

FIBER - REINFORCED CONCRETE PANELS AS PERMANENT FORMWORK FOR FLAT SLABS

PLATTEN AUS GLASFASERBETON ALS VERLORENE SCHALUNG FÜR DECKENPLATTEN

PANNEAUX EN BETON ARME A LA FIBRE DE VERRE SERVANT DE COFFRAGE PERMANENT POUR PANNEAUX PLANES

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SUMMARY

The strength and deformation behavior of formwork panels was determined in a first test series. In a second test step seven loading tests on composite single span slabs were performed. There was no disturbance of the bond between the prefabricated panels and the cast-in-place concrete until failure of the slabs. No cracks or loss of bond was observed in the contact surface. A complete lap joint of the reinforcement, even together with a longitudinal joint of the formwork panels did not reduce the bearing capacity of the composite elements.

The test specimens with the formwork panels in the tension zone failed by a compression failure of the cast-in-place concrete after yielding of the longitudinal reinforcement. For the test specimens with the formwork panels in the compression zone, failure occurred in the cast-in-place concrete at the intermediate support, also after yielding of the longitudinal reinforcement. The crack pattern was not influenced by the joints of the panels.

After the loading tests, the slabs were sawed and cores were drilled in order to inspect the contact surfaces between panels and concrete and the joints of the panels. There was a perfect bond and completely filled panel-joints.

ZUSAMMENFASSUNG

In Vorversuchen waren die Festigkeits- und Verformungseigenschaften der Schaltafeln aus Glasfaserbeton bestimmt worden. Bei der Prüfung von insgesamt sieben Verbundplatten blieb der Verbund zwischen vorgefertigten Schaltafeln und Ortbeton bis zum Bruch erhalten. In der Kontaktfuge zwischen den Schaltafeln und dem Ortbeton konnte weder Ribbildung noch Ablösung

beobachtet werden. Auch die Anordnung eines Vollstoßes der Längsbewehrung und die zusätzliche Wahl eines Längsstoßes in den Schaltafeln hat zu keiner Beeinträchtigung des Tragverhaltens geführt.

Bei den Versuchen mit den Schaltafeln in der Zugzone trat das Versagen im Ortbeton auf, nachdem die Längsbewehrung weit im Fließbereich war. Bei den gedrückten Schaltafeln versagte der Ortbeton am Auflager zwischen den Schaltafeln, ebenfalls nach Fließen der Längsbewehrung. Die Anordnung der Plattenstöße hatte keinen Einfluß auf das Ribbild.

Nach Abschluß der Belastungsversuche wurden einzelne Platten zersägt und zusätzlich Bohrkerne entnommen, um die Verbundfuge und die Füllung der Stoßfugen der Schaltafeln zu untersuchen. Der Verbund war überall vollflächig vorhanden, ohne Risse und Fehlstellen. Alle Stoßfugen waren stets voll verfüllt.

RESUME

Les caractéristiques de résistance et de déformation des panneaux de coffrage ont été déterminées lors d'une première série d'essais. Au total des essais de chargement sur sept panneaux composites ont été réalisés. Il n'y avait ni formation de fissures ni détachement entre les panneaux préfabriqués et le béton coulé sur place. Aucune fissure ou perte d'adhérence n'a été constatée dans la surface de contact. Même un recouvrement complet des armatures combiné avec un joint longitudinal des panneaux de coffrage n'a pas réduit la capacité de charge des éléments composites.

Lors des essais avec les panneaux de coffrage situés dans la zone de tension, la rupture apparaissait dans le béton coulé sur place après allongement plastique de l'armature longitudinale. Lors des essais avec les panneaux de coffrage placés dans la zone de compression, la rupture apparaissait dans le béton coulé sur place à l'emplacement du support entre les panneaux de coffrage également après allongement plastique de l'armature longitudinale. Les joints des panneaux n'avaient aucune influence sur la fissuration.

Après les essais de chargement, les différents panneaux ont été coupés en sections et des carottes cylindriques prélevées pour contrôler la surface de contact et les joints des panneaux. Il y avait une adhérence parfaite et tous les joints des panneaux étaient complètement remplis.

