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Shear test of the rectangular beam on the new to old concrete interface based on Digital Image Correlation

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Abstract. The bond property of new to old concrete is the key to strengthen and reinforce the hydraulic concrete structure, and shear strength is an important index of its bond property. With the help of advanced Digital Image Correlation (DIC), the direct shear state, fracture surface displacement, deformation and crack location of the new to old concrete bonding interface are studied through the shear test of rectangular beam, the strain distribution pattern of the bonding interface is well obtained. The results show that the interfacial roughness of specimen has great influence on the shear strength of the repaired specimen. The greater the roughness is, the better the bond property is. Due to friction, the specimen itself will be subject to the combined action of bending and shearing, which leads to bending shear failure of specimen rather than pure shear failure.

1. Introduction

The treatment of old concrete bonding interface is the first step in the repair and reinforcement work, which will greatly influence the interfacial bonding quality. The interfacial bonding quality of hydraulic new to old concrete is influenced by many factors^[1], such as the treatment method, roughness of the old concrete interface, the type of interfacial agents, the mechanical connection method of the bonding interface and so on. But up to now, no corresponding standards or regulations at home or abroad have provided for the treatment methods on the bonding interface between old and new hydraulic concrete. In the practice of reinforcing and strengthening hydraulic new to old concrete, some methods have been studied and applied to treat the interfacial roughness of new to old concrete, such as: artificial chiseling, high pressure water jetting, mechanical notch, abrasive blasting, air-based blasting, pneumatic hammer chiseling, chemical etching and so on^[2]. The study shows that the interfaces that have been treated have a better bonding property than the one untreated. In engineering practice, surface treatment methods and corresponding processes have also been studied. A number of foreign organizations provide written standards and guidelines for surface preparation^[3-6]. People have reached a consensus that adhesive bonding performance increases with higher roughness of the new to old concrete bonding interface. However, there should be some restrictions on interfacial roughness, the excessive roughness will reduce the bond property. The bonding performance of high-pressure jetting is better than that of mechanical notch. Quantifying the evaluation of the roughness of treated old concrete bonding interface and making it meet the requirement of good interfacial bond property are keys to evaluate and predict the bond property of the hydraulic new to old concrete^[7-8]. The



treatment of old concrete bonding interface is important for the repairing and strengthening work, which will directly influence the whole quality of the reinforced structure. So it is necessary to adopt suitable, simple and reliable treatment methods based on specific engineering.

The old concrete, with high volume stability, has nearly complete hydration. By comparison, new concrete is experiencing multiple chemical reactions, shrinkage and so on, and its volume deformation develops rapidly. Therefore, how to coordinate different phases of deformation remains a problem for combining hydraulic new to old concrete. Under the action of load and shrinkage, the bonding interface between the hydraulic new to old concrete is often first to fail because of shear force. It is hard to achieve the desired adhesive performance by only relying on the bonding force^[9]. At present, because the tested bonding interface of hydraulic new to old concrete structure is under non-pure shear stress and most stress concentrate on the edge of the interface, it is often difficult to get pure bonding shear strength of hydraulic new to old concrete. So optimizing the testing methods is necessary.

In order to provide a direct verification on the effect of surface roughness on the shear strength of concrete bonding interface, specimens with different roughness were used for the comparison test. In group A, the surface of concrete was artificially greencutting, while specimens retained the smooth surface for group B. The purpose of doing so is to explore the effect of the concrete surface roughness on the shear strength of bonding interface and whether the failure of specimen in the rectangular beam test method is the ideal pure shear failure.

2. Test methods and process

2.1 Preparation of old concrete specimens

The old concrete specimens were cuboids, 100 mm in length, 100 mm in width and 300 mm in height. The designed concrete strength was C25. The mix proportion for concrete specimens was shown in Table 1. The materials used were ordinary portland cement, tap water, river sand (as fine aggregate), and gravel (as coarse aggregate).

Table 1. Mix proportion for old concrete specimens

Concrete strength	Mix proportion of concrete (kg/m ³)			
	Cement	Water	Sand	Gravel
C25	367	180	649	1204

2.2 Preparation of new to old concrete specimens

The new to old concrete specimens were divided into two groups: the greencutting old concrete specimens and the no-greencutting. The 100 mm×100 mm×300 mm concrete cuboid specimens were cut into 12 concrete cubes with the side length of 100 mm, and then all of them were numbered. Among them, No.1-6 specimens were directly poured with new concrete, and No.7-12 specimens were poured after being greencutting. The new concrete designed strength was C30. The mix proportion for concrete specimens was shown in Table 2. The materials used in new concrete were the same as the old concrete.

