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A fundamental study on compressive strength, static and dynamic elastic moduli of young concrete

Yong Zhou [a,*], Jie Gao [a], Zhihui Sun [b], Wenjun Qu [a]

[a] Department of Structural Engineering, Tongji University, 1239 Siping Road, Shanghai 20092, PR China
[b] Department of Civil and Environmental Engineering, University of Louisville, Louisville, KY 40292, USA

HIGHLIGHTS

- Relationship between static and dynamic moduli of elasticity is linear.
- Aggregate volume content, water-to-cement ratio and curing temperature affect *E*.
- Aggregate volume content and maximum size are dominant factors on E_c–E_d.

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ABSTRACT

This study investigates the influence of volume content of aggregates, maximum size and type of coarse aggregates, water-to-cement ratio and curing temperature on mechanical properties, i.e. prismatic compressive strength (f_c), static modulus of elasticity (E_c) and dynamic modulus of elasticity (E_d) of concrete at early age. A new equation is proposed to correlate prismatic compressive strength and elastic moduli of concrete. Based on the experimental data and the analysis results, the E_c–E_d relationship is also proposed. It is found that the relationship between E_c and E_d is linear, and the coefficients of linear relationship are analyzed by multiple regression analysis, considering aggregate content, maximum size of the coarse aggregate, water-to-cement ratio and curing temperature. It is found that the volume content of aggregates is the most significant factor that influences the E_c–E_d relationship.

1. Introduction

The construction of concrete structures greatly depends on the mechanical properties of concrete, among which compressive strength and modulus of elasticity are mostly concerned. For example, the proper time to remove formwork and the proper time to apply pre-stress on concrete members are completely controlled by these two properties. If anything improper is done before concrete has developed its desired properties, large deformation, crushing of concrete or even catastrophic collapse may happen. Therefore, knowing the early-age compressive strength and the elastic modulus of concrete is critical to guarantee its life-time performance.

For concrete, both the compressive strength and the elastic modulus increase rapidly during its early age [1–3]. The design code recommends estimating concrete's elastic modulus based on its 28th day's compressive strength [4–9]. This recommended relationship may not be applicable to concrete at early age.

There are many influential factors on compressive strength and modulus of elasticity of concrete. Stock et al. [10] presented that the modulus of elasticity is proportional to the volume content of aggregate. Ranchero [11] indicated that volume content of aggregates, type of coarse aggregate and water-to-cement ratio were the most important influential factors. Johnson and Bawa [12] found that the modulus of elasticity increases with the increase in volume content of aggregates and decreases with the increase in water-to-cement ratio. Yıldırım and Sengul [13] pointed out that the modulus of elasticity could be lower if smaller aggregates were used. All the above researches focused on concrete at the age of 28 days or older. It is not clear that how these factors influence the modulus of elasticity at early age.

When design a concrete structure, its compressive strength and the static Young's modulus are used as recommended by the design codes. However, for field measurement, concrete quality is normally estimated via in situ non-destructive testing (NDT) methods, among which the ultrasonic pulse velocity, the wave reflection, and the impact echo methods are commonly used [14–17]. These methods are dynamic methods, measuring the dynamic modulus of concrete. Therefore, a good model to correlate

* Corresponding author.
E-mail address: yongzhou@tongji.edu.cn (Y. Zhou).

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static and dynamic moduli of concrete is needed to correlate structure design and field measurement. Although the relationship between the static and the dynamic moduli of concrete has been suggested by some researchers [11,18–20], a model based on design parameters, such as aggregate size and volume, water-to-cement ratio and curing temperature is needed to close the gap between structure design and field measurement.

This paper presents the results of a study on the development of prismatic compressive strength and modulus of elasticity, and the relationships between static and dynamic moduli of elasticity of concrete within the age of 12 h to 28 days. Meanwhile, the influences of the material parameters used in designing mix proportions (such as water-to-cement ratio, maximum coarse aggregate size, coarse aggregate type, and coarse aggregate volume content, etc.) on the relationship between static modulus (E_c) and dynamic modulus (E_d) are investigated.

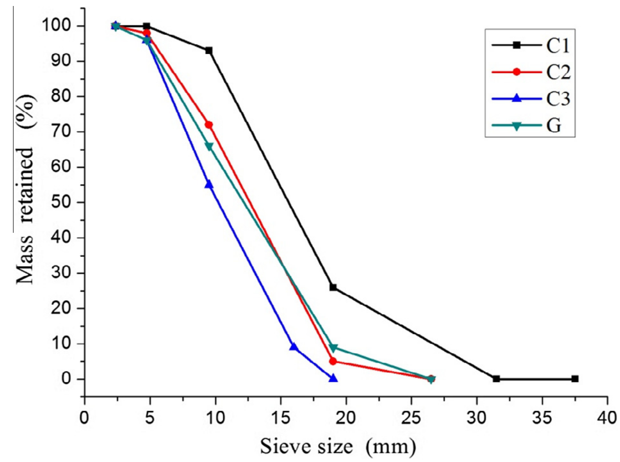

Fig. 1. Gradation curves of coarse aggregate.

2. Materials and experiments

2.1. Raw materials

Ordinary type I Portland cement was used in all the experiments. The specific gravity of the cement was assumed to be 3.15. River sand, gravel and crushed limestone were used as fine and coarse aggregates. To study the influence of maximum coarse aggregate size on the mechanical properties of concrete, the maximum diameters of crushed limestone were chosen as 16 mm, 20 mm and 31.5 mm, respectively. The maximum diameter of gravel was 20 mm. The aggregate gradation complied with GB/T14684-2011 [21] and GB/T14685-2011 [22]. In Table 1, the cumulative particle size distributions, the specific gravity under the saturated-surface-dry condition and the absorption capacities of the sand, gravel and crushed limestone are listed in details. The gradation curves of all the coarse aggregates that used in this study are plotted in Fig. 1.

Table 1
Properties of aggregates.

Crushed limestone with the diameter 5~31.5mm (C1)							
Sieve size (mm)	37.5	31.5	19.0	9.5	4.75	2.36	
Mass retained (%)	0	0	26	93*	100	100	
Density (SSD)	2634 kg/m^3		Absorption capacity		1.05%		
Crushed limestone with the diameter 5~20mm (C2)							
Sieve size (mm)	26.5	19.0	9.5	4.75	2.36		
Mass retained (%)	0	5	72	98	100		
Density (SSD)	2638 kg/m^3		Absorption capacity		0.94%		
Crushed limestone with the diameter 5~16mm (C3)							
Sieve size (mm)	19.0	16.0	9.5	4.75	2.36		
Mass retained (%)	0	9	55	96	100		
Density (SSD)	2630 kg/m^3		Absorption capacity		1.01%		
Gravel with the diameter 5~20mm (G)							
Sieve size (mm)	26.5	19.0	9.5	4.75	2.36		
Mass retained (%)	0	9	66	96	100		
Density (SSD)	2587 kg/m^3		Absorption capacity		1.02%		
River sand							
Sieve size (mm)	9.50	4.75	2.36	1.18	0.6	0.3	0.15
Mass retained (%)	0	5	15	28	43	90	98
Fineness modulus	2.63- medium sand						
Density (SSD)	2604 kg/m^3		Absorption capacity		1.81%		

*Note: mass retained should be 90% at the sieve size 9.5 mm according to GB/T14685-2011.