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Field test of an old RC bridge before and after NSM strengthening

Heeyoung Lee[a], Woo Tai Jung[b], Wonseok Chung[c,*]

[a] Department of Civil Engineering, Kyung Hee University and University of Colorado Denver, 1200 Larimer Street, Denver, CO 80217, USA
[b] Korea Institute of Civil Engineering and Building Technology, Ilsanseo-gu, Goyang-si, Gyeonggi-do 10223, Republic of Korea
[c] Department of Civil Engineering, Kyung Hee University, Yongin-Si, Gyeonggi-do 17104, Republic of Korea

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ABSTRACT

In this paper, a post-tension near-surface mounted (NSM) strengthening system is proposed to strengthen concrete structures with a relatively low amount of labor and without altering the appearance or dimensions of the structures. The main objective of this study was to investigate the structural behavior of an old reinforced concrete T (RCT) type bridge before and after using post-tension NSM strengthening systems. The 12.5 m RCT type bridge was tested using the truck loading test. The displacements of the bridge at mid-span were measured during the test. A finite element analysis model was also developed and verified with the test result. This study showed that the structural capacity and performance of the bridge were enhanced with post-tension NSM strengthening systems.

1. Introduction

Concrete bridges are uninterruptedly unprotected to external environments. During their life spans, concrete bridges frequently experience situations that cannot be predicted during design. The durability of a concrete bridge is reduced by construction defects, overloaded vehicles, material characteristics, and environmental variations. Replacing bridges to improve bridge performance can cause economic loss and inconvenient vehicle traffic. Many researchers have studied proper repair and strengthening methods to solve the problems that occur in concrete structures. Recently, strengthening of concrete bridges with fiber-reinforced polymer (FRP) has increased in most parts of the world. American Concrete Institute (ACI), Canadian Standards Association (CSA) and Japan Society of Civil Engineers (JSCE) have announced standard codes for FRP materials [1–3]. Carbon fiber-reinforced polymer (CFRP) present many advantages for bridge repair, including high strength and modulus, light weight, convenient and rapid implementation, corrosion resistance, minimal interruption to service, reduced labor for installation and maintenance, negligible relaxation under load, and favorable life-cycle costs. Thus, CFRP composites have been widely employed for strengthening for over two decades. The externally bonded (EB) system is to attach the CFRP plate to the concrete surface, and the near surface mounted (NSM) system is to mount the CFRP rods to the groove in concrete structures. Strengthening with FRP has been recognized to fail due to de-bonding between the concrete and the FRP before the capacity of FRP material is achieved; thus, the full capacity of the FRP is not used.

This defect of early de-bonding can be supplement by employing a near surface mounted (NSM) strengthening system. In a NSM system, grooves are formed into the concrete cover. FRP bars are then located in the grooves, which are then filled with epoxy or mortar filler. NSM strengthening is then bonded to the concrete, which confirms higher stress transfer between concrete and FRP than the external bonded (EB) strengthening systems. The NSM system with FRP is prevented from mechanical damage and fire by filler. Also, pre-stressing can be more effectively applied in the NSM system than in the EB system. Research is being performed on external bond systems so that the material properties of FRPs can be applied to building structures [4–6]. However, external bond systems exhibit disadvantage with respect to bond failure, vehicle accident, and fire resistance. Thus, studies of NSM systems using FRPs in concrete structures have been extensively conducted [7–15].

Casadei et al. [15] fabricated an 11.0 m pre-stressed concrete (PSC) I girder, damaged PSC I girder with a pre-loading, strengthened PSC girder with a pre-stressed external bond system and NSM system, and then tested with a four-point loading. Subsequently, they examined the influence of the groove shape, FRP shape, pre-stressing force, and failure. Al-Mahmoud et al. [16] fabricated a 2.8-m reinforced concrete (RC) beam and strengthened it with a NSM CFRP system and tested with a four-point loading and a cantilever loading test. The concrete crack and bond failure from the experimental results were compared with failure mode of the analysis model.

Post-tension NSM strengthening systems embed FRP into concrete structures to strengthen the structure by introducing post-tension to the

* Corresponding author.
E-mail address: wschung@khu.ac.kr (W. Chung).

