X선조영촬영에 의한 콘크리트강도의 추정과 콘크리트열화의 수치화

ESTIMATION OF CONCRETE STRENGTH AND QUANTIFICATION OF CONCRETE DETERIORATION BY X-RAY TECHNIQUE WITH CONTRAST MEDIUM

Mitsuhiro TAKEDA, Koji OTSUKA, Sanghun LEE

Abstract

The purposes of this study are to estimate thestrength of concrete and quantify the deterioration of concrete by a unique X-ray technique with a contrast medium. In order to estimate the strength of concrete, specimens with different water-cement ratios were fabricated using non-air-entrained concrete, air-entrained concrete and mortar to determine the relationship between their compressive strength and the transit dose obtained by the X-ray technique. Also, an experiment to quantify deterioration was carried out on specimens that were subjected to freezing and thawing action to different levels of dynamic elastic modulus. As a result of this experiment, estimation of the strength and relative dynamic elastic modulus of deteriorated mortar, concrete and air-entrained concrete was found feasible by measuring the transit dose by the X-ray technique.

본 연구의 목적은, X선조영촬영을 이용한 콘크리트강도의 평가 및 콘크리트열화의 수치화를 수행하는 것이다. 콘크리트강도를 추정하기 위하여, 물-시멘트비가 서로 다른 콘크리트를 제작하여, X선투과선량과 콘크리트강도의 관계를 구하였다. 이 실험에는 콘크리트 외에 몰탈, Non-AE 콘크리트를 이용한 실험도 수행하였다. 또한, 동결융해작용을 가해 상대동탄성계수를 변화시킨 공시체에 대하여, 열화의 수치화를 수행하였다. 실험의 결과, X선조영촬영법을 사용하면, 투과선변화량이 구해지므로, 콘크리트강도의 추정과 열화의 수치화가 가능하다는 것을 알았다.

1. Introduction

Recently, estimation of concrete strength has been attempted in need of the durability diagnosis of concrete structures. However, accurate strength measurement is difficult by the generally practiced surface hardness method when the structure is deteriorated, as this method only measures the surface strength. For durability diagnosis, it is important to measure the deterioration area from the surface toward the inside of concrete. In this regard, accurate strength evaluation in the longitudinal direction is difficult by compression testing on drilled cores. With this as a background, the authors conducted a study to develop a method of estimating the concrete strength and determining the strength profile using an X-ray technique with a contrast medium[1),2)]. Also, concrete deterioration was quantified by the X-ray technique with a contrast medium using specimens having fine cracks induced by freezing and thawing action.

* Mitsuhiro TAKEDA, Tohoku Gakuin Uni.・Associate professor・E-mail : takesan@tjcc.tohoku-gakuin.ac.jp
** Koji OTSUKA・Tohoku Gakuin Uni.・Professor
*** Member・anghun LEE Tohoku Gakuin Uni.・Associate professor

2. Experiment procedure

2.1 Specimens

For testing to estimate the concrete strength, the specimens included six types of mortars with a compressive strength of 18 to 70 N/mm^2 and six and seven types of non-air-entrained (13 to 60 N/mm^2) and air-entrained concretes (20 to 60 N/mm^2), respectively. Three cylindrical specimens 100mm in diameter were fabricated for each strength, totaling 57. For testing to quantify concrete deterioration, eight beam specimens 100 by 100 by 400 mm were fabricated with a compressive strength of 48 N/mm^{2}and air content of 3%. Before the experiment, specimens were subjected to freezing and thawing action in accordance with ASTM C 666 so that their relative dynamic modulus would range from 100% to 30%.

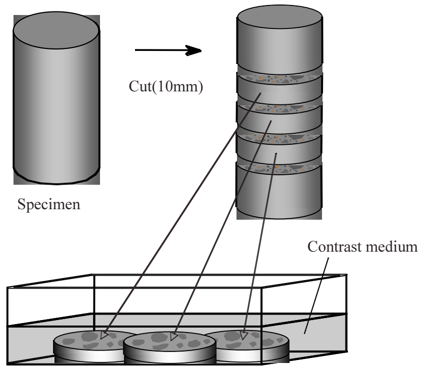

Fig.1 State of impregnation

2.2 X-ray technique with a contrast medium

X-ray photographs of specimens were taken before and 10, 60, 180, 360, and 720 min after the beginning of impregnation with the contrast medium, which was devised by the authors. Figure 1 shows the state of impregnation. Specimens were cut into 10-mm thick slices before impregnation. Figure 2 shows the photographing conditions.

