 cm.

The bending moment curve (fig. 2) due to prestressing results from equation (1):

$$M_{cp}(x) = P(x) \cdot z_{cp}(x) \tag{1}$$

with:

$P(x)$... value of the prestressing force at position x

$z_{cp}(x)$... distance between the prestressed tendon and the neutral axis of the reinforced concrete slab

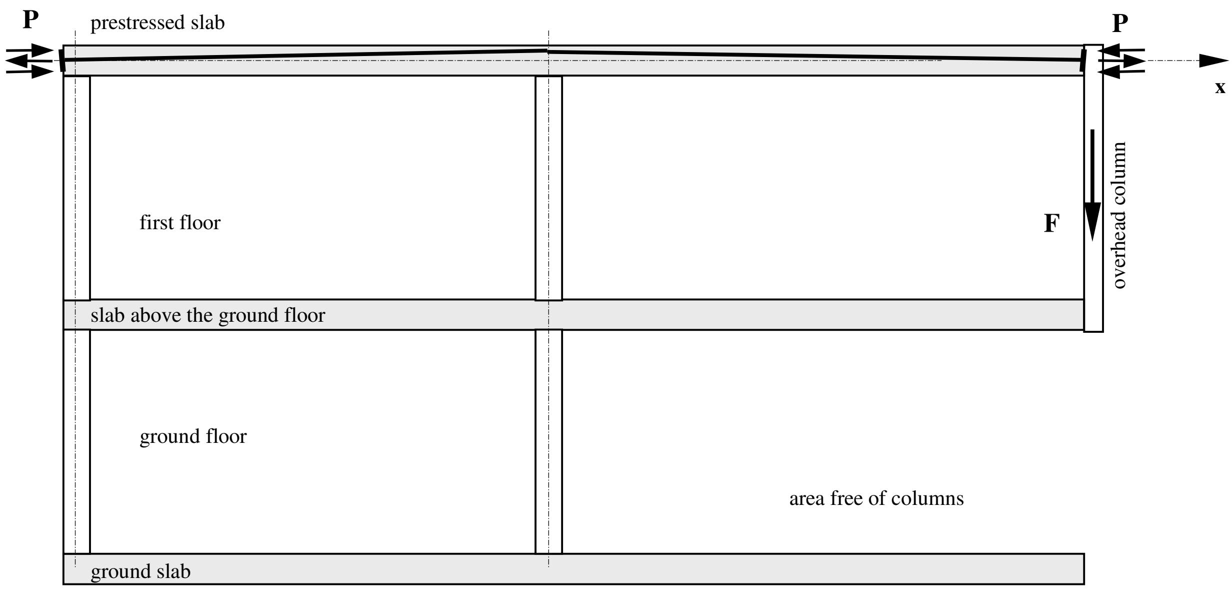

Fig. 1: longitudinal section of the building

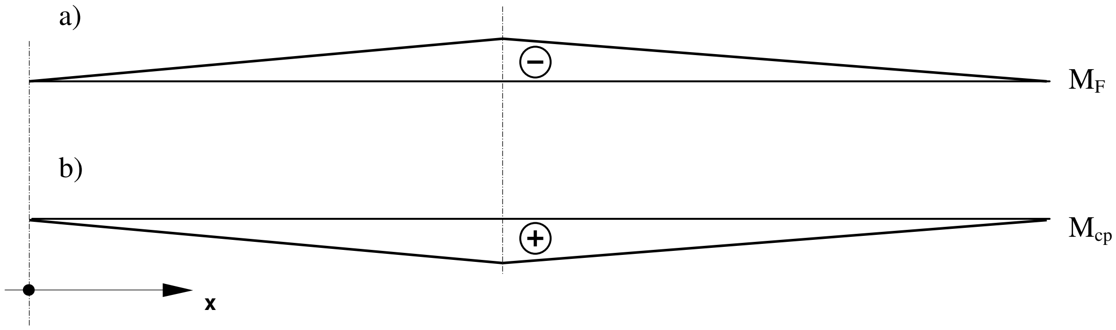

Fig. 2: bending moment curves as a result of:
a) external force F (see fig. 1),
b) prestressing force P

After prestressing, mounting the tensioned columns at the cantilever and subsequent removal of the temporary bearings of the slabs in the ground floor and in the first floor, a vertical deflection of more than 20 mm could be observed at the end of the cantilever.