KEYWORDS

Formwork panels, permanent formwork, bearing capacity, composite slab, cracking, bond, concrete cover, loading tests.

1 INTRODUCTION

Most corrosion damages on reinforced concrete elements have their origin in a too thin or/and a too porous quality of the concrete cover. One reason for this is the problem of an intensive compaction of this layer between the formwork and the plane of the reinforcement. In addition a leaking formwork and, as a consequence, a loss of cement paste produce a concrete cover, which is - even if thick enough - not sufficiently dense to protect the reinforcement against corrosion. The quality control tests (sufficient compaction, compressive strength and sometimes watertightness) normally are performed on separate test specimens, which are produced under usually much more favorable conditions; these results are therefore not always applicable for the structural element. This fact gave the idea to prefabricate the concrete cover [Curiger, 1995] to guarantee the two most important properties

- sufficient thickness of the concrete cover and
- low permeability for gases and liquids.

This was tested within the presented investigations for the application on reinforced concrete slabs. Beside the aforementioned protection of the reinforcement, another aspect was important: the prefabricated panels can be used as permanent formwork; this reduces the labor work for formwork considerably.

From the practical point of view - following the main dimensions and the bearing-capacity of the panels - the panels should be arranged as the moulds on a system of formwork-girders. Then the longitudinal and transverse reinforcement will be placed and the concrete filled, as for usual concrete slabs.

The presented investigations should create the technical conditions required to establish a general approval for the application of glass fibre reinforced panels as permanent formwork [Reinhardt, 1996].

2 DESIGN OF THE ELEMENTS, QUESTIONS, SOLUTIONS

The principal dimensions of the panels were chosen as a length of $l = 1,00$ m, a width of $b = 0,50$ m and a thickness of $t = 20$ mm, mainly due to production and practical reasons. This thickness of 20 mm should cover the very often required concrete cover of 20 mm by putting the reinforcement immediately upon the panels. Additional requirements $c > 20$ mm can be fulfilled by introducing appropriate spacers between the reinforcement and the surface of the panels. As indicated in Fig. 1 beside a rough surface a mechanical bond between panel and cast-in-place concrete was performed by swallow-tail-shaped grooves in the panels, without any transverse reinforcement.

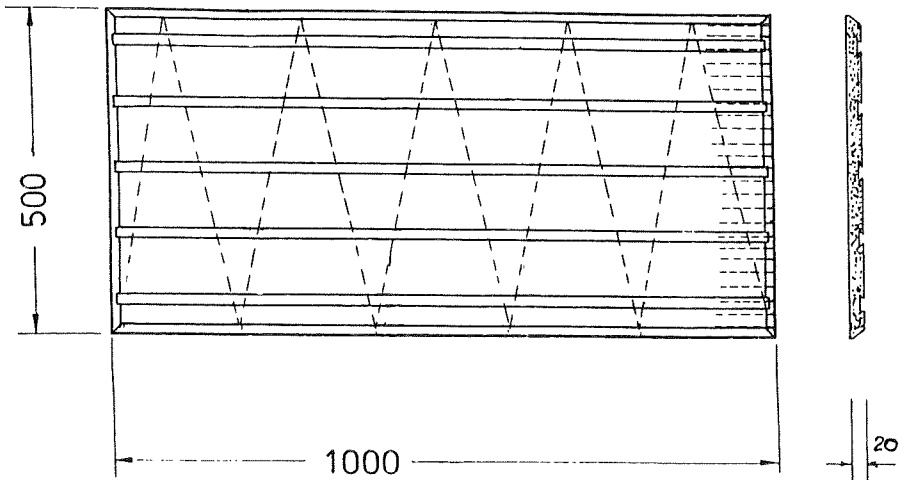


Fig. 1: Dimensions of the formwork panels

It has to be emphasized that, for the structures described here, no bond stresses have to be transferred from the reinforcement to the panels to guarantee the structural safety, unlike the usual partially prefabricated slabs, which contain the complete longitudinal reinforcement. The bond action between panel and concrete is therefore only necessary to keep the panels attached to

the concrete during the lifetime of the structure. This situation leads to the following, crucial questions, which had to be answered before a general application could be permitted:

