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Applicability of ComBAR for crack width limitation in floors of parking garages

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ABSTRACT: For the use in a specific floor system of parking garages GFRP rebars (ComBAR) with a diameter of 8 mm were studied at Kaiserslautern University. Due to the small concrete cover and the aggressive impacts the application of non-corrosive reinforcement is necessary in this system. The crack width has to be limited in order to avoid the penetration of corrosive chlorides. The suitability of an alternative to stainless steel reinforcement for the limitation of crack width in the slabs was checked in this study. The bond performance of the rebars in the typical concrete and the typical bar position was studied in pull-out-tests with short anchorage length. A mathematical description of bond behaviour due to Model Code 90 [2] was used for prediction of bond length and crack width in the slabs. The results of these calculations were verified by additional tests with large anchorage length. The influence of the concrete cover was also examined. The cracked in-plane stiffnesses could be determined by extensional tests. Those results were used to calculate the internal forces for a full size test. Finally the performance of the GFRP reinforcement system in the slab was tested with a full size test of a slab segment. In this test the loading history of car park buildings was passed through in order to gain test information about the change in crack width between different loading situations. This information is necessary for the selection of appropriate concrete coatings to ensure durability of the slabs during lifetime.

1 PULL-OUT TESTS WITH SHORT ANCHORAGE LENGTH

The tested floor system requires reinforcement for crack width limitation at support. This reinforcement is concreted with small concrete cover and ensures the serviceability of the slab. It is not taken into account for the load bearing capacity. Pull-out-tests were carried out with both GFRP rebars with a diameter of 8 mm and stainless steel rebars with a diameter of 6 mm, which are regularly used in parking floors. The concrete cover was varied from 15 mm to 30 mm. The anchorage length of the rebars was about 3 d_s and was placed in center. For all test specimens a standard ready-mixed concrete was used, which had to fulfill specific requirements due to its application in parking garages with considerable environmental exposures. The concrete strength should comply with the concrete strength class C30/37 according to DIN 1045-1 [4].

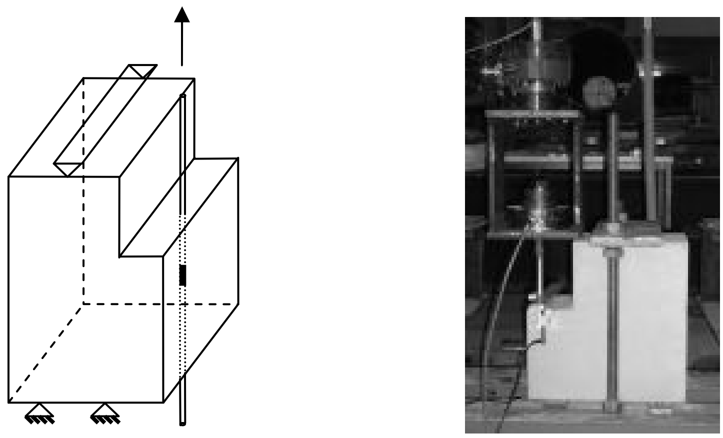

Figure 1. Geometry of the test specimens and test setup of the pull-out tests with short anchorage length

Slip was measured with an inductive displacement transducer at the opposite side of load introduction. The measured bond force was divided by the real bond length and the nominal circumference of the rebar in order to determine the bond stresses. Average values as well as design values were calculated. The design value is defined according to the regulations about composite slabs in Eurocode 4 [5], as the test results highly spread. The following figure shows the average values of the bond stresses of the different reinforcements.