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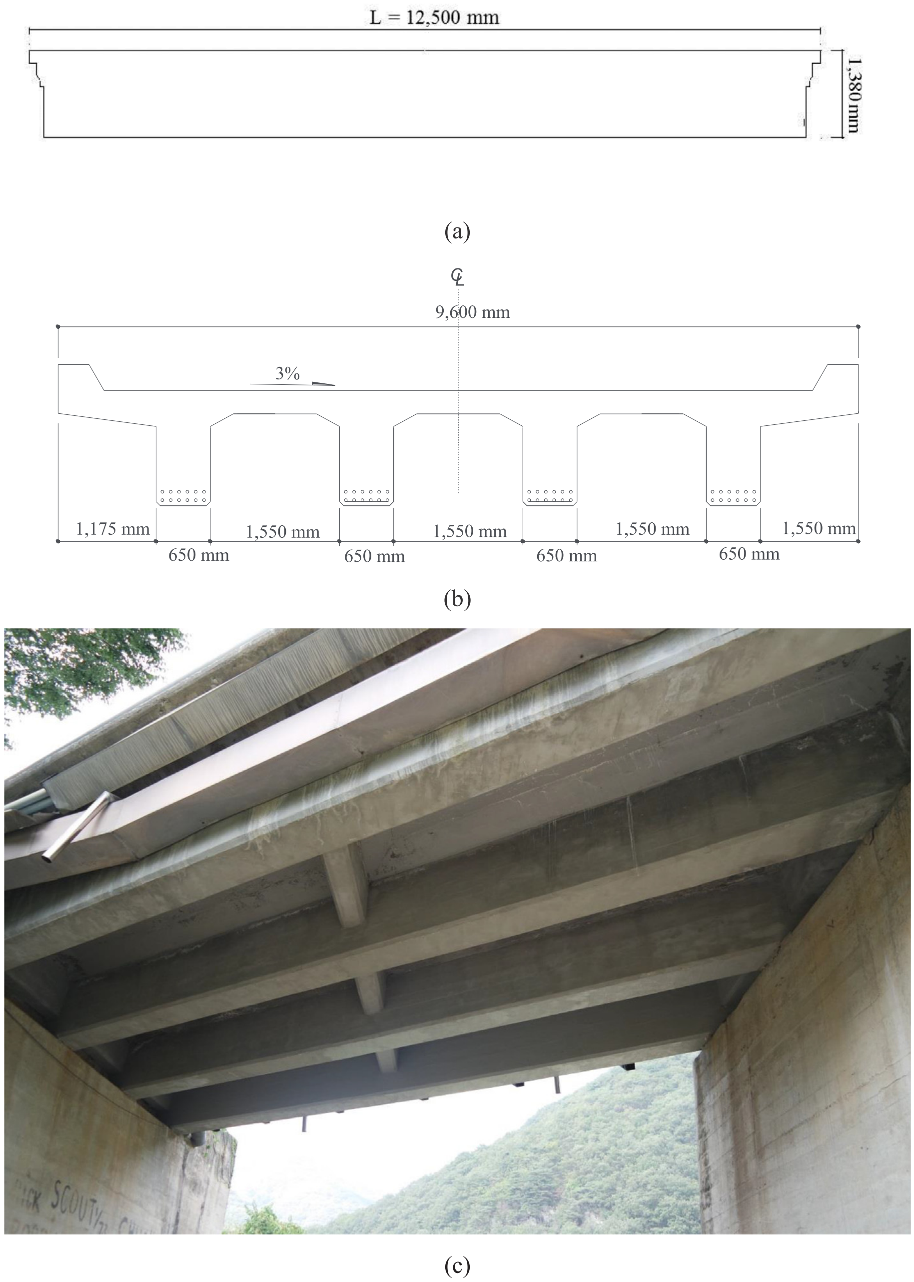

Fig. 1. Details of the target bridge: (a) front view, (b) cross-sectional view, and (c) view of girders and abutment.

CFRP bar. This allows the designer to better use the material's high strength and to upgrade the performance of existing members in terms of both load-carrying capacity and serviceability (for instance, controlled deflections and crack initiation), to levels not achievable using conventional non-prestressed NSM CFRP systems.

Several techniques have been tested for prestressed NSM CFRP systems [17–19]. Nordin and Taljsten [17] fabricated a 4 m RC beam reinforced with the NSM system and performed a 4-point load test. The flexural behavior of the strengthened RC beam was compared to a non-strengthened RC beam. Ouadah and El-Hacha [18] strengthened RC beams with NSM using CFRP bars under a variety of pre-stressing conditions and tested the fatigue performance. They also analyzed the effects of the pre-stressing force, the groove shape and the FRP shape. Lee et al. [19] investigated the NSM system with pre-tension and post-tension systems. The subsequent study by Lee et al. analyzed the strengthening performance by using a post-tension NSM system.

A number of studies were performed with RC beam in the laboratory to examine the load-carrying capacity, fatigue resistance, and ductility of pre-stressed NSM CFRP strengthening systems. Several researchers have examined the strengthening effect of concrete structures using various strengthening methods for concrete structures [20–23]. Aidoo et al. [24] have investigated the strengthening performance of bridges by strengthening EB CFRP systems on highway reinforced concrete (RC) girders. This experiment showed that de-bonding of the CFRP sheet occurred as a final failure mode due to a decrease in interfacial adhesion between CFRP and concrete. Czaderski and Motavalli [5] evaluated the structural performance by strengthening a 40-year-old 17 m pre-stressed concrete girder with a pre-stressed EB system. This study tested the possibility of constructing pre-stressed EB systems for full-scale concrete girders.

Recently, post-tensioning systems have not been enthusiastically investigated in NSM studies. Most pre-stressed NSM study has been accomplished on relatively short-span RC beams through pre-tensioning systems. However post-tension systems need to be investigated if pre-