Construction and Building Materials 186 (2018) 131–144

Contents lists available at ScienceDirect

Construction and Building Materials

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

Seismic behavior of confined masonry walls subjected to freeze-thaw cycles ☆

Lihua Niu *, Shansuo Zheng, Hao Zheng, Yan Zhou, Pei Pei

Department of Civil Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China

HIGHLIGHTS

- The mechanical of masonry materials subjected to freeze-thaw cycles were investigated.
- Four confined masonry walls subjected to freeze-thaw cycles under low cyclic loading were tested.
- Effect of freezing-and-thawing cycles on the seismic performance of confined masonry walls were analyzed.
- Shear bearing capacity formula of confined masonry walls under different freezing-thawing cycles were presented.

ARTICLE INFO

Article history:
Received 15 March 2018
Received in revised form 26 June 2018
Accepted 13 July 2018

Keywords:
Freeze-thaw cycles
Confined masonry walls
Pseudo-static tests
Seismic behavior
Nominal shear strength

ABSTRACT

This paper presented a systemic research evaluating the seismic behavior of confined masonry walls subjected to different freeze-thaw cycles (FTC). The seismic behavior of frost-damaged confined masonry walls was related to the mechanical properties of the frost-damaged masonry material. Thus, the mechanical properties of the frost-damaged masonry material were investigated firstly. Then, pseudo-static tests were conducted with four levels of frost-damage on confined masonry wall specimens. The visual damage, failure patterns, hysteresis behavior, bearing and deformation capacity, strength degradation, lateral stiffness degeneration and energy dissipation capacity were analyzed. Results showed that with an increasing number of FTC, the compressive strength, elastic modulus and Poisson's ratio of the masonry material decreased whereas the strain at peak stress increased. Moreover, with an increasing number of FTC, the peak load, strength attenuation coefficient, lateral stiffness and energy dissipation of the specimens gradually decreased whereas the cracking displacement and ultimate displacement gradually increased. After 120 FTC, the peak load were lower by 38.9%, the ultimate displacement increased by 12.4% and the cumulative energy dissipation of the wall specimens decreased by 72.6%. Finally, the formula for shear bearing capacity for confined masonry walls under FTC was derived based on the results of mechanical property and pseudo-static tests.

1. Introduction

In cold regions, frost damage has become a key durability issue for masonry structures [1,2]. Freeze-thaw damage plays a primary role in deterioration, including the deterioration of the physical and mechanical properties of masonry materials (brick and mortar) and the shear bond strength between mortar and brick, which causes a reduction in the masonry structures' mechanical properties during their service life [3,4]. Meanwhile, masonry structures are subjected to strong ground motions during their lifespan [5]. Hence, there is a growing need for providing an accurate and reliable assessment of the seismic behavior of frost-damaged masonry structures.

The mechanism for freeze-thaw damage was numerously studied [6–9]. The greatest contributors to confined masonry wall degradation are the differential energy of adsorption onto the surfaces of different size pores and the different freezing (solidifying) temperatures associated with those energies. As for freezing (solidifying) temperatures, all of the water in the material does not freeze at the same time because the freezing point of pore water decreases with pore size [7].

☆ **Supported by**: National Key Technology R&D Program of China under Grant No. 2013BAJ08B00, National Natural Science Foundation of China under Grant No. 51678475, Shanxi Provincial Key Research and Development Program under Grant No. 2017ZDXM-SF-093, and Shanxi Provincial Department of Education Industrialization Program under Grant No. 2017JC15.

* Corresponding author.
E-mail address: 895078816@qq.com (L. Niu).

https://doi.org/10.1016/j.conbuildmat.2018.07.104
0950-0618/© 2018 Published by Elsevier Ltd.

