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Creep of compression fly ash concrete-filled steel tubular members

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ABSTRACT

Because of its rational mechanical performances, concrete-filled steel tubes (CFT) have been widely used in construction. To improve the reliability of CFT structures, steel tubes are filled with fly ash concrete (FAC) to increase the workability and compactness of the concrete core. Because the hydration process of concrete changes with the addition of fly ash, creep in fly ash concrete shows obvious differences compared with common concrete. As an important long-term behavior of CFT structures, creep has significant effects such as extra deflection, or stress redistribution between steel tube and concrete core. These effects become more complicated after using FAC, and studies of the effects are limited. In this study, the compressive levels of creep in plain FAC and fly ash concrete-filled steel tubes (FACFTs) were measured. The effects of the two fly ash-replacement ratios, 20% and 40%, on creep were investigated. On the basis of an inverse analysis method, a creep model of plain FAC was regressed according to the test data. After a linear stress–strain relationship of compressive FACFTs was established, the creep model was introduced to predict the creep of FACFTs. By comparing the predicted results and by testing the creep of FACFTs, this approach for predicting the creep of compressive FACFTs has shown desirable accuracy. The findings illustrate that fly ash has un-ignorable effects on the creep of FACFTs and that using a linear model to predict the creep of CFTs under low stress levels is feasible.

1. Introduction

The popularity of concrete-filled steel tubes (CFTs) in structures can be attributed to their superior behavior, such as high compressive strength and durability, and by the composite action of steel and concrete. In addition they are a convenient method of construction [1–4]. Because of a lack of necessary conditions for vibrating, the concrete in steel tubes often presents poor compactness. As a result, fly ash concrete (FAC) is usually used to fill the steel tubes to form fly ash concrete-filled steel tubes (FACFTs), which can improve the workability and compactness of the concrete core and is suitable for pumping and pouring [5]. Fly ash had been regarded as a kind of traditional industrial waste until it was used to replace cement in concrete. Because of its active effect, morphology, and micro-aggregate, fly ash improves the workability and mechanical performance of concrete [6,7]. Therefore, adding fly ash to concrete accords with sustainable concepts in civil engineering [8]. In practice, using a higher fly ash-replacement ratio has become a recent trend.

The creep development of FAC differs from normal concrete because the hydration progress of concrete changes after fly ash is mixed [9]. Also, the creep of concrete is influenced by differing replacement ratios of fly ash [10]. With a low replacement ratio of fly ash (approximately $< 40\%$), the creep of concrete is restrained by the effects of fly ash, which means that creep decreases with incremental increases in fly ash. However, when the fly ash-replacement ratio is relatively high ($> 40\%$), the creep of FAC increases along with increases in the fly ash-replacement ratio [11]. Obviously, the creep behavior of FAC is much more complex than that of normal concrete, and common creep models could not be applied to FAC [12].

As a significant long-term behavior of CFT structures [13–15], creep could enlarge structural deformation and redistribute the internal force in the structures and stresses on the cross section, as well as affect the bearing capabilities of the structures. For example, the Yajisha Bridge in Guangzhou, China, a CFST arch bridge with a span of 360 m, gained a creep deflection of 120 mm at its mid-span cross Section 1 year after it was opened to traffic [16]. In CFT, the creep of the concrete core would be limited by the outer steel tube, which makes the creep of CFT smaller but more complicated than that of plain concrete [17]. Much research on creep theory and the related experiments have been performed in recent years [18–20]; however, only a few studies have considered the effects of fly ash on creep.

The creep of FAC with different fly ash-replacement ratios (20% and 40%) was tested, and a creep model was obtained by regression of test data on the basis of an inverse-analysis method. In addition, by

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Table 1
Mix proportions of concrete.

Substitution (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Superplasticizer (kg/m^3)
20	336	84	162.5	809	1029	5.76
40	252	168	162.5	809	1029	5.76

establishing a mechanical relationship between the steel tube and the concrete core, a predicted method of FACFT creep was proposed by introducing the regressed creep model of FAC and, by comparing the predicted results and tests on the creep of FACFTs, predictions of creep of compression CFTs have shown desirable accuracy.

2. Experimental details

2.1. Materials and mix proportions

The materials used for the experiment were as follows: normal Portland cement; Type I fly ash; river sand with a fineness modulus of 2.6; and natural crushed stone aggregate 5–20 mm. A series of concrete mixtures with water-to-binder ratios of 0.4 were designed, in which 20% and 40% of the total cementitious materials by weight was replaced by fly ash. The mix proportions are given in Table 1.