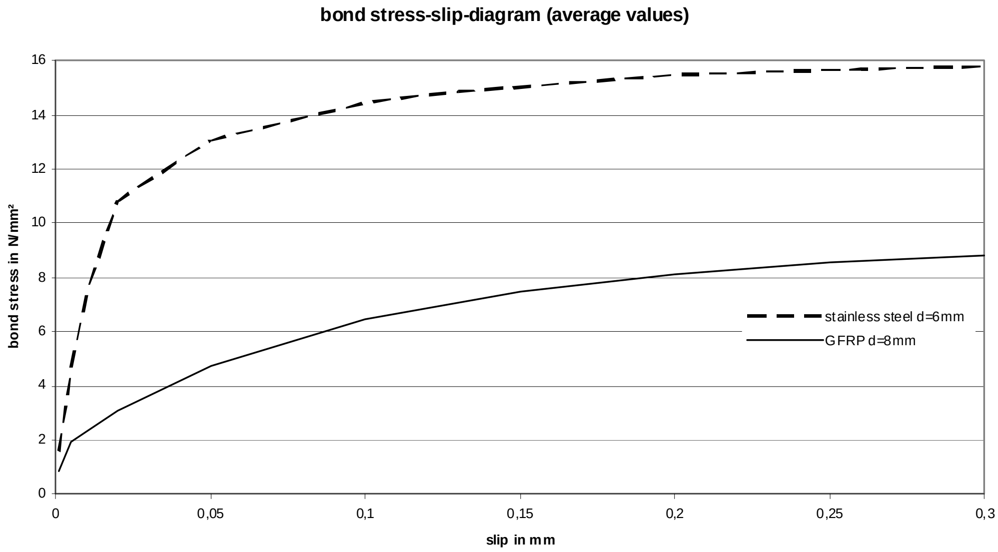

Figure 2. Average values of the bond stress-slip-relations

The dimension of the concrete cover had no influence on the stiffness of the bond behavior. With the minimum value of 15 mm the reinforcement was able to achieve the same level of bond stresses as in the case of a 30 mm concrete cover.

Model Code 90 [2] was used to define a mathematical description of the bond behavior, which corresponds with the test results especially for small slip values, where bond behavior is of interest for crack width limitation.

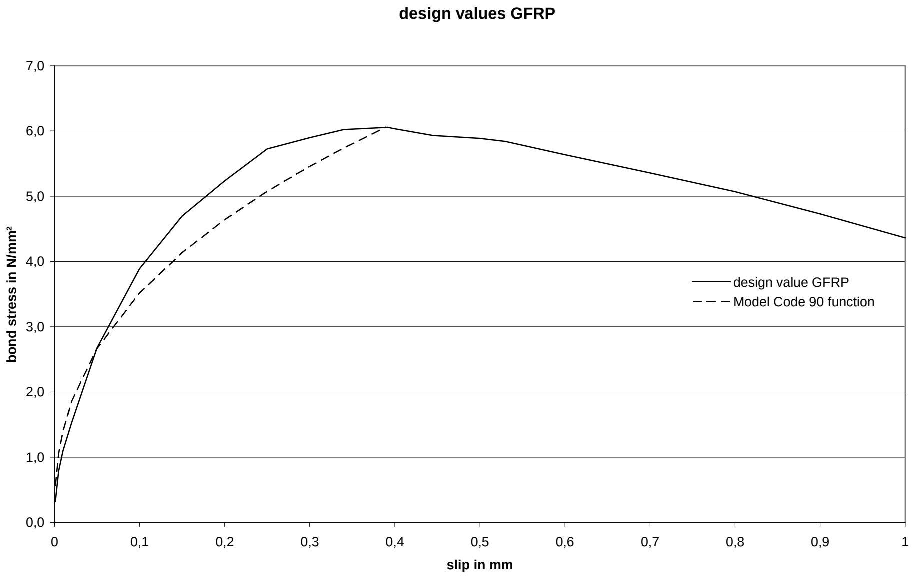

Figure 3. Design values of the tests with ComBAR and calculative curve

Based on these functions further calculations were made in order to be able to predict bond length and crack width in the parking slabs. Results of these calculations are shown in table 1.

