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Assessing the spatial variability of the concrete by the rebound hammer test and compression test of drilled cores

Taozhi Xu [a], Jie Li [b,*]

[a] School of Civil Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, PR China
[b] State Key Laboratory of Disaster Reduction in Civil Engineering and School of Civil Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, PR China

HIGHLIGHTS

- Non-destructive testing and destructive testing are conducted on concrete beams.
- Assessing the spatial variability of the mechanical properties of concrete.
- The statistical results of the mechanical properties of concrete are obtained.

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ABSTRACT

The spatial variability of the mechanical properties of concrete is an important characteristic, which plays an important role in the stochastic analysis of the concrete structures, especially in the reliability analysis. Two categories of experiments named non-destructive testing (NDT) and destructive testing (DT) are used for the laboratory concrete beams. Rebound hammer techniques as NDT and compression tests of the core samples drilled from the concrete beams as destructive testing (DT) are utilized to assess the spatial variability of the mechanical properties of concrete, respectively. The strength values of concrete at different locations of concrete beams are estimated by the rebound measured data. The complete stress-strain curves of the cylindrical core specimens at ten test areas of concrete beams are obtained from the compression tests. The corresponding statistical results, including the mean values, the standard deviations (SDs), the coefficients of variation (CVs), the correlation lengths, and the probability density functions of the mechanical properties of concrete are obtained according to the statistical methods.

1. Introduction

The quasi-brittle materials like concrete and rocks usually exhibit highly complicated behaviors when experiencing stresses. Indicated by the intrinsic heterogeneity of the material microstructure, the typical mechanical behaviors of concrete could be attributed into the nonlinearity and the randomness, which play an important role in the stochastic nonlinear behavior of the concrete structure [1]. Thus, it is important to develop a numerical model considering both nonlinearity and randomness of concrete for the stochastic analysis of concrete structure, especially in the reliability analysis.

A class of stochastic damage-plasticity constitutive models of concrete had been developed in recent years [1,2]. It can be feasible to reasonably represent the nonlinearity and the randomness as well as their coupling effect of concrete based on the micro-mechanical approach. The most widely used stochastic micro-mechanical approach was the parallel element model, which was adopted to develop the stochastic damage evolution function by introducing the micro-fracture strain of the parallel element as a basic random variable. In the early literature [3,4], this model was proposed to describe the progressive damage propagation of a brittle rod subjected to uniaxial loading. Kandarpa et al. [4] investigated the model in detail and derived the standard deviation of damage evolution. Li and Zhang [5] defined the fracture strain of the element as a one- dimension random field. Li and Ren [2] furthermore extended the model from uniaxial to multiaxial damage-plasticity framework based on the idea of energy equivalent strain. The stochastic damage-plasticity constitutive model is utilized to the structural stochastic dynamic analysis combined with finite element method [6]. However, the model fails to account for the spatial variability of concrete in real structures, which is an important feature of concrete structure. It was generally assumed that

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* Corresponding author.
E-mail address: lijie@tongji.edu.cn (J. Li).

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the mechanical behaviors of concrete at different locations were completely related to each other [6].

The need for taking into account the spatial variability in the stochastic analysis for the structures, especially in the reliability analysis, had been pointed out by Vanmarcke et al. [7,8]. However, assessing the spatial variability was often limited to the scatter estimation, like mean value and standard deviation (SD), without considering any possible spatial correlation of the mechanical properties of concrete. In recent years, some studies had been devoted to assessing spatial correlation of investigations on the concrete structures. For example, Nguyen combined several non-destructive testing (NDT) techniques to assess the spatial variability of concrete, identifying some correlation lengths of NDT measurements ranging from 0.4 to 0.6 m for the laboratory slab and the investigated bridge pier [9]. Schoefs presented a two stages procedure for the stochastic characterization of random fields from NDT measurements [10]. The concrete properties and carbonation depths were measured by destructive techniques (DT) at several points over a linear portion of reinforced concrete (RC) wall to account for spatial variability of spatial observations throughout random field models [11]. Curve fitting method and the kriging Method are used to estimate the scale of fluctuation of concrete compressive strength and concrete cover for spatial variability analysis of RC structures [12].