2.2. Specimen preparation

Two kinds of specimens were designed in this study: plain FAC prisms (100 × 100 × 300 mm) and FACFTs (ϕ114 × 2.5 × 300 mm). The specimens were cured at 20 ± 2 °C. The plain concrete prisms were unmolded after 24 h, half of which were sealed by plastic film to simulate the condition of concrete core in FACFTs. The other prisms, unsealed, were used for comparison. The strength and the elastic modulus of the steel in the FACFT specimens were 235 MPa and 205 GPa, respectively. A vibrating-wire sensor was embedded in the middle of the concrete core to test creep. Two ends of the FACFT specimens were also sealed to prevent moisture exchange with the environment. In addition, the corresponding specimens were prepared for shrinkage testing, which must be deducted from the tested creep. The quantities and numbers of the specimens are presented in Table 2.

Table 2
Specimen information.

Type	No.	Test	Fly-ash-replacement ratio (%)	Curing condition	Quantity
Plain concrete specimens	M-2-1	Creep	20	Sealed	6
	M-2-2	Creep			
	M-2-0	Shrinkage			
	M-4-1	Creep	40		
	M-4-2	Creep			
	M-4-0	Shrinkage			
	F-2-1	Creep	20	Unsealed	6
	F-2-2	Creep			
	F-2-0	Shrinkage			
	F-4-1	Creep	40		
	F-4-2	Creep			
	F-4-0	Shrinkage			
CFST specimens	G-2-1	Creep	20	Sealed	6
	G-2-2	Creep			
	G-2-0	Shrinkage			
	G-4-1	Creep	40		
	G-4-2	Creep			
	G-4-0	Shrinkage			

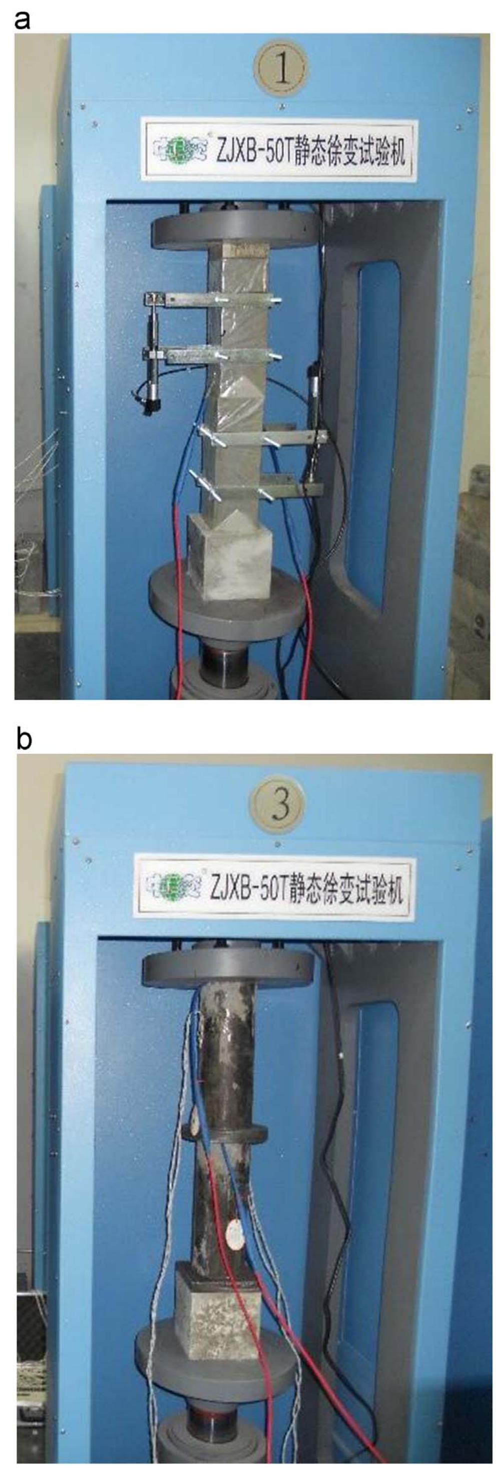

Fig. 1. (a). Creep experiment: plain FAC. (b). Creep experiment: FACFT.