- a) Applied materials: do the materials for the panels meet the general requirements for a legal application?
- b) Is there enough structural safety during the erection time, when the panels are supported along their borders?
- c) How efficient is the protection function of the panels - in particular at the joints of the panels - against corrosion of the reinforcement?
- d.) Which is the behavior of the bond surface between panel and concrete, in particular under alternate loading?
- e.) Is there enough bond capacity between reinforcement and concrete, if the reinforcing bars are placed immediately on the panels?
- f.) Some panels of multi-span slabs are in the compression zone of the structure. Which is the behavior of the panels and contact surface under this loading?

With the exception of point c), these questions were answered by the experiments. The methods of investigation and their results are summarized in the present paper.

For corrosion protection, the joints of the panels were designed in a X - shape in order to fulfill the requirements of DIN 1045 (Tab. 10, line 1.1 and 1.2), when only the upper part of the joint was filled with cast-in-place concrete. According to the philosophy for the minimum and nominal value of the concrete cover, the present construction only refers to the minimum value. The actual filling quality of the joints under practical construction conditions was tested with the composite elements.

3 MATERIAL TESTS

3.1 Tests on the different materials

In order to describe the applied materials, the following tests were performed:

- a) Long-term and alkali-resistance of the glass fibers
- b) Flexural strength of the panels in longitudinal and transverse direction.

The most important results [Knödler, Manns, 1996] are summarized in Tab 1.

Tab. 1: Results of the Material tests

SIC - Tensile Test of the glass fibers [N/mm ²]		Test	A	B	
			506	304	
Flexural strength of the GFC - prisms [N/mm ²]	LOP	Test	C	D	E
		long.	7,2	7,1	6,8
	transv.	5,8	5,4	5,6	
	MOR	long.	12,1	11,4	6,8
		transv.	5,8	5,4	5,6

Test A: 1d in air 20°/100% 4d in 80° in water

Test B: 1d in air 20°/100% 14d in 80° water

Test C: Standard climate 20°/65%

Test D: 25 temperature - water - changes

Test E: 14 days in water 80°

3.2 Tests with the formwork panels

The tests on the complete panels should demonstrate the loading and deformation behavior under construction conditions. A line load at midspan of the single span plate with $l = 0,50$ m was chosen as most critical. Extent and

results of this investigations are given in Tab. 2 [Koch, 1996]; a typical load-deformation-line is plotted in Fig. 2. After cracking - the bending strength values are in a good agreement with the material properties - the panels display a distinct load increase, which depends strongly from the type of the fiber: the safety-factor of the CEMFIL - fiber was $\gamma = 1,47$, for the NEG - fiber $\gamma = 1,93$. For both fibers, this load increase was related to large deformations, resp. to a sharp decrease of stiffness.

In order to study a possible influence of a one year storing of the panel under usual climatic conditions, further tests were scheduled; the results are not yet available.

Tab. 2: Behavior of the panels under line-load

Fiber-type	Cracking		Failure	Safety-factor
	Load kN	Flexural strength N/mm ²	Load kN	γ
NEG	1,93	7,6	3,73	1,93
CEMFIL	1,86	7,35	2,73	1,47

4 TESTS WITH THE COMPOSITE ELEMENTS

4.1 Production and practical aspects

In this test program composite elements were fabricated under usual production conditions, to study specific those parameters, which could show a unfavorable influence on the bearing- and deformation behavior at a practical application of the permanent formwork panels. Numerous deformation meas-

measurements and rigid loading conditions should point out - if given - any weak aspects of this construction method, compared to a conventional production.