Table 2. Mix proportion for new concrete specimens

Concrete strength	Mix proportion of concrete (kg/m ³)			
	Cement	Water	Sand	Gravel
C30	354.55	195	640	1160

With low engineering cost, artificial chiseling does not require complicated construction technology, or expensive and large mechanical equipment, so this method was used to treat the surface of the concrete in this study. The first step was to chisel off the laitance on the concrete surface until the internal aggregate was revealed, and then we cleaned up the detritus and flushed away the loose mortar block. The last step was to clean the crushed aggregate with water. It is important to note that

the depth of the main chiseling points should be at least 10 mm, so as to ensure that the closely combination of bonding interface between the new concrete and the old .

When preparing the new to old concrete specimens, the old concrete specimen was placed in the middle of the mould (the size of mould was $100 \times 100 \times 300$ mm) and the new concrete was poured on its two sides. Specimens were cured for 28 days to form the final new to old concrete specimens. The schematic diagram of specimen preparation was shown in Figures 1.

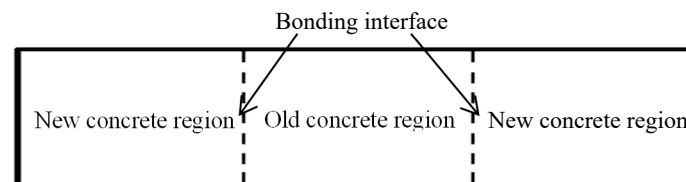


Figure 1. New to old concrete preparing schematic diagram.

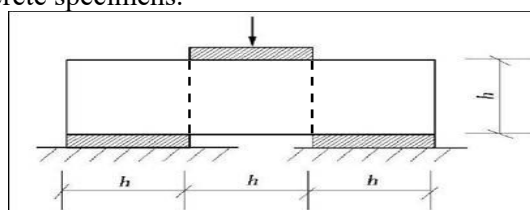
2.3 Concrete shear test process based on DIC

The test scheme was shown in Figure 2. Three steel plates were placed on the upper and lower parts of the specimen, respectively, for fixing, and the instrument pressure head exerts the same force on the specimen. In this paper, the Digital Image Correlation (DIC) was used to measure the strain field distribution at the meso-scale during the concrete shear failure process. The technology is a modern and optical method for non-contact and high-precision measurement of mechanical field deformation. Its principle can be summarized as follows: through image correlation matching, the speckle (random dot mark) image on the specimen surface is analyzed before and after the deformation to track the motion of these geometric points to get the deformation field. On the basis of this, the strain field is obtained by calculation. In order to get enough data, the time interval of digital image data acquisition was set to 10s and the image analysis was performed every 10s. The specific loading conditions of the test instrument were as follows:

Step1: The test entered the step2 when the displacement velocity was equal to 5mm/min or the loading was equal to 0.3kN.

Step2: The displacement velocity was controlled in 0.05mm/min, until the specimen was cracked.

In the whole process, the traditional rectangular beam shear test was respectively carried out on old concrete specimens, no-greencutting new to old concrete specimens and greencutting new to old concrete specimens.



(a) Force diagram of specimens



(b) Testing field diagram

Figure 2. Traditional rectangular beam shear test

3. Results and discussion

3.1 Fracture surface analysis of the bonding interface

During the test, it was found that the failure location of old concrete specimens had no obvious characteristics. Cracks generally appeared at the bottom of specimens, and then the failure interface expanded with the development of the crack until the specimens lost stability ultimately. The fracture surface was basically on edge of the aggregate and the "transition layer" of mortar. No-greencutting new to old concrete specimens failed abruptly. Its failure, once appeared, was along the bonding interface on the entire specimen without any obvious omens. The fracture surface was smooth. The failure process of specimen with rough bonding interface was slow after the appearance of obvious

cracks. The failure was mostly on the "transition layer" of the bonding interface of the exposed aggregate between new to old concrete. Its fracture surface morphology was more complex compared with the no-greencutting specimens. The failure morphology pictures of no-greencutting specimens and specimens with rough bonding interface were shown in Figures 3.

