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Experimental study on modulus of elasticity of steel tube-confined concrete stub columns with active and passive confinement

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ABSTRACT

This study presents the results of an experimental investigation on the initial and reloading elastic modulus of steel tube-confined concrete (STCC) stub columns with active and passive confinement. Here, a new method was used to create an active confinement in the STCC columns, in which the fresh concrete was compressed by applying an external pressure and subsequently the steel tube was pretensioned in the circumferential direction. The prestressed steel tube-confined compressed concrete (PSTC) was produced in two ways: long- and short-term pressure to reach high and low prestressing levels, respectively. A total of 135 confined concrete specimens including non-prestressed steel tube-confined concrete (NPSTC), short-term prestressed steel tube-confined compressed concrete (SPSTC), and long-term prestressed steel tube-confined compressed concrete (LPSTC) along with 45 reference concrete specimens in 15 experimental groups were tested to investigate the effect of reference concrete strength, diameter to thickness ratio of the steel tube, and prestressing level on the initial and reloading modulus of elasticity. The results showed that prestressing the STCC specimens by the present method significantly enhanced the initial modulus of elasticity between 46% and 184% for the SPSTC and between 51% and 280% for the LPSTC. Moreover, the reloading elastic modulus increased considerably compared with the first loading elastic modulus for the passive specimens while the opposite trend was observed for the active specimens. Finally, by separating the contribution of prestressing to increasing the elastic modulus of the active specimens from that of compressing the fresh concrete, a significant contribution of prestressing was indicated.

1. Introduction

The application of steel tube-confined concrete (STCC) columns is increasing significantly in many modern structures such as housing structures, high-rise buildings, and bridges. Modulus of elasticity or stiffness is considered one of the most important elastic properties of STCC columns from the viewpoint of design and structural behavior.

Although little research has been conducted on the elastic modulus of STCC columns, useful results have been achieved regarding the mechanical properties of concrete-filled steel tube (CFST) columns as well as the columns confined by steel strips and FRP. The confinement affects CFST columns by improving their stiffness, strength, and ductility [1–4]. Ho and Lai [5] studied the compressive behavior of CFST columns confined by tie bars. They tested 30 CFST specimens with various dimensions and different values of concrete compressive strength. They concluded that using tie bars is not effective on the improvement of elastic stiffness of CFST columns. Lai and Ho [6] also conducted a study on the effect of continuous spirals on CFST columns, in which they tested 38 specimens and found that spirals are able to increase the initial stiffness of CFST columns. Binici [7] investigated the behavior of unconfined concrete under triaxial compression and concrete confined by FRP and the steel tube. He concluded that the initial stiffness and ultimate strength of the unconfined concrete and the concrete confined by steel tube and FRP are equal, while their overall behaviors are significantly different to one another. Sezen and Miller [8] studied the effect of various methods including the use of FRPs, steel jackets, concrete jackets reinforced with spiral rebar, concrete jackets with welded wire fabric, and steel reinforcement called PCS on the axial behavior of reinforced concrete columns. They found that all the strengthening methods increased the axial strength and stiffness of the columns.

In general, confinement can be applied to composite columns in two manners: active and passive. In passive confinement, no

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Nomenclature

STCC	Steel Tube-Confined Concrete
CFST	Concrete-Filled Steel Tube
LPSTC	Long-term Prestressed Steel Tube-Confined Compressed Concrete
SPSTC	Short-term Prestressed Steel Tube-Confined Compressed Concrete
NPSTC	Non-Prestressed Steel tube-Confined Concrete
PSTC	Prestressed Steel tube-Confined Compressed Concrete
LPCC	Long-term Pressure-Compressed Concrete
SPCC	Short-term Pressure-Compressed Concrete

Notation

D	outer diameter of steel tube
D_{con}	portion of compressing fresh concrete in relative increase of elastic modulus of PSTC
D_{nst}	nominal prestressing portion in relative increase of elastic modulus of PSTC
D_{tot}	total relative increase of elastic modulus of PSTC
D_{tst}	actual prestressing portion in relative increase of elastic modulus of PSTC
E_A	initial elastic modulus of PSTC
E_{iS}	initial elastic modulus of SPCC
E_{iR}	initial elastic modulus of reference concrete
E_L	initial elastic modulus of LPSTC
E_P	initial elastic modulus of NPSTC
E_S	initial elastic modulus of SPSTC
E'_L	reloading elastic modulus of LPSTC
E'_P	reloading elastic modulus of NPSTC
E'_S	reloading elastic modulus of SPSTC
f_{cR}	reference concrete compressive strength
f_l	lateral confining pressure
f_y	yield strength of steel
l	initial length of concrete
P_f	final pressure (prestressing level)
P_i	initial pressure
t	wall thickness of steel tube

