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Concrete Repair with Shotcrete

Réparation du béton par béton projeté

Betonreparaturen mit Spritzbeton

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SUMMARY

Shotcrete appears to be useful in repairing vertical and overhead surfaces of deteriorated concrete structures. It is essential that water-jetting, cleaning and shotcreting operations are all carried out meticulously. Nine reinforced concrete beam specimens sawn out of water-jetted and shotcreted concrete slabs have been loaded statically and under fatigue conditions. The varying parameter was the ratio between shotcrete thickness and total beam depth. According to the test results, the interface between old concrete and shotcrete should not coincide with the reinforcement plane.

RÉSUMÉ

Il est possible d'utiliser du béton projeté pour réparer les constructions endommagées en béton. Les travaux relatifs au traitement par jet d'eau, au nettoyage et à la projection de béton doivent être exécutés méticuleusement. Neuf poutres en béton armé sciées à partir de dalles traitées au jet d'eau et revêtues de béton projeté ont été soumises à des charges statiques et dynamiques, la variable étant le rapport entre l'épaisseur de la couche de béton projeté et la hauteur totale de la poutre. Les essais ont montré que la jonction entre l'ancien béton et le béton projeté ne doit pas coincider avec le plan d'armature.

ZUSAMMENFASSUNG

Spritzbeton ist offensichtlich auch zur Reparatur der Betonkonstruktionen geeignet. Dabei sind aber sämtliche Arbeiten wie Wasserstrahlbearbeitung, Reinigung und Spritzen sorgfältig auszuführen. Bei den Versuchen wurden neun Stahlbetonbalken aus wasserstrahlbearbeiteten und mit Spritzbeton versehene Betonplatten mit statischer Last und Ermüdungslast beansprucht. Variierender Parameter war der Anteil der Spritzbetonschicht an der Gesamtbalkenhöhe. Nach den Versuchsergebnisssen sollte die Fuge zwischen dem alten Beton und dem Spritzbeton nicht in der Bewehrungsebene liegen.

1. INTRODUCTION

Extensive damage due mainly to de-icing salts and repeated freeze-thaw cycles is found on many concrete bridges. The deteriorated concrete has to be removed and replaced by new concrete. For some years now the water-jet technique has been the most frequently used method of concrete removal in Sweden. Using water-jets technique or hydrodemolition means that concrete is removed by high pressure water-jets, see [4].

Experience from repair of concrete bridge decks in Sweden and laboratory tests carried out at the Department of Structural Mechanics and Engineering, the Royal Institute of Technology, Stockholm [1] and [2], has shown that a good bond between old and new concrete can be obtained without expensive stud bolts. In replacing deteriorated concrete on vertical and overhead surfaces, shotcreting is more convenient than making complicated shuttering and pouring convential concrete.

Can shotcrete be used to repair a structural concrete member and assuredly adhere to carry its share of static and fatigue load? The tests described in this paper were aimed at answering this question. Since the damage thickness varies within a single concrete structure and between structures, the purpose was also to study how the location of the interface in relation to the reinforcement plane influences the load-bearing capacity of the composite structure. Reference [3] deals in detail with the test results.

2. TEST SPECIMENS AND TEST SPECIMEN PREPARATION

The test programme embraced a total of twelve reinforced concrete beams cut from slabs. Four concrete slabs were cast. Three slabs were water-jetted and the varying parameter was the thickness of the concrete removed. The aim was to precisely reach the reinforcement on the first slab (A), to uncover half of the reinforcement bars on the second one (B), and to completely uncover the reinforcement on the third slab (C). The fourth slab was a reference slab (R) which was not water-jetted.

In a second phase of test specimen preparation, the removed concrete was replaced by shotcrete to the level of the original slab thickness. The slabs were finally sawn into strips, resulting in beam specimens. The test specimens were designated A1, A2, A3 etc. The cross-sections are shown in Fig. 1 and material properties are listed in Table 1.