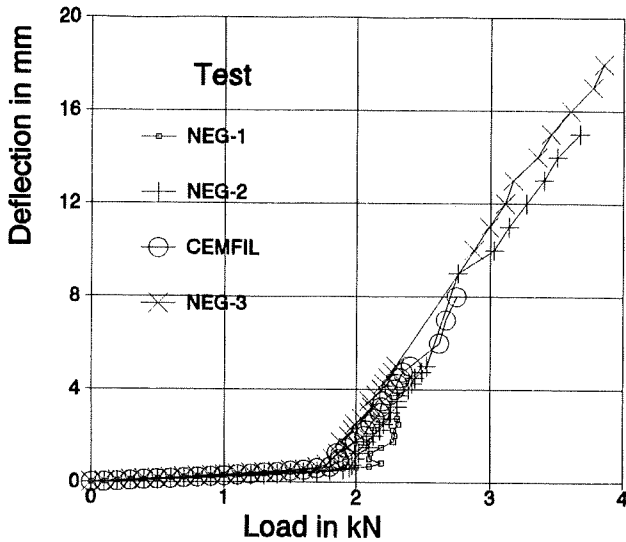


Fig. 2: Load - Deformation Curve for Midspan Load

The basic design condition was the nominal shear stress for slabs without shear reinforcement given in DIN 1045 for B 25 ($\tau_{011} = 0,50 \text{ N/mm}^2$).

The applied static system (single span slab) and the dimensions, given in Fig. 3 lead to percentage of the longitudinal reinforcement of $\mu_s = 1,13 \%$, this means an allowable bending moment of 31,5 kNm and an allowable load - in addition to the dead load - of 58 kN.

4.2 Parameters

As listed in Tab. 3, the following parameters were investigated [Koch, 1996]:

1) *Position of the panels*: In multispan slab systems, the formwork panels are predominantly in the tensile zone. In the area of the intermediate supports yet, the panels are in the compression zone. Thus the tests No. 1 to 5 were performed with tensioned panels, the tests No. 6 and 7 with panels in compression. For the first system the span of the single span slab was chosen to $\lambda = 3,00$ m with loads in the third points of the span. For the second group the shearspan of $a = 1,00$ m resulted in a system with two cantilevers; it was tested for practical reasons - in the upside down position as a single span slab with $\lambda = 2,00$ m and a load at midspan.

Tab. 3 Tests with composite elements

No	Name	Position of the panels	Arrangement of the panels	Longitudinal reinforcement	Ultimate Load [kN]
1	MO2-2/1	Panels in the tensile zone	Full panels	Continuous reinforcement	125,7
2	MO2-2/2		longitudinal		129,6
3	MO2-3/1		Half panels		124,6
4	MO2-3/2		transverse		127,6
5	MO2-4/1		Longit. joint	100% joint	134,5
6	MO2-5/1	Panels in the compr. zone	full and half panels	Continuous reinforcement	152,4
7	MO2-5/2				153,1

2) *Arrangement of the panels*: In general, for single span slabs, the rectangular panels will be arranged as full plates in the direction of the span; this application is tested in specimen No. 1 and 2. To imitate the behavior in transverse direction, half panels, 0,50 m long, were used for specimen No. 3 and 4. The

tests with the panels in the compression zone, No. 6 and 7, had full length plates in one half and half length plates in the other cantilever. In specimen No. 5, with a lap joint of the reinforcement, the panels had a longitudinal joint by using half wide panels with $b = 0,25 \text{ m}$

3) Arrangement of the longitudinal reinforcement: in 6 of 7 specimen the reinforcement reached from one support to the other; only specimen No. 5 had a 100% lap splice joint in one shear span in order to produce a critical condition concerning transverse tensile stresses around the reinforcement in combination with the longitudinal joints of the panels.

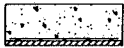
As examples, Fig. 4 shows the arrangement for specimen MO2-3 with half size panels in the tensile zone and Fig. 5 the principal dimensions for specimen MO2-5 with panels in the compression zone.

4.3 Test-Results

4.3.1 Ultimate loads

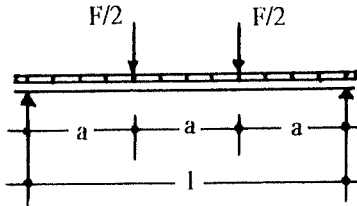
All specimens failed by crushing in the compression zone, preceded by a distinct yielding of the reinforcement and consequently by large deflections. The average ultimate load for the 3 m specimens was $F_U = 128,4 \text{ kN}$ (out of 5 tests), without any influence of the tested parameters (see Tab. 3). The less slender specimens with 2 m span had an approximately 20% higher ultimate load. The average value (out of 2 tests) was $F_U = 152,8 \text{ kN}$, with no indication of any influence of the panels on the failure mechanism. The higher ultimate load of these specimens can be explained by the actual moment line at the concentrated load, compared to the nominal value. (See Fig. 3).