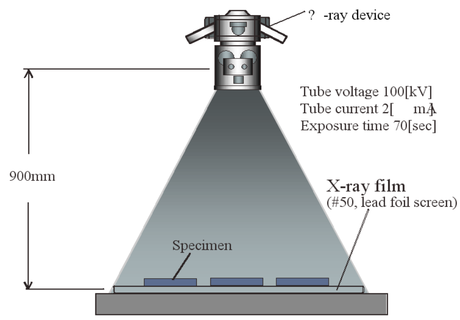

Fig. 2 Photographing conditions.

2.3 Measurement of transit dose by X-ray technique

By radiographic visualization, objects with a lower X-ray absorption coefficient, such as air in voids and cracks, allow more X-ray photons to pass through, resulting in a darker image on the film. On the contrary, objects with a higher absorption coefficient, such as contrast media, allow less X-ray photons to pass through, resulting in a more transparent image on the film. It follows that, in regard to concrete having a large volume of voids that can be filled with a contrast medium, its radiograph after impregnation with the contrast medium should be whiter than that before impregnation. The amount of air voids can therefore be quantified by determining the loss in the transit dose of concrete after impregnation with a contrast medium (transit dose loss). The strength of concrete may then be estimated from these results. In order to determine the transit dose loss, it was necessary in the beginning to determine the X-ray transit dose. Since the color density of an image on the X-ray film depends on the transit dose, it was decided to determine the transit dose by measuring the color density of the film image. An illuminometer was used for the

Fig.3 Illuminance measurement setup

measurement of the transit dose. The illuminance was measured first through a dark box placed on a 'schaukasten'(X-ray film viewing device) to determine the incident illuminance, I_0. An X-ray film image of concrete was then inserted between the schaukasten and the dark box to measure the transmitted illuminance, I_t. The X-ray film density, D, was determined using these illuminance values as $D = \log (I_o/I_t)$. Figure 3 shows the illuminance measurement setup.

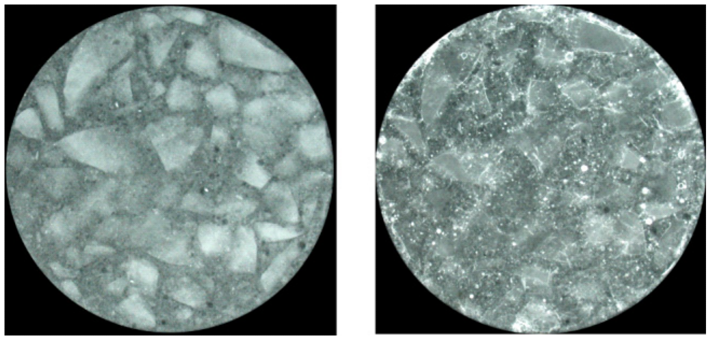

Photo1 X-ray film images of an air-entrained concrete specimen

(Before impregnation with a contrast medium) (After impregnation with a contrast medium)

3. Relationship between concrete strength and X-ray transit dose loss

Photo 1shows typical X-ray film images of an air-entrained concrete specimen with a compressive strength of 23 N/mm^{2}taken before and after impregnation with a contrast medium for 10 min. The image before impregnation is generally darker, with coarse aggregate particles being more luminous than the surrounding film densities. Also, only macroscopic air bubbles, which appear to be entrapped air, are detected as black spots, while no entrained air was visible despite the use of an air-entraining admixture.

On the other hand, the film image of the impregnated specimen shows complicated entanglement of micro-cracks and cracks on mortar-aggregate interfaces that presumably developed after placing but could not be detected before impregnation. Fine air bubbles that appear to be the entrained air are also found to be uniformly distributed over the area.

Figure 4shows the relationship between the transit dose loss and the impregnation time of air-entrained concretes with different strengths. The transit dose loss tends to rapidly increase immediately after the beginning of impregnation and gradually level off. Also, the transit dose loss increases as the strength decreases.