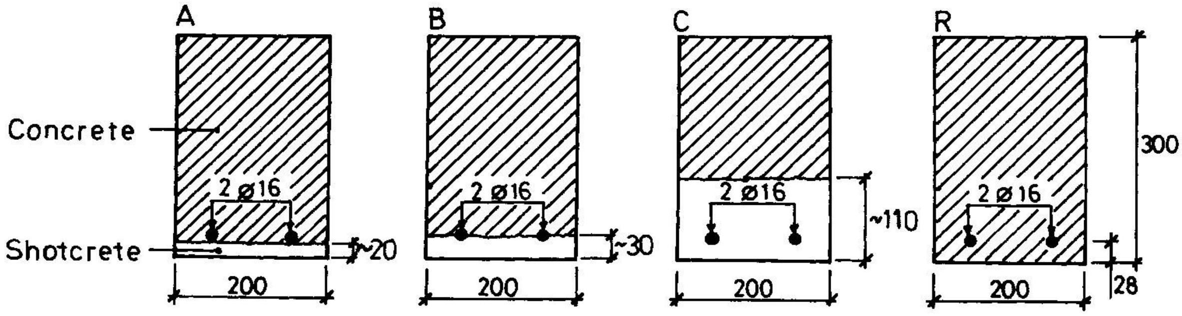


Fig. 1 Cross sections of specimens of type A, B, C and R.

	Cube length (mm)	Age (days)	Compressive strength (MPa)	Splitting tensile strength (MPa)
Concrete of 1st casting	150	238	31.5	2.8
Shotcrete	100	92	77.7	6.0
		Diameter (mm)	Yield strength (MPa)	Ultimate strength (MPa)
Reinforcement bars		16	466	579

Table 1 Material properties of the test specimens

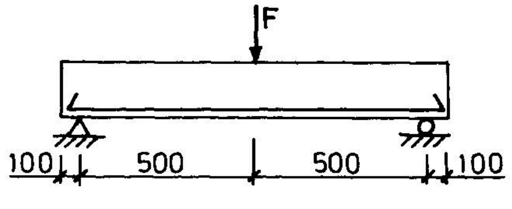
3. MAPPING OF THE LOCATIONS OF THE INTERFACES

After casting of the original concrete slabs the concrete cover was about 20 mm on all slabs. The concrete cover and a varying amount of concrete surrounding the reinforcement bars was removed by water-jet operations. Minimum, maximum and average values of the thickness of the removed concrete and of the ratio between uncovered perimeter and total circumference of the reinforcement bars were measured and are shown in Table 2.

Slab No.	Thickness of removed concrete (mm)			Ratio between uncovered perimeter and total circumference of rebar (percentage)		
	Minimum	Average	Maximum	Minimum	Average	Maximum
A	14	22	37	0	2	30
B	15	30	45	0	23	50
C	75	110	135	100	100	100

Table 2 Data on removed concrete and uncovered reinforcement bars

4. LOADING



One beam specimen of each type was statically loaded to failure and two of each type were loaded by fatigue. All beams were simply supported on two supports and loaded by a central single load according to Fig. 2.

Fig. 2 Loading of the beam specimens

5. STATIC TESTS

The results of the static tests are shown in Table 3. For specimen No. B2 with the interface between concrete and shotcrete coinciding with the reinforcement plane a combined shear and anchorage failure occurred. For the other three specimens flexural failures occurred. Calculated yield load at flexure and ultimate shear load for a monolithic R.C. beam with equal dimensions and material properties were 96 and 167 kN respectively.

