Construction and Building Materials 188 (2018) 101–118

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental and numerical studies on bonded prestressed concrete beams at low temperatures

Jian Xie, Xueqi Zhao, Jia-Bao Yan *

School of Civil Engineering, Tianjin University, Tianjin 300350, China
Key Laboratory of Coast Civil Structure Safety of Ministry of Education, Tianjin University, Ministry of Education, Tianjin 300350, China

HIGHLIGHTS

- Low temperature improves cracking and ultimate resistances of bonded PC beams.
- Proposed theoretical models predict well resistances of bonded PC beams at low temperatures.
- Proposed FEM predict well behaviours of bonded PC beams at low temperatures.
- Strength and elastic modules of concrete decrease after freeze-thaw cycles.
- Behaviours of PC beams were changed by low temperatures and freeze-thaw cycles.

ARTICLE INFO

Article history:
Received 23 June 2018
Received in revised form 17 August 2018
Accepted 17 August 2018

Keywords:
Low temperatures
Prestressed concrete beams
Concrete strength
Freeze-thaw cycles

ABSTRACT

This manuscript studied the structural performances of bonded prestressed concrete (PC) beams at different low temperatures (+20 °C to −100 °C). The main parameters of analysis and discussion were temperature and prestress levels. Theoretical models were proposed to predict the cracking and ultimate resistances of the bonded PC beams at low temperatures. Numerical model was also proposed to simulate behaviours of PC beams at low temperatures. The accuracies of these theoretical and numerical models were validated against the test results. Compressive tests on concrete after freeze-thaw cycles were also carried out to obtain the corresponding mechanical properties. With these test results as input information, numerical parametric studies were performed to study the behaviours of bonded PC beams at low temperatures or after freeze-thaw cycles.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Prestressed concrete (PC) members are widely used in civil engineering constructions, e.g., long-span structures and bridges [1]. Due to their improvements on the initial stiffness and cracking resistance, PC beams are also applicable to constructions suffering harsh environments. In order to meet the needs of economic development and resource explorations or storage, engineering constructions with PC beams were built in cold regions or exposed to low-temperature environments, e.g., infrastructures in cold regions, liquefied natural gas (LNG) containers, the Arctic onshore and offshore platforms. For cold regions in northern China or Tibet, the recorded lowest temperature could drop to −60 °C [2] whilst the lowest temperature in the Arctic was about −70 °C [3,4]. For the structures exposed to low temperatures, e.g., LNG containers, the external concrete members may suffer low temperature of about −165 °C in the scenario of leakage of LNG [5]. Thus, PC beams used in these structures exposed to low temperatures and freeze-thaw cycles. All these would result in impacts on their structural behaviours that need to be carefully studied and considered in the designs.

Previous studies showed that the mechanical behaviours of constructional materials changed with the decrease of temperature, e.g., concrete and steel. As the temperature decreased from 20 °C to −160 °C, the tensile strength, compressive strength and elastic modulus of concrete, the yield and ultimate strengths of steel all increased [6,7]. Therefore, these changes of material properties improved the structural behaviours of reinforced concrete beams and prestressed concrete beams made of such materials. Liu et al. [8] tested six reinforced concrete (RC) beams at different temperature levels (+20 °C to −180 °C). It showed that with the decrease of temperature, the cracking load, yield resistance, and ultimate resistance all increased. Yan et al. [9] studied the structural performance of twelve RC beams at temperatures of 20 °C,

---

* Corresponding author.
E-mail address: ceeyanj@163.com (J.-B. Yan).

https://doi.org/10.1016/j.conbuildmat.2018.08.117
0950-0618/© 2018 Elsevier Ltd. All rights reserved.