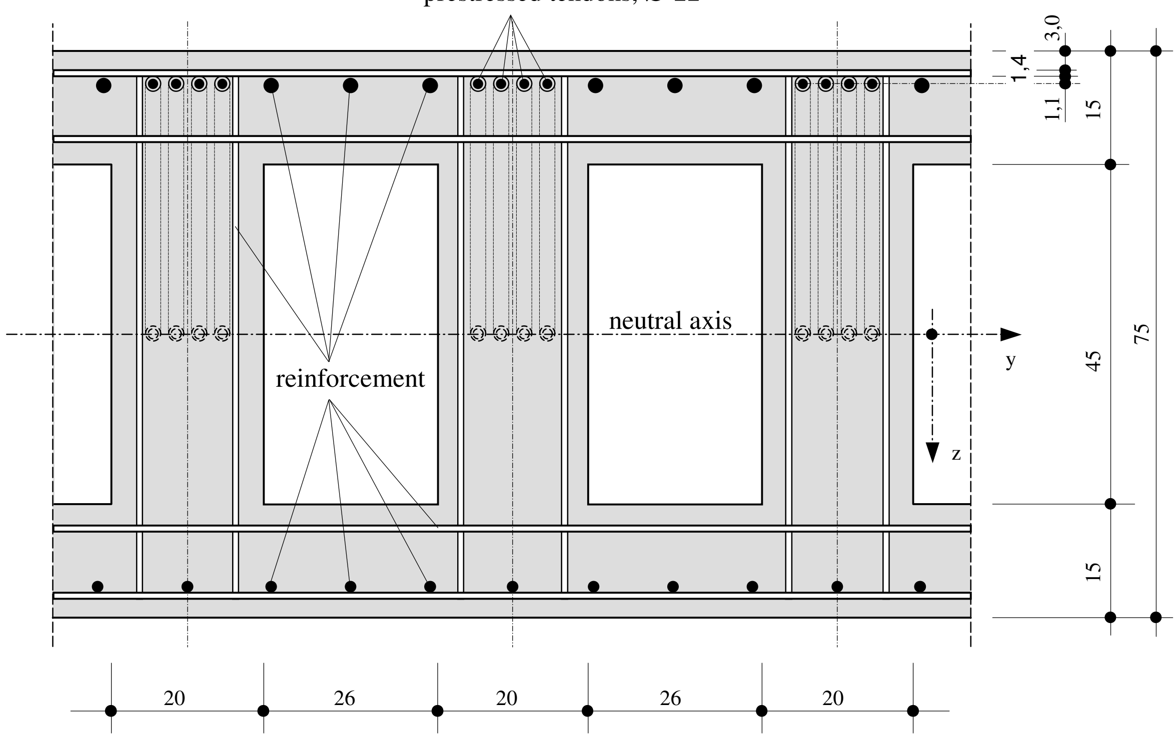

Fig. 3: cross section of the slab

The consulting engineers office stated that these deformations could not be expected according to static calculations and exceed the determined tolerances for the planned cladding structure. Based on a comparison between the measured and the calculated values it was stated that the deflection of the cantilever meets the expected values for a non-prestressed slab.

Reliable records of prestressing were not available. It was supposed that the applied prestressing force did not reach the calculated values [1].

2. PERFORMED TESTS AND RESULTS

The easiest way of determining the actual prestressing force would have been to engage a hydraulic ram at the ends of the tendons and measure force and displacement of the ram. The slope of the load-displacement-curve changes when the force of the ram exceeds the actual prestressing. This method was not possible because the ends of the tendons have been cut short behind the wedges after prestressing.

The following alternative method was chosen in order to carry out a mostly non-destructive test of the actual prestressing force:

- The upper surface of the concrete slab was stemmed at a length of 1,2 m (in the axis 204, 229 and 256 of the building) and the tendons were uncovered, see fig. 4.
- A transversal force was applied to the tendons and the corresponding displacement was measured using a tensiometer procep MS 150 (see Fig. 5). The tensiometer works on the principle shown in fig. 6, but must be calibrated on the diameter of the strand or wire and on additional boundary conditions. The displacement was chosen to reach certain displayed values on the tensiometer of 80, 90, 100 and 110 which correspond to the range of expected prestressing forces according to calibration tests. Four measurements were taken at different positions along each strand in order to minimise the influence of strand twist.
- The actual prestressing forces were determined from the comparison between measured values on site and values obtained on a reference tendon in the laboratory.