Table 1. Comparison of the reinforcement systems in case of same force (design values of bond behavior)

force in kN	3,0	5,0	8,0	10,0	12,0
corresponding slip of stainless steel in mm	0,011	0,025	0,056	0,078	0,104
corresponding slip of GFRP in mm	0,032	0,067	0,135	0,184	0,240
corresponding bond length of stainless steel in mm	42	62	86	100	112
corresponding bond length of GFRP in mm	90	120	154	173	189

The calculated crack width for stainless steel corresponds sufficiently with the expected crack width given in the general technical approval [1] for this floor system of parking garages.

2 PULL-OUT TESTS WITH LARGE ANCHORAGE LENGTH

Test specimens with GFRP rebars and large anchorage length were fabricated in order to verify the calculations of bond length and crack width. The GFRP rebars were concreted centrically into concrete cubes with an anchorage length of 160 mm and 180 mm respectively. The achieved results could be compared to the calculations of bond length (see 1). The following diagram shows that the test results are definitely located above the calculated curve of the design values of bond behavior.

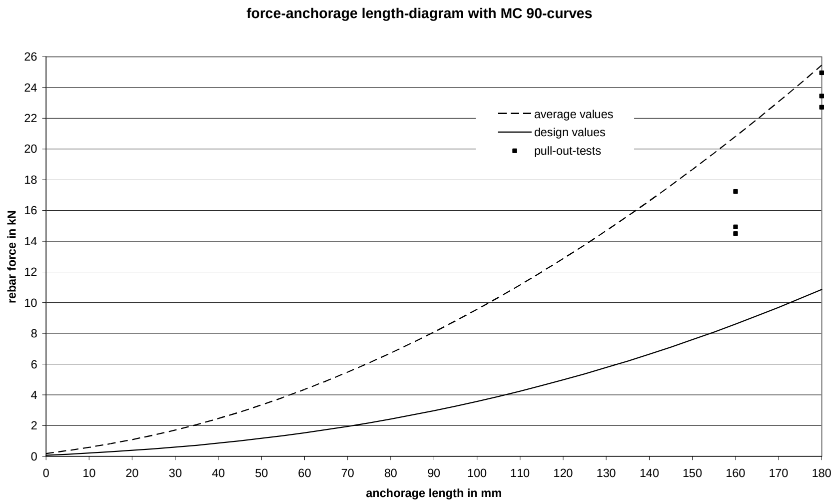

Figure 4. Comparison of the test results with the calculative assumptions

3 EXTENSIONAL TESTS

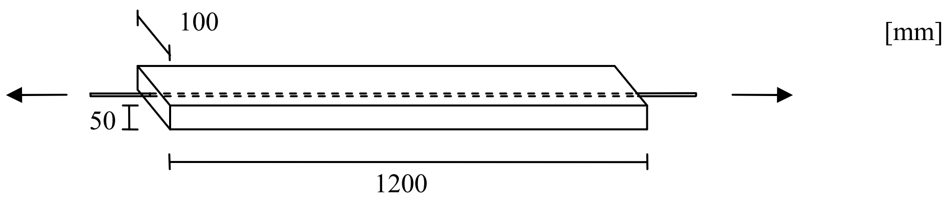

Figure 5. Geometry of the test specimen for an extensional test

For the extensional tests one rebar was concreted centrically into a specimen with an area of 50 cm². This area is about the concrete's effective tensile cross section in a real parking slab. Therefore the results were suitable for the further planning of the full size test.

The test specimens were loaded in steps and the cracking and changing of crack width were documented. Afterwards 100 load cycles were applied to the rebars in order to gain information about the change of bond stiffness under repeated loading.

