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BOTDA based investigation on the effects of closure strips in bottom plate during the construction of navigation lock

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ABSTRACT

The effects of closure strips was investigated by combining a distributed optical fibre sensing technology with a conventional monitoring scheme for analysing strain distribution, subsidence, earth pressure, and structural stress. It was found that the changes of the structural stress in each block were small and the strain distribution on the block surface was uniform. The closure strips effectively reduced the stress concentration and cracks induced by differential settlement and earth pressure of different RC blocks. The lock head BP underwent coordinated deformation after the sealing of the closure strips. This indicated that the construction of blocks exerted negligible interactive effects because of the closure strips. The results of some conventional point sensing methods, such as the rebar stress, earth pressure and subsidence show the same conclusion. The feasibility and effectiveness of distributed optical fibre sensing technology for structural monitoring of navigation lock construction were also verified.

1. Introduction

Navigation locks are usually constructed in rivers with substantial variations in water level [1], which are generally large-scale, require high quality, and involve short construction cycles. Inadequate construction technologies can incur undesirable effects on lock structure, such as differential settlement and cracking. Meanwhile, cracking in early age concrete is highly complex and no rational methodologies for its control have yet been established. A navigation lock head involves complex stress conditions and serves as the key part of the navigation lock. A navigation lock head pertains to a reinforced concrete (RC) dock-type structure constituting bottom plate (BP), culverts, engine rooms, and empty cases. Because lock head BP are large structures with a foundation that incorporates side blocks and gates, such structures are subjected to uneven stress, which easily incurs cracks in the RC structure of the BP. To control and prevent engineering failures in large-scale construction projects, closure strips are commonly applied to conduct block casting to control cracks in cast-in-place concrete caused by temperature, structural loads, or differential settlement [2–5]. After the upper structure was casted and the subsidence of the structure foundation was stabilised, closure strips were casted and sealed to facilitate the concrete curing into a rigid compact entity. This facilitates not only alleviating the stress generated through uneven foundation subsidence, but also decreasing the BP thickness effectively. However, some experiments show that the closure strips may have a distinct effect on the overall stiffness of structures [6]. The location of closure strips is determined empirically or according to the similar projects, typically at the quarter span where moments are small. For nonprestressed structures, the width is usually about 0.9–1.2 m. The exact behavior of closure strip is rarely determined by structural monitoring [7]. It is essential to monitor the overall stress condition of a construction site before and after closure strip sealing to verify and optimize the structure design and construction.

Conventional sensors for construction monitoring include earth pressure cells and reinforcing bar (rebar) stress meters, which are kind of point sensing technology and thereby frequently fail to detect abnormal conditions. Sometimes, the installation of such sensors can disturb construction if the number of sensor is enormous. Hence, conventional sensors may not meet the monitoring requirements of large-scale RC projects. Distributed optical fibre sensing technologies have emerged in the field of engineering monitoring from 1990s [8–12]. This type of technology enables distributed monitoring over distances spanning tens of kilometres, potentially replacing tens of thousands of point-based sensors. Because optical fibres are flexible, they can be easily implanted into the surface or internal structure of RC, thus barely disrupting the overall construction process. In addition, optic fibre sensors are immune to electromagnetic interference, intrinsically safe, very stable, and have good corrosion resistance. Therefore, optical fibre sensing has been increasingly prevalent in the quality control and structural health monitoring of infrastructure [13–16]. However,

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studies reporting applications of such technology to the distributed monitoring of navigation lock construction are lacking.

BOTDA, a kind of distributed optical fibre sensing technology, provides a spatially continuous profile of strains which is superior of the conventional point-based sensors. The technology was applied for monitoring and analysing the internal structural strain of navigation lock BP. Meanwhile, conventional methods were combined with for monitoring subsidence, rebar stress, and earth pressure to explore the characteristics of structure internal force and deformation. The effects of closure strips on the structural stress and deformation of the lock head were also examined. The study results facilitated verifying the feasibility and effectiveness of distributed optical fibre sensing technologies in structural health monitoring of navigation lock.

