

A New Method of Controlling Shrinkage Cracking in Repaired Concrete Structures Using an Interface Layer of Carbon Fiber Reinforced Cement Mortar

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Abstract: Bonding an overlay of new concrete onto the damaged concrete is a usual repair method. Because of the different shrinkage rate of the new and old concrete, restrained shrinkage cracks will appear in the new concrete. The cracks will reduce durability and strength of the repaired structure. A new repair method using an interface layer of carbon fiber reinforced cement mortar between new and old concrete was developed in this paper. The new method was found to be very effective in reducing shrinkage cracking of repaired beams and slabs. Comparing with normal repaired beams, the maximum observed width of the resulting cracks was decreased by up to 43%, the cumulative width was decreased by up to 78%, the cumulative length was decreased by up to 73%, and the total area of the cracks was decreased by up to 81%.

1 Introduction

Because of heavy traffic and some other reasons, bridge and road slabs would be damaged easily. The usual method of repairing the slabs is to bond an overlay of new concrete to the damaged old concrete surface. Because of the different shrinkage rate of the new and old concrete, the free shrinkage of the new concrete is restrained by the old concrete, so tensile stresses will develop in the new concrete. The tensile stresses can make new concrete crack, especially at early ages. So the usual repairing method can't provide adequate durability and strength to the repaired concrete structure. Moreover, a large number of bridge and road slabs need to be repaired, so a kind of simple, yet successful and durable repairing method is urgently needed. This problem can be solved by reducing the shrinkage rate of the new concrete and strengthening the bonds between the old and new concrete. Some research has been conducted in this field. Work performed by N. Banthia, et al. [Banthia, Yan and Mindess, 1996] shows that steel fiber reinforced concrete was very effective in reducing restrained shrinkage cracking. But the size of their specimens was too small to compare them with actual structure, so the new concrete had not enough shrinking accumulative amount. Work performed by W. Jason Weiss, et al. [Weiss, Yang and Shah, 1998] shows that adding 2% SRA(shrinking reducing admixture) to normal strength concrete can reduce the restrained shrinkage cracking in slab specimens. By adding 1% and 2% SRA, the average crack widths reduce 19% and 69% at 50th days. But the restraint condition and the size of the specimens differs greatly from the actual structures. D.W. Pittman and S.A.Ragan [Pittman and Ragan, 1998] found the drying shrinkage of Roller-Compacted Concrete was relatively lower compared to conventional concrete for pavements, and the combined effects of moisture content and aggregate grading (paste volume) on the drying shrinkage of RCC were found to be significant. But moisture content is hard to controll in the actual structures. P. Chen et al. [Chen, Fu and Chung, 1995] and the authors [Shen and Xie, 2001] of this paper investigated the formulation and mechanical performances of carbon fiber reinforced mortar, and found the drying shrinkage is decreased and the bonding strength is increased greatly in the mortar. To increase the durability and reduce cracks, a new repair method was presented by using carbon fiber reinforced mortar as a transition layer between the new and old concrete in this paper. It is more economical to use just a transition layer of carbon fiber mortar than a new whole carbon fiber concrete. Compared comparing with normal repaired specimens, the test results are satisfactory.

2 Experiment and materials

2.1 Experiment

The beams and slabs were repaired at 18 months old. So the shrinkage of the old concrete can be ignored. Both amounts of slabs and beams are six. The surface of the old concrete was given an enhanced roughness to obtain

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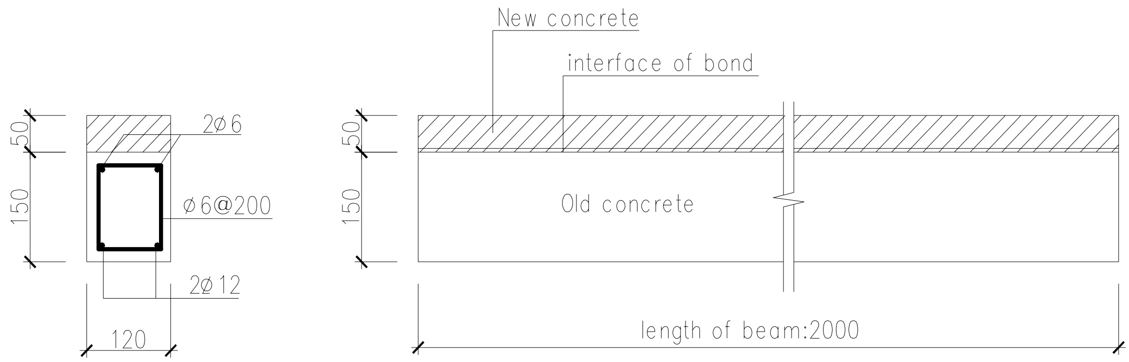

