Construction and Building Materials 69 (2014) 133–142

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of moisture content on static compressive elasticity modulus of concrete

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HIGHLIGHTS

- Concrete specimens are immersed with a series of time.
- Moisture content concerns different immersion time, strength and curing conditions.
- Increasing moisture content will increase elasticity modulus of concrete.
- A formula indicating elasticity modulus of concrete versus moisture contents is proposed.

ARTICLE INFO

Article history:
Received 15 March 2014
Received in revised form 31 May 2014
Accepted 30 June 2014
Available online 7 August 2014

Keywords:
Concrete
Elasticity modulus
Moisture content
Immersion time
Experimental

ABSTRACT

For concrete under humid conditions, the mechanical properties of concrete are significantly affected by the moisture content, which differs in terms of different immersion times. This paper presents an experiment to investigate the dependence of the moisture content on the immersion time and the influence of the moisture content on the static compressive elasticity modulus. The results show that the saturated moisture content declines with increasing concrete strength grades and also declines with increasing area–volume ratios. The moisture content is slightly higher for specimens cured under the natural conditions than ones cured under the standard conditions in the same immersion times. The elasticity modulus increases with the moisture content increasing. The elasticity modulus of the fully saturated concrete has an increase of 30% over the fully dry concrete. Besides, a slight reduction occurs in the elasticity modulus for the specimens cured under the natural conditions than the ones cured under the standard conditions when the moisture content is almost the same. Based on the experimental data and the analytical results, a formula for the moisture content effect on the elasticity modulus of the concrete is proposed.

1. Introduction

The modulus of elasticity is one of the most important elastic properties of concrete from the point of view of design and behavior of structures. This parameter is determined for the structural assessment and retrofitting of structures. It is also used to estimate deflections of structures for serviceability requirement and to calculate deformation and drift in seismic analysis [1].

It is well established that concrete structures are dynamic systems subjected to continuous changes in moisture content. Structures such as dams, bridge piers, offshore platforms, and waterfront structures are all with operating conditions under water. The effect of the moisture content on the elasticity modulus of concrete has been analyzed already for a long time. Early in 1929, Davis and Troxell [2] reported that the static elasticity modulus of concrete was 12–30% higher for wet concrete than for dry concrete. In the 1960s, Johnston [3] reported a decrease in the tensile elasticity modulus on air-drying and oven-drying of the concrete system. And Cook [4] also observed changes in the instantaneous elasticity modulus of concrete in tension under different exposure conditions and reported a 32% decrease in the modulus on decreasing the relative humidity (RH) from 100% to 30%. He attributed these reductions in the modulus values to the possible influence of shrinkage induced micro-cracking. In recent years, experimental researches related to the effect of moisture content on the mechanical properties of concrete have also been carried out, which are accredited to be more specific. It is well acknowledge that the mechanical behavior of concrete is predominately dependent on its composited structures. The presence of pores can adversely affect the concrete's mechanical properties

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http://dx.doi.org/10.1016/j.conbuildmat.2014.06.094
0950-0618/

such as failure strength, elasticity and creep strains [28]. Some researchers studied porosity in concrete to obtain the change regulations of the strength and elasticity modulus, which showed that the strength and elasticity modulus decreased with the porosity increasing [10–12,29,30]. Various porosities breed different moisture contents for concrete structures underwater, which can have an influence on the mechanical properties of concrete. Some researchers carried out the experiments through investigating the saturation degree of concrete specimens, which showed that the concrete strength decreased whereas the static and dynamic elasticity modulus increased with the saturation degree increasing [5–9]. The results of these researches are in accordance with the conclusion of the previous studies.

However, there still seems to be no consensus as to the variation occurring in the mechanical behavior as the moisture content changes. Changes in amplitude of the static elasticity modulus with the moisture content varying differ between experiments. Yaman et al. [10,11] found that the elasticity modulus and Poisson's ratio of saturated concrete increased compared to dry concrete in the case of the same porosity, and the elasticity modulus had an increase of 6–25% over dry samples, while the elasticity modulus of concrete was 3–55% higher for saturated concrete than dry according to the study of Wang and Li [12]. Han et al. [13] believed that whatever mix proportion and curing time, the elasticity modulus of dry concrete declined 15%, compared to wet concrete. Hou et al. [14] indicated that there was a reduction in the axial compressive strength and the elasticity modulus of concrete under dry conditions through testing both properties at typical ages of concrete cured under different RH conditions. Generally speaking, cement hydration resulted in humidity reductions of the interior concrete [15], but humidity reductions in turn stemmed the cement hydration process by reducing the cement hydration rate, which affected the strength and modulus [14]. Some studies concerning the dynamic elasticity modulus also showed a greater dispersion. Rossi et al. [16] investigated the effect of moisture content on tensile elasticity modulus at strain rates between 10^{0}–$10^{0.3}$ s^{-1} and 10^{-6} s^{-1} for saturated and dry concrete, whose elasticity modulus increased by 26.6% and decreased by 4.5% respectively. Wu et al. [17] indicated that there was a 29–77% increase in the modulus value on increasing water content at strain rate 10^{-6} s^{-1} and 30–63% increase at strain rate 10^{-3} s^{-1}, while 4–36% increase at strain rate 10^{-6} $s^{-1}$and 23–42% increase at strain rate 10^{-4} s^{-1}, according to Wang and Li [18]. They both recommended that a decrease of micro-cracking was a possible mechanism responsible for the increase of the modulus on rewetting.

