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Research on Evaluation Technique of Concrete Cracking Performance under Restraint Condition

Zhibin Gao[1,2]
[1]School of civil engineering, Tsinghua University, Beijing 100083, China
[2]Tianjin Binhai International Airport Co., Ltd, Tianjin 300300, China

Abstract:

A measurement technique is invented to estimate the crack resistance for concrete materials under constraints. This barbell measurement technique is helpful to estimate the influence on the crack resistance of concrete materials by using the strain generator device. Through this technique, the crack resistance performance for different materials is able to be quickly estimated on the job site. This article makes some comparative experiments on the other measurement way of concrete crack resistance under constraints (ring plate technique and plate technique).

Keywords*: Evaluation technique, Cracking performance, Restraint condition, Strain generator, Barbell technique.*

I. INTRODUCTION

The concrete crack performance measurement in constrained state is considered to be closer with that of concrete in construction site. Up to now, the national standard has no standard measurement technique for the crack resistance of concrete under restraint conditions. All the techniques in the world are being measured, and people still can't draw a conclusion [1].

The main techniques to measurement the crack resistance of concrete under constraints are flat plate technique, steel hoop technique and prism technique. Although the techniques above can test concrete cracking, they all have their own shortcomings. The flat plate technique invented by Kraai [2], on the year of 1985, cannot accurately estimate the cracks of concrete because of irregular crackings. Steel hoop technique which was invented by Roy Carlson in 1942 [3] also has its own shortcomings. The test cycle of this technique is very long, generally takes tens of days, and the sensitivity is very general. The prism technique, introduced by Springenschmid [4], is able to find propagation rate of concrete cracking, but the field measurement is inconvenient, expensive and the instrument requires high sensitivity.

For overcoming the above limitations, one new technique to estimate the performance of concrete crack under constraints is proposed in this article. The use of its strain generator will lead to rapid cracking of concrete, which provides a fast technique for estimating the concrete cracking performance and

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convenient field simulation measurement.

II. BARBELL TECHNIQUE FOR CRACKING MEASUREMENT

A new measurement technique, barbell technique, is proposed to estimate the concrete crack performance under constraints (Fig 1). On this basis, a barbell device with strain generator for cracking measurement is invented. In principle, the device is equipped with one strain crack generation system, which can induce concrete cracking. In addition, the end of the device can provide constraints to crack the concrete.

After many comparative experiments on repeatability and reproducibility, it is proved that the barbell technique is more effective for rapid cracking. The schematic diagram of this device is shown in the figure below.

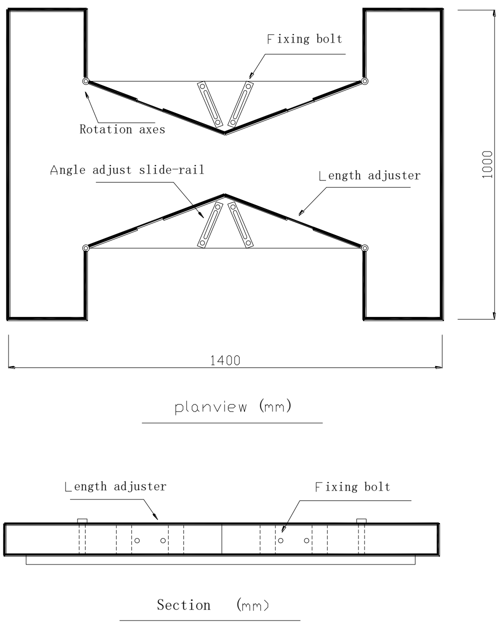

Fig 1: Measurement device with strain generator

There are strain generator devices with adjustable angle in the middle of the device. With the pouring of concrete into the device, the strain concentration is induced by the strain generator, and both ends of the device can provide constraints. The shrinkage deformation of concrete is the main cause of harmful cracks. When the shrinkage strain of concrete is bigger than the tensile stress, Cracks will occur in the center of the specimen.

The bottom plate, the fixed ends on both sides and the movable end in the center of the test device are all made of steel. (Fig 2). The angle of the strain generator can be freely adjusted within the design range. If the angle is too small, the concrete material will lose the sample representative. Too much angle will affect the sensitivity of the test system.

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Therefore, the strain generator with variable angle function will be able to find the best angle to induce cracking of different concrete materials. After determining the best angle of the strain generator, all the movable ends of the instrument should be fixed and the test of concrete cracking should be conducted. This technique is very suitable for estimating the early concrete crack performance .The invention has strong test sensitivity and high accuracy, and is very convenient for use in the site laboratory.

