STUDY ON DYNAMIC DAMAGE PROCESS OF CONCRETE BASED ON X-RAY CT TECHNIQUE

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ABSTRACT : Research on the strength and the failure mechanism of concrete under dynamic loading is a weak point in seismic safety assessment for concrete structures. X-ray computed tomography (CT) technique is a useful tool to detect the process of the initiation, propagation and continuous accumulation of interior micro damage leading to macro crack and finally to the complete failure of concrete by non-destructive way. A portable test device for dynamic tensile and compressive loading specially designed to fit the conventional medical CT scanner has been manufactured. Based on the medical CT scanning system and the special designed and manufactured portable test device the static and dynamic real time CT tests for concrete specimens under compressive loading have been carried out. The provided CT images verified the expected requirements to the designed CT test system. The difference of cracking process between the static and dynamic compression loading conditions was investigated in detail. In high strain rate, concrete fracturing points increase and meso-crack seems straight. The phenomenon that crack cut across aggregate grows. So concrete dynamic strength can increase. The preliminary results prepared the ground for setting the crack evolution models of concrete under different loading conditions. In order to intuitively demonstrate the crack morphology character and crack evolution process during the loading, the formation of 3D images and the animated cartoons displaying technique of the crack development by using the CT test results have been completed using 3DMAX software. All the abovementioned research works have brought forth some new ideals in the study on dynamic behavior of concrete for evaluation seismic safety of concrete structures.

KEYWORDS: Concrete, CT technique, meso-mechanics level, formation of 3D images, failure process

INTRODUCTION

The dynamic characteristic research of concrete materials is a weak point and a key problem to evaluate earthquake engineering security of concrete structure, which is shown as the difficulty on choosing the concrete dynamic strength parameters. This phenomenon does not suit the level of earthquake-input and structural dynamic analysis. To make full use of the concrete materials' dynamic strength is very important to reduce engineering cost. At present, dynamic characteristic research of concrete material mainly focuses on the aspects of its dynamic macro-mechanical property and damage mechanism. Macro test focuses on studying fully-graded concrete and little wet screening concrete difference under static and dynamic load. At the same time micro-numerical simulation focuses on studying concrete damage process. Because of limitation of the research technique, there aren't any effective approaches to observe a real-time damage process of concrete. Micro-numerical simulation analysis can explain in a certain sense dynamic character of concrete and the failure mechanism of the internal structures, but it is lack of test verification.

With the invention of X-ray medical CT(Computed Tomography), it become a useful tool to detect internal structure of material. At the end 1980s, medical CT and industrial CT have been used to explore internal structure of rock. But this kind of detection belongs to static experiments, which means to scan the cross of specimen using CT after load-off. This kind of experiment is easily carried relatively. The reference [1] has got several CT images from different kinds of rock specimens by

medical CT and these CT image can show distinct crack of rock. The reference [2] has got distinct image containing aggregate, mortar, and cavity of concrete using CT.
In 1999, Ge[3] firstly designed a special static loading device to fit conventional medical CT scanner. This device suits for frozen soil, rock and concrete materials. Using the special loading device，a real-time CT scanning test can be carried when specimen is loaded.
John S.Lawer has analyzed the damage pattern of concrete to analyze the three-dimensional character of the internal crack using the X-ray mic-CT(XMT, that is industrial CT, seen figure1). He finds X-ray CT can successfully describe crack shape of concrete and discusses the influence of aggregate shape, crack shape to the strength and ductility when concrete damages. The shortage is that the size of the concrete specimen is too small which is only a cube 38.1×12.7×12.7mm and it takes a long time for scanning to get a CT image.