Specimen No.	Yield load (kN)	Ultimate load (kN)	Final failure mode
A2	95	98	Flexural failure
B2	90	95	Combined shear and anchorage failure
C2	90	100	Flexural failure
R2[1]	95	101	Flexural failure

[1] Homogeneous reference beam

Table 3 Obtained failure loads and failure modes

6. FATIGUE TESTS

The load varied sinusoidally and the frequency was increased from 1 Hz at the first cycle of repeated loading to 4 Hz at approximately the 1000th cycle. Thereafter the frequency was kept constant. The results are shown in Table 4. In conformity with the static tests, combined shear and anchorage failure occurred

Specimen No.	F_{max}[1] (kN)	F_{min}[2] (kN)	N[3]	Failure mode
A1	70	10	313 000	Flexural failure
B1	70	10	23 000	Combined shear and anchorage failure
C1	70	10	227 000	Flexural failure
R3[4]	70	10	220 000	Flexural failure
A3	75	15	205 000	Flexural failure
B3	75	15	20 000	Combined shear and anchorage failure
C3	75	15	166 000	Flexural failure
R1[4]	75	15	268 000	Flexural failure

[1] F_{max} = maximum value of the sinusoidal load
[2] F_{min} = minimum value of the sinusoidal load
[3] Number of cycles of repeated loading at failure
[4] Homogeneous reference beam

Table 4 Number of cycles at failure and failure modes for the two beams (B1 and B3) with the interface coinciding with the reinforcement. In all other cases flexural failure occurred. The number of cycles of repeated loading at failure for beams No. B1 and B3 was about one tenth of the corresponding number for the other beams, both composite and homogeneous.

7. PULL-OFF TESTS AND TORSIONAL TESTS OF CORES

The tests were terminated with pull-off tests and torsional tests of cores according to Fig. 3. The results are shown in Table 5. Since no pure interface failure occurred it can only be stated that the tensile and shear strength of the interface cannot have been less than the failure values obtained. The failure stress was 1-2 MPa at tension (pull-off tests) and 3-4 MPa at shear (torsional tests). No differences dependent on the location of the interface in relation to the reinforcement plane could be determined according to these tests.

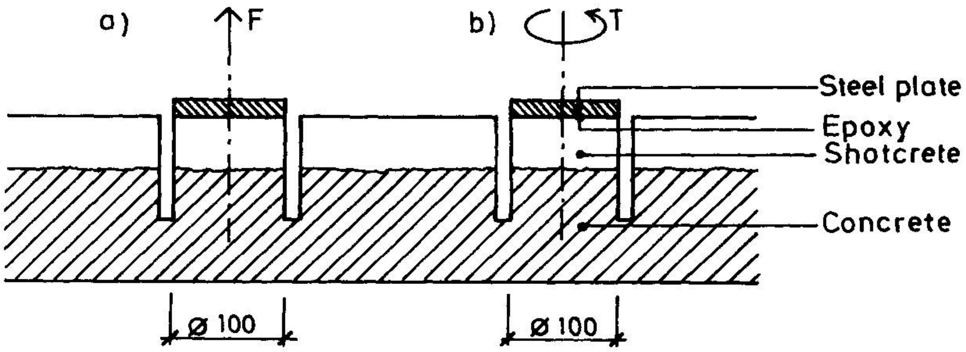


Fig. 3 Pull-off tests (a) and torsional tests (b) of cores

Specimen No.	Pull-off tests: Number of cores	Pull-off tests: Failure stress average (MPa)	Torsional tests: Number of cores	Torsional tests: Failure stress average (MPa)
A2[1]	3	1.47	3	2.99
A1[2]	3	1.73	3	3.04
B2[1]	2	1.92	2	3.81
B1[2]	2	1.36	2	3.38
C2[1]	3	1.77	3	3.41
C3[2]	3	2.06	3	3.62
R2[1]	3	1.64	3	2.68
R3[2]	3	1.95	3	2.86

[1] The specimen was previously loaded statically
[2] The specimen was previously loaded by fatigue

Table 5 Pull-off tests and torsional tests of cores Φ100 mm

8. CONCLUSIONS

Shotcrete appears to be useful in repairing vertical and overhead surfaces of deteriorated concrete structures. It is essential that water-jetting, cleaning and shotcreting operations are all carried out meticulously. According to the tests the interface between old concrete and shotcrete should not coincide with the reinforcement plane. The test results show a change in failure mode and less resistance to fatigue for this case. The probable explanation is that the bond between reinforcement and concrete is less if the interface between old concrete and shotcrete coincides with the reinforcement plane.

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