2. Project overview

The BP of the navigation lock head was 53.8 m wide, 28.5 m long, and 2.6 m thick. To prevent large-volume RC from generating cracks during the construction period, the lock head was constructed using a block-casting approach, and space was reserved for closure strips. The steel bars in the closure strips are not truncated. Two closure strips with a width of 1 m were designed to divide the entire lock head BP into the left, right, and middle blocks. An empty case was constructed in the mass concrete area of the side block, the upstream and downstream regions of which were notched to reduce the amount of masonry work and decrease the temperature effect induced by the construction of the mass concrete area. Fig. 1 illustrates the design and cross-sectional diagram and size of the lock head.

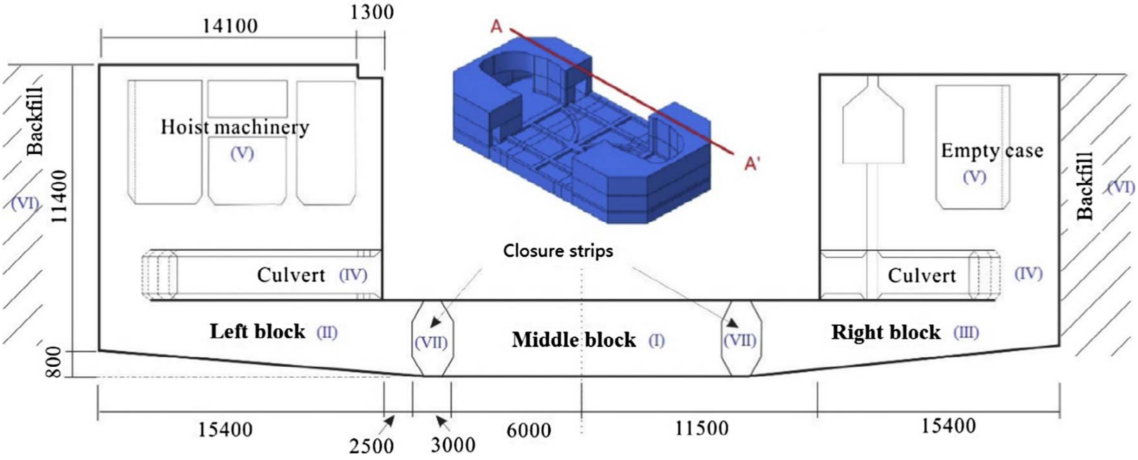
Table 1
Parameters of the BOTDA.

Measurement distance (km)	Spatial resolution (cm)	Strain measurement accuracy (με)	Range of strain measurement ($\times 10^4$ με)
25	10	± 7.5	−3 to +4

3. Monitoring design

Distributed strain sensing optical cables were installed along the main rebar on the upper and lower surface layers of the BP. Brillouin optical time domain analysis (BOTDA) [17,18], a distributed optical fibre sensing technology was applied to obtain the strain distribution of the sensing cables during the construction. The model of BOTDA analyzer used in this research is NEUBRESCOPE 6050A, which was made by Neubrex Co., Ltd. Table 1 lists the technical parameters of the BOTDA system. The sensing cable thereby provided a cross-sectional monitoring across the entire lock head BP, as the bold line shown in Fig. 2. Surveying was employed to measure structure subsidence and deformation. Earth pressure cells were used to measure the earth pressure at the bottom of BP. Rebar stress meters were adopted to analyse the changes in the structural stress. These conventional point-based sensors were installed at five monitoring points (MPs) along the cross section. MP #3 located at the centre of middle block. MP #1 and #5 situated 2 m away from the outer boundary of the BP. MP #4 and #2 were about 10 m away from the outer boundary. In particular, the rebar stress meters were installed on the upper and lower surface of the three blocks, and the direction of the meter was identical to that of the

(a) Rendering graph of the navigation lock head



(b) A-A' section view and main components of the lock head (unit: mm)

Fig. 1. Design of the lock head (A is on the left side of the lock head and A′ is on the right side. A-A′ section is the monitoring section where the sensing cables and conventional sensors was installed. The Roman numerals indicate the construction order).