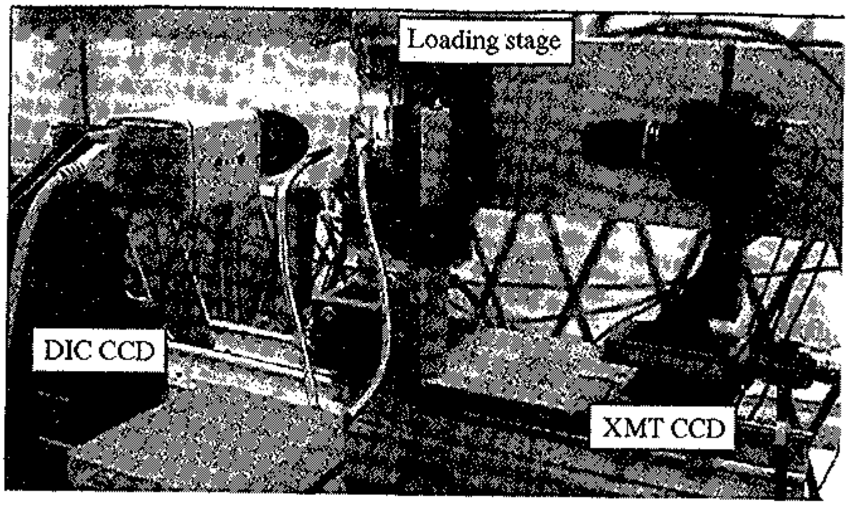

Figure1 the XMT system for concrete by John S.Lawer

For dynamic character study of concrete, the problem of CT experiment system mentioned above is that the loading device can not carry dynamic load, particularly it can not run dynamic tension load, so current concrete test system with medical CT could not fit the need of dynamic test of concrete in a real-time observation.
This paper introduces authors how to design and manufacture a portable test device to fit medical CT and some results using this test system.

1 DESIGN AND MANUFACTURE OF A PORTABLE TEST DEVICE

1.1. Design Goal

Based on medical CT , develop a portable test device mainly for one or two-graded aggregate concrete to get CT image of concrete at arbitrary time and arbitrary cross to observe internal structure and damage process, such as crack appearance, extension, connection and penetration under dynamic load.

1.2. Operation Principle of the Portable Test Device to Fit Medical CT

The image of concrete using CT can show meso-crack in concrete material. Meso-crack is showed by linear or circle low-density band in CT image of concrete. The width of the crack in the concrete is very small, although we use the method of image enhance processing. The width magnitude we can observe is less than 0.1mm initially. Meso-crack appears generally when concrete reach its 60%-80% of peak strength, in the mean time the shape of the macro stress-strain curve may change the linear state. Because density of aggregate, mortar and cavity have a big difference, CT image of concrete scanned by conventional medical CT have a high image resolution. So the scan device is defined as medical CT in this work.

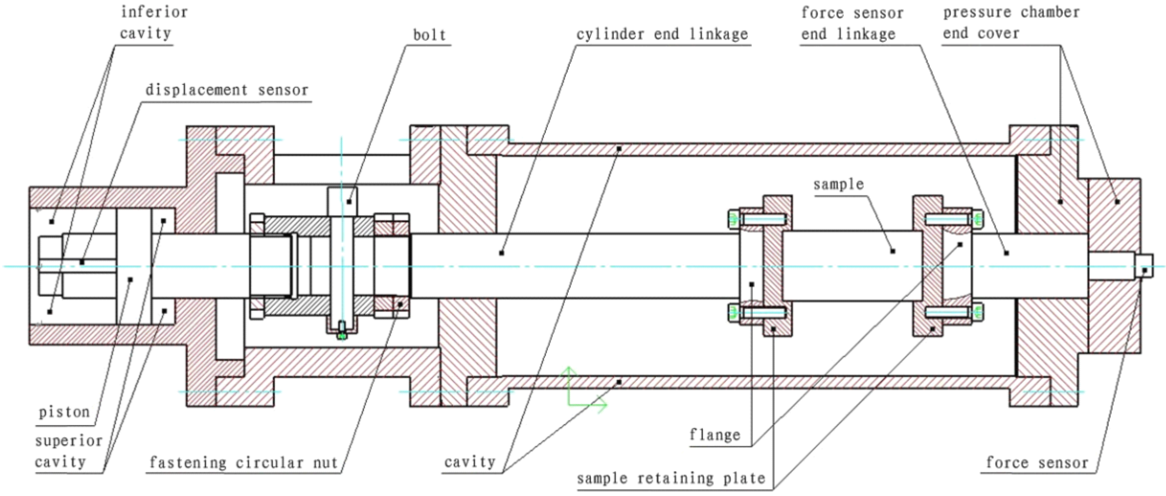

Figure 2 scheme of operation principle of the portable device to fit medical CT

The operation principle of the portable device is similar to the special loading device by Ge'. Its pressure chamber as a load shelf is a self-balance system. The portable device and the medical CT form a test system. The difference between the author's and Ge' is that this portable device can control piston's up-down motion by giving oil mass to superior or inferior cavity to generate tension or pressure. The dynamic load is fulfilled by controlling frequency of piston motion.

