Material Characterization of Porous Concrete Using Nano Indentation

Cho, Young Sang[a] Hong, Seong Uk[a], Lee, Je Hyeok[a], Jang, Hyun Seok[a], Chen, Xi[b]

Department of Architectural Engineering, Hanyang University, Ansan, R.O. Korea 425-791 ycho@hanyang.ac.kr

Department of Civil Engineering and Engineering Mechanics, Columbia University, New York, NY 10027-6699

Introduction

This research is to study the material characterization such as the compressive strength of porous concrete based on the ratio of air-entrained agent of concrete slab specimen using the cylinder test, NDT methods such as Impact Echo (IE) method and nanoindentation technique. Strength prediction using NDT can be obtained from the relationship between compressive strength and primary wave velocity. The impact of air ratio, that has been created by the mix of air entrained agent of 0 %, 0.15 %, 0.3 %, 0.7 % and 1.5 % by weight, in the stress wave velocity and the compressive strength has been tested using cylinder test and nondestructive test. The reduction range of compressive strength and stress wave velocity has been decreased after reaching the air ratio of about 4%. This paper is to study that The yield compressive strength, stiffness of concrete and concrete compressive strength have also been simulated and analyzed based on the varying air entrained agents of 0 %, 0.15 %, 0.3 %, 0.7 % and 1.5 %, corresponding air content of 1.25 % , 3 %, 4.9%, 7.8% and 10 % respectively, using nanoindentation technique.

Impact echo method

Impact echo (IE) method uses resonant frequency obtained from the signal processing of data collected from the tests using an impact source, one transducer, and data acquisition system as shown in Fig. 1. The details of this NDT method can be obtained in the literature (Cho, Y.S. 2003).

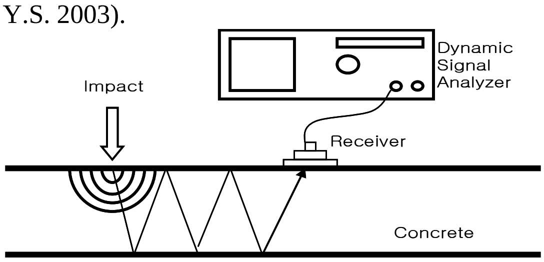


Fig. 1 Impact echo method

The correlation between the compressive strength and compressive wave velocity have been developed as shown in equation (1) using the impact echo test. These results can be used to predict the compressive strength of concrete based on the stress wave velocities obtained from the nondestructive tests. The equation (1) have been developed using the analysis of nondestructive test results and numerical analysis as shown in Fig. 2.

$$V_p = 1675.7 f_{ck}^{0.2362} \quad (1)$$

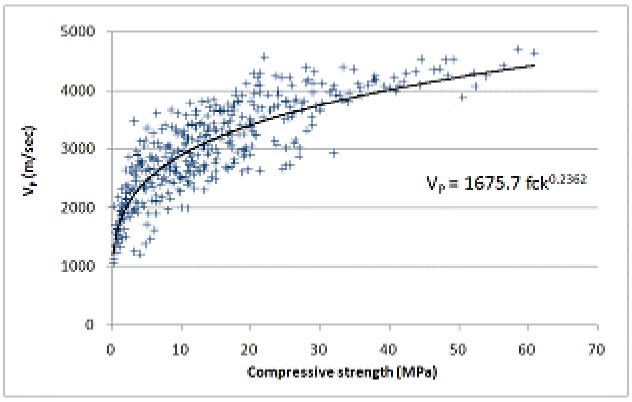


Fig.2 The relationship of compressive wave and compressive strength

The tests measuring air contents have been conducted based on varying air entrained ration of 0%, 0.15%, 0.3% and 0.7%. The corresponding air contents came out as 1.25%, 3%, 4.9% and 7.8%. In the case of 1.5% of air entrained agent, the corresponding air content exceeded 10%.

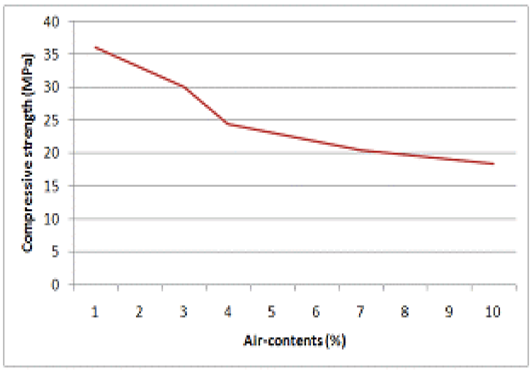


Fig.3 The relationship of air content and compressive strength

The experimental result shown in Fig. 3 represents the relationship between air-contents and compressive strength. The result shows that the compressive strength has been decreased as the air contents increase. This seemed to have been caused by increasing the AE-agent, which could have increased the workability of concrete and compact-ability. As Fig. 3 shows, the slope of compressive strength graph after the air content of 4% is smaller than before the air content of 4 % because the compressive strength has increased due to the improvement of workability and compact-ability.