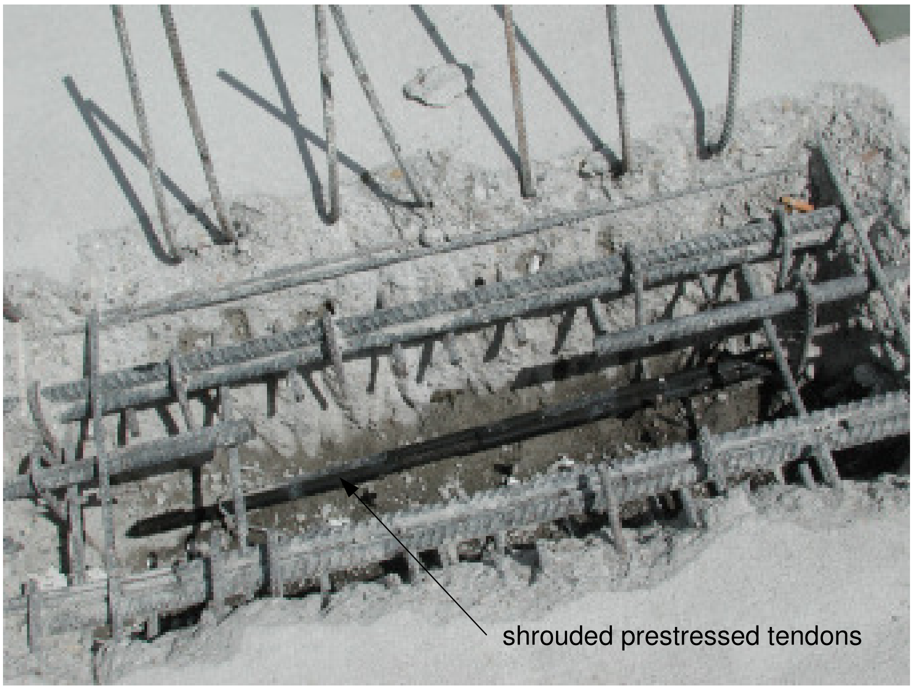

Fig. 4: stemmed surface of the slab in the area of tendons (axis 204)

Fig. 5: tensiometer proceq MS 150

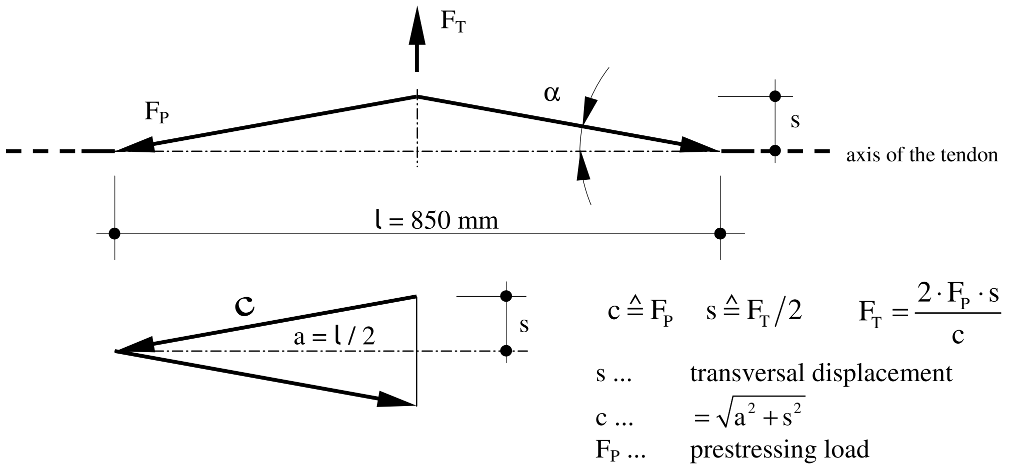

Fig. 6: force-triangle as a result of transversal displacement of the tendon by the tensiometer proceq

The results of the measurements on site are summarized in table 1.

Table 1: measurement results of detecting prestressed loads by proceq and the corresponding average values of transversal displacements of tendons in the concrete slab

displayed tensiometer value	**average transversal displacements [mm]**											
	prestressed tendon axis 204				**prestressed tendon axis 229**				**prestressed tendon axis 256**			
80	1,60	1,56	1,82	1,56	1,54	1,62	1,41	1,61	2,38	2,42	2,45	2,35
90	2,14	2,06	2,35	2,23	2,06	2,20	2,05	2,18	2,85	2,94	3,05	2,91
100	2,72	2,70	2,82	2,72	2,64	2,72	2,90	2,70	3,39	3,49	3,49	3,38
110	3,22	3,12	3,40	3,26	3,22	3,32	3,31	3,17	3,90	4,02	4,01	3,92

The reference tendon (St 1570/1770 ø 15,7 mm, 4 m long) was first prestressed to the maximum admissible tensile load of $P_{t=0}$ = 186 kN, established by static calculation. Then the tensiometer was applied and the prestressing force was reduced step by step to 170, 160, 150 and 140 kN in order to gain displacement values for a reasonable range of prestressing forces. A loss of prestressing force of 15 % due to creep an shrinkage would yield a remaining force of

$$P_{t\to\infty} = 186 \cdot 0{,}85 = 158\ \mathrm{kN}$$

which is about in the middle of the tested range.