1.3 Full Appearance of the Test System

Figuee 3 The portable test device to fitting medical CT scanner

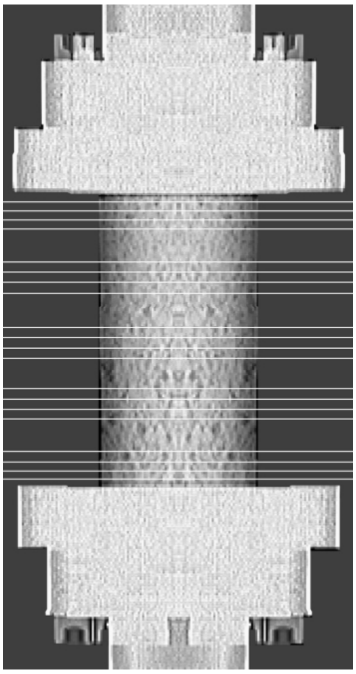

Figure 4 Scan location on specimen

According to the design goal, many key problems have been solved ,a portable test device to fit medical CT has been manufactured. This test device includes a actuator (the part on CT bed, 65 kilograms weight), fuel tank (40×50×60cm), a controller, a distributing box, a portable computer, two high pressure oil hoses, two handcarts to lay the actuator and the fuel tank separately. The full appearance of the test system is seen in figure 3.Figure 4 indicate the scan position of the concrete specimen CONC13 (each white line expresses a scan position).

2 LOADING CURVE

Figure 5 and figure 6 are sine wave loading amplitude curves, which shows that the portable test device has reached the design requirement. In order to demonstrate load process completely in the two charts, a small proportion is used and therefore it is unable to see clearly the profile. In fact, the sinusoidal waveform is ideal in a large proportion demonstration. In order to carry CT scan, several minutes will be cost to stop loading.