However, the main concern in the assessing of the spatial variability of the mechanical properties of concrete is the lack of data [12]. Although some studies analyzed spatial variability for the strength of concrete using NDT [9], the mechanical properties of concrete materials cannot be measured directly by the NDT. The mechanical behavior is estimated by empirical relationship based on the experiments. Accordingly, it is quite meaningful to directly determine the spatial variability with the measurement from the drilled cores at various locations of the concrete structure. The present manuscript aims at studying the random field characterization of the nonlinear mechanical properties of concrete using both NDT and DT approaches. For these purposes, rebound hammer techniques and compression tests of the cores drilled from the concrete beams as DT are conducted to obtain the data first. The corresponding statistical results, including the mean values, the standard deviations (SDs), coefficients of variation (CVs), and the correlation lengths, and the probability density functions of the mechanical properties of concrete are calculated using the statistical methods then. The most relevant conclusions are drawn finally.

2. Test program

This paper focuses on modeling spatial variability of the mechanical properties of concrete. Based on the previous studies [7,8] the random fields of the mechanical properties of concrete can be assumed to be isotropic. A one-dimensional spatially distributed field is considered here. Plain concrete beams are cast in laboratory to achieve the purpose of this paper. Considering the required minimum area of the rebound test [13,14] and the dimensions of conventional specimens [15–17] for the compression test, the size of the cross sectional area of concrete beam is set to 200 × 200 mm. The length of concrete beam is set to 2100 mm, which is approximately 3–5 times of the correlation length of concrete strength [9,10,12]. In order to consider as many samples as possible in the tests, ten plain concrete beams, with the dimensions of 200 × 200 × 2100 mm, are constructed, as Fig. 1 shows. Specimens are cast in wooden molds, compacted by hand rodding, demolded after 48 h and moist cured until test time. The ten concrete beams are denoted as Beam1–Beam10.

The used concrete is made with Portland cement, yellow and medium sand, and crushed diorite gravel with the particle size of 5–16 mm. Slag and fly ash are added to improve the workability and strength of concrete. The mix proportions of concrete are given in Table 1. The designed compressive strength of concrete is around 30 MPa at 28 days. Rebound hammer tests are performed firstly at 28 days age. Then specimens dedicated to the compression tests are cored and stored in a humid chamber at a relative humidity of 95% and a temperature of 20 °C before tests.

2.1. Rebound hammer test

Rebound Hammer test is a NDT method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. The rebound hammer is also called as Schmidt hammer that consist of a spring controlled mass that slides on a plunger within a tubular housing. The working mechanism of the rebound hammer test is shown in Fig. 2. When the plunger of the rebound hammer is pressed against the surface of concrete, a

Table 1
Mixture ratio of concrete.

Constituent	Weight, kg/m3
water	134
Portland cement	248
Sand	840
Gravel	1010
Fly ash	65
Entraining superplasticizer	6.11
Slag	69

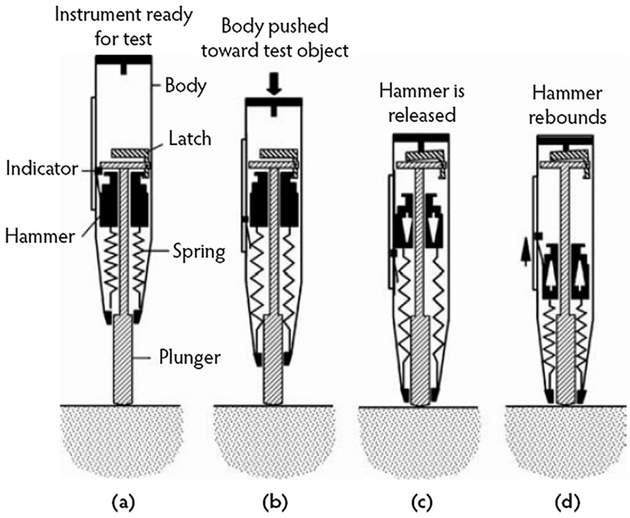

Fig. 2. The working mechanism of the rebound hammer test.

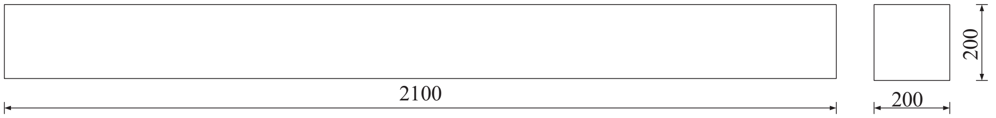

Fig. 1. The dimensions of the plain concrete beam.