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Experimental and numerical study of hollow core slabs strengthened with mounted steel bars and prestressed steel wire ropes

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HIGHLIGHTS

- Strengthening hollow core slab with mounted steel bar and prestressed steel wire rope.
- Mounted steel bars can enhance the flexural performance of the slabs.
- Prestressed steel wire ropes are more efficient in improving cracking behavior.
- Location and amount of the ropes are critical for the slab behavior.
- The finite element model is capable of predicting the overall slab response.

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ABSTRACT

Hollow core slabs are widely used in prefabricated buildings either as slab elements or bridge decks because of their economic benefits. However, little attention has been given to developing strengthening techniques that are especially suitable for hollow core slabs to recover or improve the original serviceability and load carrying capacity. In this study, two novel techniques for strengthening hollow core slabs with mounted steel bars and prestressed steel wire ropes (P-SWRs) were proposed. Six slab specimens were tested to failure under a four-point bending configuration, and the strengthening effects of the mounted steel bars and P-SWRs on the hollow core slab performance were studied. The experimental results indicated that the steel bars mounted in the cores were capable of enhancing the flexural performance of the hollow slabs. The prestressing technique and anchorages developed in this paper could be used to feasibly and easily prestress the steel wire ropes. P-SWRs were found to be more efficient in improving cracking load than mounted steel bars because of the prestress in P-SWRs. External P-SWRs were better at improving the cracking load, yield load and precracking stiffness compared with internal P-SWRs. The simultaneous use of both internal and external P-SWRs obtained the highest flexural capacity. A three-dimensional finite element (FE) model was developed incorporating the smeared-crack model for concrete and elastic-linear strain hardening model for steel. The validity of the FE model was verified through comparisons with experimental results. Thus, this study provides both experimental evidence and finite element model for the application of the proposed strengthening techniques for hollow core slabs.

1. Introduction

Hollow core slabs are flat slabs that contain longitudinal cores along their span and concrete is removed from where it is not required to achieve a much lighter component. Hollow core slabs are mostly used in prefabricated buildings either as slab elements or bridge decks. Since hollow core slabs are commonly designed to resist bending moments under uniformly distributed loads, their flexural strength is of great importance. Even though hollow core slabs exhibit excellent performance when subjected to bending moments, numerous factors can impair their performance throughout their service life, such as external impact or material corrosion by surrounding environment. In such cases, employing strengthening techniques to hollow core slabs becomes a necessity to recover or improve the original serviceability and load carrying capacity.

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The near-surface mounted (NSM) technique using steel bars or fibre-reinforced polymer (FRP) composites has become a popular and effective method to strengthen reinforced concrete (RC) structures. Since the steel bars or FRP composites are embedded in the grooves that are cut on the concrete cover of the RC structures, the effects of infaust environmental factors can be mitigated. Numerous studies have been conducted to investigate the behavior of RC structures strengthened with NSM technique [1–4]. These studies have shown that the NSM technique can greatly improve the flexural capacity of strengthened RC structures and has less probability for debonding failure compared to that of the externally bonded system. However, little attention has been payed to the flexural behavior of NSM strengthened hollow core slabs [5,6]. Additionally, enough space for the grooves and clear spacing between NSM bars are of great importance to the mitigation of tensile stress overlapping and debonding failure. The concrete cover of hollow core slabs is relatively thin, thus placing an upper bound on the diameter and number of NSM bars that can be employed for a slab. Therefore, specialized strengthening techniques should be developed for hollow core slabs.

The bonded overlay strengthening technique has also been employed to restore or improve the structural performance of slabs by casting a thin layer of concrete on the compression side of existing slabs. Baran [7] and Rahimi et al. [8] investigated the flexural behavior of slabs with concrete topping on the compression side. Girhammar and Pajari [9] conducted both experimental and theoretical analyses of the shear strength of slabs that were strengthened with concrete topping. In recent years, a hybrid strengthening technique comprising bonded overlay on the compression side and FRP composites on the tension side was also proposed and investigated by researchers. Kankeri and Prakash [10] investigated the flexural performance of seven full scale slabs that were strengthened with the hybrid strengthening technique. The test results demonstrated that the hybrid strengthening led to a highest increase in the flexural capacity and ductility compared to NSM or bonded overlay strengthening. Kankeri and Prakash [11] studied the efficiency of hybrid strengthening technique at different levels of shear span to depth ratios. Kankeri et al. [12] conducted theoretical and numerical analyses of the behavior of hollow core slabs strengthened with the hybrid technique.