CROSS SECTION



$b = 0,500 \text{ m}$ $h = 0,180 \text{ m}$
 $d = 0,153 \text{ m}$ $z = 0,127 \text{ m}$
 Reinforcement $2 \phi 16 + 3 \phi 14$
 $A_s = 864 \text{ mm}^2$
 $\mu_s = 1,13 \%$

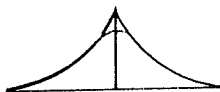
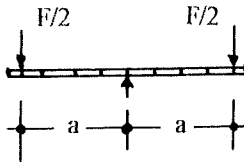
Statical system, moment and shear forces for panels in tension



$g = 2,25 \text{ kN/m}$
 $\max Q_g = 3,4 \text{ kN}$
 $\max M_g = 2,5 \text{ kNm}$

$F = 58 \text{ kN}$
 $\max Q_F = 29,0 \text{ kN}$
 $\max M_F = 29,0 \text{ kNm}$
 $\max \tau_0 = 0,53 \text{ N/mm}^2$

Statical system, moment and shear forces for panels in compression



$g = 2,25 \text{ kN/m}$
 $\max Q_g = 2,2 \text{ kN}$
 $\max M_g = 1,1 \text{ kNm}$

$F = 60,8 \text{ kN}$
 $\max Q_F = 30,4 \text{ kN}$
 $\max M_F = 30,4 \text{ kNm}$
 $\max \tau_0 = 0,51 \text{ N/mm}^2$

Fig. 3: Statical system and forces

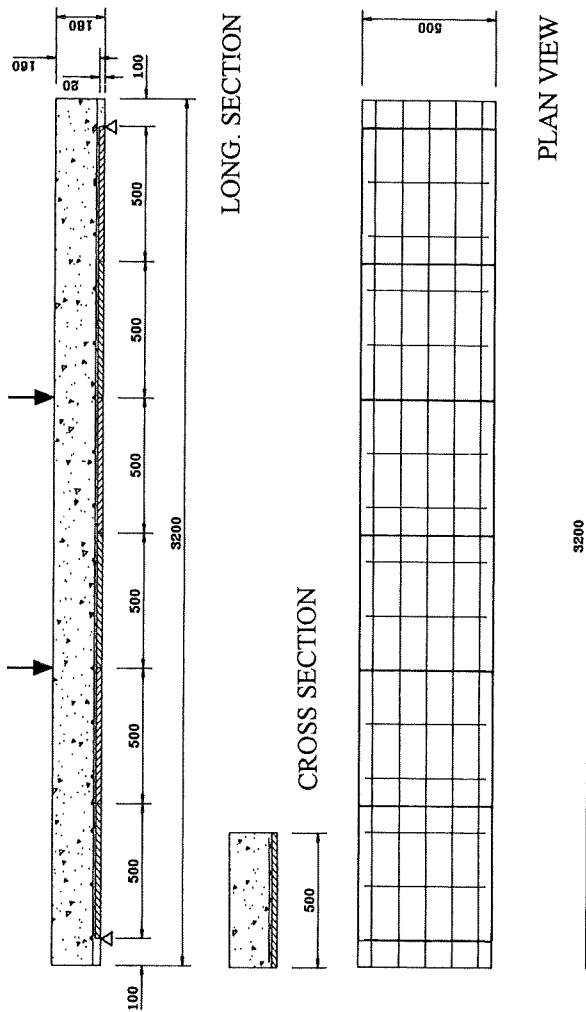
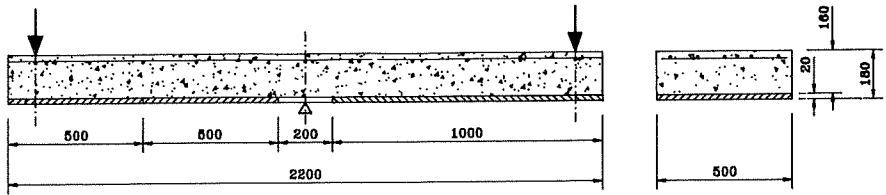
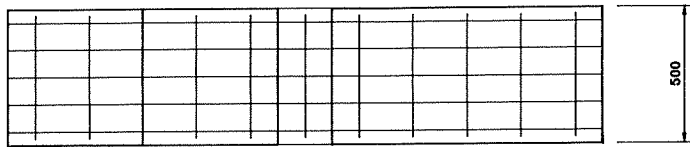