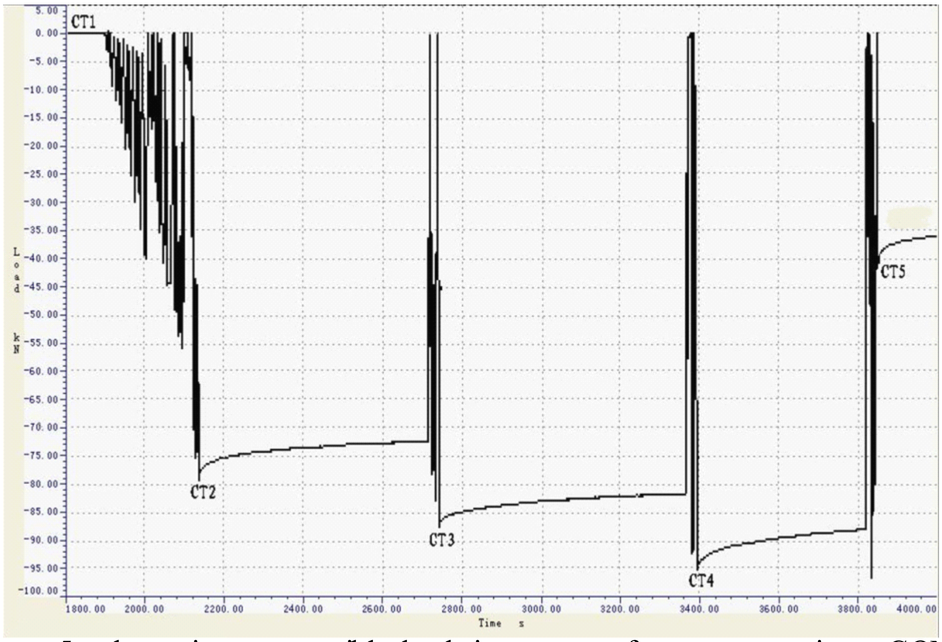

Figure 5 dynamic compressible load-time curve of concrete specimen CONC–13

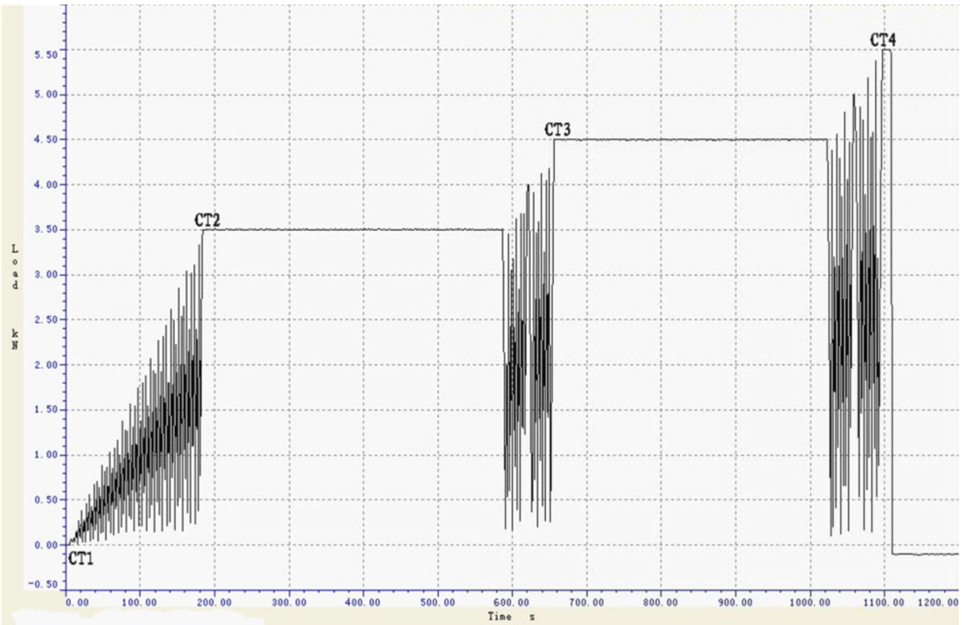

Figure 6 dynamic tensile load-time curve of concrete specimen CONC–29

3 TEST RESULTS

Using the portable device and medical CT, we obtain a series of CT images of concrete shown in the Figure7,8, 9.According to the CT images of the concrete specimen in different stress stages, we can observe clearly the crack initiation, expansion, penetration whole process of CONC13. The size of cylinder specimen is ∅60×120mm.

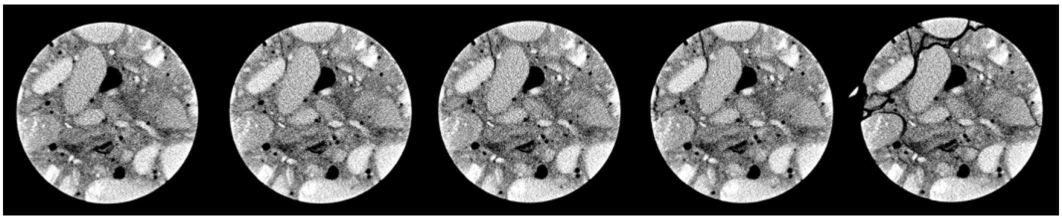

Figure 7 a series CT image of the concrete specimen CONC13-1-2 cross under different dynamic compressive load