Steel wire rope is also a promising material for strengthening RC structures because of its high strength, light weight and high flexibility properties. Behavior of RC structures strengthened with steel wire rope has been widely investigated in recent years. Wu et al. [13,14] conducted both an experimental study and a theoretical analysis on the flexural behavior of RC beams strengthened with P-SWRs. Kim et al. [15] studied the shear strengthening technique for RC beams using P-SWRs. Wei and Wu [16] investigated the compression behavior of concrete columns strengthened (confined) by steel wire ropes. The main findings and conclusions have been adopted by JGJ/T325-2014 guide [17]. However, overlooked applications such as hollow core elements and one-way slabs need further experimental study. Besides, the P-SWRs strengthening system should be adapted to be flexibly employed in hollow core slabs.

The current research aims at developing two novel techniques for strengthening hollow core slabs with mounted steel bars and P-SWRs. Steel bars were mounted in the slab cores, and cement mortar was cast into the cores to anchor the steel bars and protect them from corrosion. Different prestressing systems and anchorages were developed for internal and external P-SWRs, respectively, and cement mortar was cast as a bond and protective material. Afterwards, strengthening effects of the mounted steel bars and P-SWRs on the flexural performance of hollow core slabs were investigated. Variables including number of mounted steel bars and number, prestressing and arrangement of the P-SWRs were studied. Six slab specimens were tested to failure under a four-point bending configuration. The flexural capacity, ductility and stiffness of the strengthened slabs were compared with the control specimen. A three-dimensional FE model was developed to simulate the flexural behavior of the hollow core slabs strengthened with mounted steel bars and P-SWRs. Comparisons of the finite element results and experimental data of the tested slabs were conducted to verify the accuracy of the FE model.

2. Experimental program

2.1. Specimen configurations

Six simply supported hollow core slabs were constructed and tested. The length of the slabs was 3.96 m. The slabs had a trapezoid cross section with an average width of 425 mm and a constant depth of 120 mm. There were four hollows in each slab, and the diameter of the hollows was 70 mm. Fig. 1 shows the slab details and test setup. All specimens were cast using normal weight, ready-mix concrete with a measured compressive strength of 20.40 MPa at 28 days. The specimens were cast at a local precast manufacturing company and were carefully transported to the laboratory. The slabs were reinforced by nine steel bars of 4 mm diameter. The tested elastic modulus and elongation of the reinforcement bars were 2.05×10^5 MPa and 12.3%, respectively. The tested yield strength and ultimate strength were 355.88 MPa and 593.13 MPa, respectively. The thickness of the concrete cover

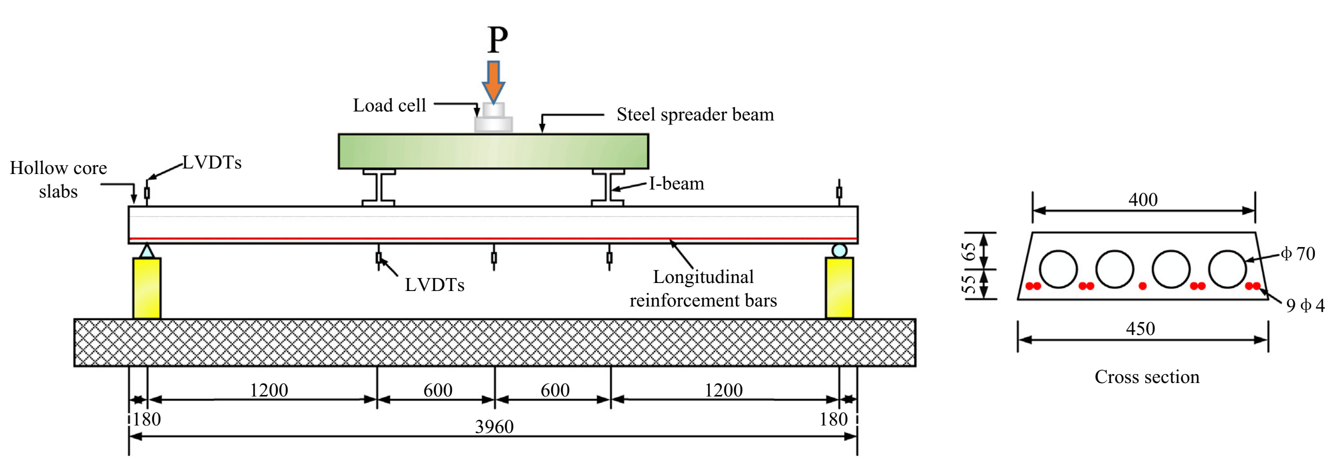

Fig. 1. Slab details and test setup (unit: millimetres).