Figure 1 : The model of repaired beams

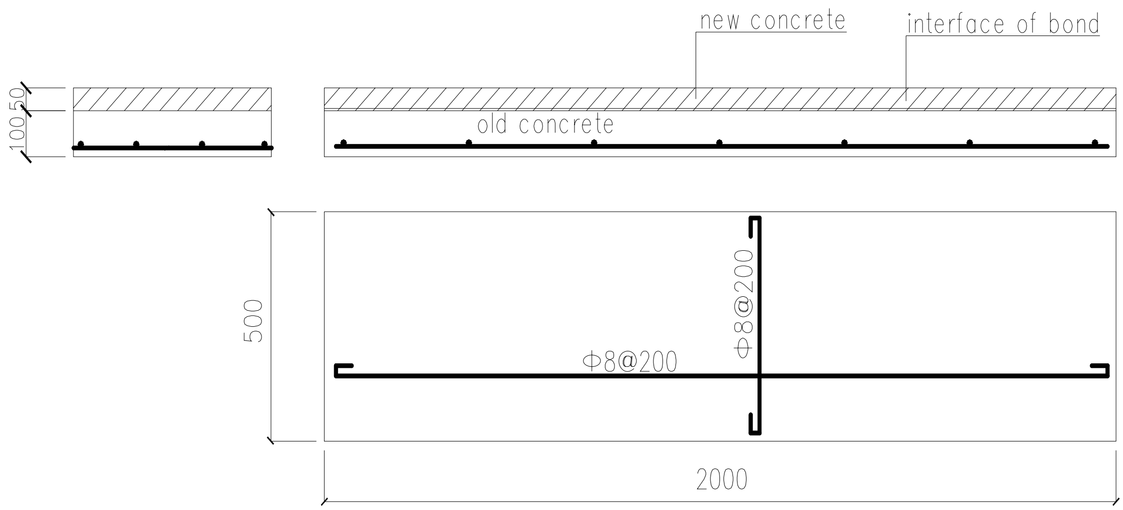

Figure 2 : The model of repaired slabs

Table 1 : Mix Proportions for Concrete

f_c(Mpa)	Cement	Water	Sand	Aggregate(25mm)
30	1	0.44	0.38	2.45

a good bond surface. Three of them were repaired by normal method,called as Nor.B or Nor.S. A 50mm deep overlay of the new concrete was bonded to the surfaces of old beams and slabs. The other three of them were repaired by the new method, called as CF.B or CF.S. First, a 5mm deep layer of carbon fiber reinforced mortar as a transition layer was bonded to the surfaces of old concrete, and then a 45mm deep layer of new concrete was poured onto the transition layer after 5 minutes. The models of repaired beams and slabs are shown as Fig 1 and Fig 2 . Their sizes are close to actual sizes of beams and slabs in engineering. Raw materials for concrete are shown in Table 1

Table 2 : Properties of carbon fibers

Tensilie strength(Mpa)	20003000
Tensile modulus(Gpa)	175215
Density(g/cm^3)	1.741.77
Electrical resistivity Ω·cm	3.0×10^{-3}
Filament diameter (μm)	7
Average length (mm)	5

Table 3 : Mix Proportions for carbon fiber reinforced mortar

Cement	0.77	Methylcellulose	0.4%
Silica fume	13%	Defoamer	0.02%
Sand	1.5	Water reducing agent	2%
Water	0.5	Accelerate agents	0.62%
Carbon fiber	0.5%		

2.2 *Materials for carbon fiber reinforced mortar*

The short carbon fibers((PAN,nominally 5 mm in length) were used. They were provided by Shanghai Xinxing Carbon Co., LTD. The properties are shown in Table 2. The raw materials and mix proportions for carbon fiber reinforced mortar are listed in Table 3.

