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Bridge Widening and Strengthening Using CFRP Composites – Experimental Investigation

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Abstract
Increase in traffic load dictates widening highway bridges rather than construction of new bridges, as it offers an economical solution. Bridge widening depends on many factors, for example, bridge type and system, soil condition, required amount of widening, etc. This paper investigates of the possibility of realisation of widening of hammerhead bridge pier with extensions on verges and strengthened using CFRP composites. This widening system is designed according to ASSHITO code and other publications. Design detail and construction procedure are illustrated in this paper. Three quarter-scaled specimens were tested to investigate structural behaviour of widened pier cap beams strengthened with CFRP composites. It was observed that the proposed widening system exhibited good structural behaviour in terms of ultimate strength, stiffness and ductility.

Keywords: Bridge widening, Pier Cap Beam, Strengthening, CFRP Composites

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Introduction

The widening of bridges has become common, especially in recent decades. There are several factors that contribute to the demand for wider bridges such as increased traffic volumes, safety hazards of narrow bridges and provision for bike lanes or pedestrian ways. In order to prevent stresses caused by differential settlements, bridge widening usually involves addition of un-connected new substructure, along with un-connected new superstructure. For limited widening of bridges, for example addition of one driving/emergency lane, extension of the pier cap beam offers an attractive economical solution. Depending on the strength of the existing pier column and foundation, limited strengthening of the column will probably be needed. Several systems could be used for bridge strengthening in general, and bridge widening in particular. These strengthening systems include external post-tensioning steel, and ordinary reinforced concrete jacketing (cast-in-place or shotcrete). However, these strengthening systems have disadvantages such as difficult in application, increased in permanent loading and lack of durability. Carbon fibre reinforced polymer (CFRP) composites have been widely used for bridge strengthening in Europe and North America. Applications included flexural and shear strengthening of girders, axial strengthening of circular pier columns, and seismic strengthening of pier columns for improved ductility.

Proposed Widening System

As an alternative of construction of new piles, a bridge could be widened by just extending the pier cap beams, as shown in Figure 1. In order to maintain the same centre line of the highway, the pier cap beams are extended on both sides, rather than on one side. Unless the existing pier column and foundation have extra reserved strength, such increase in bridge width is associated with increase in the width of the bridge pier, as well as strengthening of the bridge columns and foundation
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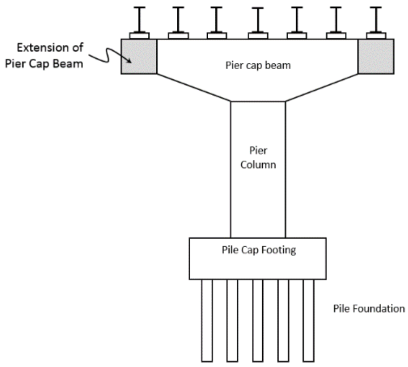

Figure 1: Bridge widening by the addition of overhanging extensions

For a typical hammer headed bridge pier, the widening procedure could be designed as follows,

a. Estimation of the capacity of existing structure.
b. Determination of amount of widening and corresponding strengthening systems.
c. Exposure of the tips of the main top bars of the cap beam.

d. Assembling of steel cages for the extensions and connecting its main bars to the exposed main bars of the existing beam using mechanical splices. If shear strength at the interface is critical, install dowel bars at the interface.
e. Cast the extension concrete.
f. Apply appropriate flexural and shear strengthening systems for the beam and axial strengthening systems for the column, as well as foundation strengthening if necessary.

Casting procedure could be summarized in Figure 2.

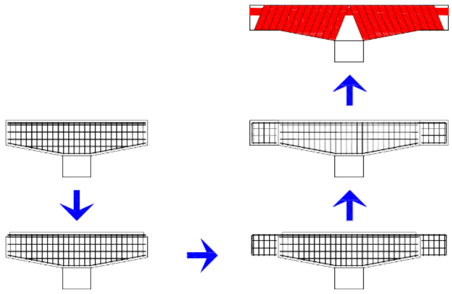

Figure 2: Steps for construction of extensions

Experimental Test

This experimental program aimed to investigate the effectiveness of various CFRP strengthening systems used on cap beams, extended on verges. A total of three non-prismatic hammer-headed pier cap beam were casted and tested. PB1 was a reference specimen, PB 2 and PB3 was strengthened in flexure using 400 mm^2 CFRP plates with an anchor system (CFRP sheets) and 400 mm^2 fully wrapped CFRP sheets, respectively.

Specimen description and test setup

In this study, specimens were made of the same batch of concrete. The average concrete compressive strength was 38.1 MPa. The internal flexural and shear steel had a nominal yield strength of 500 MPa. Details of tested specimens are shown in Figure 3.

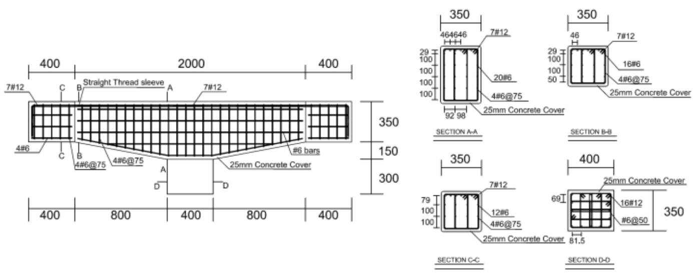

Figure 3: Details of specimens

The CFRP plate used for flexural strengthening was a commercial unidirectional fibre product having a tensile strength of 2400 MPa. The CFRP sheet used was a unidirectional carbon fibre sheet. The CFRP sheets had a tensile strength of 3400 MPa, and a nominal thickness of 0.167 mm. The beams were subjected to monotonic loading at the free end of the cantilevers using two vertical positioned 1000 kN MTS actuators. Loads were applied using displacement control of 3 mm per load stage, until failure.

Test results

Test results are summarized in Table 1. PB1 failed by crushing of concrete in the compression zone after the steel had yielded. PB2 failed by CFRP plate slipped its anchorage system, after concrete has crushed in compression zone at bottom, which was visible. PB3 failed by CFRP sheet rupture at corner of the specimen.

Table 1: Test results

Specimen	Description	Ultimate Load (kN)	Failure Mode
PB1	Reference	250	Concrete crush
PB2	400 mm^2 CFRP plates strengthened	376	Anchor failure
PB3	400 mm^2 CFRP sheets strengthened	391	CFRP rupture

Load deflection responses of tested specimens are shown in Figure 4. It was observed that CFRP strengthened beams exhibited much higher ultimate strength and relatively good ductility. In addition, CFRP reinforcement could slightly increase stiffness of the widened pier cap beams.

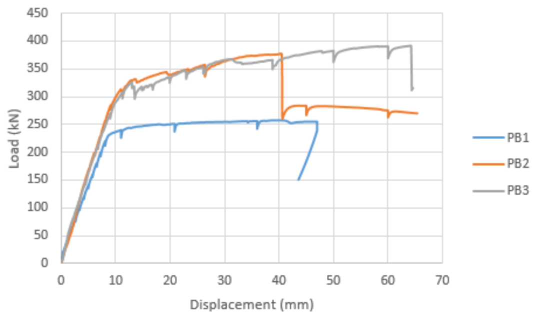

Figure 4: Load deflection responses

Conclusion

It can be concluded that, for hammer head non-prismatic pier cap beams, extensions on verges and reinforced with CFRP systems is an effective solution for widening bridges. Flexural CFRP composites are effective in improving the ultimate flexural capacity of extended pier cap beams. However, for CFRP plated beams, prevention of debonding is a key factor affecting the ductility.

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