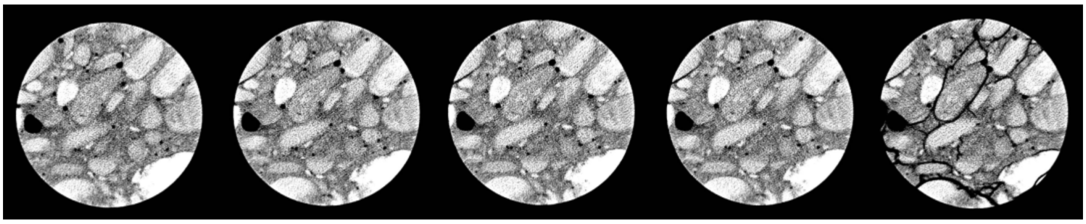

Figure 8 a series CT image of the concrete specimen CONC13－3－2 cross under different dynamic compressive load

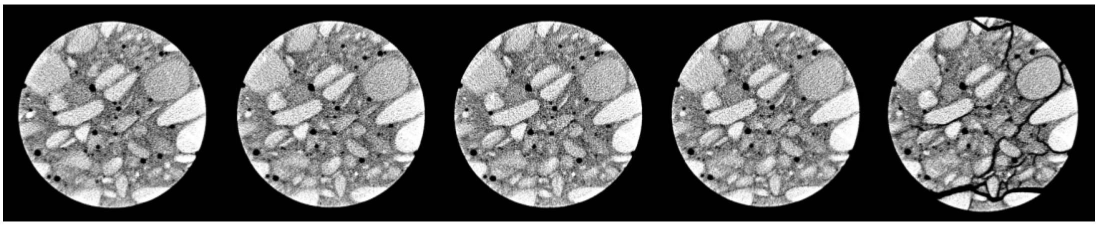

Figure 9 a series CT image of the concrete specimen CONC13－4－2 cross under different dynamic compressive load

From the figure 7,8, 9, , there are several cracks initiation in different position under sinusoidal wave compressive condition. Most cracks have a straight shape. This character has a big difference in damage shape under static pressure.

There are two kinds of crack in CT image of sample CONC13.One kind is at the up left region of the CT image. The crack initiation occurs at the early load stage and it evolutes during the whole load stage. When crack expansion encounters aggregate， it will stop expansion or change expansion direction. This crack evolution process has similar pattern as crack evolution law under static load.

The other kind of crack appears at the last CT scan. This crack appears in a burst manner. There are two main cracks in scan section 3－2、4－2.These cracks have straight shape and aggregate factors have little influence on the crack expansion direction. Concrete fracturing points increase.The phenomenon that crack cut across aggregate grows. Because this crack's burst manner and more cutting aggregate phenomena, concrete material damage will cost more energy and it has a high dynamic strength.

4 3-D DAMAGE IMAGE

In order to intuitively demonstrate the crack morphology character and crack evolution process during the loading, the formation of 3D images and the animated cartoons displaying technique of the crack development by using the CT test results have been completed using 3DMAX software(figure 10). The movable spatial crack morphology much intensifies the visualized effect of the damage evolution process of the specimen during the loading and will lead to further deepening understanding of the failure mechanism of concrete.

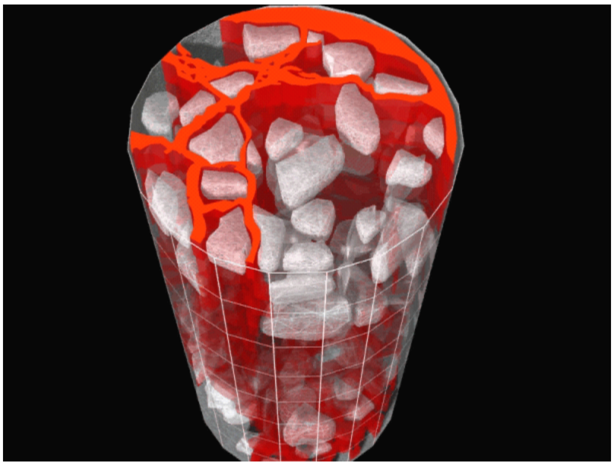

Figure 10 3-D damage image of concrete under dynamic pressure

5 CONCLUSION

A portable load device to fit for medical CT has been manufactured. The test to carry dynamic destruction on small gradation concrete and obtain clear CT images of concrete has been proved a preliminary success. All the abovementioned research works have brought forth some new ideals in the study on dynamic behavior of concrete for evaluation seismic safety of concrete structures.

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