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Behavior of SCC confined in short GFRP tubes

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Abstract

While there is abundant research information on ordinary concrete confined in FRP tubes, there is little data on the behavior of self-consolidating concrete (SCC) under such condition. Because of the usually higher total shrinkage and lower coarse aggregate content of SCC compared to that of ordinary concrete, its composite performance under confined conditions needs special investigation. SCC confined in FRP tubes can have unique structural applications. For instance, cast-in-place deep foundations such as drilled shaft piles are often subjected to two sources of problems. First, the integrity and uniformity of the cross-sectional area of these structural elements cannot be assured using normal concrete because of limited accessibility and visibility during construction. Cavities and soil encroachments leading to soil and air pockets can jeopardize the load-bearing capacity of such piles. Second, corrosion problems of steel reinforcement in deep foundations have been costly, requiring annual repair costs of more than $2 billion in the US alone. SCC, which is able to consolidate under its self-weight without vibration, can be cast into GFRP envelopes that act as corrosion-resistant reinforcement to offer an alternative pile construction method that addresses both challenges cited above. To demonstrate the concept, this paper presents results of a laboratory investigation on the behavior of SCC confined in short GFRP tubes and subjected to axial and transverse load, including the effect of using expansive cement and shrinkage-reducing admixtures to enhance the GFRP tube-SCC interfacial contact.

Keywords: Self-consolidating concrete; Fiber-reinforced polymer; Stress–strain; Compression; Bending

1. Introduction

The ultimate load-bearing capacity of cast-in-place concrete piles is significantly affected by the compressive strength of concrete, the pile cross-section, the amount of steel reinforcement and various soil properties. Both the compressive strength of concrete and the integrity of the pile's cross-section depend on the consolidation of fresh concrete during placement.

Generally, concrete is consolidated with mechanical vibrators, a process that is operator-sensitive. In deep concrete piles where accessibility and visibility are limited, consolidation of concrete is particularly difficult. Over-consolidated concrete might segregate or destabilize soil particles around the shaft wall causing it to collapse into the concrete core. Under-consolidated concrete can have voids and cavities, leading to air and soil pockets and exposure of steel reinforcement to corrosion attack. Consequently, the integrity and uniformity of the pile's cross-section cannot be assured, concrete strength is adversely affected and the load-bearing capacity of the pile is jeopardized.

To alleviate both the problem of air cavities and soil pockets in the concrete and corrosion of steel reinforcement, a novel technology for the construction of drilled-shaft concrete piles is proposed in this study. Self-consolidating concrete (SCC), a material that consolidates under its own weight with no vibration and without exhibiting segregation or bleeding, can be used instead of normal concrete to assure the structural integrity and uniformity of the cross-sectional area of deep foundations. Self-consolidating concrete can be cast into a fiber-reinforced polymer (FRP) envelope, which acts as stay-in-place structural formwork. In addition, the FRP envelope acts as a protective jacket in aggressive environments such as in the case of marine piles [1] and piles constructed in soils rich in chloride ions and sulfate salts [2], and may provide total or

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Nomenclature

Notations

α	winding angle of glass fibers in the FRP tubes
ν	Poisson's ratio
Δ_{co}	maximum axial deflection of unconfined cylinders at concrete failure
Δ_{cc}	maximum axial deflection of confined cylinders at concrete failure
Δ_{ult}	ultimate axial deflection of confined cylinders at failure
Δ_{max}	maximum mid-span deflection of specimen subjected to pure bending
ε_{co}	maximum axial strain of unconfined cylinders
ε_{cu}	ultimate axial strain of confined cylinders
ε_{c}	strain
ASHA	anti-shrinkage admixture
C	cement
D	inside diameter of FRP tubes
E	modulus of elasticity of FRP tubes
E_1	slope of the first linear zone
E_2	slope of the second linear zone
EC	expansive cement
FA	fly ash
f'_c	compressive strength of unconfined concrete specimen
f'_{cu}	ultimate compressive strength of confined concrete specimen
f_0	reference stress (the intersection of the second linear zone with the stress axis)
f_c	stress
G	gravel
GBFS	ground blast furnace slag
GFRP	glass fiber-reinforced polymer
L	length of specimen
NC	normal concrete
NCE	normal concrete with expansive cement and anti-shrinkage admixture
n	curve-shape parameter
OPC	ordinary portland cement
P_{co}	maximum axial load of unconfined cylinder at concrete failure
P_{cc}	maximum axial load of confined cylinder at concrete failure
P_{ult}	ultimate axial load of confined cylinder at failure
P_{max}	maximum transverse load of cylinder subjected to pure bending
S	sand
SCC	self-consolidating concrete
SCCE	self-consolidating concrete with expansive cement and anti-shrinkage admixture
SP	superplasticizer
t	thickness of the GFRP tube
VMA	viscosity-modifying admixture
W	water
W/C	water to cement mass ratio
W/B	water to binder mass ratio

partial replacement for steel reinforcement. More importantly, the FRP tube provides a uniform lateral confinement to the concrete core in piles and significantly enhances the compressive strength of concrete and its ductility [3,4].

The confinement of concrete is the restraint of its lateral deformation under axial loading. Extensive research has been conducted on concrete-filled steel tubes for use as piles and columns [5,6]. However, FRP tubes provide several advantages over steel tubes when used as confining protective jackets for concrete piles. In addition to their high strength-to-weight ratio, FRP materials are known for their high corrosion-resistance. Unlike the confining effect provided by steel tubes, which reaches a threshold value once the steel yields, FRP tubes provide a continuously increasing confining pressure until failure, which adds to both the ultimate compressive strength and ductility of the concrete member [7,8].

The focus of this study is to investigate the confinement effect of glass fiber-reinforced polymer (GFRP) tubes on the strength and ductility of short SCC cylindrical columns subjected to uniaxial compression and transverse loading. Specimens made both of normal concrete (NC) and SCC were tested and their behavior was compared. Moreover, because the interfacial contact between the concrete core and the confining tube is important for achieving a composite behavior, especially under transverse loading, SCC and NC specimens prepared using Type 10 Canadian ordinary portland cement (ASTM Type I) and expansive cement along with a shrinkage-reducing admixture were investigated. Both ends of specimens tested under transverse loading were monitored for any slippage between the concrete and the confining tube. While the behavior of confined ordinary concrete has been well studied and documented, there is a lack of data on the structural performance of confined self-consolidating concrete. SCC is often associated with higher shrinkage and a lower coarse aggregate content compared to that of ordinary concrete, which may affect its behavior under confined conditions. This paper provides valuable data in this area, with special focus on the use of SCC confined in GFRP tubes in deep foundation applications.