The transverse displacements were chosen to achieve displayed values of 80, 90, 100 and 110 like on site and again four positions were measured along the strand to account for the strand twist.

The results of the measurements of the reference tendon are shown in table 2.

Table 2: test results obtained on the reference tendon

displayed tensiometer value	**prestressing loads applied by the load equipment [kN]**				
	186	**170**	**160**	**150**	**140**
	average transversal displacements [mm]				
80	1,42	1,97	2,32	2,54	2,55
90	1,95	2,41	2,56	2,78	3,06
100	2,40	2,95	3,07	3,21	3,66
110	2,88	3,40	3,59	3,70	4,28

The real prestressing force of the tendons in the building were calculated by interpolating with the deformation values measured on site between the prestressing forces of the reference tendon and averaging a total of 16 values for each tendon.

The results of this evaluation are given in table 3.

Table 3: identified prestressing forces

axis	**P_{t1} [kN]**
204	175
229	178
256	148

The measured prestressing forces of the axis 204 and 229 are approximately 6 % smaller than $P_{t=0}$.

By taking into consideration the loss of prestressing forces by creep and shrinkage the values correspond to the anticipated forces with a loss of 5-7 % of the initial prestressing. The determined prestressing force $P_{t1} = 148\,\text{kN}$ of axis 256 is approximately 20 % lower than the value $P_{t=0}$.

The deviation of the prestressing force in one of the tested strands from the nominal value might be due to a bigger sag of the strand after mounting of the hydraulic ram but before prestressing or by a bigger slip of the wedge than those of the other 3 strands.

In order to gain information on possible differences between prestressing forces of the single strands of a 4-strand-tendon, 4 strands were mounted in an anchorage plate and loaded with a tensile force of:

$$P_{compl} = 4 \cdot 186 = 744\,\text{kN}$$

The transversal displacements of each of the strands at defined tensile forces were measured with the tensiometer proceq like in the tests described earlier. The results are listed in table 4.

Table 4: average transversal displacements of 4 single strands simultaneously stressed

measured values of prestressed forces by proceq [kN]	**average transversal displacements [mm]**			
	strand 1	**strand 2**	**strand 3**	**strand 4**
90	1,97	1,83	1,91	1,84
100	2,46	2,32	2,44	2,34
110	2,95	2,80	2,93	2,82

The largest deviation of single transversal displacements compared to the mean value of all strands is equal to 7 %. For small deviations an almost linear relation between prestressing force and displacement can be assumed and therefore this values describes the deviation of forces as well.

Assuming that at the time of measurement the loss of prestressing force due to creep and shrinkage of the concrete slab was approximately 5-7 %, ($P_{t1} \approx 0{,}94 \cdot 186 = 175$ kN) the prestressing force of the strand in axis 256 (minimum value obtained) is about 15 % less compared to the expected value.

In the most unfavorable case that this minimum value of the prestressing force (148 kN) is valid for every strand, the calculated value of the deflection at the end of the cantilever would still be significantly smaller than the measured deflection of 20 mm.

Consequently insufficient prestressing of the concrete can be precluded as cause of the appeared deformations. The bearing capacity of the concrete slab isn’t impacted by the deformation.

A possible reason of the measured cantilever deflection may be a pre-deformation caused by lowering the formwork when casting the fresh concrete. Further tests are recommended.

3. CONCLUSION

Because of unexpected deformations in a prestressed reinforced concrete slab (unbonded prestressing) it was necessary to determine the existent grade of prestressing by a non-destructive test. Therefore the strands were uncovered at three places by stemming the upper surface of the concrete slab.

By using the load measuring equipment proceq the transversal displacements of the strands were measured at certain transversal loads. In order to determine the existent prestressing forces a calibration of the results was performed on a reference tendon. Transversal displacements at defined transversal and prestressing loads were measured in those reference tests in a stationary equipment. By comparing these measurement values with those of the concrete member the existent prestressing forces in the concrete slab could be determined.

One of the strands measured on site showed a prestressing force which was roughly 15 % less compared to the other strands measured and 20 % less compared to the nominal initial prestressing. Assuming this reduced prestressing for all tendons would still yield much smaller displacement of the cantilever than the value of 20 mm obtained on site. Therefore a lower grade of prestressing of the concrete slab than required can be excluded as reason of the measured deformations provided the static calculations submitted by the consulting engineers have been correct. Other possible reasons for the deflection may e. g. be deformations of the formwork during pouring of the concrete.

4. REFERENCES

[1] Structural Analysis of the Building of Electronic Data Processing Center at the University Stuttgart. Office of Civil Engineering "Pefferkorn Ingenieure", Stuttgart 2002.