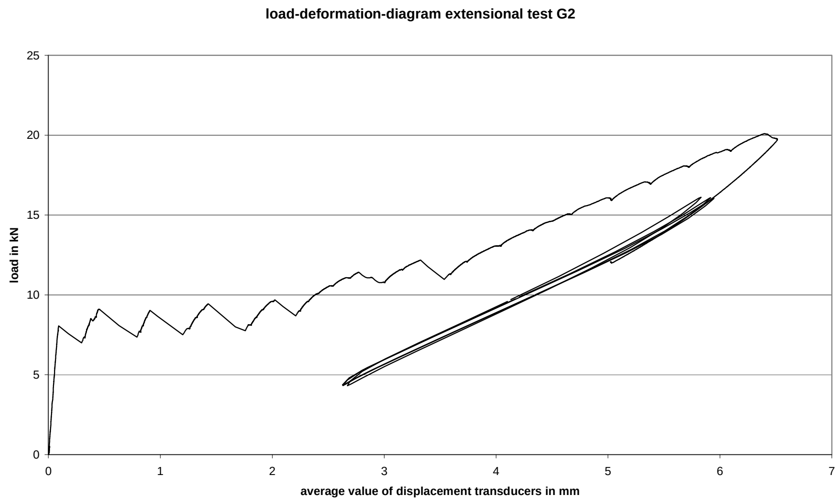

Figure 6. Load-deformation-behavior of extensional test G2

Overall GFRP rebars did not show a larger loss of stiffness of bond performance than stainless steel reinforcement. In addition it was possible to determine the extensional stiffness of the cracked specimen including tension stiffening. This stiffness was used for the precalculation of the test with a full scale specimen.

4 FULL SIZE TEST

For the full size test a two-span parking slab with a span of each 1,60 m and a width of 1,50 m was constructed. All conditions of the general technical approval [1] were kept. The 600 mm long GFRP rebars for crack width limitation were positioned in a distance of 95 mm over the middle steel girder. Thus the rebars had an anchorage length of 190 mm on both sides of the outside edges of the girder.

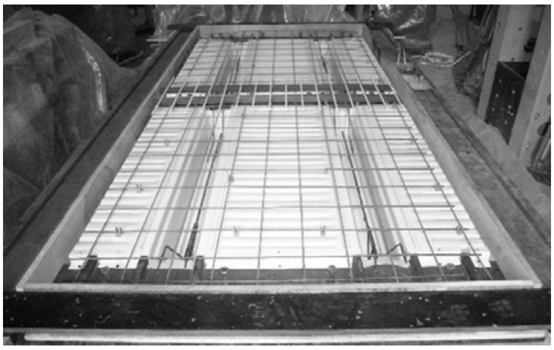

Figure 7. Construction of the full size test

The calculation of the internal forces for the load steps of the full size test was determined with a realistic system of a parking garage. Different flexural stiffnesses at mid-span and at the internal support as well as cracking were considered in the model of a four-span slab with each 5 m span. The used differences of temperature are taken from a FE-analysis, which studied the thermal influences on this slab. The following load steps were used for the test procedure:

1. self-weight of slab and girder + live load p=2 kN/cm²
2. self-weight of slab and girder + live load p=2 kN/cm² + difference of temperature day-night ΔT=-2,4 K
3. self-weight of slab and girder + live load p=2 kN/cm² + difference of temperature day-night ΔT=-2,4 K + shrinkage according to DIN 4227 [3]
4. self-weight of slab and girder + live load p=2 kN/cm² + difference of temperature day-night ΔT=-2,4 K + shrinkage according to DIN 1045-1 [4]
5. 10 load cycles live load + difference of temperature day-night ΔT=-2,4 K
6. self-weight of slab and girder + live load p=2 kN/cm² + shrinkage according to DIN 1045-1 [4] + summer thunderstorm ΔT=-34,5 K
7. failure load of the test specimen

A measuring grid for crack measuring as well as inductive displacement transducers were applied at the intermediate support of the slab in order to get information about the development of crack width.