Figure 5shows the relationship between the compressive strength and the transit dose loss after impregnation for 60 min. The measured values plots and the resulting regression equation curves)showed

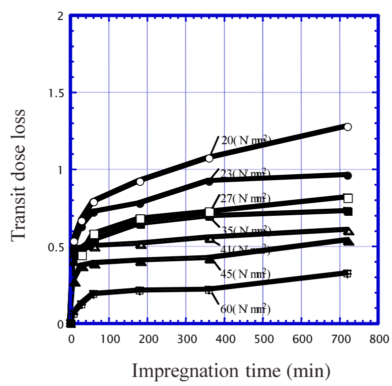

Fig.4 Relationship between the transit dose loss and the impregnation time (AE concrete)

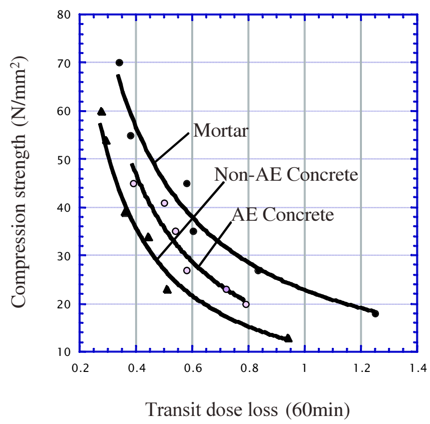

Fig.5 Relationship between the compressive strength and the transit dose loss (60 min)

significant correlation with a correlation coefficient of not less than 0.95. It is therefore inferred that concrete strength can be estimated by determining the transit dose loss. The longitudinal strength profile can also be estimated using 10 mm slices of specimens.

4. Quantification of concrete deterioration

Figure 6 shows the relationship between the transit dose loss and the impregnation time of concretes with different relative dynamic modulus. Tendencies similar to Fig. 4are observed for all concretes. The transit dose loss tends to increase as the relative dynamic modulus decreases. It is therefore inferred that the deterioration of concrete can be quantified by examining the transit dose loss after a certain period of impregnation with a contrast medium.

Figure 7 shows the relationship between the relative dynamic modulus and the transit doseloss after impregnation for 60 min, which turned out to be a linear relationship with a correlation coefficient of 0.95. Accordingly, the amount of freezing and thawing-induced micro-cracks quantified in terms of transit dose loss determined by radiographwith a contrast medium is found to be closely related to the relative dynamic modulus of elasticity. This method is therefore considered adequate as a means to quantify air voids and micro-cracks in concrete.

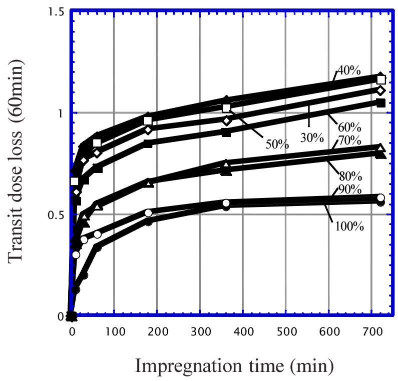

Fig.6 Relationship between the transit dose loss and the impregnation time

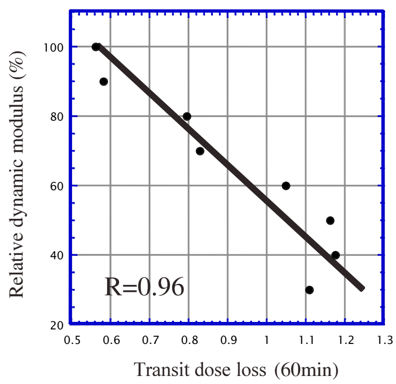

Fig.7 Relationship between the relative dynamic modulus and the transit dose loss (60 min)

5. Conclusions

Within the range of the present tests, the following can be said:

(1) As a result of radiography with a contrast medium, differences in the denseness of concrete due to different mixture proportions and early defects were found to lead to differences in the X-ray transit dose (transit dose loss). Since a strong correlation was observed between the transit dose loss and compressive strength, the strength of various mortars and concretes can be estimated by the present technique.

(2) Radiographic images of air-entrained concrete specimens subjected to deterioration due to freezing thawing action were taken using a contrast medium, and their transit dose losses were determined from the X-ray film. As a result, the transit dose loss after impregnation with the contrast medium tended toincrease as the degree of deterioration increased, with a strong correlation being observed between both. The degree of deterioration of air-entrained concrete can therefore be quantified by examining the transit dose loss.

References

1. Mitsuhiro TAKEDA, Koji OTSUKA"FEstimation of concrete strength by x-ray technique with contrast medium"CJapan society of civil engineers,Vol.62,No.2,pp.376-384,2006.5(2)Mitsuhiro TAKEDA, Koji OTSUKA"FQuantification of concrete degradation and evaluation of freeze-thaw resistance using x-ray technique with contrast medium, Japan society of civil engineers Vol.62, No.4, pp728-738"C2006.11