At first, dissolve the methylcellulose in the water and then add carbon fibers and defoamer to the water and mix around for 5min. Put this mixture, sand, cement, silica fume and water into a special mixer and again mix for 5min, and then add the water reducing agent and accelerating agents and mix for 5min. Before repairing, a vibrater must be use the mortar to make it compact and decrease the amount of air bubbles.

2.3 *Crack observation*

Because of the property of concrete, the shrinkage of the new concrete will develop quickly at early age. In the first month, the shrinkage can reach at 30%∼40% of total shrinkage developed in 20 years, and it grows gradually slowly at following time. The relative humidity also affects the shrinkage of concrete. The shrinkage rate of normal concrete in 50% relative humidity environment is twice that in 80%. So we observed shrinkage cracking in normal environment (humidity 70-80%) for 28 days, and then the specimens were placed in a dry small room with a relative humidity kept at 40% by 8 dehumidifiers to accelerate shrinking. The developing of shrinkage cracking was observed continuously until no longer develop obviously. A small hand held microscope equipped with a vernier was employed for this purpose.

3 Test Results

After the specimens were demolded, the crack observations began. The widths and lengths of the various cracks are measured as a function of time. Using the product of the crack width and length yielded , a parameter termed the total crack area. In Fig. 3 and Fig. 4, the evolution of the total crack area is plotted as function of time for the two repair methods. The final results at the termination of the test are given in Table 4. Some cracked specimens are shown in Fig.5 and Fig.6. It is obvious, shrinkage cracking of Nor. B and Nor. S was greater than that of CF.B and CF.S from Fig.5 and Fig.6.

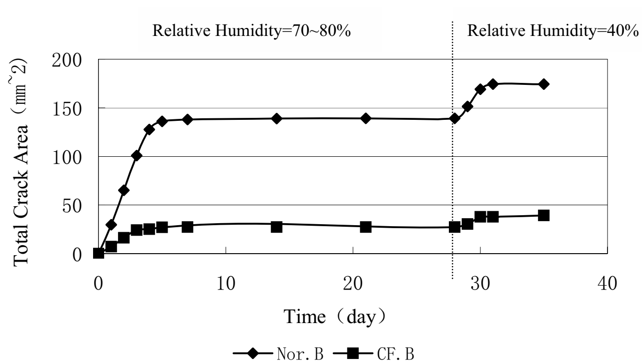

Figure 3 : Evolution in the total crack area in beam

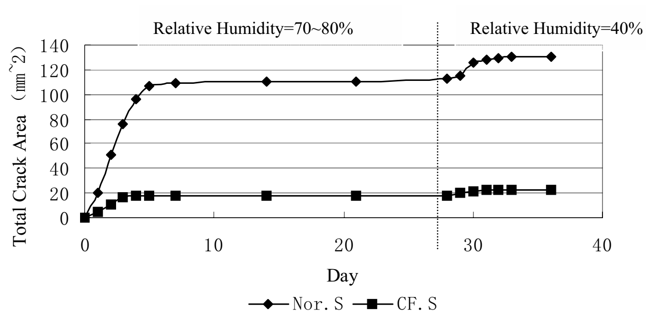

Figure 4 : Evolution in the total crack area in slab

4 Conclusion

Using a mechanical model of restrained shrinkage in the new and old concrete, the strain caused by the different

Table 4 : Shrinkage Test Results

	$W_{max(mm)}$	$W_{c(mm)}$	$L_{c(mm)}$	$A_{crack(mm)}$	N
Nor.B	0.39	4.28	762	175	19
CF.B	0.22	1.44	250	48	9
Nor.S	0.37	3.95	492	123.5	16
CF.S	0.21	0.87	133	23.3	5

Nor.B: beam repaired by normal method, CF.B: beam repaired by new method
Nor.S: slab repaired by normal method, CF.S: slab repaired by new method
W_{max}: max observed crack width, W_c: cumulative crack width
L_c: cumulative crack lengths, A_{crack}: cumulative crack area
N: number of cracks