For the past few years, the effect of freeze-thaw cycles (FTC) on masonry building materials (mortar, brick units) was primarily studied. The freezing and thawing damage was a complex process and depended on many parameters. Certain parameters and properties with respect to the durability of different kinds of mortar had been extensively investigated, such as anti-aggressive properties, physical properties, porosity changes, microstructure, compressive strength, vapor permeability and water absorption, as can be seen in [10–13]. Cultrone G [14] demonstrated that the main parameters were the porosity and pore-size distribution by assessing the durability of masonry building materials exposed to freezing and thawing damage. Other investigators [15,16] also pointed out that the decay owing to FTC was more noticeable in mortars with high porosity and low strength. Meanwhile, significant degeneration may also occur in brick or stone when exposed to freezing and thawing damage. A few studies [17–22] evaluated the physical mechanical performance and durability (frost resistance) of bricks or stone and their compatibility with other building materials. These research results showed that with an increasing number of FTC, the mass loss and dynamic modulus of elasticity of stone decreased whereas the porosity, water absorption by immersion and capillarity increased. The uniaxial compressive strength and elastic modulus of stone decreased with FTC [19].

The effect of FTC on the mechanical properties of masonry structures had been investigated by some researchers. Amde [23] investigated the mechanical properties of brick masonry prisms after an extended period of wet curing and discovered that the presence of moisture caused significant reduction of their compressive strength and elastic modulus. Mojmir Uranjek [24] showed that with an increasing number of FTC, the damage of brick surfaces and mortar joints increased, but the compressive strength of the wallets remained unchanged. Tan et al. [25] researched the effect of freezing-and-thawing action on the mechanical properties of granites and concluded that the axial strain at the peak stress increased whereas the compressive strength, elastic modulus and cohesive strength decayed exponentially with an increasing number of FTC. When the superficies of walls were subjected to severe moistening and freezing-and-thawing action for a long period of time, the strength reduction of large massive walls reached 85% [26].

In conclusion, previous studies have evaluated the freeze-thaw induced deterioration of the masonry material, including the deterioration of mortar prisms, brick units and brick-mortar prisms at different degrees of freezing-thawing damage. However, the deterioration caused by the reversed cyclic loading and frost action on confined masonry wall components have not been investigated yet.

The objective of this work was to experimentally assess the mechanical properties and seismic behavior of confined masonry walls under freeze-thaw cycles, obtain the deterioration law caused by reversed cyclic loading and frost action, and describe their damage process and failure mechanism. Therefore, a pilot experimental research on the mechanical properties and seismic behaviors of confined masonry walls exposed to various freeze-thaw cycles were performed. Then, the visual damage, failure patterns, hysteresis loops, load-carrying and deformation capacity, strength degradation, lateral stiffness degeneration and energy dissipation capacity were analyzed. Based on the experimental and analytical results, a formula for shear bearing capacity of confined masonry walls under different freeze-thaw cycles was proposed.

2. Freeze-thaw cycles

The accelerated freeze-thaw tests were carried out in the environmental chamber of Xi'an University of Architecture and Technology. The environmental chamber was equipped with an advanced intelligent digital control system. The chamber was manufactured by Wuhuancq (model ZHT/W2300) and its dimensions were 2.5 m long, 2 m height and 2 m wide [27], as shown in Fig. 1.

The temperature variation of each FTC is shown in Fig. 2. The freeze-thaw rules are listed as follows: (1) A spray phase was maintained for 30 min before the start of each FTC in order to ensure better freeze-thaw effects on the specimens. (2) The freezing process consisted of temperature change and minimum temperature maintenance stages. The temperature change stage decreased from 10 °C to the minimum temperature (−15 °C) at a cooling rate of 1.12 °C per min and the minimum temperature was maintained for 4 h. (3) The thawing process consisted of temperature change and maximum temperature maintenance stages. The temperature change increased from the minimum temperature (−15 °C) to the maximum temperature (45 °C) at a heating rate of 2 °C per min and the maximum temperature was maintained for 2 h. Each freeze-thaw cycle lasted 8 h.

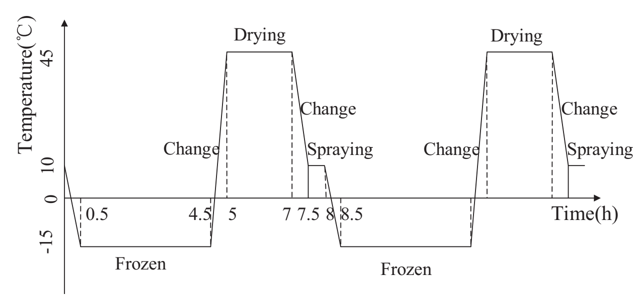

Fig. 2. Freeze-thaw cycles pattern.

Fig. 1. Environmental chamber.