In 2010, Shoukry et al. [19] conducted a thorough experiment to examine the effect of temperature and moisture variations on the mechanical properties (compressive strength, split tensile strength, elasticity modulus and Poisson's ratio) of concrete that completely cured. They also developed relations that can be used to determine the properties of concrete at different temperatures and moisture contents. In this paper, the elasticity modulus test was completed by an MTS actuator with a capacity of 49 kN supported by a 6 m high steel frame. A small environmental chamber was designed and built to be situated under the actuator. The specimen was positioned in the chamber and loaded axially with the actuator. The strains of specimens in radial and axial directions under the axial force at different ages were recorded to calculate the elasticity modulus and Poisson's ratio. The relationship between moisture content and elasticity modulus was expressed by Eq. (1).

$$E(M) = 28.835 - 0.048653M \quad (1)$$

where E denotes the modulus of elasticity of concrete (GPa), and M denotes the moisture content (%). As can be seen from Eq. (1), the elasticity modulus inversely correlated with the moisture content. Bjerkli et al. [20] conducted an experimental investigation to study the strain development and the static compressive strength of concrete cylinders exposed to high water pressure loading, which presented that pore pressure related to permeability coefficients and absorption ability developed in the concrete specimens, and the presence of the pore pressure did not reduce the compressive strength and elasticity modulus of concrete. Nevertheless, according to Biot pore mechanics, a water pressure occurs in the pores of porous materials under load, and excess pore-water pressure will develop for free water in the pores and micro-cracks of concrete loaded, which will make a difference to the properties of concrete.

In terms of the dispersion of the experimental results and the inconsistent conclusions, it is essential to do further studies concerning the elasticity modulus of concrete under different moisture contents. The objective of this paper is to investigate the change regulations of the moisture content in concrete and the influence of moisture content on the static compressive elasticity modulus of concrete via a full set of experiments considering the different dimensions, curing conditions and strength grades of the concrete specimens. Furthermore, the research also aims at developing relations of the moisture content and the static compressive elasticity modulus to predict or determine the static compressive elasticity modulus of concrete with different moisture contents.

2. Experimental program

2.1. Specimens preparation

In this investigation, an ordinary Portland Cement (P.O42.5) produced in the Lima cement plant of China was used in all compositions, and all its properties were in accordance with the standard of Common Portland Cement [21]. The aggregate included medium sand (fine aggregate) and pebbles (coarse aggregate) produced in the Zhongxing plant of Zhuozhou in Hebei Province, and the fineness modulus, clay content, apparent density and bulk density of the sand were 2.68, 1.6%, 2.66 g/cm^3, 1559 kg/m^3 respectively, while the clay content, apparent density, bulk density and maximum aggregate size of the pebbles were 0.6%, 2.65 g/cm^3, 1563 kg/m^3, 2.65 mm, respectively. Fly ash and JK-05 pumping admixture were chosen as the concrete admixture and chemical admixture. The mix proportion of concrete used is given in Table 1, are according the Specification for Proportion Design of Ordinary Concrete [22].

The strength grade of concrete in this research were C30 and C40, whose mechanical index can be referred to the Code for Design of Concrete Structure [23]. The concrete mixture was casted into 100 × 100 × 100 mm, 100 × 100 × 300 mm, 150 × 150 × 150 mm for C30 concrete and 100 × 100 × 100 mm for C40 concrete, which were cured under the standard conditions (20 °C ± 2 °C, RH > 95%) for 28 days, as shown in Fig. 1. Besides, C30 concrete specimens with the dimension of 100 × 100 × 100 mm and 100 × 100 × 300 mm were cured under the natural conditions (outdoor environment, maximum temperature and minimum temperature were 26 °C and 12 °C respectively), as shown in Fig. 2. The curing method was carried out according to the Standard for Evaluation of Concrete Compressive Strength [24].

2.2. Instrumentation

The pressure apparatus used in this work is an electro-hydraulic servo testing machine controlled by a computer in the material laboratory of Beijing Jiaotong University. The maximum capacity is 1000 kN and the accuracy is ±1%, as illustrated in Fig. 3.

The electric thermostat blast drying box produced by Shanghai Jinghong Laboratory Instrument Co., Ltd. was used to dry the specimens, as shown in Fig. 4.