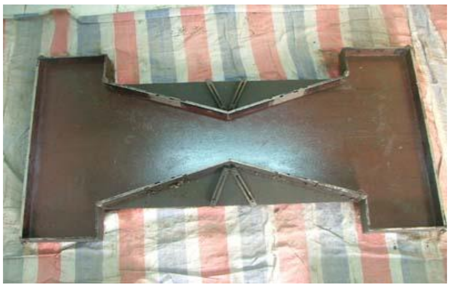

Fig 2: Barbell technique measurement photo

III. Mechanism Analysis of the measurement technique

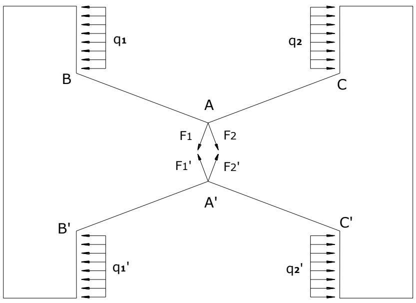

Fig 3: Mechanical analysis of specimen shrinkage under restraint

From the strain analysis of specimen shrinkage under restraint (Fig 3), the concrete will shrink in the dry environment after pouring. Under the action of shrinkage force generated by concrete shrinkage, at a certain point, the molds AB and AC on both sides of the strain generator will produce reaction forces F1 and F2 on the concrete sample. The directions of F1 and F2 are perpendicular to the sample surface. Similarly, at point A' on the other side, the reaction forces F1' and F2 'are generated by A'B' and A'C of the mold.

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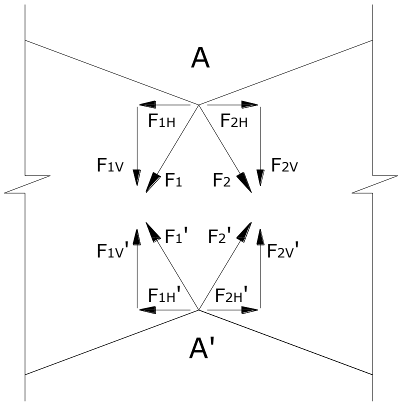

Fig 4: Analysis of strain rising key point

According to the strain analysis of point A and point A' on both sides of the strain generator by the triangular analysis technique, as shown in Figure 4. The results show that the molds AB and AC on both sides of the strain generator produce reaction forces F1 and F2 on the concrete specimen. From the resolution of forces F1 and F2, as shown in Fig 4, F1V, F'1V, F2V, F'2V are vertical directions; F1H, F'1H, F2H, F'2H are horizontal directions.

The concrete at A point on the strain generator is affected by the forces F1 and F2 caused by the shrinkage of the concrete (Fig 4). Under the forces F1H and F2H in the horizontal direction and F1V and F2V in the vertical direction, the strain concentration occurs at one point and one point on both sides of the strain generator. Therefore, from the perspective of strain analysis, one point and one point belong to the most dangerous point.

Therefore, under the action of strain generator induction and die end constraint, the crack shape is closer to a line (A-A' line). Therefore, crack observation and crack width measurement are more convenient and quicker.

IV. RESULTS AND DISCUSSION

In principle, when the shrinkage strain of concrete is greater than the tensile stress of concrete, the concrete specimen will crack. The sample selected for the plate technique is the concrete plate (0.6m×0.6m×0.063m) [5]. After pouring the concrete, steel bolts around the mold limit the shrinkage of the concrete (Fig 5). The evaluation indexes of plate technique are average crack area, crack number and total crack area.

The method of barbell test avoids the problem of irregular cracks in concrete. 24 hours after the start of the test, the crack showed a stable state and no longer expanded. The average width of cracks can be measured by point measurement or image analysis. ACW is defined as the average crack width, that is, the average crack width within 24 hours, which is an important index of barbell testing technology.

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ICT (initial crack time) can also be used as an important index of barbell testing technology. ICT is defined as the initial cracking time of concrete specimen. The longer the ICT, the better the cracking resistance of concrete. The time starting point of the initial cracking time is the time when the concrete is poured into the device, and the end time is the time when the cracking occurs for the first time.

Fig 5: Plate measurement device

The quantitative indexes of flat plate technique are the average crack width and the occurrence time of the first concrete crack. The die of steel hoop technology includes two inner and outer steel rings and a steel base (as shown in Fig 6). The concrete shall be poured between the inner and outer steel rings, and the outer steel ring shall be removed after initial setting. When the outer concrete shrinks, the inner steel ring can provide constraints on the concrete specimen. Under the tensile strain [6] caused by ring restraint, cracks will appear at the sample interface.