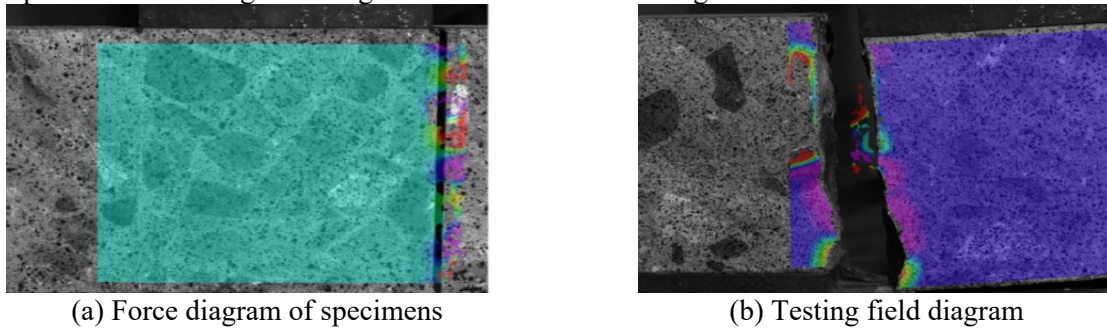


Figure3. Fracture surface of the new to old concrete specimen

Comparing three kinds of concrete specimens in the test, the bonding interface of old concrete need not only be greencutting but also must be moistened with water before the new concrete is poured. The water saturation degree of the bonding interface has certain effect on bonding strength. If the degree of saturation is insufficient, the old concrete will absorb moisture from the new concrete. This will lead to excessive loss of water near the new concrete bonding interface and further cause the hydration reaction of concrete to be inadequate and affect the bond strength.

3.2 Results of shear strength of specimen bonding interface

The load-displacement curves of the three kinds of specimens were shown in Figure 4. The shear strength was calculated and shown in Table 3.

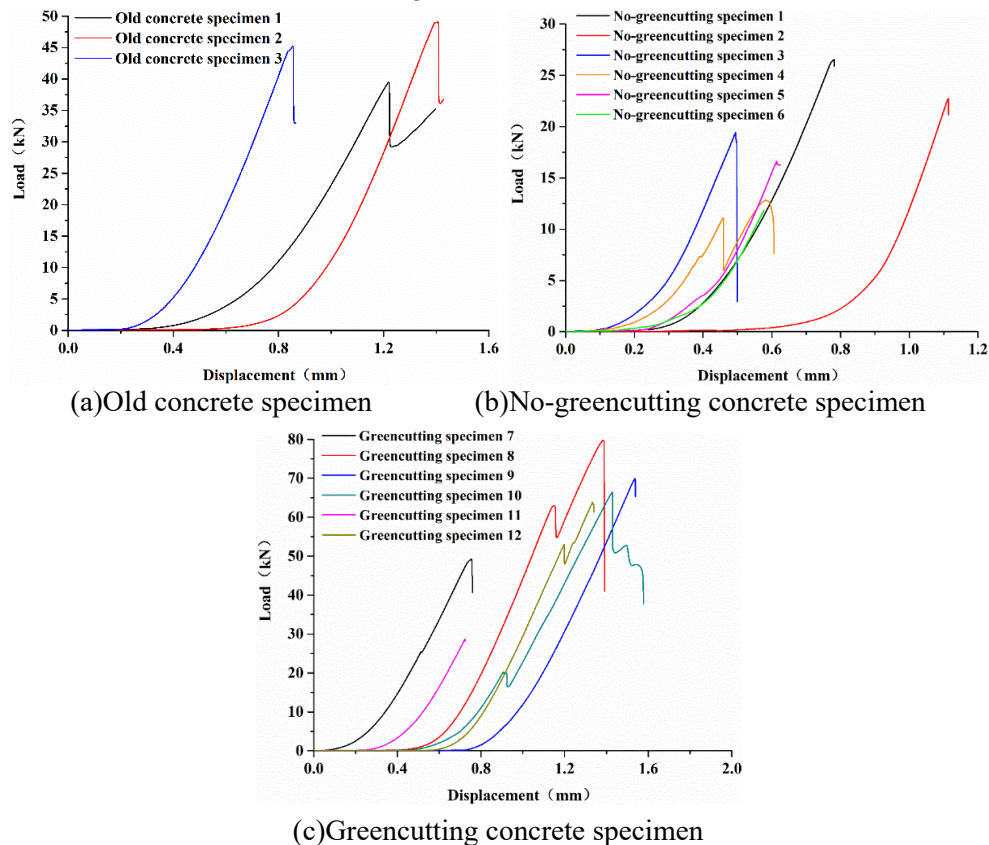


Figure4. Load-displacement curves

Table 3. Calculation results of specimen interfacial shear strength

Specimen	Number	Shear strength (MPa)	Mean (MPa)
Old concrete specimen	1	1.97	2.23
	2	2.45	
	3	2.26	
No-greencutting concrete specimen	1	1.33	0.92
	2	1.14	
	3	0.97	
	4	0.64	
	5	0.83	
	6	0.59	
Greencutting concrete specimen	7	2.46	2.98

From the results of shear failure in Table 3 and the curves in Fig. 4, it can be found that the shear failure strength of the bonding interface of old concrete specimens is 2.23Mpa. According to this, it can be estimated that the original shear strength of these specimens is about 2.23MPa. The shear failure results of no-greencutting concrete specimens show discrete distribution. The shear strength of bonding interface is 0.59Mpa ~ 1.33MPa and the average value is 0.92MPa. The shear strength of bonding interface of greencutting concrete specimens is 1.43MPa~3.99MPa and the average value is 2.98Mpa, significantly higher than that of old concrete specimens and no-greencutting concrete specimens.