nanoindentation

The theoretical analysis of nanoindentation data has been well developed in the last two decade (Oliver et al 1992, Doermer et al 1986, Cheng et al 1998), and here we summarize its essential ingredients briefly. Fig. 4a shows the illustration of typical indentation test on homogenous bulk materials with a sharp indenter (with angle α) with an applied indentation load *P*. The indentation depth δ can be continuously recorded during the penetration of indenter into the materials, and the indentation load – depth curve undergoing one complete cycle of loading and unloading is shown in Fig. 4b. If friction and the finite compliance of the measuring system and the indenter tip are neglected, the hardness, H , and indentation modulus, E_r , of the indented material are:

$$\frac{1}{E_r} = \frac{(1-\nu^2)}{E} + \frac{(1-\nu_i^2)}{E_i} \qquad (2)$$

$$H = P_{max}/A \qquad (3)$$

E , ν and E_i , ν_i are Young's modulus and Poisson's ratio of indented and indenter materials, respectively.

Indentation modulus, E_r can be deduced from the following equation

$$E_r = \frac{2}{S\sqrt{\pi}}\gamma\sqrt{A} \qquad (4)$$

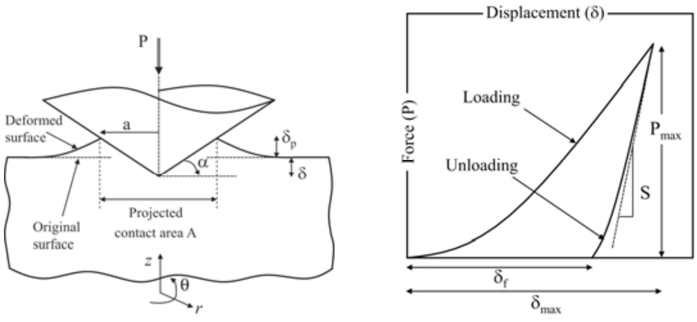
Here, the $S = dP/d\delta$ is contact stiffness and can be obtained from the slope of the initial portion of the elastic unloading curve (Fig. 4(b)); γ is a indenter geometrically dependent correction factor, and is about 1 for a rigid asymmetric indenter (Hay et al 1999, Chen et al 2006). The projected contact area A is a function of contact depth δ_c ($\delta_c = \delta + \delta_p$)

$$A = B_o\delta_c^2 + B_1\delta_c + B_1\delta_c^{1/2} + ...$$

In this equation, B_o , B_1 ,...., B_n are constant coefficients which can be determined by the curve fit.

Numerical Simulation of Nanoindentation

Fig.5 shows the typical indentation force (F) – indentation depth (h) curves with different AE fractions. It is obvious that for the same



(a) (b)

Fig.4 (a) sharp indentation (b) P-δ curve

penetration depth, the indentation load decreases with increasing porosity due to the presence of voids. The porosity (air content) is denoted by *f*.

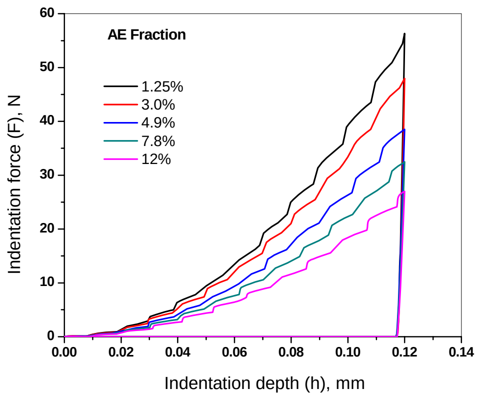


Fig.5 The influence of the AE fraction on the indentation force (F) – indentation depth (h)

Conclusion

1. Compression wave velocity and compressive strength have the correlation with $V_p = 1675.7 f_{ck}^{0.2362}$

2. Numerical simulation using nanoindentation shows that prediction of concrete compressive strength, yield strength and stiffness can be possible.

(The writers wish to acknowledge support by the SRC/ERC program of MOST (grant #R11-2005-056-01004-0).

Reference

1. Cho, Y. S., Non-destructive testing of high- strength concrete using spectral analysis of surface waves, NDT & E International, 36, pp.229～235, 2003.

2. Chen, X., Xiang, Y., Vlassak, J. J., Novel technique for measuring the mechanical properties of porous materials by nanoindentation. J. Mater. Res. 21,715(2006).