Fig 6: Steel hoop measurement device

Both sides of the test piece are restrained by the fixed end of the device. The strain generator in the center of the device makes the concrete produce stress concentration and induces cracking. The barbell measuring device is composed of a fixed end and an adjustable strain generator in the middle. The volume change of concrete under constraints, especially concrete shrinkage, is the main inducement of concrete cracking. When the shrinkage I deformation of concrete is greater than the tensile stress of concrete, the specimen will crack. Barbell testing technology is very convenient to be used in the field laboratory. It can quickly compare the crack resistance of concrete materials with different mix proportions, and has better test cycle and test sensitivity.

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Fig 7: Barbell measurement device

This experiment is to complete the comparative test of three different concrete mix proportions, using three different amounts of fiber, and each material is measured by three different test techniques. The mix proportion data of concrete are as follows (TABLE I).

TABLE I. Concrete mix ratio

Material (kg/m^3)					Slump (mm)	Slump Flow (mm)[
C	S	G	W	Fiber		
361	798	1198	139	0.9	200	430/450
361	798	1198	139	1.2	190	450/450
361	798	1198	139	1.5	200	430/450

Firstly, from the test results, although fiber reinforced concrete is more difficult to crack, three different test technologies show the same test results. The obtained laws are also consistent and accurate. The higher the fiber content, the longer the ICT and the smaller the ACW. The measured results are consistent with the theoretical analysis and actual measurement results.

TABLE II. Measurement Result

Fiber		barbell	plate	steel hoop
1.5kg/m^3	ICT	2h:17min	2h:29min	6d
	MCW	0.95mm	0.70mm	0.36mm
1.2kg/m^3	ICT	1h:51min	2h:12min	4.6d
	MCW	1.14mm	0.90mm	0.60 mm
0.9kg/m^3	ICT	1h:30min	1h:49min	4.1d
	MCW	1.33mm	1.10mm	0.79mm

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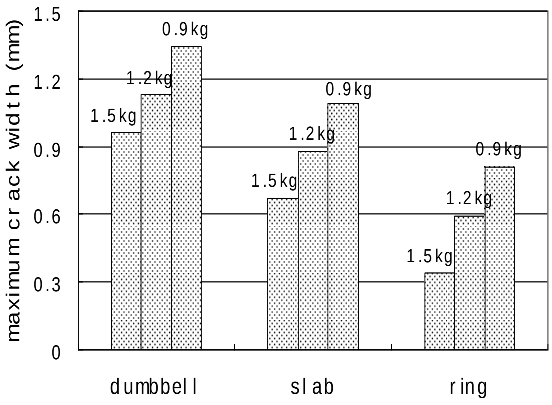

Fig 8: Maximum crack width measured by three techniques

Among the three different test technologies, the test cycle of barbell test technology is the shortest, and its maximum crack width is the widest. Therefore, from the perspective of sensitivity, barbell measurement technique is better than plate and steel hoop technique in estimating crack performance. From the measurement results , for the fiber dosage of 1.5kg/m3, the barbell technique is more sensitive for cracking(as shown in TABLE II), which is better than the flat plate technique and steel hoop technique (Fig 8). The initial time of the steel hoop technique is much longer than the first two techniques. In terms of the MCW, the barbell technique is 1.07mm, which is much larger than the other two techniques of 0.64mm and 0.52mm. The concrete with fiber content of 0.9kg/m3 and 1.2kg/m3 also shows the same law. The larger the maximum crack width is, the more obvious the cracking performance of concrete is, the easier the crack measurement is and the smaller the measurement error is.

Fig 9: Measurement photo with different techniques (barbell, plate, steel hoop)

Through TABLE III, we can see the comprehensive comparison of the performance of three different concrete cracking test techniques. From the perspective of data measurement, the crack produced by barbell test technology and steel hoop test technology is a long and straight crack (Fig 9). In this way, the time of crack occurrence and the average width of crack can be easily measured. However, the concrete specimens tested by the flat plate method produce more cracks with different directions and lengths, which are difficult to measure and identify. Therefore, in terms of measurement, barbell test technology and steel hoop test technology are better than flat plate method. In the application of construction site, barbell technique and flat plate technique have strong sensitivity and can show concrete crack performance in a very short time, which is more important for the application of construction site. Therefore, it is convenient to carry out horizontal comparison measurement in the field. Due to the long measurement cycle, the ring measurement technique cannot be suitable for the requirements of short measurement cycle in site laboratory.

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TABLE III. Three techniques performance

	barbell	plate	steel hoop
measurementing cycle	short	short	long
Operability	good	average	above average
Application on job site	good	above average	average
Sensitivity	good	above average	average

V. CONCLUSION

This article innovatively develops the barbell test technology. It is a new testing technology for early cracking of concrete. It is suitable for the evaluation and test of early cracking performance of concrete. It has the advantages of test cycle end, high sensitivity, high accuracy and convenient use in the field laboratory. In terms of sensitivity, measurement time, operability and engineering application, barbell technology is superior to plate technology and steel ring technology.

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