The reason for such results is that concrete is a kind of composite material with many cracks and holes in its own causing greater randomness of its fine tube structure.

According to the data, the shear strength of the bonding interface of old concrete specimen is about 2.23Mpa, and that of the no-greencutting concrete specimen is about 0.92Mpa. By comparison, the shear strength of greencutting concrete specimens is as high as about 2.98Mpa. In addition, the fracture surfaces of greencutting and no-greencutting concrete specimens were near the bond interface. Among them, the one of no-greencutting concrete specimen was relatively smooth and the failure is abrupt. The fracture surface of greencutting concrete specimens was complex. Obvious cracks appeared on the surface before fracture.

The shear strength of bonding interface directly affects that of the whole specimen. The roughness of new to old concrete bonding interface has considerable influence on the shear strength. After analyzing the results, the conclusion can be made that:

The shear ability of specimens with no-greencutting bonding interface is lower than that of old concrete specimens and they are more vulnerable to shear failure. The rough bonding interface can enhance the shear ability of specimens and make specimens less likely to be damaged by shearing.

3.3 Strain nephograms based on DIC

Due to special requirements of DIC for light source and surface roughness of the measured object, outer surface of the concrete edge should be removed before shearing test, so as to show the internal micro morphology as natural speckle field to be measured by DIC. The high resolution industrial CCD was used for surface image acquisition. Specific operation is as follows:

(1) Cut the surface of concrete specimen to be measured with depth of 1 cm to expose the interface and internal micro morphology of the aggregate layer.

(2) Clean the surface of the specimen to keep it smooth.

(3) Spray paint on specimen surface after it was cleaned up. Raise the spray can to make the specimen surface evenly painted and ensure that there are black paint spots all over the specimen surface so that the high-speed camera can perform data positioning and analysis more accurately.



Figure 5. Surfaces after cutting and spraying



Figure 6. Test instrument of DIC

Based on DIC method, the strain distribution nephograms of no-greencutting and greencutting concrete specimens before failure were shown in Figure 7.

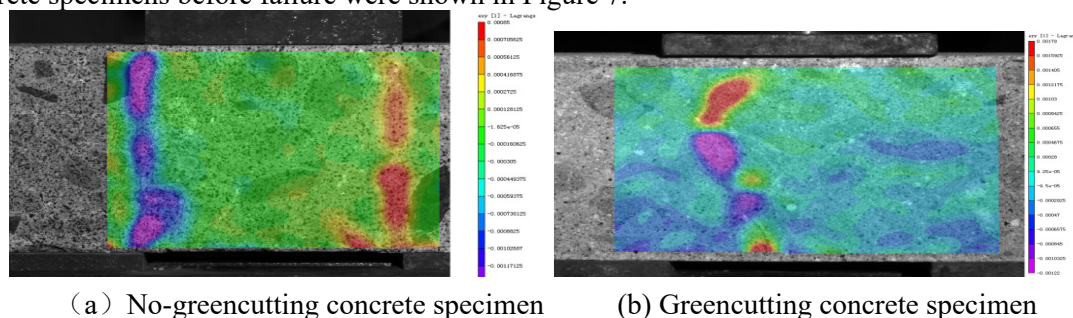


Figure 7. Strain distribution nephograms of bonding interfaces of new to old concrete specimens

It can be clearly seen from the strain distribution nephograms that the strain of these two types of specimens under direct shear force mostly occurred near the bonding interface. The maximum strain both starts from the bonding interface and eventually leads to the failure of specimen. The differences between the two strain nephograms are:

- (1) Under shear force, the distribution of the strain on the bonding interface of no-greencutting concrete specimen close to failure is far less than that of greencutting concrete specimen.
- (2) Under shear force, the distribution of the strain on the bonding interface of no-greencutting concrete specimen close to failure is linear while that greencutting concrete specimen is relatively complex.
- (3) Under shear force, the strain on the bonding interface of no-greencutting concrete specimen close to failure is slightly smaller than that of greencutting concrete specimen.

4. Conclusions

- (1) The roughness of the specimen's bonding interface has a great influence on the shear strength of repaired specimen. Roughness treatment of the specimen can significantly improve shear strength. There are two reasons for this difference. Firstly, compared with the concrete bonding interface without treatment, the concrete bonding interface after roughness treatment has more shear zones. Secondly, the concrete bonding interface after roughness treatment has stronger mechanical bite force.
- (2) Specimens are subject to both bending and shear forces, which lead to bending and shear failure rather than pure shear failure. Based on nephograms data and simulation results, we found that during the rectangle beam experiment, due to the existence of friction, the specimen itself would subject to a

considerable amount of bending shear action, resulting in both bending and shear failure rather than pure shear failure. In order to get more accurate test data, the following test needs more reliable test methods.

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