Fig. 4: Dimensions for specimen MO2-3



LONG. SECTION

CROSS SECTION



PLAN VIEW

2200

$2 \phi 16 + 3 \phi 14$

460

Fig. 5: Dimensions for specimen MO2-5

4.3.2 Deflection

The deflection at midspan is plotted versus the applied load. Fig. 6 shows the results for the panels in tension. There is only a slight scatter of the results for the tests with compressed panels, which are plotted in Fig 7. The calculated values are indicated both for the uncracked specimen and for the cracked system without tension stiffening effect. The unloading branch is also plotted after 100 resp. 10000 cycles to service load.

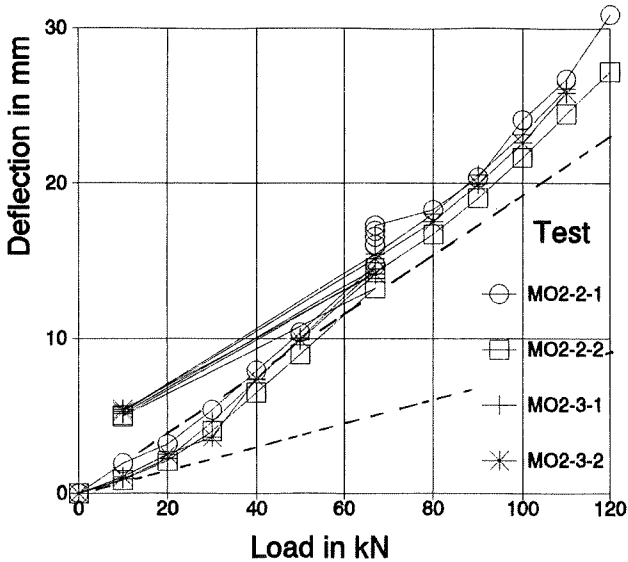


Fig. 6: Deflection at midspan (Panels in tension)

4.3.3 Strains in the panels

The distribution of strains at the external surface of the panels was determined by a mechanical strain indicator with a gauge length of 200 mm. The position of the DEMEC-points was chosen - depending on the length of the panels - to get strain values within a panel and across the joints. Fig. 8 and 9 show the distribution of these strains for two selected load levels (service load and highest load with measurements): The results of the 4 tests with tensioned panels are given in Fig. 8; Fig. 9 shows the results of the 2 tests with compressed panels. The joints of the panels are also marked.

The scatter of the results for the tensioned panels is wide due to the fact that cracking does not always occur at the same position; so measurements in-

cluding a crack show higher values than those between cracks. The results with the panels in compression are not influenced by this effect and display a much smaller scatter. For both stress situations there is no concentration of strains in the joints of the panels.

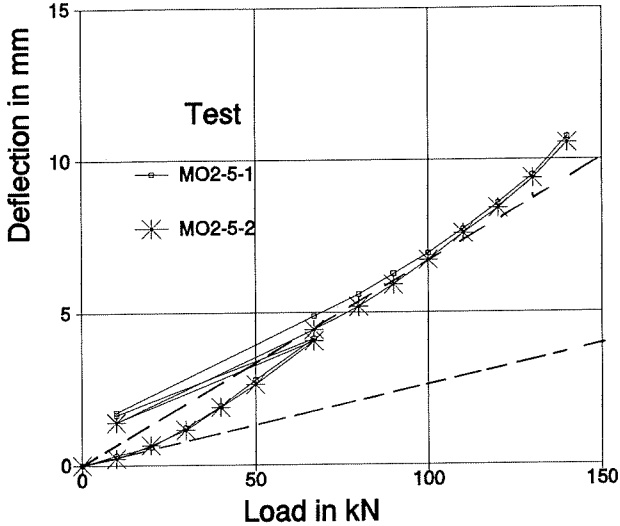


Fig. 7: Deflection at midspan (Panels in compression)