Nomenclature

A_p	section area of prestressing strand
A_0	cross section area of concrete beams
A_{ps}	area of prestressing strand
A_s	area of nonprestressed tension reinforcement
A_s'	area of compression reinforcement
E_{cT}	elastic modulus of the concrete at temperature T
E_{ccD}	elastic modulus of the concrete after freeze-thaw cycles
I_0	the moment of inertia of the section
L_a	shear span of the beam
M_{crT}	bending moment at temperature T
P_{cr}	crack-initiation resistances
P_u	ultimate resistance
T	temperature
W_0	elastic resistance moment
a_p	distance from extreme compression fibre to centroid of prestressing strand
a_s'	distance from extreme compression fibre to centroid of longitudinal compression reinforcement
b	width of the concrete section
e_{p0}	distance from centroidal axis to preloading point
f_{cT}'	specified compressive strength of concrete cylinder at temperature T
f_{cT}	compressive strength of the concrete at temperature T
f_{yT}	yield strength of nonprestressed longitudinal tension reinforcement at temperature T
f_{yT}'	yield strength of compression reinforcement at temperature T
f_{ps}	stress in prestressing reinforcement at nominal flexural strength
f_{pyT}	yield strength of the prestressing strand at temperature T
f_{puT}	ultimate strength of the prestressing strand at temperature T
f_{ccD}	ultimate compressive strength of the concrete after freeze-thaw cycles
f_{tT}	tensile strength of the concrete at temperature T
h_0	distance from extreme compression fibre to centroid of nonprestressed longitudinal tension reinforcement
x	equivalent height of the compressive concrete
y_0	distance from centroidal axis to the tensile edge of the beams
ε_{0T}	compressive strain of the concrete against the ultimate compressive strength f_{cT} at temperature T
ε_{ccD}	strain against f_{ccD} of the concrete after freeze-thaw cycles
ρ	reinforcement ratio of nonprestressed flexural reinforcement
ρ'	reinforcement ratio of compression reinforcement
ρ_b	reinforcement ratio of prestressing tendons
τ_{cr}, s_{cr}	bond stress of cracking and its corresponding slip
τ_u, s_u	peak bond stress (bond strength) and its corresponding slip
τ_r, s_u	residual bond stress and its corresponding slip
σ_{pc}	prepressing stress at tensile edge of the concrete
σ_{pe}	effective tensile stress in the prestressing strand

−40 °C, −70 °C and −100 °C. It was observed that low temperature can improve resistances of RC beams and a nonlinear finite element model (FEM) was developed to predict the behaviours of tested beams at low temperatures. DeRosa et al. [10] reported performance of four RC beams at room temperature and −20 °C. Four-point loads at service levels were applied to the tested beams for 48 h before the beams were loaded to failure. It showed that the crack width decreased and ultimate resistance increased at low temperature whilst the effect of temperature on stiffness was marginal. Mirzazadeh et al. [11] studied the performance of four large-scale beams at 15 °C and −25 °C. They found that both their ductility and ultimate resistance were increased with the decrease of temperature. The cracking resistance of beams increased while the number and the depth of cracks were reduced at −25 °C. Recently, Xie et al. [12] studied the behaviours of unbonded PC beams within temperature ranges of +20 °C to −100 °C. Their test results showed that the cracking load, yield and ultimate resistances, and elastic stiffness all increased almost linearly with the decreasing temperature.

The numerical analysis method has also been widely used to investigate structural behaviours of PC beams. Mercan et al. [13] presented a nonlinear 3-D FEM for PC spandrel beams to investigate their sensitivities to different parameters, e.g., tension stiffening, finite element type and fracture energy. Yapar et al. [14] developed a nonlinear FEM to predict the structural behaviours of bonded PC beams especially on the damage behaviour of concrete and bond-slip behaviour between the concrete and prestressing strand. Ayoub et al. [15] developed a FEM to study the nonlinear responses of bonded PC girders, and an analytical method was proposed to give an accurate prediction for the prestressing operation. Arab et al. [16] presented two numerical methods to simulate the bonded concrete members and concluded that embedment technique could accurately predict the behaviours of bonded concrete members in comparison with the extrusion method. Abdelatif et al. [17] developed a FEM to simulate the transferring mechanism of prestress in PC elements. Post-cracking behaviour and shrinkage of concrete were considered in this model. A parametric study was performed to study the effect of the concrete strength, diameter of prestressing steel and initial prestress on prestress transfer between concrete and strand.

From these previous studies, it can be found that most of experimental studies focused on the behaviours of RC beams at low temperatures and there are still few studies focused on PC beams at low temperatures especially on bonded PC beams. The numerical investigations on PC beams mainly focused on their structural behaviours in ambient temperature environment. The numerical studies on structural behaviours of PC beams at low temperatures have not been thoroughly studied. Thus, it is necessary to experimentally investigate the structural performance of PC beams at low temperatures and develop numerical model to predict their behaviours at low temperatures.

This manuscript firstly reported 12 quasi-static tests on bonded PC beams at low temperatures. The main investigated parameters were prestress levels and temperatures (+20 °C to −100 °C). The effects of these parameters on the behaviours of the bonded PC beams were analysed and discussed. Theoretical models that can predict the crack-initiation resistances and ultimate resistances of bonded PC beams at low temperatures were developed. A detailed numerical model on the behaviours of the bonded PC beams at low temperatures was developed. The accuracies of these theoretical and numerical models were both validated against the test results. Based on the experimental results, the stress-strain curves equations of concrete after freeze-thaw cycles were developed. Finally, parametric studies were performed to study the

Download English Version:

https://daneshyari.com/en/article/8947043

Download Persian Version:

https://daneshyari.com/article/8947043

Daneshyari.com