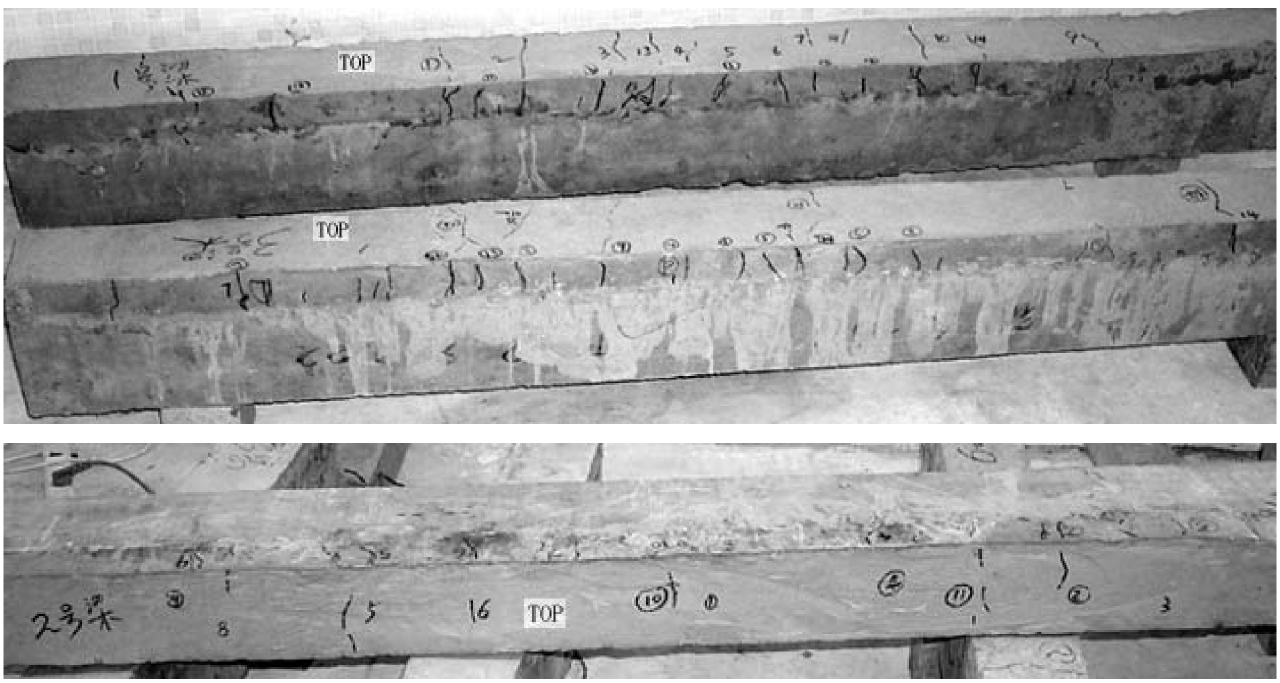

Figure 5 : Comparison of Cricks Between Nor. B (upper) and CF. B(under)

shrinkage rates at a cross section is shown as Fig.7 [Yuan, 1996]. Obviously, the largest tensile stress appears at the interface of new-to-old concrete in the repaired specimens. Because there are better mechanical performances in carbon fiber reinforced mortar than normal mortar [Chen, Fu and Chung, 1995, Shen and Xie, 2001], such as lower shrinkage strain and larger tensile strength, so the shrinkage difference of new and old concrete can be reduced and bonding strength can be heightened by using CFRM as a transition layer. Our experimental tests proved that the maximum crack width decreased up to 43%, the cumulative crack width was decreased bup to 78%, the cumulative crack length decreased up to 73% and the total crack area decreased up to 81%, by comparing with normal repaired beams. Obviously, using this method to repair concrete structures can increase the structure's durability and decrease the shrinkage cracking. The method is also economical because the majority of the new concrete used is normal concrete.