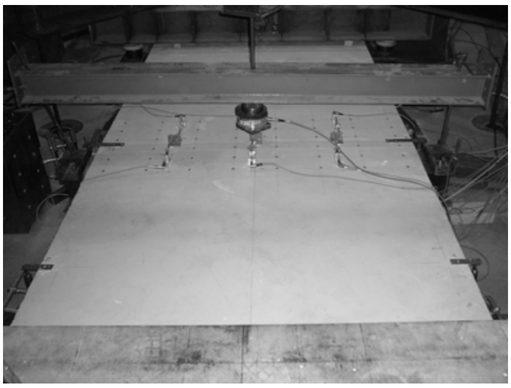

Figure 8. Full size test with measuring equipment

During the test procedure near-surface shrinkage cracks appeared at lower load steps. The crack width of these cracks was very small. The first crack that reaches the reinforcement occurred at load step 3 (self-weight + live load + difference of temperature day-night + shrinkage). That means a cracking moment of 6,99 kNm/m. The tension force in a rebar at the beginning of cracking is the maximum loading of the reinforcement and was 12,4 kN in the test. Afterwards the rebar forces decreased due to cracking accompanied by a reduction of flexural stiffness. The full size test acted as a real floor of a parking garage as two cracks ran along the outside edges of the steel girder. The maximum crack width that was measured was 0,12 mm. So the crack width remains in a dimension for which suitable concrete coatings exist. Table 2 contains a comparison of the measured crack width and the calculated crack width at different load steps.

Table 2. Comparison of measured and calculated crack width

load step	corresponding rebar force in kN	corresponding measured crack width in mm average value	corresponding calculated crack width in mm average value of bond
g + p	1,33	0,004	0,007
g + p + ΔT=-2,4K	1,68	0,010	0,010
g + p + ΔT=-2,4K + shrinkage (old)	2,68	0,022	0,020
g + p + ΔT=-2,4K + shrinkage (new)	3,50	0,037	0,031
g + p + shrinkage (new) + ΔT=-34,5K	8,20	0,115	0,123

It can be seen that the calculated crack widths were not or just marginally reached in the full size test. The results also show that the assumptions for calculation lead to realistic results. Failure of the slab occurred with cracking at the end of the reinforcement at a support moment of 23,07 kNm/m, which meant a tension force in one rebar of 40,8 kN.
Figure 9 shows the crack pattern after completion of the test. The two cracks along the outside edges of the steel girder are clearly visible. The outer cracks appeared at failure of the slab segment.

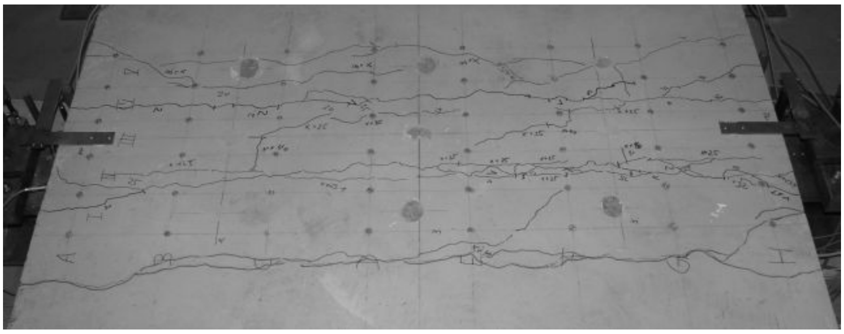

Figure 9. Crack pattern after completion of the test

5 REFERENCES

[1] General technical approval Z-26.1-44 for Hoesch Additiv slab, German Institute for Standardization 07.01.2003

[2] CEB-FIP Model Code 1990 Design Code, Comite Euro-International du Beton, 1993

[3] DIN 4227: Prestressed concrete - structural members made of normal weight concrete, with limited concrete tensile stresses or without concrete tensile stresses, 07/1988, Beuth Verlag Berlin

[4] DIN 1045-1: Concrete, reinforced and prestressed concrete structures - part 1: design, 07/2001, Beuth Verlag Berlin

[5] Eurocode 4: Design of composite steel and concrete structures - part 1-1: General rules and rules for buildings, 07/2006, Beuth Verlag Berlin