4.3.4 Cracking

During all tests the cracks were marked on one surface of the specimen. At selected load levels the width of these cracks was measured with a microscope in the level of the longitudinal reinforcement. The crack pattern always developed completely independent from the layout of the panels. The measured values for crack distance and width were listed in Tab. 4:

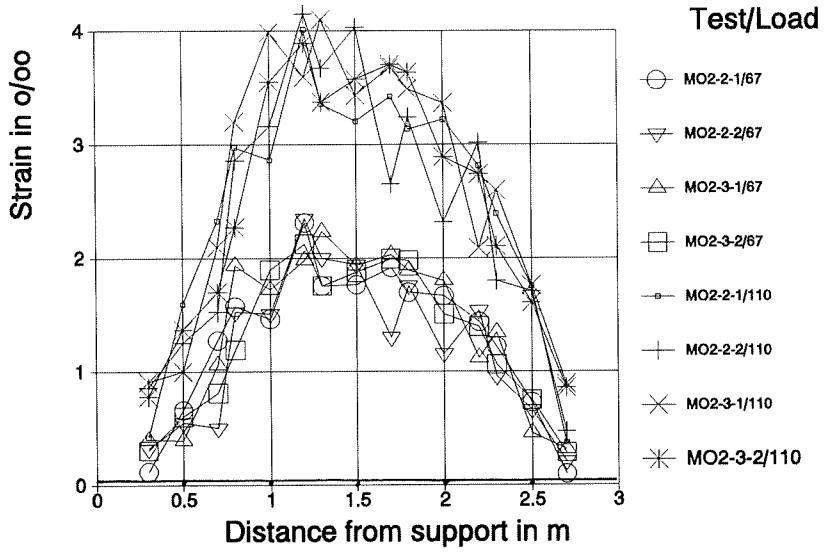


Fig. 8: Strain distribution in the panels (Panels in tension)

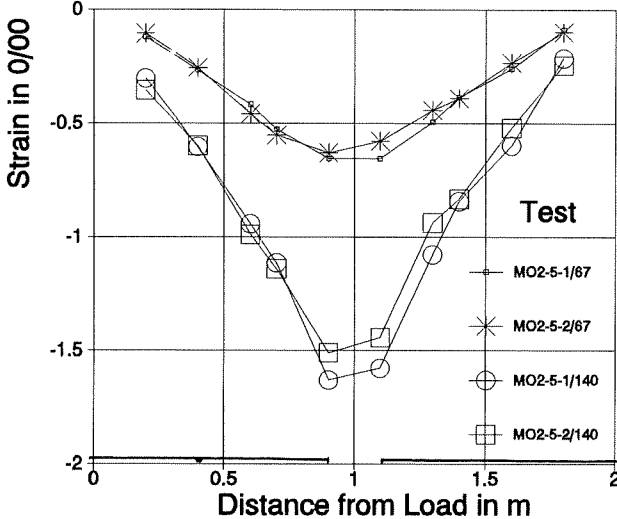


Fig. 9: Strain distribution in the panels (Panels in compression)

Tab. 4: Crack distance and crack width

No.	Name	Average crack distance [mm]	Average crack width[mm]
1	MO2-2-1	114	0,07
2	MO2-2-2	104	0,09
3	MO2-3-1	89	0,06
4	MO2-3-2	82	0,05
5	MO2-4-1	92	0,06
6	MO2-5-1	111	0,03
7	MO2-5-2	90	0,05

5 FINAL REMARKS

Together with theoretical and numerical investigations, the performed tests have shown that the application of prefabricated glass fiber reinforced panels as permanent formwork leads to structures with a good load- and deformation behavior. The long-term behavior could not be investigated within the presented test program. For all relevant criteria such as durability, corrosion protection and bond action, a behavior at least similar to conventionally manufactured slabs could be observed.

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