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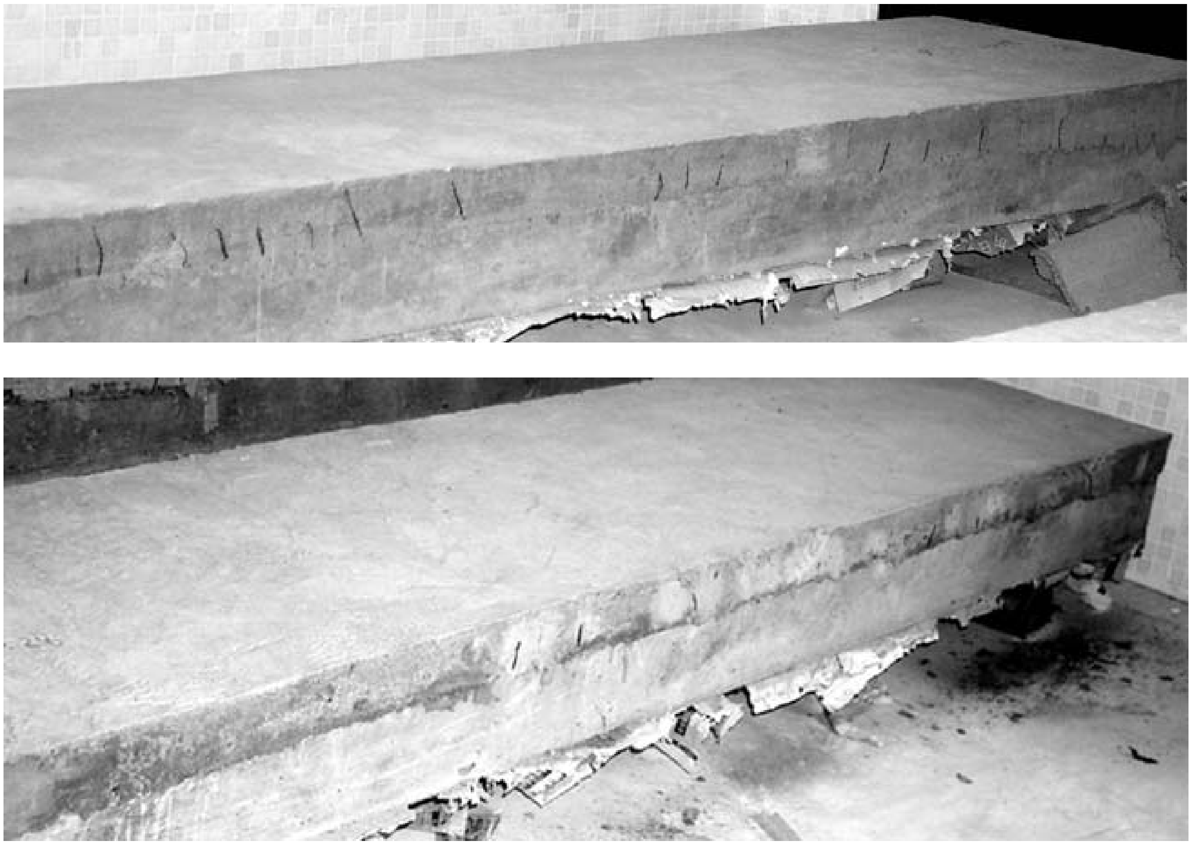

Figure 6 : Comparison of Cricks Between Nor. S (upper) and CF. S(under)

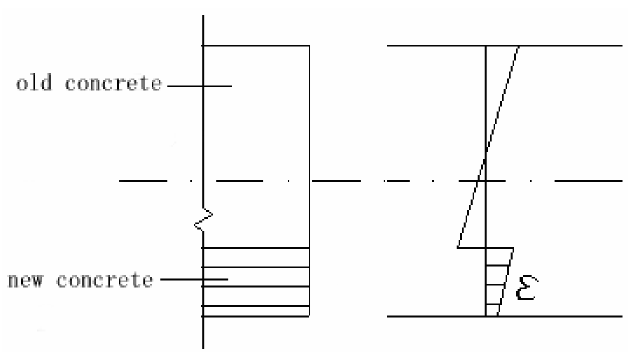

Figure 7 : Distribution of shrinkage strain

Province(1498009).

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