lateral pressure is applied to the concrete core before applying the axial compressive load. In order to obtain an effective lateral pressure in passive confinement, a large deformation of concrete is needed in the lateral direction, which is not allowable in accordance with deformation limitations of design codes of practice. Creating initial lateral pressure on the concrete core is one way to prevent large deformations of concrete and the resulting damages, which commonly leads to active confinement. Currently, there are only a limited number of methods to initiate active confinement. Adding an expansive material to the concrete mixture [9–11], prestressing the transverse hoops [12–16], thermal prestressing of the steel confining components [17], and using the self-stressing composites [18,19] are the most common methods used for producing an actively-confined concrete.

Chang et al. [9] studied the mechanical performance of CFST columns prestressed by the expansive cement. They found that the stiffness of prestressed CFST columns increased as the steel ratio (the ratio of the steel tube cross section area to that of the concrete core) increased. Tran et al. [20] experimentally investigated the concrete cylinders confined actively and passively by using shape memory alloy (SMA) wires. Their results showed that the active confinement improved the performance of concrete relative to the passive confinement in terms of the strength and ductility, but it had no effect on the stiffness. Moghaddam et al. [16] conducted a study on the compressive behavior of cylindrical and prismatic concrete columns confined by post-tensioned steel strips. Considering the axial stress–strain curves presented in their research, it can be found that the initial elastic moduli of the active and passive specimens are almost equal to each other. Mokari and Moghadam [17] investigated square concrete columns confined by thermal post-tension steel jacketing and concluded that these steel jackets led to an increase in the stiffness, ductility, and strength as well as an improvement in axial stress–strain behavior of the concrete.

In this research, a new technique was used to prestress the STCC columns and create an active confinement. In this method, the concrete is converted to a compressed material and the steel tube is pretensioned in the circumferential direction via compressing the fresh concrete in the steel tube by a manufactured prestressing apparatus. This method was first used by Nemati [21] and then completed by Nematzadeh [22]. In the present study, the STCC specimens were tested in three groups of non-prestressed steel tube-confined concrete (NPSTC), short-term prestressed steel tube-confined compressed concrete (SPSTC), and long-term prestressed steel tube-confined compressed concrete (LPSTC), and the effect of parameters including the compressive strength of reference concrete, diameter to wall thickness ratio of the steel tube, and the prestressing level on the initial and reloading modulus of elasticity was investigated. The results showed that the transverse prestressing of the STCC columns using the present technique improved the initial modulus of elasticity significantly. Moreover, unlike active specimens, the reloading modulus of elasticity of passive specimens was considerably increased compared with the corresponding initial modulus of elasticity.

2. Experimental program

2.1. Test specimens

In this research, a total of 135 confined concrete specimens in triplicate were produced in 15 series. Each series included 9 specimens; of which three were non-prestressed steel tube-confined concretes (NPSTC) and six were prestressed steel tube-confined compressed concretes (PSTC) including 3 with short-term pressure and the other 3 with long-term pressure. In short-term prestressed steel tube-confined compressed concrete (SPSTC) specimens, the effect of applying short-term pressure that gives a low level of prestressing on the improvement of the behavior of STCC specimens was investigated. In these specimens, the pressure applied to the fresh concrete was eliminated immediately after reaching an arbitrary and stable value of the initial pressure within 15–30 min. After eliminating the pressure and removing the specimens from the prestressing apparatus, due to friction between the concrete aggregates, some level of prestressing was preserved [23,24].

In long-term prestressed steel tube-confined compressed concrete (LPSTC) specimens, the effect of applying long-term pressure for reaching a high level of prestressing on improving the behavior of confined concrete specimens was evaluated. In these specimens, the applied pressure on the fresh concrete was kept for 6 days. In order to conduct a comparison, the initial pressure applied to the LPSTC in each series of specimens was similar to the SPSTC. In addition, physical and mechanical properties of the active specimens before prestressing were similar to those of the passive specimens.

In addition to the above-mentioned specimens, three unconfined concrete specimens in each series (45 specimens in total) were built to determine the compressive strength of concrete core